Heating design of cowshed floor heating system based on solar energy / air source heat pump in plateau cold area

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Abstract. According to the high altitude and cold environment of the agricultural and pastoral areas, it is of great significance for the growth of yaks to adjust the ambient temperature of the cowshed appropriately so that yaks can have a more comfortable growth environment under the condition of low external temperature. Floor heating technology is a new scientific feeding technology, which can save labor, increase efficiency, reduce investment and operate easily, and adapt to the development of modern yak breeding industry. At the same time, the solar energy system and the air source heat pump system are coupled to operate as the heat energy source, that is, energy saving and environmental protection, with the best economic benefits. In this paper, through coupling the advantages of these three systems, we design the "Cowshed floor heating system based on solar / air source heat pump".

Keywords: Alpine region of Plateau; Solar energy; Air source heat pump; Cowshed heating.

1. Introduction
With the continuous improvement of people's living standards, the domestic consumption demand for yak meat and related dairy products will continue to grow. How to ensure the supply of yak meat and related dairy products is an important problem for yak breeding. Therefore, for the high altitude and cold farming and animal husbandry areas, the heating technology to ensure the milk production of the Female Yak and improve the survival rate of the small yak is very important to improve the economic benefits of the cowshed and the rate of the yak out of the market. As a scientific breeding technology, the floor heating technology has attracted more and more attention[1]. The purpose of floor heating in the cowshed is not to improve the ambient temperature of the whole cowshed. It is mainly used to heat the rest area of yaks and provide a suitable hotbed for yaks. Its heating principle is to arrange the ground heating pipeline in the underground of yak rest area to radiate heat from the bottom to the air, so as to provide heating for yak rest. As the heat source of the ground heating system, renewable energy is the first consideration in this paper. As a kind of low-grade energy, air can be easily obtained without any environmental pollution, and air source heat pump technology has been a mature and widely used technology. But at the same time, when the ambient temperature is low, the air source heat pump system is difficult to achieve efficient energy saving[2]. Tibet's Naqu area is rich in solar energy resources, and solar energy is also a kind of green and clean energy. Therefore, on the basis of making full use of solar
energy, this paper coupling the solar energy system and air source heat pump system[2]. When the solar radiation is not sufficient, the hot water temperature is increased through the air source heat pump system. When the ambient temperature is low, the air source heat pump system uses the solar energy system to obtain the radiant heat to improve the system energy efficiency, and then optimizes the operation of the two heat utilization technologies, so as to achieve the purpose of energy conservation and environmental protection.

In this paper, the advantages of solar energy system, air source heat pump system and ground heating system are effectively coupled. For the "One village one union" cowshed in Jiajia Village, Luoma Town, Naqu City, Tibet Autonomous Region, "Cowshed floor heating system based on solar / air source heat pump" was designed. The purpose of this system is to use solar energy and air energy, two kinds of renewable energy, to provide 12°C regional heating for yak rest area in cowshed in winter cold season (outdoor environment average temperature is -30°C). In order to improve the milk yield of Female Yak and the survival rate of small yak in winter.

2. Project overview

2.1. Local meteorological data
Longitude and latitude: 31°29′ n, 92°04′ e;
Annual average temperature: 7.5°C, annual sunshine hours: 3130.4 h, annual irradiation amount: 8705.22 MJ(m²·a), annual average daily irradiation amount: 23.85 MJ (m²·d), annual average daily irradiation amount of collector inclined surface is 23850KJ/m² (Since the installation angle of the transverse intubation collector is 15°, the compensation ratio is not considered).

Basic water temperature: 9°C. The make-up water of the system is groundwater, and the change trend of water supply temperature of groundwater is basically consistent with that of atmospheric temperature. Therefore, the calculated temperature of cold water is the average groundwater temperature.

