Optimization design and compare of different solar-ground source heat pump system of office building in cold regions

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Abstract. This paper presents two different operation modes of Solar-Ground Source Heat Pump System (SGSHP(S)). With the simulation tool TRNSYS, two different SGSHP system models were built to taking simulation. After making analysis and compare of different simulation results, series operation mode was believed to be better than parallel in the target building.

1. Introduction

Since the industry revolution, the shortage of energy and the deterioration of environment have been the two serious problems in this era. If we can take full use of earth or solar energy could reduce the consumption of primary energy source greatly in building. The solar-ground source heat pump system (SGSHP(S)) with ground heat exchanger being as heat storage can effectively overcome the declining efficiency and stability of system which caused by intermittent and unstable solar energy. The solar collector in system can apply solar energy to retrieve the soil temperature decrease caused by longtime operation of ground heat exchanger. So SGSHP system may be a great potential system contributing to our destination of sustainable development.

Research of solar-ground source heat pump system started from 1950s by Penrod[1][2]. After the energy crisis in 1977, some countries like American put a lot of research fund into research of ground source heat pump and solar-ground source heat pump system [3-5]. During 1979-1981, solar-ground source heat pump system has been simulated by many researchers (Bose J E, Klein, Parker, etc) [7-9]. In 1996, M Inalli applied Matlab to take calculations of soil temperature and researched the relationships between soil temperature and factors such as solar collector area [12]. In 2003, Andrew D.Chiasson and Cenk Yavuzturk used TRNSYS to take simulations of (SGSHP(S)) for the first time. They took 20 years as the operating period to research the law of soil temperature variation, system cost, etc. in their simulation [14]. In 2006, Trillat tried to establish a solar-ground source heat pump system and the result of it seems good with COP being higher than 3.75 [17]. In 2009, Kjellsson established different operation modes of (SGSHP(S)) to research their performance based on real projects [20, 23]. In 2013, FarzinM.Rad proved that (SGSHP(S)) is suitable for cold region, but there

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exists a problem of imbalance soil temperature which should be solved by applying different operation modes [28].

SGSHP system has many kinds of operation mode, different modes lead to different COP and performance. This paper compared two kinds of main operation mode, in series and in parallel, to pick up the suitable mode for small office building in Beijing area.

(1) In series: heat-exchange fluid takes circular flow through the solar collector, ground heat exchanger, and finally the heat pump.

(2) In parallel: heat-exchange fluid flow through the solar collector and ground heat exchanger simultaneously, then converge into the heat pump.

Taking a small office building as target to research the SGSHP(S) optimization under different coupling-mode conditions based on the building type, features of loads, local climate, and solar/geothermal energy resources, this paper uses TRNSYS to simulate the operation of SGSHP(S) in two operation modes in consideration of the coupling relationship between system design and operation mode. Based on the simulation results, get the final conclusions.

2. Preliminary design of SGSHP(S)

2.1 Object building and load calculation
2.1.1. Introduction of object building and region
The object building researched in this paper is located in north third ring road of Beijing which belongs to cold region. Dry and cold in winter, rainy and hot in summer, along with short transition season, are the characters of this region. The object building is a new small office building with construction area of 4509 m^2 and heating area of 3800m^2. The main building has four layers on the ground with height of 17.3m. The podium building has two layers on the ground with height of 8.05m. In main building, there are hall, conference room, control room and office, etc. on the ground floor; conference room and office, etc. on the first floor; office, etc. on the second floor; meeting room and office, etc. on the third floor. In podium building, the ground floor serves for refrigeration machine room and the first floor serves for multi-function room.

2.1.2. Load calculation
Energy simulation software DeST-C is applied to get the full-year heating load of this building as 238834.88kWh and cooling load as 155118.74 kWh. Because the type and characters of office building, it is required to keep 5℃ indoor in winter night but no need of air conditioning in summer night. As the result of this operation mode, the annual accumulative cooling load takes only 65% of heating load. Based on the calculation results of load, we take the following indicators to make preliminary design of air conditioning system in this building: maximum heating load as 250kW and maximum cooling load as 210kW.

2.2 Equipment selection and TRNSYS model building
TRNSYS simulation software is a dynamic simulation program based on modules. A complete system is composed of many small modules with different functions. Simulation of the system can be performed by invoking modules required and inputting the required parameters [21, 24, 26].

We choose the Flat-plate solar collector (Type 1 in TRNSYS) with liquid propellant working medium to collect solar energy which exchange heat indirectly (According to *Technical code for solar heating system GB 50495-2009*) [11]. It will be put on the roof of main building and podium building, facing south with fixed angle of 50 °. We choose heat storage water tank (Type 4) as the seasonal heat storage facility.

Fan coil plus fresh air system is used as the end form of system combined with consideration of the building type [16, 25].

Comprehensively consider about the climate condition, geological condition and useable area of this project, we select the ground heat exchanger with single U-shaped vertical buried tube (Type 557)

instead of horizontal buried tube to take the heat exchange work of ground in order to get a better performance on heat-exchange. Because the vertical buried tube can get more stable heat-exchange progress away from the influence of environment. After taking an estimated calculation and empirical estimation, we decided that tubes to be buried 100 meters deep with 5 meters far from each other. And external diameter of the buried tubes is 32mm.

According to the calculation results of load, we choose water -water single-stage pumps (Type927) to carry the loads [16, 25]. There are two kinds of control signal of this module which controls heating and cooling. The heating control is prior to the cooling control. TRNSYS will active the subroutine of heating and power consuming automatically when the heat pump starts to work.

To avoid frequent start-stop problems of water pump and heat pump, this project use the differential controller (Type2) to control temperature. To take control of time, we choose the time step function module (Type14). And we also take the Manifold/ Siamese module (Type11) to help finish our work.

3. Establishment of series and parallel modes of SGSHP(S)

There are many kinds of operating modes of Solar—Ground Source heat pump system. From the point of system connection, series and parallel connection types are mainly be used. In series connection mode, heat-exchange fluid takes circular flow through the solar collector, ground heat exchanger, and finally the heat pump. In parallel connection mode, heat-exchange fluid flow through the solar collector and ground heat exchanger simultaneously, then converge into the heat pump.

