Matching Design of Two Heat Collecting Modes in Solar Water Heating System in Alpine Region

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Abstract. In view of the practical problems of using hot water in production and life in this remote farming and pastoral area in Guoluo, Qinghai Province, this paper studies and realizes the technology of multi-module integrated heating system for agriculture and animal husbandry in the alpine region. In the alpine region represented by the Guoluo area, there are sufficient solar radiation resources. This paper adopts the heat collecting method of Fresnel collector and electric auxiliary heating, and takes into account the actual situation of solar radiation, water demand and seasonal energy demand in the Guoluo area. The matching design of two important parameters of Fresnel solar collector area and electric auxiliary heater power in the system model is studied to realize the high-efficiency photothermal comprehensive utilization of solar energy and achieve effective low-cost coupling with electric heating. Finally, through the research of this paper, with the principle of low cost and low energy consumption, it will effectively solve the problem of agricultural and livestock production and living water in alpine regions, and provide examples for solving the problem of heating in winter in agricultural and pastoral areas.

1. Introduction

With the progress and development of human society, fossil fuels and coal resources are continuously decreasing. As a non-renewable energy source, it will one day disappear and become exhausted. Therefore, in order to reduce the consumption of non-renewable resources, human beings are constantly looking for new renewable energy sources. On the other hand, as a renewable energy source, solar energy has the advantages of environmental protection and pollution-free. Although the development prospect is very broad [1], the application situation is adapted to local conditions. Therefore, this article aims at the actual energy demand of hot water in the remote agricultural and pastoral areas of Guoluo, Qinghai Province.

At present, the research on solar integrated heating systems is aimed at the design of solar-air source heat pump systems for independent residential buildings [2-3], and there are studies on the installation methods of solar collectors for specific application environments [4]. There are researches on the overall planning of solar photovoltaic solar thermal systems connected with air conditioning systems [5], and research on the thermal performance of flat-plate collectors and heat pipe vacuum tube collectors [6]. Based on field investigations and full analysis of the actual environmental conditions and water demand for agriculture and animal husbandry in the Guoluo area of Qinghai Province, Fresnel and electric-assisted heating methods are used to complement the advantages and multi-factor modularization of the heat collection system Application research, scientific analysis and
design of a solar integrated heating system model, in order to achieve efficient solar energy comprehensive utilization of light and heat, and achieve effective low-cost coupling with electric heating. Through the research of this paper, the principle of low consumption will effectively solve the problem of water for agricultural and animal production and life in high-cold areas, and provide an example to solve the problem of winter heating in agricultural and pastoral areas.

2. Regional Situation
In high-altitude and high-altitude terrain areas, there are large seasonal temperature differences, large temperature differences between day and night, and the use of hot water in the production and living of agriculture and animal husbandry is very difficult, especially in the Guoluo area of Qinghai Province. But the unique advantage is that the area has sufficient solar radiation resources and huge available space.

2.1. Solar Radiation in the Region
The annual local solar radiation is about 5852-6680 MJ/m², the annual sunshine hours are 3000-3200 hours, and the average annual sunshine time is 4.45-5.08 hours under standard lighting standards [7]. There is a large amount of solar radiation in summer (March to August), and a relatively small amount of solar radiation in winter (September to February of the following year), and the overall distribution is relatively uniform. The average daily solar radiation in summer and winter is 18.8 MJ/m², 13.9 MJ/m².

2.2. Analysis of Regional Energy Needs
Assuming that the water consumption throughout the day is 22.2 tons, the water temperature is 40 °C. Taking into account solar radiation and seasonal differences in regional temperatures, we are also divided into summer (March to August) and winter (September to February of the following year) two application scenarios to analyze energy demand in the Guoluo region. In China’s weather network to find the average temperature changes in summer and winter in the Guoluo region, and combined with the weather temperature and water conditions to make the following analysis. The formula for calculating the energy based on the calculation process is equation (1).

\[ Q = C \cdot m \cdot (T_L - T_C) / (3.6 \times 10^6) \]

(1)

where \( Q \) is required energy, \( C \) is water ratio heat capacity, \( T_L \) is the hot water temperature for users, here its value is 40 °C, \( T_C \) is the initial water temperature, taking into account the regional temperature, it takes the initial temperature of different heating periods.

