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Economic Performance Study on the Application of Ground Source Heat Pump System in Swine Farms in Beijing China

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Abstract

To investigate the economic performance of applying the ground source heat pump system in swine farms in Beijing China, initial investment and operating cost of ground source heat pump (GSHP) heating and cooling system, coal fired heating system (CFH), wet curtain fan cooling system (WCFC), air conditioner heating and cooling system (AC) were analyzed and compared. The results showed that the initial investment of GSHP heating and cooling system was higher than that of the CFH system integrated with WCFC system, the relative operating cost of the heating systems of GSHP, CFH and AC was 0.94, 1.00 and 0.98 , respectively. The relative operating cost of the cooling system of the GSHP, WCFC and AC system was 4.50, 1.00 and 6.38, respectively.

Key words: ground source heat pump; economic performance; swine farms; Beijing China

1. Introduction

The proportion of renewable energy sources is increasing every year in global energy consumption[1]. Renewable energy sources make a big difference in reducing greenhouse gases, improving energy security and promoting sustainable development[2]. As the largest developing country, because of the rapid economic development, China is facing with huge challenge in environmental pollution, energy shortage and climate

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change. The energy shortage is the most serious problem and the pressure is increasing on energy supply since the building energy consumption is growing year by year.

In 2009, the coal consumption is 26.65 million tons, and the ratio of renewable energy to the total energy consumption is 2.7% in Beijing. To save energy, reduce CO_2 emission and improve air quality, Beijing has made a Development Plan named Green Beijing, i.e., by 2015, coal consumption will be controlled within 20 million tons and the ratio of renewable energy to the total energy consumption will be 6%. Beijing is the first city of controlling the total coal consumption in China. The ground source pump system (GSHP) uses the natural heat storage capacity of the earth or ground water for energy-efficiently heating and cooling. A GSHP system does not directly produce combustion pollutants. A GSHP can actually produce more energy than intakes because the GSHP draws additional free energy from the ground. The reductions in energy consumption by 30–70% in the heating mode and by 20–50% in the cooling mode can be obtained. Energy savings are even higher when compared with fossil fuels, wood or electrical resistance heating systems[3].

In 2009, Beijing has had 18 million m^2 of buildings utilizing ground source pump system. It is expected that by 2015, the area of ground source pump system utilization will increase to 50 million m^2. The capacity and performance of shallow groundwater heat pumps in Beijing Plain area were evaluated by researchers[4-5],and the city government of Beijing has made a layout of feasibility of ground source heat pump in Beijing Plain, , swine farms in Beijing hereby can decide whether it is feasible in technique and policy to apply ground source heat pump[6].

Since July 1,2006, the buildings in Beijing utilizing ground source pump system for heating and cooling can be given an allowance of 5.55 to 7.93 US$ per square meter. Most swine farms in Beijing now use coal fired heating system (CFH), and few use air conditioner heating system(AC). In addition, most swine farms were not equipped with cooling system. Only a few of them have cooled swine houses with wet curtain fan cooling system (WCFC). However, swine houses in Beijing not only need to be heated in winter but also needed to be cooled in summer. GSHP technique had been applied in the Chinese solar greenhouse[7] and it has also been used in the only two swine farms in Hebei province, northern China[8]. However, GSHP application in swine farms has not been reported in Beijing and other countries.

The objective of this article was to investigate the economic performance of the GSHP to heat and cool swine farms in Beijing China by comparing with conventional methods.

2. Assessment of the economic performance of the GSHP system

2.1. Initial investment of the GSHP system in Beijing swine farms

To compare the economic performance of GSHP system with other conventional methods in Beijing, a swine house with an area of 920 m^2 in Beijing was used as an example. The indoor temperature was designed to be 20℃in heating period and no more than 28℃ in cooling periods. Heating capacity and cooling capacity were designed to be 94 kW and 91 kW, respectively. GSHP, CFH, AC and WCFC system were designed and analyzed. Technical parameters and initial investment of each heating and cooling method were shown in Table 1.