3.1 Series operation mode

In series operation mode: heat-exchange fluid takes circular flow through the solar collector, ground heat exchanger, and finally the heat pump (Shown as Figure 1). Under series operation mode, solar energy can be stored into ground heat accumulator to keep balance in absorbing and releasing of soil heat when the solar energy being sufficient.
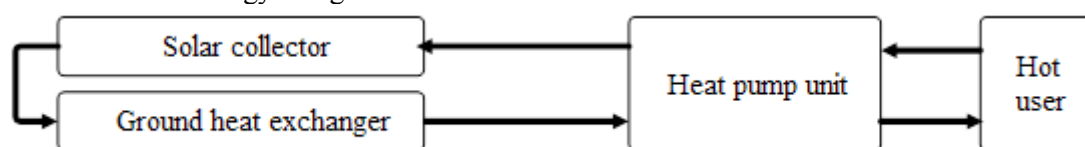

Figure 1 Function diagram of series mode

3.1.1. Operating conditions in different seasons

(1) In winter

Heat-exchange fluid flow through the solar collector first, then ground heat exchanger, and finally provides heat for heat pump as heat source. (In the right parts of the following Figure 2, takes the red lines marked No.1 in winter instead of the blue lines marked No.2.)
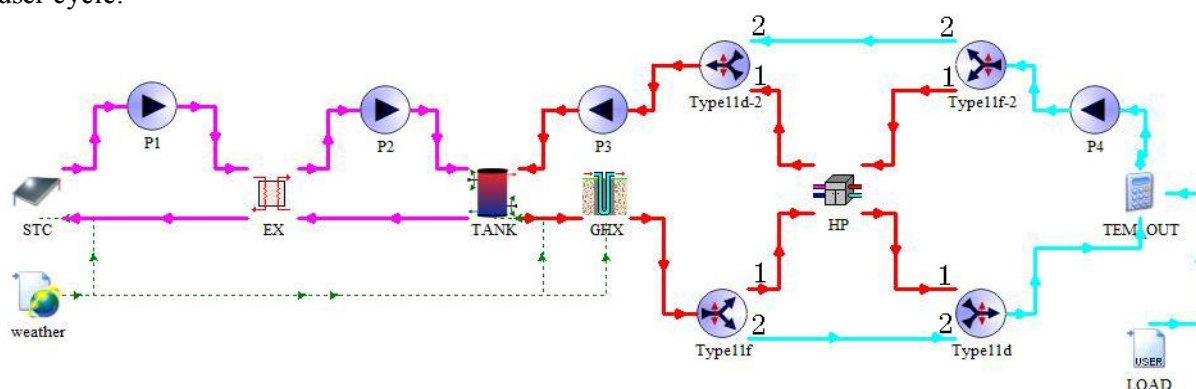
(2) In summer

Solar collector only absorbs heat in summer so it is always being closed during summer. The ground heat exchanger plays the role of the only cold source for heat pump. The left side parts of TANK (Founded in the following Figure 2) will be closed in summer.(In the right parts of the following Figure 2, takes the red lines marked No.1 in summer instead of the blue lines marked No.2.)

(3) In transition seasons

Heat load in transition seasons is small so it can be removed off only by the output water of ground heat exchanger without opening heat pump. The left side parts of TANK (Founded in the following Figure 2) will be closed in transition seasons. (In the right parts of the following Figure 2, takes the blue lines marked No.2 in transition seasons instead of the red line marked No.1.)

3.1.2. Main module connection of series operation mode

The main modules in TRNSYS as well as their connection form in series operation mode are shown in Figure 2. The main used modules are as below: meteorological parameter module(Type15); simple calculation module of soil temperature(Type77); flat-plate solar collector module(Type1); single-stage water pump module (Type3); convection heat exchanger module (Type5); heat storage water tank module (Type4); ground heat exchanger of single U-shaped buried tube module (Type557); Manifold/Siamese module (Type11); water-water source heat pump unit module (Type927); calculation module; date file reader (Type9).From the illustration diagram of series mode constructed in TRNSYS, there are five cycles in the system operating process yearly: first cycle of solar collection, second cycle of solar collection, buried tubes-heat pump cycle, heat pump-user cycle, buried tubes-user cycle.

Notes: Solid lines in figure represent fluid cycle; Dotted lines in figure represent the input of external weather conditions.

Figure 2 Illustration diagram of series mode constructed in TRNSYS

3.2 Parallel operation mode

In parallel operation mode: heat-exchange fluid flow through the solar collector and ground heat exchanger simultaneously, then mixes in Siamese and flow into the heat pump finally (Shown as Figure 3). In the daytime with sufficient solar energy, we can increase the flow of heat-exchange fluid in solar collector if the water temperature from the output of solar collector is high. It can reduce the heat load carried by ground heat system which does benefits for the soil temperature maintenance. Conversely, in the operating time without sun, we can close the solar collector system to improve the operating efficiency of the whole system.
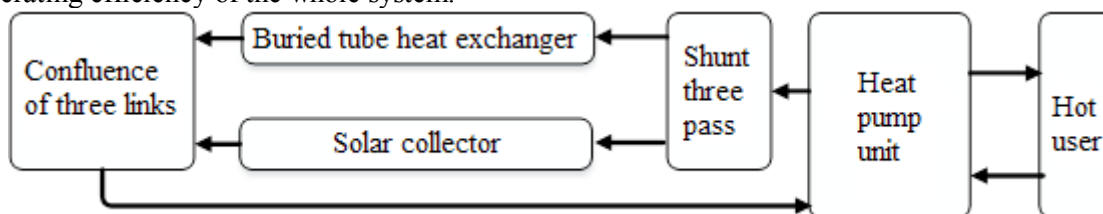

