Ekoloji 27(106): 761-770 (2018)

Comparative Study on the Technology of Seasonal Solar Energy Storage

Kun-Ru Ma [1*], **Rui-Jiao Yu** [1]

[1] College of Architecture Engineering, Hebei University of Science and Technology, Shijiazhuang, Hebei 050018, CHINA

[*] Corresponding author: makunru@163.com

Abstract

Seasonal solar energy storage means that the solar energy is stored when it is sufficient and used when the weather is getting cold. It is not only conducive to the application of green energy, but also to the saving of primary energy. The technology studied in this paper is the soil heat storage. First, use the Gambit to establish cases with different buried pipes intervals; then, use the Fluent to simulate the soil heat storage under different heat taken conditions; and finally, analyze the data that make the system achieve balance. In this way, we can obtain the amount of heat storage and heat taken and the difference of the area of the solar collectors that are applied in the direct and indirect systems. After matching, we can know the final soil temperature, the amount of heat storage and heat taken, and the ratio between heat storage and heat taken under different temperatures of return water and intervals of buried pipe. With the conclusion, we can provide reference for future projects with regard to the area of solar collector and the total length of buried pipe.

Keywords: solar energy, buried pipe, heat storage, heat supply, energy efficiency

Ma K-R, Yu R-J (2018) Comparative Study on the Technology of Seasonal Solar Energy Storage. Ekoloji 27(106): 761-770.

INTRODUCTION

Nowadays, climate change is a great threat to the mankind. One of the most important reason is the use of fuel in cooling and heating for buildings (Ma 2015). Solar energy is a kind of clean and renewable energy. Of all the renewable energy, the solar energy is superior in distribution and acquisition (Ma 2010).The annual amount of solar energy that reaches the Earth is as high as 4×10^{15} MW, which is equivalent to 3.6×10^{4} billion tce (ton of standard coal equivalent), about 2000 times of the global energy consumption (Yuan et al. 2011).The annual average solar radiation amount across the country is 586kJ/cm^2·a (Li 2008), while the sunshine duration in Hebei province is 3000~3200 hours throughout the year, and the radiation quantity is 586~670x10^4kJ/m^2·a (Jin 2010), equivalent to the heat provided by 200~225kg standard coal. So, solar energy is getting more and more popular.

The research on the heating modes of the cross-season utilization of solar energy is late in China, but with the change of environment and climate in recent years, people pay more attention to the use of solar energy, and the cross-season energy storage also becomes a research focus (Zhou 2012). In 2007, Li Xinguo and others proposed the combination of the thermal utilization of solar energy and the ground-source heat pump (SGCHPSS) (Han 2007).

In 2011, Di Bing and others established a heating system by using the heat pump supported by the cross-season solar energy storage technology, and the heating area is 50m^2 (Di et al. 2010). In 2013, Li An'gui and others used solar energy soil heat storage to provide heat for standard greenhouses and residential buildings, and it passed the Fluent simulation (Chang 2013). In 2014, Wang Enyu and others conducted a numerical simulation on the buried pipe heat exchanger that is used in the solar energy cross-season heat storage (Sun 2014).

The geometric model and the system schematic diagram of the solar energy cross-season heat storage

There are a total of 16 single U pipes in this geometric model. They are in square arrangement horizontally and vertically. Water enters from the outer U pipes, where every two of them are in horizontal series first and then in parallel. Within the U pipes, water is taken as heat transfer medium, namely, the hot water that absorbs the solar energy. Backfill (light sand) is applied outside the pipes, and the exterior of backfill

Received: 5 Jul 2016 / Accepted: 7 Sep 2018

Table 1. The size of the model buried pipe heat exchanger

Intervals between two U pipes	Outer diameter of U pipes	Intervals between water supply pipe and water return pipe	Depth of U pipes	Backfill diameter	Medial soil radius	Lateral soil radius
2m	32mm	100mm	35m	160mm	7m	15m
3m	32mm	100mm	35m	160mm	8.5m	15m
4m	32mm	100mm	35m	160mm	10m	15m