Table 1 Technical parameters and initial investment of each heating and cooling methods

Cooling system	Initial investment （US$）	Function	Heating /Cooling capacity	input power of cooling
GSHP	60262.9	Heating and cooling	91kw（cooling） 94kw（heating）	23.4kw(cooling system); 28.9kw(heating system)
CFH	15858.7	Heating		
WCFC	4377.0	Cooling		5.2kw
AC	16493.0	Heating and cooling	91kw	33.2kw

Table 1 shows that the GSHP system and AC system can both heat and cool swine houses. CFH system only can heat swine houses and WCFC system only can cool swine houses. As mentioned before, swine houses need to be heated in Winter and be cooled in Summer in Beijing. Thus, swine houses heated by CFH system need to be equipped with a cooling system.

As to initial investment for the cooling and heating systems, GSHP is higher than AC system, CFH system with a WCFC system. The initial investment of CFH system together with WCFC system was the lowest. Therefore, though GSHP system can save energy and reduce emission compared to CFH system[8], fund subsidies are necessary for applying GSHP system to swine farms due to its high investment.

2.2. Energy consumption and operating cost of the GSHP system in heating period

The annual heating cost of different heating mode is a function of the energy calorific value(CV_k), conversion efficiency(C_k) , and the price per unit energy(P_k). Assuming a GSHP was used for the swine house designed for this study, an annual heating days of 120 with heating duration of 14 hours per day, and a heating capacity of 94kw, the heat consumption of the swine houses was estimated to be 157920 kWh which is equal to 568512MJ. The price of coal and electricity was assumed to be 160 US$ per ton and 0.10 US$ per kWh respectively in the district designed for this study, thus, the price ratio of coal (US$ per ton) to electricity (US$ per kWh) was 1600.

Firstly, annual primary energy consumption of heating (E_{ch}) from GSHP, CFH and AC was determined by Calorific value(CV_k) of standard coal and electricity and energy conversion efficiency（C_k） of each heating system.

$$E_{ch} = \frac{568512 \times 1000}{CV_k \times C_k} \quad (1)$$

Secondly, total heating cost（THC） was calculated by Eq.(2).

$$THC = E_{ch} \times P_k \quad (2)$$

Except for initial investment of each heating and cooling method, operating cost of heating must be taken into consideration by the swine farmers. Table 2 shows the energy consumption and economic performance comparison results of heating between GSHP, CFH and AC during one heating year. The GSHP would need 48591 kWh to heat the swine houses as described above, the CFH would require an equivalent of 32.3 tons of standard coal, the AC would consume 50454 kWh. Taking the heating cost of CFH as a reference, then the relative heating cost of GSHP and AC to CFH was 0.94 and 0.98 respectively. The heating cost of GSHP was lower than CFH and AC.

The price of coal and electricity was not the same in different districts and times in Beijing. The price ratio of coal to electricity decides relative operating cost of the different heating systems comparison. In order to know which operating cost is lower between GSHP and CFH, total heating cost of GSHP and CFH was assumed to be equal, annual primary energy consumption of heating (E_{ch}) from GSHP, CFH and air conditioner were shown in Table 2, then the price ratio of CFH system to GSHP system was calculated. The GSHP system

heating cost was lower than CFH when the energy conversion efficiency C_k of GSHP system was equal to 3.25 and the price ratio of coal (US$ per ton) to electricity (US$ per kWh) was more than 1 503.

Table 2 Comparative economic analysis on operating cost of swine farm heating systems in Beijing

Heating systems	Calorific value(CV_k)， kJ	Energy conversion efficiency （C_k） [a]	Total energy consumption of heating(E_{ch})[b]	Energy price(P_k),US$[c]	Total heating cost(*THC*), US$	Relative heating cost
GSHP	3 600kWh^{-1}	3.25	48591 kWh	0.10 kWh^{-1}	4859.1	0.94
CFH	29 300kg^{-1}	0.60	32339kg	0.16 kg^{-1}	5174.2	1.00
AC	3 600 kWh^{-1}	3.13	50454 kWh	0.10 kWh^{-1}	5045.4	0.98

a The C_k values were from reference [9] and Table 1.
b Based on 568512 MJ that heating provided to swine houses with area of 920 m^2.
c Based on average exchange rate of 1.000 US$ to6.3057RMB from12 Dec. 2011 to7 May.2012[10].