Water quality requirements of solar hot water system: Due to different water quality conditions in different regions, the use of solar hot water system will seriously affect its use effect in areas with poor water quality. Therefore, the water quality of its water supply must meet the following indicators (refer to the standard for drinking water and sanitary water), as shown in Table 1.

| Project                  | Index | Project                  | Index |
|--------------------------|-------|--------------------------|-------|
| Total hardness (mg/L)    | ≤75   | Dissolved oxygen (mg/L)  | ≤10   |
| Suspended matter (mg/L)  | ≤5    | Oil content (mg/L)       | ≤5    |
| PH value (25°C)          | ≥7    | Iron content (mg/L)      | ≤0.3  |

2.2. Building overview
The project is a yak shed floor heating project in Naqu City, Tibet Autonomous Region, with an altitude of 4800m and a nature of farm. The cowshed is 3.2m high, 63m from the east to the west, 9m from the south to the north and covers an area of 601m². The solar collector is arranged beside the cowshed, and the water tank is placed inside the cowshed, covering an area of 10m². The floor heating area of cowshed is about 273.46 m², 200W/m² is adopted according to the national standard heat load index, and the total heating heat load is 54.692 kW. The plan of the cowshed is shown in Figure 1. The 370mm thick brick wall is below 1.5m of the wall elevation, and the brick wall above ±0.00 of the elevation is built with MU10 sintered KP1 brick and M5 mixed mortar. MU10 ordinary shale brick and M7.5 cement mortar are used for masonry below the elevation of ±0.00. The wall with elevation above 1.5m is 100mm thick metal color steel sandwich panel.
3. System design

3.1. System principle
The main working principle of the solar / air source heat pump coupled ground heating system in winter operation of cowshed is as follows: First, when the weather is clear and the solar energy is sufficient, the air source heat pump system will not operate temporarily. Only the solar energy system operates and continuously heats the hot water in the heat storage tank to 70℃. Second, when it snows or the weather is bad and the solar energy is not enough, the solar energy system is the main priority operation, and the air source heat pump system is the auxiliary heat source secondary operation, heating the hot water in the heat storage tank to 70℃. Under the two operation modes, from 5:00 to 6:00 p.m., the hot water in the heat storage tank flows to the ground heating coil through the circulating water pump, and the hot water in the ground heating coil uses radiation heat exchange to transfer the heat to the yak rest area from the bottom to the top, so as to maintain the temperature of the yak rest area at ±12℃. When the temperature of the hot water in the storage tank is lower than 40 ℃, the air source heat pump system will start automatically and heat the hot water in the storage tank. The system principle is shown in Figure 2.
3.2. Main calculation parameters

3.2.1. Collector area

\[ A_c = \frac{Q_w C_w (t_{\text{end}} - t_i) f}{J_T \eta_{cd} (1 - \eta_L)} \]  \hspace{1cm} (1)

Where: \( A_c \) is the daylighting area of the direct system collector, m\(^2\); \( Q_w \) is the daily average water consumption, 20000kg; \( t_{\text{end}} \) is the end temperature of water in the water storage tank, 40℃; \( C_w \) is the constant pressure specific heat capacity of water, 4.18kJ / (kg·℃); \( t_i \) is the initial temperature of water, 8.8℃; \( J_T \) is the annual average daily solar radiation on the daylighting surface of the local collector, kJ / m\(^2\); \( f \) is the solar energy guarantee rate, dimensionless; \( \eta_{cd} \) is the collector's whole day heat collection efficiency, which is determined according to the actual test results of the collector products. Here, 0.44 is taken; \( \eta_L \) is the heat loss rate of pipeline and water storage tank, dimensionless, 0.2 is taken here. [3]

3.2.2. Design flow. When the temperature difference of circulating water is 8℃, the circulating flow of the collector per square meter is 0.012 L/(s·m\(^2\)). For the solar hot water system, if the collecting and circulating pipeline is a closed circuit, the calculated flow of the pipeline is the circulating flow. Calculated according to the following formula:

\[ q = A \cdot Q_s \]  \hspace{1cm} (2)

Where: \( q \) is the circulating flow, L/h; \( Q_s \) is the circulating flow of the collector, L/(h·m\(^2\)); \( A \) is the total area of solar collector, m\(^2\). [4]

3.2.3. Pipe diameter calculation

\[ d_j = \sqrt[6]{\frac{4q}{\pi \nu}} \]  \hspace{1cm} (3)

Where: \( q \) is the design flow, m\(^3\)/s; \( d_j \) is the calculated inner diameter of the pipe, m; \( \nu \) is velocity, m/s.