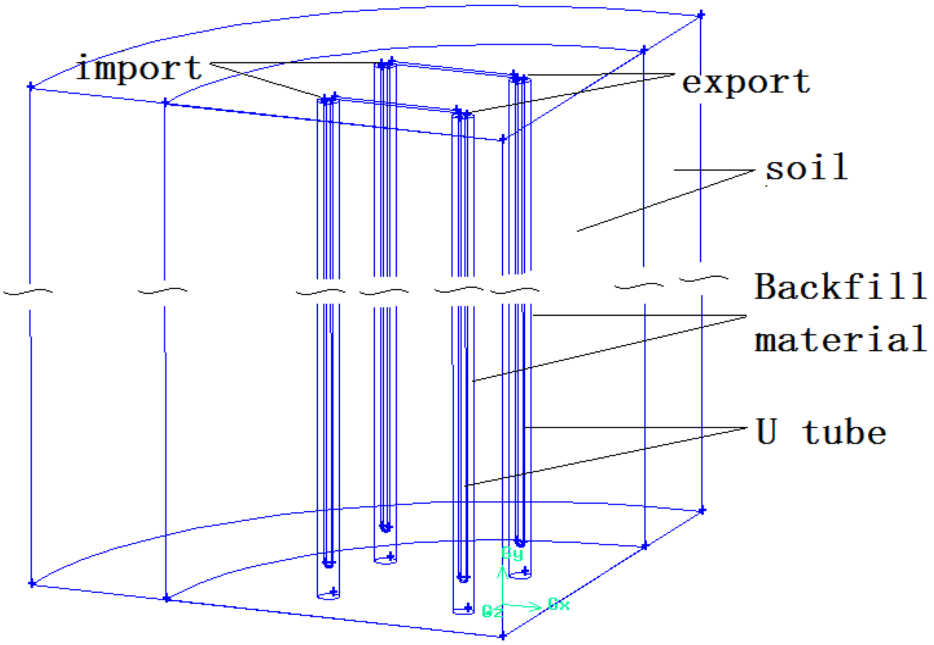

Fig. 1. General diagram of the model

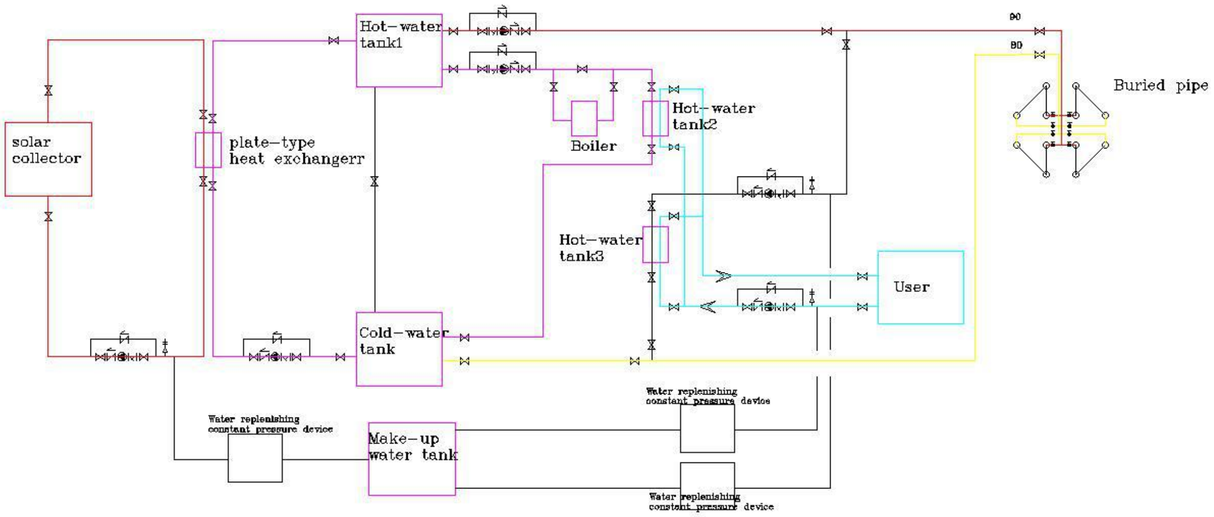

Fig. 2. System schematic diagram

is ordinary soil. The whole model is composed of four symmetrical models, so, in this study, the writer just uses 1/4 of the whole model to simulate to get the heat transfer of the whole model.

Change the intervals between two U pipes and the inside soil radius. Use Gambit to establish models with different intervals of buried pipes. The general situation is shown in **Table 1**, **Figs. 1** and **2**.

NUMERICAL SIMULATION PROCESS AND RESULTS ANALYSIS U PIPE

The site of this study is Shijiazhuang, Hebei Province. Shijiazhuang is a cold area, where the heating period is relatively long. Every year, the amount of heat extracted from underground is much larger than the amount of heat recharged by the air conditioning in

Table 2. Physical parameters of materials (Technical Specification for Ground-Source Heat Pump System 2009)

	Water	**Backfill Material (Light Sandy Soil)**	**Soil**
Density (kg/m^3)	998.2	1285	2082
Specific Heat Capacity (J/Kg·K)	4182	1167.32	837
Heat Transfer Coefficient (W/m·K)	0.6	1.2	0.8