Figure 3 Function diagram of parallel mode

3.2.1. Operating conditions in different seasons

(1) In winter

When the temperature of output water of solar collector higher than that of ground heat exchanger, heat-exchange fluid flow through the solar collector and ground heat exchanger simultaneously, and finally provides heat for heat pump as heat source (In the right parts of the following Figure 4, takes the red lines marked No.1 in winter instead of the blue lines marked No.2.). When the temperature of

output water of solar collector lower than that of ground heat exchanger, solar collector will be shut down, heat-exchange fluid flow through the ground heat exchanger only, and finally provides heat for heat pump as heat source (In the right parts of the following Figure 4, takes the red lines marked No.1 in winter instead of the blue lines marked No.2. In the left parts of the following Figure 3.4, the purple red lines marked No.2 will be closed in this case).
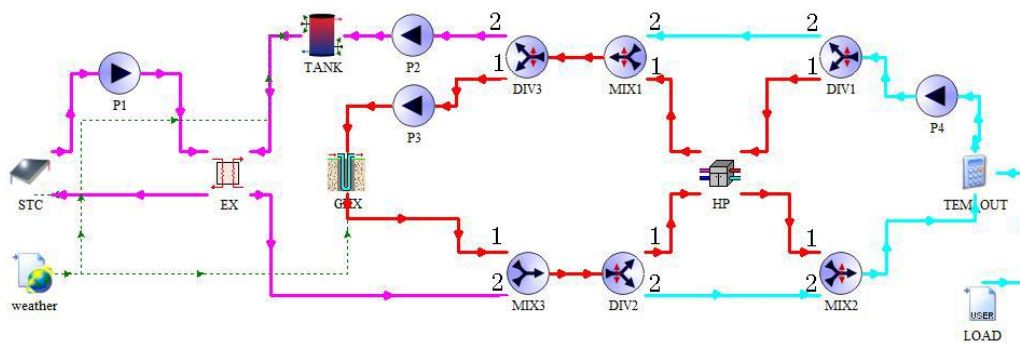
(2) In summer

Parallel operation mode in summer is as same as the series mode (refer to *3.1.1*). Solar collector will be shut down. All the left side parts represented by purple red lines (Founded in the following Figure 4) will be closed in summer. (In the right parts of the following Figure 4, takes the red lines marked No.1 in summer instead of the blue lines marked No.2.)

(3) In transition seasons

Parallel operation mode in transition seasons is as same as the series mode (refer to *3.1.1*). All the left side parts represented by purple red lines (Founded in the following Figure 4) will be closed in transition seasons. (In the right parts of the following Figure 4, takes the blue lines marked No.2 in transition seasons instead of the red lines marked No.1.)

3.2.2. The parallel operation mode main module connection

The main modules in TRNSYS as well as their connection form in parallel operation mode are shown in Figure 4. The main modules and five operating process cycles in parallel mode are the same as those in series mode.

Notes: Solid lines in figure represent fluid cycle; Dotted lines in figure represent the input of external weather conditions.

Figure 4 Illustration diagram of parallel mode constructed in TRNSYS

4. Indicators and variables

In order to get the optimal operation mode of SGSHP(S), this section takes simulations of two different operation modes in series and in parallel connection separately based on the fore part. In each mode, we will evaluate the system performance from two indicators (accumulated system operation COP and temperature of soil) by changing the area of the solar thermal collector and the number of vertical ground heat exchanger tubes. Besides of these two indicators, we also take an economic indicator called LCC (Life Cycle Cost) into consideration. Finally, we will conclude the optimal operation mode by comparing the results.

4.1 Accumulated system operation COP

COP (Coefficient of Performance) refers to the ratio of operational heat (cold) load and operational input power. Accumulated system operation COP in this paper refers to the ratio of accumulated

operational heat (cold) load and operational input power from the system beginning to the time point of making calculation.

$$Accumulated\ system\ operation\ COP = \frac{Operational\ Heat\ (Cold)\ Load\ (accumulated\ from\ beginning\ to\ end)}{Operational\ Input\ Power\ (accumulated\ from\ beginning\ to\ end)}$$

4.2 Average temperature of the ground heat accumulator
Ground heat accumulator refers to the cylindrical soil at the place of vertical ground heat exchanger including the tubes. Temperature can be considered as a uniformly distribution inside the ground heat accumulator but being as a radial-gradient distribution outside due to the effect of ground heat exchange. Computational method of the ground heat accumulator's volume shows as below:

Volume of ground heat accumulator=π×number of tubes×depth of tubes×(0.525×distance between tubes)^2 (1)

In the equation:
    Depth of tubes——100m;
    Distance between tubes——5m;
The average temperature of the ground heat accumulator derives from the output 3 of module Type557 in TRNSYS.

4.3 Life cycle cost LCC
LCC means the whole cost during the whole life of an equipment or a system. Initial investment (IC), operation cost (OC) and disposal cost (DC) are all included. The mathematical model of LCC in this system would be expressed as below:

$$LCC = IC + \sum_{k=1}^{n} OC(1+i)^{-k} + DC(1+i)^{-n} \qquad (2)$$

In the equation:
IC——Initial investment (equipment fee, installation fee, bore-hole fee)
OC——Operation cost (maintenance and operating fee)
DC——Disposal cost(ignored in this case because of only 20-year operating simulation)
k——Time of equipment operating (year)
n——Economic life period of system (year)
i——Discount rate (estimated as 8%)

Maintenance fee (MF) here is estimated as 10% of depreciation expense (DE)
$$MF = 10\% \times DE \qquad (3)$$
$$DE = IC \times ADR \qquad (4)$$
$$ADR = [(1 - ENRV)\ /\ DL] \times 100\% \qquad (5)$$

In the equations:
ADR——Annual depreciation rate
ENRV——Estimated net residual value (estimated as 4%)
DL——Depreciable life (20 years in this case)
    Economic indicator LCC is a subsidiary indicator in this paper to support the analysis, so we do not expand introduction of detailed specific calculation values here.

4.4 Variables settings

Optimal design of the SGSHP(S) combined with the operation mode analysis is the final purpose of this research. Based on the overseas study work, area of the solar thermal collector and length of vertical ground heat exchanger as well as their coupled relationship exert the most influence on the performance of system. Now being convenient for calculation, we take the area of solar thermal collector and the number of vertical ground heat exchanger tubes as variables to make optimal system design. The number of vertical ground heat exchanger tubes ranges from 40 to 80 at step of one tube. The area of solar thermal collector changes to make sure that solar fraction ranges from 0% to 50% at step of ten percents.