3.2.4. Head of water pump

\[ H_x = h_{jx} + h_j + h_f \]  \hspace{1cm} (4)

Where: \( H_x \) is the lift of circulating water pump of solar energy collection system, m; \( h_{jx} \) is the resistance loss along the path and part of the circulation pipeline of the heat collection system, m; \( h_j \) is the resistance loss of the heat collection cycle through the collector, m; \( h_f \) is the additional pressure, 2-5m.

3.3. Equipment selection

3.3.1. Selection of air source heat pump. Considering that solar energy heat collection system is greatly affected by weather and environmental factors, and there is an extreme situation of no heat compensation, therefore, five air source heat pumps with built-in water pumps of a company are selected for the air source heat pump. The heat production capacity of the air source heat pump is 23.5kW, the total power consumption rate of heat production is 9.8kW, the circulation flow is 5.9m\(^3\)/h, and the heat production cop is 2.4. The working principle of air source heat pump is shown in Figure 3. The site photos are shown in Figure 4.
3.3.2. Selection of solar collector. According to the above formula, considering that in non-heating season, solar energy collection system only provides users with domestic hot water heat, too large area is easy to cause resource waste, which will increase the total investment of the system. Therefore, a company's "high temperature resistant, cold resistant, high-efficiency absorption" vacuum tube solar collector is selected in this paper. The number of vacuum tubes is 50, and the heat collection area is 7.6m². Polyurethane insulation material is used. The field photo of the solar collector is shown in Figure 5. The pipeline insulation is shown in Figure 6.
3.4. Economic analysis
Since the completion of the project in November 2018, by March 2020, the milk production of 45 female Yaks in winter has increased from 550L/month to 1100L/month, and in January 2020, 23 young yaks will be born, and the mortality rate of young Yaks in winter cold period is 0 (Young yaks are generally born in May to June every year, with a mortality rate of about 10%). As shown in Figure 7.

At the same time, in order to evaluate the economy of the heating system, this paper uses the dynamic investment benefit evaluation method to analyze and evaluate its price economy, its calculation formula is[5]:

$$Z = \frac{i(1+i)^n}{(1+i)^n-1}K + D$$ (5)

Where: $Z$ is the annual cost, yuan/year; $i$ is the interest rate; $K$ is the total investment of equipment, yuan; $D$ is the annual operation cost of the system, yuan/year; $n$ is the service life of the system, year. Assuming that the annual interest rate is 10%, the service life of air source heat pump system equipment is 15a, the service life of solar energy heat collection system is 15a, and the service life of electric heating boiler system is 10a[6].

The calculation results of dynamic annual cost of three systems are shown in Figure 8. The annual dynamic cost of electric boiler is 1.49 and 1.62 times of that of air source heat pump system and solar / air source heat pump system respectively. The initial investment of the electric boiler system is the smallest, but its service life is shorter than the other two systems, resulting in the annual conversion value of the initial investment of 40.03% and 6.2% higher than the other two systems respectively. The
annual operation cost of solar / air source heat pump system is 37.2% lower than that of electric boiler system, and 70.1% lower than that of air source heat pump system alone. In general, the solar / air source heat pump system has the best economy.

4. Conclusion
In this paper, through the effective coupling of solar energy system, air source heat pump system and ground heating system, a "Cow shed ground heating system based on solar energy / air source heat pump" is designed in high altitude and cold area. Although the initial investment of the system equipment is a little high, the system has a long service life and relatively low annual operation cost, and effectively improves the milk production of the Female Yak in winter and the survival rate of the small yak, which can effectively shorten the payback period of the investment. Solar energy and air energy, as a kind of high-quality renewable energy, are strongly supported by national policies. Therefore, the full use of solar energy composite system is more conducive to solve the contradiction between high energy consumption and energy shortage in China.

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Integrated demonstration of new type of yak warm shed design and high efficiency breeding technology of Female Yak in northern Tibet Plateau (XZ201801NB41).

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