Table 3. Study contents

number	**Velocity (m/s)**	**Buried pipe intervals (m)**	**Return water temperature during heating (℃)**
1	0.5	2	30
2	0.5	2	35
3	0.5	2	40
4	0.5	3	30
5	0.5	3	35
6	0.5	3	40
7	0.5	4	30
8	0.5	4	35
9	0.5	4	40

summer. As time goes by, the temperature of underground soil becomes lower and lower, so the heating effect becomes bad (Han 2013), and the ground source heat pump system even can not operate normally. Therefore, we have to look for auxiliary heat sources to replenish heat to maintain the operation of the ground source heat pump system. The north is rich in solar energy, but it is difficult to restore the underground temperature field on the same day by using solar energy to recharge. So, to increase the buried pipes' heat taken amount during the winter heating period, we have to store heat by using the abundant solar energy resources in summer and transition seasons (Liu 2016).

The physical parameters of materials in Shijiazhuang are shown in **Table 2**.

The study is shown in **Table 3**.

Establish grids under different intervals of buried pipes and temperatures of return water, and set up boundary conditions. During heat storage, for all the models, the temperature of the entering water is 90 °C, and the heat storage lasts 5880 hours (245 days); During heat taken, it lasts 2880 hours (120 days) according to different heat taken conditions. In these two processes, the UDF program is loaded, which is convenient to control the time of solar illumination. This process can't stop until the heat storage and heat taken process achieve balance. And then, we will analyze the effects of different situations on the results.

ANALYSIS OF NUMERICAL SIMULATION RESULTS UNDER DIFFERENT CONDITIONS

Comparison and Analysis under Same Buried Pipe Intervals but Different Heat Taken Conditions

From **Figs. 3-5**, we can know: for the case where the buried pipe interval is 2m, whether from the end of the first year's heat taken process or after the state where the system's heat storage and heat taken is relatively stable, when the temperature of the return water is 30°C during the heat taken process, the soil temperature is relatively low after each year's heat taken process; for the case where the buried pipe interval is 3 m, for the first two years, when the temperature of the return water is 35 °C during the heat taken process, the soil temperature is relatively low , and as time goes by, when the system is balanced and the temperature of the return water is 30 °C, the soil temperature is relatively low after the end of the heat taken process; for the case where the buried pipe interval is 4 m, whether from the end of the first year's heat taken process or after the state where the system's heat storage and heat taken is relatively stable, when the temperature of the return water is 30 °C, the soil temperature is relatively low after the end of heat taken process. Therefore, in actual projects, when the interval between buried pipes is 2 m, 3 m, and 4 m, during the heat taken process, the temperature of the return water should be 30 °C.