Table 1 Solar collector system variables settings

Solar fraction (%)	0	10	20	30	40	50
Area of solar thermal collector (m^2)	0	163	325	490	650	815
Volume of water tank (m^3)	0	8	16	24	33	41
Area of plate heat exchanger (m^2)	0	1.80	3.59	5.39	7.18	8.98
Flow of cycle pump (m^3/h)	0	1.63	3.30	4.90	6.50	8.15

5. Results and discussion

In this section, we will take twenty-year simulations of SGSHP(S) in series and parallel connection modes separately by TRNSYS. Based on the results of accumulated system operation COP and temperature change of soil (two kinds of results: after 20-year operating period and during 20-year operating period), we make the analysis and discussion.

5.1 Analysis of series operation mode
In this section, we will make simulations to figure out the accumulated system operation COP of the SGSHP(S) and soil temperature after operating system in series mode for 20 years, results from TRNSYS shown as below.
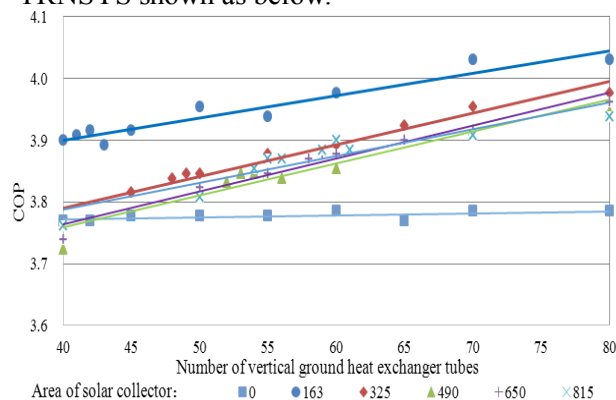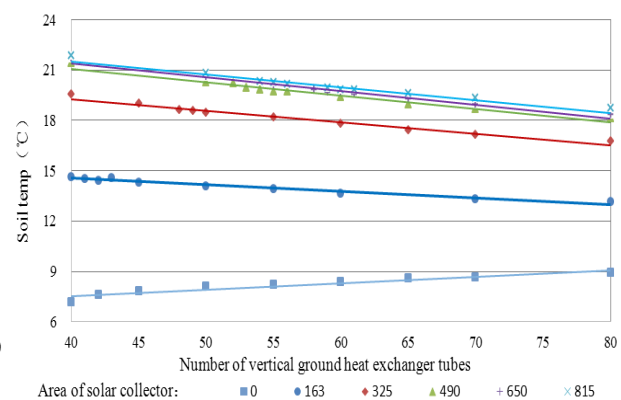

Figure 5. (a)Accumulated system operation COP   Figure 5. (b)Soil temperature

Figure 5 Accumulated system operation COP and soil temperature after 20-year operating in series mode

From the Figure 5.(a) we can see that functioned solar collector in system can improve the COP up to 7% under the chosen condition of solar collector area and ground heat exchanger tubes, but increase the area of solar thermal collector larger than 163m^2 does not bring improvement of the accumulated system operation COP in series operation mode efficiently for a longtime. So, 163m^2 would be the most preferable area of solar collector to get the peak accumulated COP. To make analysis of it, if the area of solar collector being larger than 163m^2, the temperature of heat-exchange water must be higher than that of 163m^2 which may influence the soil temperature more heavily. And the increase of soil temperature with increasing area of solar collector has been proved in Figure 5. (b). If the soil

temperature being higher than that one at area of solar collector being $163\,\mathrm{m}^2$, the effect on cooling process may be stronger than that on heating process throughout the whole year which will result in the decrease of system COP. Another conclusion from Figure 5. (a), accumulated system operation COP observed to rise in a long operating time with increasing number of ground heat exchanger tubes.

The average soil temperature of Beijing is 13.1℃. We can see that the soil temperature increases with the tubes number increasing without solar collector. It can also be considered as that the soil temperature decreases not so much compared to the average soil temperature of Beijing with the increasing tubes number. To make analysis of it, we should note that the heating load is far more than cooling load which has been calculated before. So the soil temperature will decrease in a long time without solar energy supply due to the difference between the releasing heat in summer and absorbing heat in winter. With the increasing number of ground heat exchanger tubes, the tubes become more and more crowded, so the heat cannot be released easily which will result in the increase of soil temperature (Same reason for Figure 9. (b)). And from the Figure 5. (b) we can conclude that increasing the area of solar collector will improve the soil temperature. But it will not cause an obviously ascending of the average temperature of ground heat accumulator in a longtime when the solar collector being larger than $490\mathrm{m}^2$. It may be due to the limitation of the heat conduction ability of soil.

Another conclusion from Figure 5. (b), amplitude of temperature variation reduces gradually with increasing number of ground heat exchanger tubes because that more tubes lead to larger volume of ground heat accumulator. And this conclusion may also be the reason for the rising of accumulated system operation COP in long operating time which mentioned before.