2.3. Electricity consumption and operating cost of the GSHP system in cooling period

Each mode of cooling needs to consume electricity energy. The annual cooling cost of different cooling modes is significantly affected by the input power of cooling (*IPC)*. Using the above example swine house with a cooling capacity of 91kw, the input power of each mode of cooling was shown in Table 1.

Firstly, annual electricity consumption (E_{cc}) of cooling from GSHP, Wet-curtain Fan-cooling System and air conditioner cooling system was determined by input power of cooling (*IPC)* and cooling time of each cooling system. In Beijing swine farms, cooling time of each cooling system was assumed to be 10 hours in one day and 120days in one summer, thus, cooling time of each cooling system (*CD*) was 1200 hours.

$$E_{cc} = IPC \times CD \tag{3}$$

Secondly, total cooling cost（*TCC*） was calculated by

$$TCC = E_{cc} \times P_k \tag{4}$$

Table 3 shows the economic performance by comparison results between GSHP, WCFC and AC cooling system during one cooling year. The GSHP,WCFC and AC cooling system would need 28080 kWh, 6240 kWh and 39840 kWh respectively to cool the swine houses as described above. Assuming the price of electricity is 0.10 US$ per kWh, the cooling cost for GSHP, WCFC and AC cooling system for a summer was 2894.5 US$, 643.2 US$ and 4106.8 US$ respectively. Using the cooling cost of WCFC as a reference, then the relative cooling cost of GSHP and AC to WCFC cooling system was 4.5, and 6.4, respectively. The cooling cost of GSHP was lower than AC, but higher than WCFC, the operating cost of WCFC was the lowest among the three cooling methods.

Table 3 Comparative economic analysis on operating cost of swine farm cooling systems in Beijing

Cooling system	Cooling capacity	input power of cooling	Energy consumption of cooling E_c (kW)	cooling cost(US$)	Relative Running cost
GSHP system	91kw	23.4kw	28080	2894.5	4.50
Wet curtain Fan cooling System(WCFC)		5.2kw	6240	643.2	1.00
Air conditioner(AC)	91kw	33.2kw	39840	4106.8	6.38

3. Discussions

According to economic performance analyzing of three heating and cooling system, we know that the initial investment and operation cost of cooling of GSHP was the highest among the three heating and cooling systems. So, we can conclude that GSHP system was difficult to be accepted by swine farmers without fund subsidy by the government at present in Beijng.

Whereas, WCFC system causes air-cooling in the swine houses but at the same time, it causes an increase in humidity[11] .This is usually acceptable in regions with hot-dry climates, but in wet regions or in hot-wet days, due to the adverse effects on indoor humidity, WCFC system cannot cool the swine houses effectively in fact. GSHP system and AC systems can avoid an increase in humidity in swine houses. In addition, GSHP system does not produce PM2.5 while CFH system can produce PM2.5 in heating periods. At present, Beijing government is endeavouring to control PM2.5 via different methods.

Thus, considering cooling effect of and energy saving in heating period and air pollution from PM2.5, the GSHP system was likely to be accepted in the future.

4. Conclusions

The key findings of this study are:

(1) The investment of the GSHP heating and cooling system is more than the coal fired heating system integrated with wet curtain fan cooling system and air conditioner heating and cooling system.

(2) Assuming the energy conversion efficiency y_{Ck} of GSHP system was equal to 3.25 and the price of coal and electricity was 160 US$ per ton and 0.10 US$ per kWh respectively, the relative operating cost of the heating system of the GSHP system, coal fired heating and air conditioner heating was 0.94, 1.00 and 0.98, respectively.

(3) The GSHP system heating cost was lower than CFH when the energy conversion efficiency C_k of GSHP system was equal to 3.25 and the price ratio of coal (US$ per ton) to electricity （US$ per kWh） was more than 1503.

(4) On condition that the technical parameters of each cooling system were described as in this paper, the relative operating cost of the cooling system of the GSHP system, wet curtain fan cooling system and air conditioner cooling was 4.50, 1.00 and 6.38 respectively. The GSHP system heating cost was higher than wet curtain fan cooling system.

(5) Swine farmers will not apply GSHP system without fund subsidies from the government at present in Beijing. Considering cooling effect of and energy saving in heating period and air pollution from PM2.5, the GSHP system will to be accepted in the future.

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