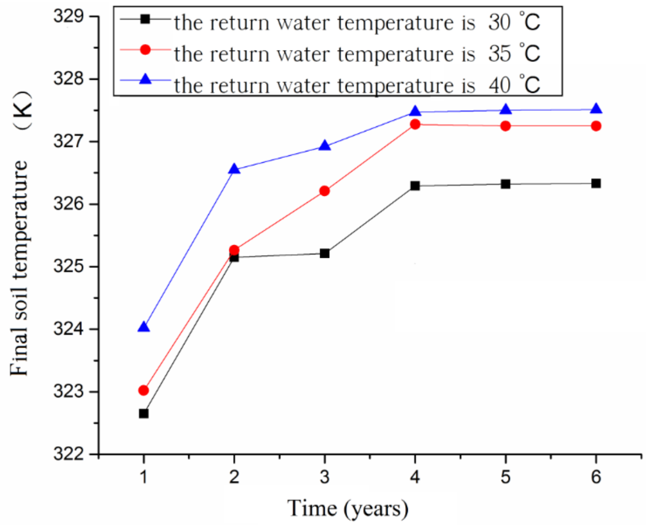

Fig. 3. The buried pipe interval is 2 m

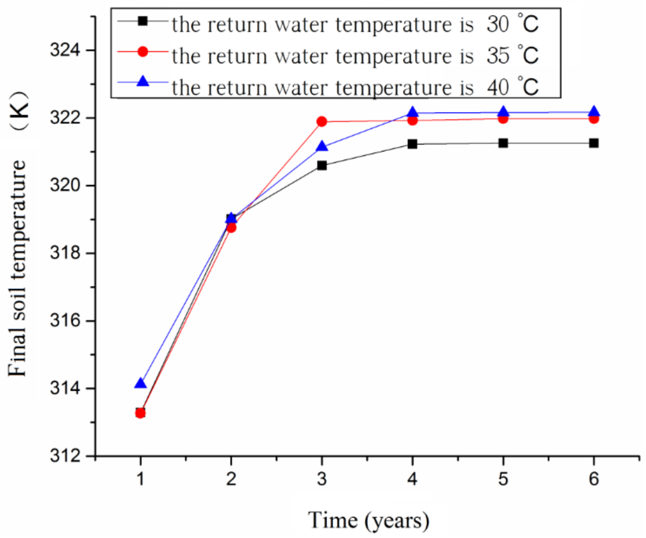

Fig. 4. The buried pipe interval is 3 m

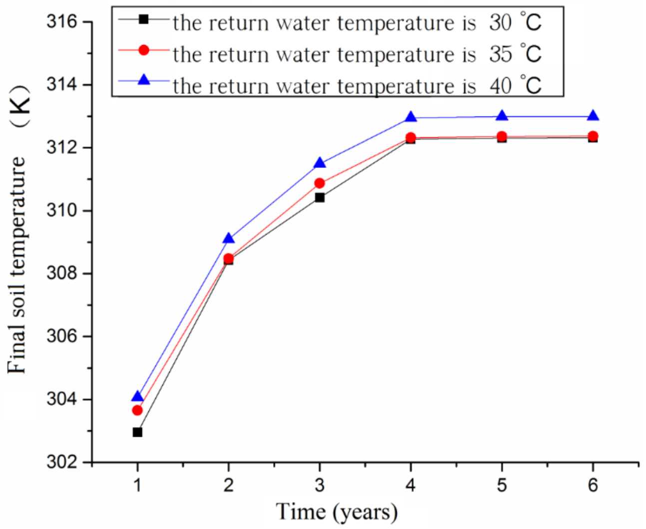

Fig. 5. The buried pipe interval is 4 m

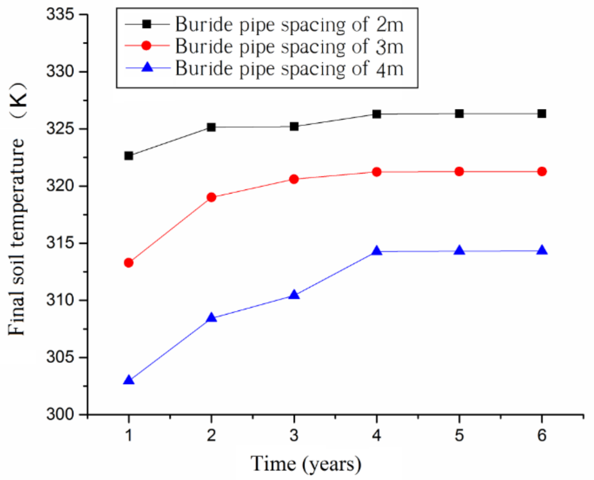

Fig. 6. The return water temperature is 30 °C during the heat taken process

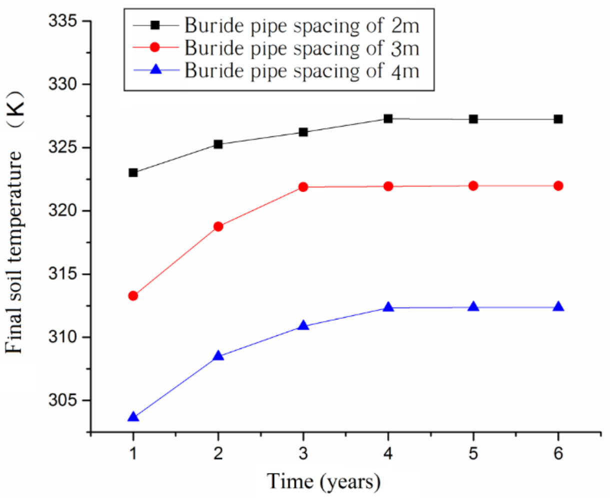

Fig. 7. The return water temperature is 35 °C during the heat taken process

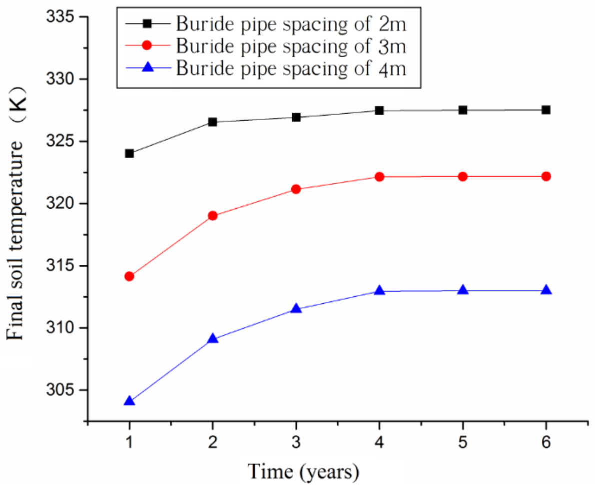

Fig. 8. The return water temperature is 40 °C during the heat taken process

Comparison and Analysis of Heat Storage and Heat Taken Under Same Heat Taken Temperature but Different Buried Pipe Intervals

From **Figs. 6-8**, we can know that the trend is basically same for the three situations with different return water temperature during the heat taken process, namely, the soil temperature is relatively high when the buried pipe interval is 2 m, and the soil temperature is relatively low when the buried pipe interval is 4 m.