Taking economic factors into consideration, the LCC of system after 20-year operating in series is shown as below. From the figure, we can see that the LCC of system without solar collector is higher than that with solar collector area in $163\mathrm{m}^2$.The key reason of it is OC. OC of system without solar collector is higher due to the annually decrease of soil temperature which result from the lack of solar heat complement. By observing the variation of LCC in different solar collector areas, 60 seem to be a key number which should be noted to select the optimal number of vertical ground heat exchanger tubes.
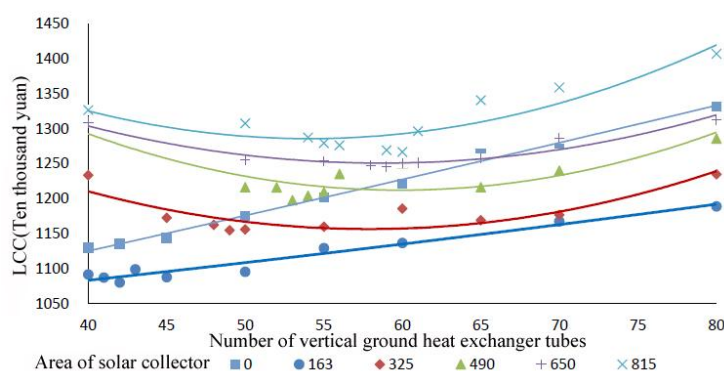

Figure 6 LCC of system after 20-year operating in series

On the basis of above analysis, area of solar thermal collector ranges from 0 to $325\mathrm{m}^2$ with the number of vertical ground heat exchanger tubes ranges from 40 to 60 may be considered as suitable choice for the system design. We will following choose 9 groups of variable settings which vary in different solar collector areas in $0\mathrm{m}^2$, $163\mathrm{m}^2$, $325\mathrm{m}^2$ along with different numbers of vertical ground heat exchanger tubes of 40, 50, 60 to take simulations and observe the results of accumulated system operation COP as well as change of soil temperature in 20-year period.
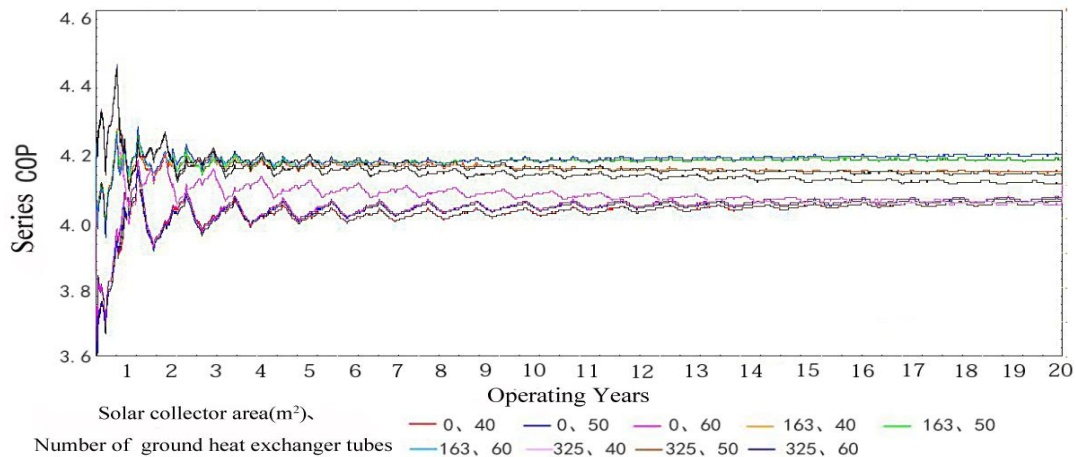
Figure 7 Fluctuation of accumulated system operation COP in series during 20-year operating period

In Figure 7, the accumulated system operation COP seems to change periodically by year which being lower in summer and winter. And in transition seasons, it will be higher due to the direct using of cycle water in ground heat exchanger tubes without operating the heat pump.

Operating in series connection mode, the accumulated system operation COP observed to be less fluctuant during the operating period and more stable after 20 years while the solar collector area being 163m^2. In the same time, we can see that the accumulated system operation COP being increased with increasing number of vertical ground heat exchanger tubes.

Notably the solar collector area being 325m^2 with the number of vertical ground heat exchanger tubes being40, accumulated system operation COP decreases sharply. It is probably resulted from significantly increase of soil temperature due to the excess solar heat input. If the solar heat input so much, the temperature of heat-exchange fluid throughout the heat exchanger tubes will be lifted up and this may result in the increase of soil temperature. This presage will be validated in the following part of the analysis about soil temperature variation. If the soil temperature increases, the useable temperature difference for heat pump system will be reduced in summer, it will decrease the COP of system in summer. And due to the releasing heat in summer is more than absorbing heat in winter based on the analysis before, COP of system throughout the whole year must be decreased for the increasing soil temperature.
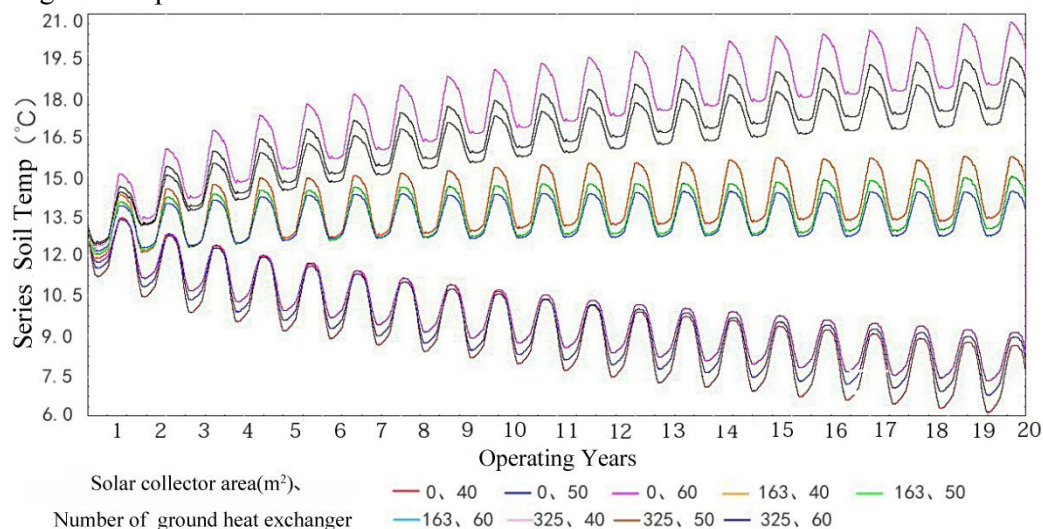

Figure 8 Variation of soil temperature in series during 20-year operating period

In Figure 8, the soil temperature seems to change periodically by year and being less fluctuant during the operating period while the solar collector area being 163m^2. If we do not operate solar system, soil temperature will decrease each year. If we choose the solar collector area as 325m^2, soil temperature will increases year by year owing to the overheat from sun. Especially with the number of ground heat exchanger tubes as 40, soil temperature increases sharply which can prove the presage of accumulated COP mentioned above.