The average daily temperature changes in summer and winter in Guoluo region were found on China Weather Online, and the regional water consumption was investigated. Finally, the average daily energy requirements for summer and winter in Guoluo region were 1050 kW·h, 1228 kW·h.

2.3. Summary of Regional Situations
Based on the above analysis of solar energy radiation and energy demand in the two application scenarios of spring, summer and autumn and winter in the Guoluo region, the following conclusions can be reached: through the calculation analysis, it is learned that in the summer and winter two application scenarios, if only the use of electric heating to supply hot water, then will need about 1050 kW·h, 1228 kW·h of electricity per day, electricity costs per degree 0.5 yuan calculation, a total of about 210,000 yuan per year. If the use of solar heating and electric heating methods to meet the needs of daily water supply, the collector per square meter per square meter can receive 1 kW·h energy, utilization rate of 60%, according to the solar collector average five hours per day to calculate, 200 m² solar collector can save 600 kW·h of electricity per day, can save 110,000 yuan per year electricity.

Therefore, the design of a reasonable integrated solar energy heating system is conducive to the wide utilization of clean energy, effectively solve the non-linear problem of the time interval of agricultural and animal husbandry production and living water and the diversification of water
methods, bringing great benefits to the pasture, while achieving the dual goal of increasing environmental protection.

3. System Implementation

By absorbing radiant energy from the sun, the solar heat collection system converts it into heat energy for use through heat transfer media, typically consisting of five basic components: solar collector, auxiliary electric heater, hot water storage tank, pipeline and control system [8], as shown in Figure 1.

![Figure 1. Structural diagram of solar integrated heating system.](image)

The solar collector is the core component of the system, which is responsible for centralizing the dispersed solar energy, while the auxiliary heater is responsible for providing heat when there is no solar radiation. The pipeline is responsible for connecting the components and the control system is responsible for allocating and managing heat for efficient use of energy. The heat storage tank is responsible for storing heated hot water and providing it to the user.

3.1. System Model Parameters

Based on scientific analysis and accurate calculation, this paper takes into account the actual situation of solar radiation factors, water demand factors and seasonal energy demand factors in Gulo region, and coordinates the distribution to determine the important parameters of frenetic solar collector area and auxiliary heater power. In order to achieve the solar integrated heating system model cost optimization design.

The cost of solar integrated heating system can be regarded as the cost of two kinds of heat collection mode subsystem, that is, the total system cost consisting of the Fresnel heating system and the electrical auxiliary heating system. According to market research, the cost of frenetic heat collection system is proportional to the solar heat collection area \( x \), and the relationship between system cost and heat collection area is as follows by the results of the data after a second fitting:

\[
S_1 = -1.28x^2 + 2848x + 4030
\]

Given the weather and changes in people's water use, there may be continuous rainy weather, the heat collected by the solar heat collection system is not sufficient to meet the water demand, or when people use more water, solar energy cannot heat water to the right temperature on time. In order to ensure the stable and continuous operation of the solar energy system, the selection of electromagnetic heaters needs to be selected according to the hot water supply of heat load. After market research, it is learned that the cost of electric auxiliary heating system is proportional to the heating power \( y \), and the relationship between system cost and heating power is as follows by the data results after a second fitting:

\[
S_2 = 0.1468y^2 + 731.04y + 70
\]
In this paper, the cost of Fresnel heat collection system and electrical auxiliary heating system is based on the market research results after a second fitting, because the brand and market differences between collectors and electrical auxiliary heaters, so the cost of the system used in this paper only represents the cost of some products on the market, so its fitted relationship can be used for simulation calculation.