Table 4. The specific values of the heat taken and storage amount

Time (years)	The return water temperature is 30 ℃			The return water temperature is 35 ℃			The return water temperature is 40 ℃		
	2m	3m	4m	2m	3m	4m	2m	3m	4m
	Calorie intake（GJ）								
1	106.53	116.79	65.01	104.14	112.09	62.15	101.75	105.43	59.00
2	117.2	132.4	129.28	115.96	124.28	128.48	112.84	120.12	124.24
3	123.6	137.2	146.48	121.28	128.76	133.88	119.28	126.36	128.68
4	129.68	147.72	151.28	131.52	136.84	140.12	127.2	132.84	136.4
5	135.92	149.64	152.48	134.24	141.8	144.96	131.04	137.72	140.72
6	136.32	149.92	153.2	135	142.64	145.88	131.52	138.32	141.48
	Heat storage(GJ)								
1	399	391.92	286.4	399	391.92	286.4	399	391.92	286.4
2	221.97	266.40	266.01	226.93	257.84	272.78	188.70	210.37	267.18
3	186.14	220.93	250.39	198.17	211.43	234.06	177.24	192.04	245.57
4	165.62	192.34	247.19	184.46	196.05	228.95	170.28	189.23	254.00
5	165.15	189.90	244.75	170.14	185.36	215.39	162.78	184.61	238.51
6	164.64	189.29	242.02	168.96	184.05	213.90	161.77	183.69	236.59

Analysis of Soil Equilibrium State

Either way, from the beginning of the first year's heat storage to the end of the heat taken, because the heat stored in the soil can't be taken out 100 percent, so the soil temperature is higher than the initial one. And it can be predicted that in the following years, the temperature of the soil will gradually rise. Because, during the heat storage process, only 90 ℃ hot water can be used to heat the soil, and as the temperature of the soil increases gradually, the difference between the temperature of hot water and the soil will gradually decrease. According to the heat transfer ratio equation, it can be seen that the higher the temperature difference between the two sides of the flat wall is, the greater the heat conduction ratio is, but when the temperature difference decreases, the thermal conductivity rate will decrease. Therefore, as time goes on, the soil temperature will gradually rise, and the soil heat storage capacity becomes worse and worse. However, during the heat taken process, the temperature of the entering water is low and it is considered to be a fixed water temperature, so, with the rise of the soil temperature, the temperature difference between the two sides of the buried pipe gradually expands, resulting in the increase of the thermal conductivity rate. In the process where the heat storage rate decreases while the heat taken rate increases, a balance will eventually be reached. The parameters appeared when the balance is achieved are the final effect of the system. So, the simulation data that we provide here only continues to the date when the system is balanced.

ANALYSIS OF HEAT STORAGE AND HEAT TAKEN AMOUNT

Heat storage amount is the annual heat amount stored in the soil, which reflects the soil heat storage capacity, while the heat taken amount is the annual heat amount that is taken from the soil to heat the building. The ratio of heat taken and storage is the ratio of heat taken to heat storage in a heat storage and heat taken period, which reflects the ability of the soil accumulation effect. The higher the ratio is, the less heat stored in the soil after the end of annual heat taken process is, that is, the heat amount that is taken out from the soil is large. The soil heat taken amount and storage amount can be calculated by the following formula:

$$Q = cm\Delta T$$

Q——quantity of heat, J

m——quality, kg

c——specific heat capacity, $J/(kg \cdot k)$

ΔT——difference in temperature, K

After six years' simulation, after calculation according to the above formula, the heat taken and storage amount of the whole model are listed in **Table 4**.

The ratio of soil heat storage and taken is the ratio of heat taken to heat storage of the system in a heat storage and heat taken period, which reflects the ability of the soil heat accumulation effect. The higher the ratio is, the less heat stored in the soil after the end of annual heat taken process is. With the increase of heat taken ability and the decrease of heat storage ability, the ratio of heat storage and taken will reach a relative equilibrium state. The system's heat storage and taken ratio is shown in **Figs. 9-11**.