We can also conclude from Figure 5.4 that soil temperature tends to be more stable when the number of ground heat exchanger tubes increase. It would also be a result of growing volume of ground heat accumulator.

5.2 Analysis of parallel operation mode
In this section, we will make simulations to figure out the accumulated system operation COP of the SGSHP(S) and soil temperature after operating system in parallel mode for 20 years, shown as below.
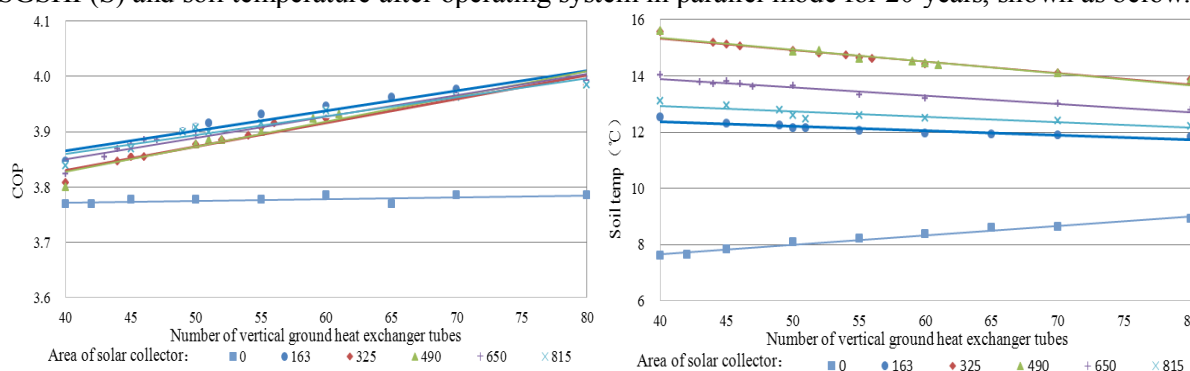

Figure 9. (a)Accumulated system operation COP   Figure 9. (b)Soil temperature

Figure 9 Accumulated system operation COP and soil temperature after 20-year operating in parallel mode

From the Figure 9. (a) we can see that functioned solar collector in system can improve the COP up to 5.8% under the chosen condition of solar collector area and ground heat exchanger tubes, but increasing the area of solar thermal collector does not result in improvement of the accumulated system operation COP in parallel operation model obviously for a longtime. But 163m^2 still be the most preferable area of solar collector to get the peak accumulated COP which can be observed.

Same with conclusion from series, accumulated system operation COP observed to raise in a long operating time with increasing number of ground heat exchanger tubes. And the values of accumulated system operation COP in different solar collector areas tend to focus on 4.02 finally.

The average soil temperature of Beijing is 13.1℃. From the Figure 9. (b), we get different conclusions from series mode. The soil temperature increases sharply with the solar collector area change from 0 to 325m^2, but increases no more than the peak amplitude (solar collector area in 325m^2) with the solar collector area increases from 490m^2 to 815m^2. The amplitude of calescence becomes smaller with the increasing area of solar collector. To make analysis of it, the reason should be the flow difference from series mode. Due to the increasing area of solar collector, the heat-exchange flow in solar collector will increase with the heat-exchange flow in ground heat exchanger decrease as a result. From the area 0 to 325m^2, the effect of rising temperature of heat-exchange fluid in ground heat exchanger tubes on soil temperature increasing is stronger than that effect of heat-exchange fluid decreasing in ground heat exchanger tubes. So the amplitude of calescence increases with the increasing area of solar collector. From the area 325m^2 to 490m^2, the effects on soil temperature variation from these two reasons may be offset with the increasing area of solar collector. Larger than 490m^2, the effect of heat-exchange fluid decreasing in ground heat exchanger tubes on soil temperature variation may be stronger, although the temperature of heat-exchange fluid is being rising

all the time. So the tendency of soil temperature variation becomes weak with the area of solar collector increasing larger than 490m^2.

Same with conclusion from series, amplitude of temperature variation reduces gradually with increasing number of ground heat exchanger tubes because that more tubes lead to larger volume of ground heat accumulator. And this conclusion may also be the reason for the rising of accumulated system operation COP in long operating time which mentioned before.

Taking economic factors into consideration, the LCC of system after 20-year operating in parallel is shown as below. From the figure, we can see the same phenomenon that the LCC of system without solar collector is higher than that with solar collector area in 163m^2 which due to the same reason as analyzed before in serious. By observing the variation of LCC in different solar collector areas, there seems no key number which should be noted to select the optimal number of vertical ground heat exchanger tubes that differs from serious mode. But we can see the LCC of system seems to increase more quickly after the number 55 of ground heat exchanger tubes. Considering of being matched with serious mode, we also choose the number 60 to be the maximum tubes number to make the following simulations.
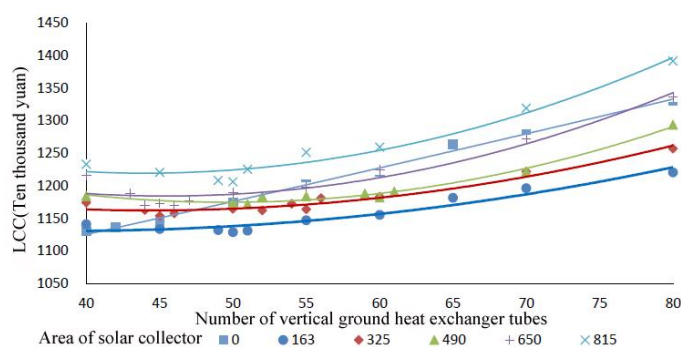