3.2. System Model Building
According to the parameters analyzed in the preceding article, a function of the total cost of the target to be optimized can be obtained as equation (4):
\[
 f(x,y) = S_1 + S_2
\]
where \( f(x,y) \) is the total system cost, \( S_1 \) is the cost of the Fresnel heat collection system, and \( S_2 \) is the cost of the electric auxiliary heating system.

According to the principle of the aggregate energy demand of different seasons in the region and the principle of the equal equilibrium of the total heat collection of the two heat collection methods, the binding relationship between the heat collection system in summer and winter is as equations (5) and (6):
\[
\begin{align*}
18.8x\eta + y & = 1050 \\
13.9x\eta + y & = 1228
\end{align*}
\]
where \( x \) is the solar heating area of the Fresnel heating system, \( y \) is the heating power of the electrical auxiliary heating system, and \( \eta \) is the utilization rate of the Fresnel collector, is set to 0.6 under normal circumstances.

The optimization problem solved in this paper is the minimization of the total cost of the Fresnel heating system and the electrical auxiliary heating system in the solar energy integrated heating system, in which the solar heating area \( x \) and the heating power \( y \) of the electric auxiliary heating system are optimized variables. According to the above analysis, we can see that the model of this optimization is divided into two (summer and winter), respectively:

Model 1:
\[
\begin{align*}
\min \quad & f(x, y) \\
\text{s.t.} \quad & 3.13x + y = 1050
\end{align*}
\]
Model 2:
\[
\begin{align*}
\min \quad & f(x, y) \\
\text{s.t.} \quad & 2.32x + y = 1228
\end{align*}
\]

3.3. System Model Solution
For the above two models to be optimized, we study the solution of the following models:
\[
\begin{align*}
\min \quad & f(x, y) = w_1 x^2 + w_2 x + w_3 y^2 + w_4 y + w_5 \\
\text{s.t.} \quad & Ax + By = C
\end{align*}
\]
That is, the problem of seeking the minimum value of \( f(x, y) \) under the condition of \( Ax + By = Cf(x, y) \), which is the case of a constraint condition of a binary function. We use the Lagrange multiplication method to solve the model. That is, the Lagrange function is:
\[
\mathcal{L}(x, y, \lambda) = f(x, y) + \lambda(Ax + By - C)
\]
The \( \lambda \) is the Lagrange multiplier. We solve the minimum of \( \mathcal{L}(x, y, \lambda) \) below, that is, find its KKT condition:
\[
\begin{align*}
\frac{\partial \mathcal{L}}{\partial x} & = 0 \\
\frac{\partial \mathcal{L}}{\partial y} & = 0 \\
\frac{\partial \mathcal{L}}{\partial \lambda} & = 0
\end{align*}
\]
That is:

\[
\begin{align*}
2w_1x + w_2 &= 0 \\
2w_3y + w_4 &= 0 \\
Ax + By - C &= 0
\end{align*}
\] (12)

This converts the original problem to the equation (12) to solve it quickly. Next, we solve in model 1, model 2 parameters into the equation (12) to get the following results: According to Model 1, the thermal area required to use the Fresnel solar collector system in summer is approximately 280 m², and the power of the electric heater is approximately 173 kW. According to Model 2, the thermal area required for the use of the Fresnel solar collector system in winter is approximately 322 m², and the power of the electric heater is approximately 480 kW.

4. Conclusions
This paper studies the technology of multi-modular integrated heating systems for agricultural and pastoral water in the high and cold regions. The following work is studied with Guoluo as a typical representative: A solar integrated heating system is designed and the specific use plan is introduced; According to the actual solar radiation and water use in the Guoluo region of Qinghai Province, a detailed analysis of energy demand under the two application scenarios of summer (March to August) and winter (September to February of the following year) was carried out; Based on the principle of low cost and low consumption, the area of solar collector in the integrated solar thermal system and the power distribution scheme of auxiliary electric heater are given.

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