From **Figs. 9-11**, it can be seen that for the three return water temperatures during the heat taken process, the maximum heat storage and taken ratio can be obtained when the interval between the buried pipes is 2m, so, the interval between the buried pipes is 2 m.

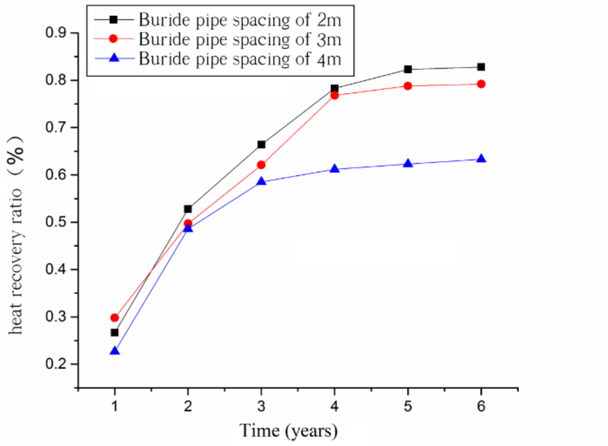

Fig. 9. The return water temperature is 30 ℃ during heat taken process

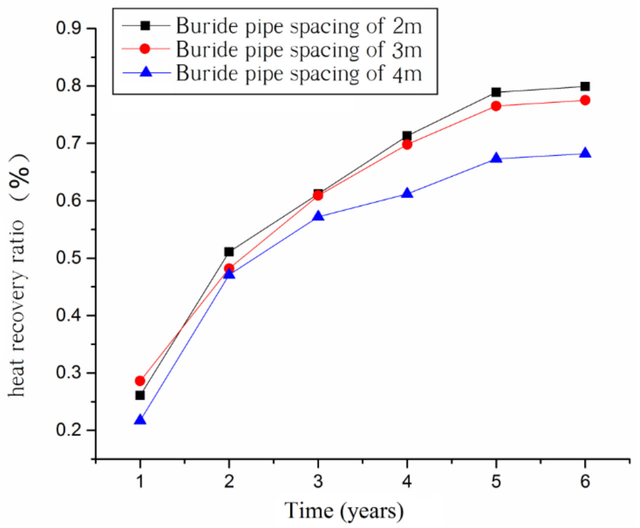

Fig. 10. The return water temperature is 35 ℃ during heat taken process

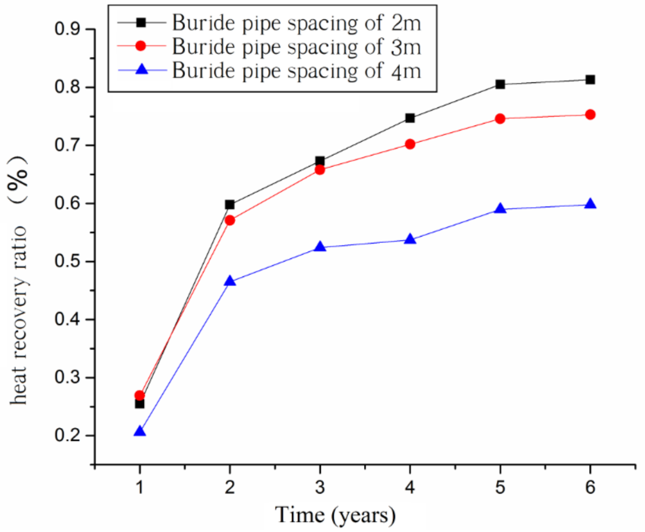

Fig. 11. The return water temperature is 40 ℃ during heat taken process

CALCULATION OF THE AREA OF THE SOLAR COLLECTOR PANEL

If heating a 300m^2 building, after taking the 10% energy consumption induced by the user and the 5% heat loss occurred in the pipeline during the heat taken process into consideration, we provide 15% heat surplus. If the index of building heat loss (the building adopts thermal insulation measures) is 50W / m^2, so the heat load of the 300m^2 building during the heating season is $300 \times 50 \times 120 \times 18 \times 3600 = 134.14GJ$. Therefore, the corresponding heat amount that has to be acquired from the soil is $116.64 \times 1.15 = 134.14GJ$. After simulation calculation, the soil heat taken and storage amount under different conditions when the system achieves relative stability have been given. After taking the energy loss occurred in the solar energy storage process into account, the writer provides 10% surplus. Through the manual, the total area of direct system solar collector can be calculated by the following formula:

$$A_c = 1.1 \times \frac{Q_f}{J_T \eta_{cd}(1-\eta_L)}$$

A_c——total area of the direct system collector, *m²*

Q——the amount of heat the system requires from solar energy each year, MJ

J_T——average annual total solar radiation over the lighting area of local collectors, *MJ/m²*