Figure 10 LCC of system after 20-year operating in parallel

On the basis of above analysis, area of solar thermal collector ranges from 0 to 325m^2 with the number of vertical ground heat exchanger tubes ranges from 40 to 60 may be considered as suitable choice for the system design. We will following choose 9 groups of variable settings which vary in different solar collector areas in 0m^2, 163m^2, 325m^2 along with different numbers of vertical ground heat exchangers tubes of 40, 50, 60 to take simulations and observe the results of accumulated system operation COP as well as change of temperature of soil in 20-year period.
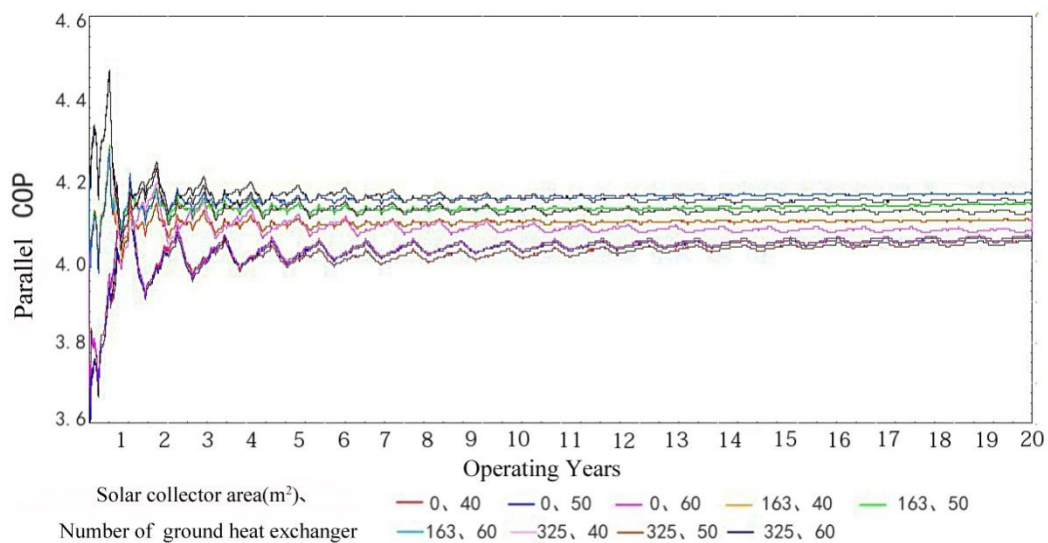
Figure 11 Fluctuation of accumulated system operation COP in parallel during 20-year operating period

In Figure 11, the accumulated system operation COP seems to change periodically by year which being lower in summer and winter. And in transition seasons, it will be higher due to the direct using of cycle water in ground heat exchanger tubes without operating the heat pump.

Operating in parallel connection mode, the accumulated system operation COP observed to be less fluctuant during the operating period and more stable after 20 years while the solar collector area being 163m^2. In the same time, we can see that the accumulated system operation COP increased with increasing number of vertical ground heat exchanger tubes.

Notably the same phenomenon as series connection mode, accumulated system operation COP decreases sharply under the condition of solar collector area being 325m^2 with the number of vertical ground heat exchanger tubes being 40. The reason of it is the same as series mode and can be validated in the following part of the analysis about soil temperature variation.
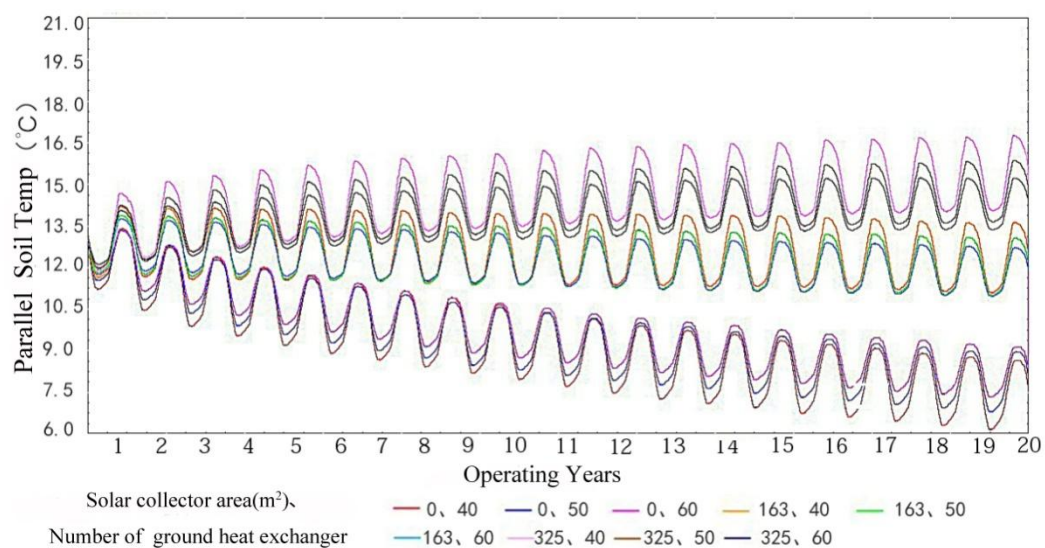
Figure 12 Variation of soil temperature in parallel during 20-year operating period
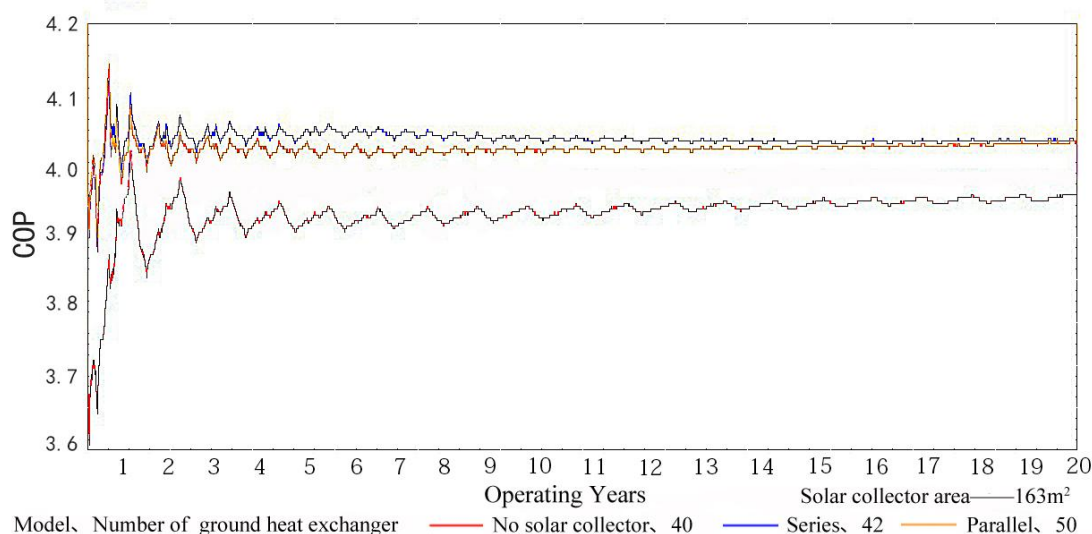
In Figure 12, the soil temperature seems to change periodically by year and being less fluctuant during the operating period while the solar collector area being $163m^2$. Its variation pattern is the same as that in series. But different from series mode, the soil temperature tends to be more stable than that in series because that there is no direct heat exchange between solar collector system and ground heat exchanger system.

5.3 Discussion and compare of series and parallel operation modes.

Based on an overall analysis and conclusion above, $163m^2$ should be the most preferable solar collector area in Beijing for both of series and parallel mode from all aspects of COP, soil temperature and LCC of system. Peak COP of system, lowest increase of soil temperature, most stable soil temperature variation and smallest cost of system, all of these will be realized in the choice of $163m^2$ compared to the other area choices.

And the best number of vertical ground heat exchanger tubes in series would be 42 while 50 in parallel. It can be find the proof from the economic analysis. In the analysis of COP and soil temperature, system perform better with the increasing number of the ground heat exchanger tubes, so we get two optimal choices of 42 in serious while 50 in parallel from the aspect of economy.

So we choose these two competitive modes in optimal area of solar collector and number of ground heat exchanger tubes to take simulations and figure out the optimal mode finally. The simulation results are as below:

Figure 13 Compare of accumulated system operation COP in series and parallel during 20-year operating period
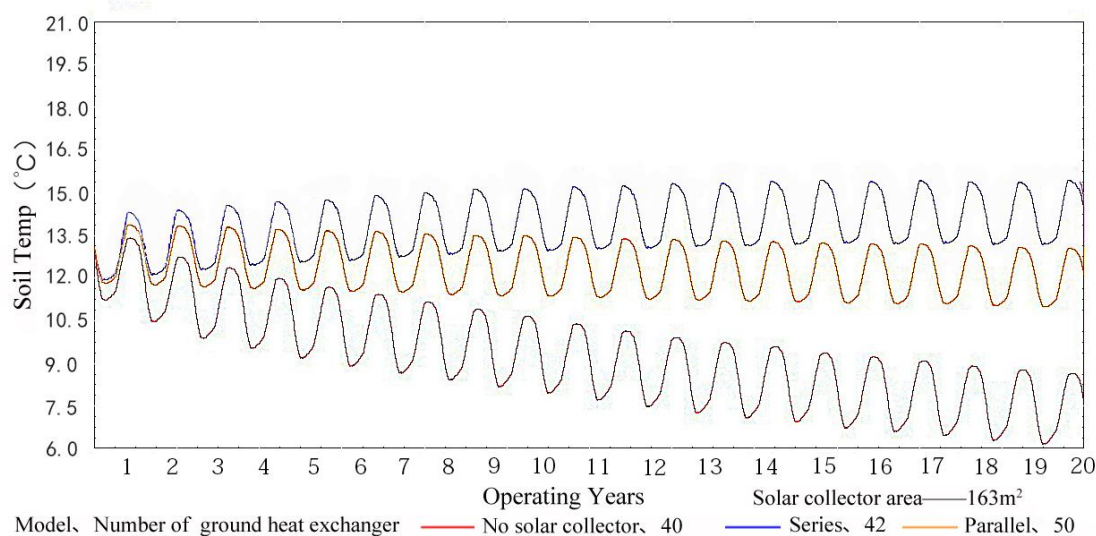
Figure 14 Compare of soil temperature in series and parallel during 20-year operating period

From the Figure 13, we can see the accumulated system operation COP in series is almost 5% higher than that in parallel in the first ten years. But in the later ten years, two of them come closer to each other.

From the Figure 14, we can see that the soil temperature in both of these two modes could make thermal equilibrium with environment. In series mode, soil temperature increases about 1℃ than the average soil temperature in Beijing. In parallel mode, soil temperature decreases about 1℃ than the average soil temperature.

Taking all of these conclusions into consideration, series mode performs better than parallel mode that would be the suitable mode of SGSHP(S) for the type of small office building in cold region which this paper researched in.

6. Conclusions

Two modes of SGSHP system, in series and parallel connection, were modeled and simulated using TRNSYS software in this paper. We took the area of solar collector and number of ground heat exchanger tubes as the variables to make 20-year simulations to get the following conclusions.

- Heat pump system with only heat (cold) source based geothermal energy is not suitable for the office building in Beijing area. It is necessary to take some actions to ensure the recovery of ground heat resource, or the soil temperature would decrease after system taking a longtime operation.
- In series connection mode, accumulated system operation COP increases first and then decreases while soil temperature increases all the time with the increasing area of solar collector. And both of accumulated system operation COP and soil temperature vary linearly with the increasing number of ground heat exchanger tubes.
- In parallel connection mode, there is no apparent change in accumulated system operation COP when the solar collector area increases with the soil temperature increasing first and then decreases. And both of accumulated system operation COP and soil temperature increase linearly with the increasing number of ground heat exchanger tubes.
- For all of the SGSHP system in office building in Beijing area, solar collector system should be subsidiary system in the whole system with appropriate solar fraction on 10%.

- Taking all of the indicators into consideration, the series mode performs better than parallel mode with the solar collector area in 163m^2 (10%solar fraction) and 42 ground heat exchanger tubes under the condition of office building in Beijing.

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