η_{cd}——collector hear collection efficiency based on total area, %

f——solar energy guarantee rate, %

η_L——heat loss rate of pipe and heat storage unit, %

In the process of calculating collector area in direct system, the solar energy guarantee rate of cross-season energy storage system is 1 (Ye 2010). Annual mean total solar radiation on the lighting surface of collector in Shijiazhuang is 4800-5200MJ/m^2, and the value for the system is 5 000 MJ/m^2. According to the experience value, the collector's heat collection efficiency should be 0.25-0.55, and the value for the system is 0.48. According to the experience value, the heat loss of the pipeline should be 0.20-0.30, and the value for the system is 25% (2011).

Compared with the direct system, the indirect system has higher operating temperature. The reason is the existence of the difference of heat transfer temperature of the heat exchanger, which decreases the efficiency of the collector. Therefore, the collector area of indirect system needs to be compensated. According to the *Technical Manual for Solar Water Heating Systems in Civil Buildings*, the total area of solar collector in indirect systems is as follows:

$$A_{IN} = A_c \cdot \left(1 + \frac{F_R U_L \cdot A_c}{U_{hx} \cdot A_{hx}}\right)$$

A_{IN}——total area of indirect system collector, *m²*

A_c——total area of the direct system collector, *m²*

$F_R U_L$——collector total heat loss, *W/(m²·℃)*, plate type collector take 4~6, vacuum tube collector take 1~2, the specific value should be based on the test results of the collector product;

U_{hx}——heat transfer coefficient of heat exchanges, *W/(m²·K)*; steel-plate tube of volumetric water heater with diversion type 616~945, copper coil 680~2200; volumetric water heater steel tube 326~349, copper coil 384~407; semi volumetric water heater steel tube 733~942, copper coil 814~2000;

A_{hx}——heat transfer are aof indirect system Heat Exchanger, *m²*.

The heat transfer area of a solar water heater may be determined by the following formula:

$$A_{hx} = \frac{C_r Q_z}{\varepsilon U_{hx} \Delta_{t_j}}$$

A_{hx}——heat transfer area of water heater, *m²*;

Q_z——heat from solar collector systems, *W*

U_{hx}——coefficient of heat transfer, *W/(m²·K)*;

ε——scaling influence coefficient, *0.6~0.8*;

Δ_{t_j}——it can generally be determined according to the performance of the heat collector desirable 5~10, Collector performance good temperature difference take high value, otherwise take low value;

C_r——heat loss coefficient of hot water system, *1.1~1.2*;

In the process of calculating collector area in indirect system, the total heat loss coefficient of collector is calculated according to vacuum tube collector, and 1.8 is used in this paper. The heat transfer coefficient of the heat exchanger is calculated according to the steel tube of the volumetric water heater, and 340W/(m^{2}K) is used in this paper. The scaling coefficient takes 0.6, and the temperature difference value Δ_{t_j} takes 6 ℃, and the heat loss coefficient of hot water system takes 1.2.

Thus, the area of solar panels required for direct and indirect systems under different circumstances is shown in **Table 5**.

Table 5. The area of solar collector under different circumstances

Return water temperature during heat taken process (°C)	**30°C**			**35°C**			**40°C**		
Buried pipe spacing (m)	2m	3m	4m	2m	3m	4m	2m	3m	4m
Ration of heat taken and storage (%)	0.828	0.792	0.633	0.799	0.775	0.682	0.813	0.753	0.598
The heat provided by solar collectors and needed by the system each year (GJ)	178.2	186.3	233.1	184.7	190.4	216.4	181.5	196.0	246.7
Direct system solar collector area (m^2)	108.9	113.9	142.5	112.9	116.4	132.2	110.9	119.8	150.8
Indirect system heat exchanger area (m^2)	5.6	5.9	7.3	5.8	6.0	6.8	5.7	6.2	7.8
Indirect system solar collector area (m^2)	120.1	125.5	157.1	124.4	128.3	145.8	122.3	132.0	166.3

Table 6. The depths of buried pipes under different conditions

Return water temperature during heat taken process (°C)	**30**			**35**			**40**		
Buried pipe spacing (m)	2	3	4	2	3	4	2	3	4
Buried pipe depth (m)	26.77	28.16	23.00	25.59	26.22	23.60	25.36	24.71	20.07

It can be seen from **Table 5** that under different conditions, the spacing of buried pipes and the temperature of the return water during the heat taken process have some influence on the selection of the area of the solar collector plate. When the energy consumption of the building that has to be heated is certain, and the temperature of the return water during the heat taken process is certain, the required area of the solar collector plate for the system with 4m buried pipe spacing is relatively large and for the system with 2m buried pipe spacing is relatively small. In the case of the same buried pipe spacing, when the buried pipe spacing is 2m and the temperature of the return water during the heat taken process is 35 °C, the required area of solar heating plate is relatively large. And when the buried pipe spacing is3m and 4m, respectively and the temperature of the return water during the heat taken process is 40 °C, the required area of solar heating plate is relatively large.

Also, in either case, the heat provided by solar collectors and needed by the system each year is sufficient to meet the normal operation of the system, so the depth of buried pipes used in engineering practice is calculated by the following formula:

$$H = 35 \times \frac{q}{Q_z}$$

q——annual caloric intake after stable operation of the system, GJ

Q_z——heat from solar collector systems, GJ

Therefore, the corresponding depths of buried pipes under different conditions are shown in **Table 6**.

CONCLUSION

In engineering practice, whether direct or indirect systems, the most important thing besides considering the change of soil temperature after heat taken is to consider the use and utilization of resources. If a $300m^2$ building has to be heated, and the index of building heat loss is $50W / m^2$, the conclusions of this paper are as follows:

1) During the heat taken process, if the temperature of return water is 30 °C, the interval between buried pipes should be 2m. In this case, the area of solar collector plate required by the direct system and the indirect system is $108.9m^2$ and $120.1m^2$, respectively. And the depth of buried pipe is 26.77m.
2) During the heat taken process, if the temperature of return water is 35 °C, the interval between buried pipes should be 3m. In this case, the area of solar collector plate required by the direct system and the indirect system is $116.4m^2$ and $128.3m^2$, respectively. And the depth of buried pipe is 26.22m.
3) During the heat taken process, if the temperature of return water is 40 °C, the interval between buried pipes should be 3m. In this case, the area of solar collector plate required by the direct system and the indirect system is $119.8m^2$ and $132.0m^2$, respectively. And the depth of buried pipe is 24.71m.

ACKNOWLEDGEMENT

This paper is supported by the Shijiazhuang science and technology research and development program (Soft science): A policy study on the application of energy saving and solar heating in rural areas -- a case study of Shijiazhuang City (185230055A).

REFERENCES

Chang L (2013) Design of Cross-Season Solar Heating System. [Master thesis of Xi'an University of Architectural Science and Technology]. Xi'an: Xi'an University of Architecture and Technology.

Di B, Ma C, Zhang G (2010) Experimental Study on An Underground Thermal Energy Storage System Using Borehole Heat Exchanger. Journal of Engineering Thermophysics, 31(5): 813-816.

Han M (2007) Theoretical and Experimental Study on Solar-Ground Coupled Heat Pump with Seasonal Storage. Tianjin: Tianjin University.

Han M (2013) Heat Transfer Analysis of Buried Pipes Underground Seasonal Thermal. Shandong: Shandong Jianzhu University, 2-6.

Jin Z (2010) Design and Running Analysis of Solar PV System. [Master thesis of Hebei University of Technology]. Tianjin: Hebei University of Technology.

Li L (2008) The Present Situation and Prospect of Household Solar Photovoltaic Power Generation System. A View of Labour Unions. Theoretical Study, (10): 52-53.

Liu N (2016) Analysis of the Underground Heat Transfer of the Solar Energy Seasonal Thermal Storage with Buried Pipes and Its Application. Shandong: Shandong Jianzhu University, 2-4.

Ma T (2010) Preliminary Study on Fast and Efficient Solar Heat Storage with Biogas. Lanzhou. Lanzhou University of Technology.

Ma T (2015) The Study on the Performance of Hybrid Heat Exchanger GSHP System. Chongqing: Chongqing University.

Sun Z (2014) Numerical Model for Application Study of Ground Heat Storage Exchanger with Solar Energy Seasonal Storage. [Master thesis of Hebei University of Technology]. Tianjin. Hebei University of Technology.

Technical Specification for Ground-Source Heat Pump System (GB50366-2005) (2009) Beijing: China Architecture & Building Press.

Ye X (2010) The Study of Solar Fraction of Solar Assisted Ground-Source Heat Pump System. Dalian: Dalian University of Technology.

Yuan X, Gu X, Wang J (2011) Research Progress on the Assessment of China's Solar Energy Resource. Journal of Guizhou Meteorology, 35(5): 1-1.

Zhao W (2011) Simulation and Experimental Study on Parallel Solar-Assisted Heat Pump Hot Water system. Qingdao: Qingdao University of Technology.

Zhou M (2012) Numerical Simulation for Pipe Connection of Ground Heat Excharger with Solar Energy Seasonal Storage. Tianjin: Hebei University of Technology, 12-13.