Economic Analysis of the Combined Heating System of Solar Collector and Gas Boiler

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Abstract. The combined heating system of solar energy and gas-fired boiler is designed, the mathematical model of comprehensive heating cost is established, the suitable solar collector area is determined, three typical operating conditions of complex heating system are analyzed, and the consumption of various heating fuels is discussed. The results show that the efficiency of condensing boiler is more than 15% higher than that of non-condensing boiler. The combination of solar heating and gas-fired boiler has the most energy-saving heating effect, which can save more than 50% fuel compared with the boiler running alone.

1. Introduction
In recent years, solar heating has been greatly improved, European countries have developed rapidly. Since the 1990s, China's solar energy industry has developed rapidly with the support of the government[1]. In response to the call of low-carbon and environmental requirements of the national, solar energy heating began to be applied to building. This can reduce large amount of coal, natural gas and other primary energy consumption, reduce greenhouse gas emissions[2]. As people's living standards and the demand for residential comfort increasing, low temperature radiant floor heating technology has developed rapidly, and its inlet and outlet water temperatures are lower, more suitable for combination with solar heating systems[3]. Although solar heating alone does not waste fossil energy and has a low operating cost, solar radiation is affected by random factors such as day and night, season, latitude, natural conditions, and so on, which has great intermittence and instability. Therefore, the operation condition of solar heating system alone is not stable[4]. In order to operate continuously for a long time, auxiliary heat source must be used to meet the requirements of indoor temperature. With the energy prices follows the international standards, gas prices gradually increase, the affordability of residents using gas boiler for heating is declining. How to achieve more economical heating operation mode is imminent. This paper puts forward solar energy collector and gas boiler joint operation mode, focused on the composite heating system of the complex factors that impact on heating.

2. Composite heating system
In this paper, we use solar collectors combined with gas boiler heating system, which have three operation namely solar heating alone, the gas boiler heating alone and solar combined with the gas boiler heating. The collector absorbs solar radiation in the daytime. When the tank temperature meeting requirements, it begins to heating, and excess heat stored in the heat storage tank. When the
intensity of solar radiation is weak, the storage energy is released. As the tank water temperature continues to decline, only partly to meet the needs of the room load, at this time gas boiler and thermal storage tank operation together. Along with the water tank temperature continues to decrease, then using the gas boiler alone. Three ways alternate operation to make the purposes of use the solar energy fully.

Considering most of the day time the hot water in tank will exceed 45℃,and this heating water inlet and outlet temperature is 45℃ / 35℃, so we increased water mixing valve in the back of forced circulation pump to ensure the provide water temperature stability at 45℃. When the noncondensing or condensing boiler is running, the water mixing valve is increased also to meet the requirements of output water temperature. In order to ensure the accuracy of flow and pressure when gas boiler and thermal storage tank operation together, the circulation pump was three-speed pump. Solar collectors and boiler heating system are shown in figure 1.

1-collector. 2,15-circulation pump. 3-storage hot water tank. 4,13-solenoid valves. 5-supply water pipes. 6-back water pipes. 7-gas pipes. 8-gas boiler. 9,14-mixed water valves.10-water supply pipes. 11-radiant floor systems. 12-expansion tank. 16,17-thermometer.

Figure 1. Solar collectors and boiler heating system.

3. Mathematical model of the composite heating costs
Compared with gas-fired boiler heating alone, we know that the decrease of operating cost of composite heating system is mainly due to the introduction of solar collector[5]. The following analysis focuses on determining the reasonable collector area. Mathematical model introduced as follows:

- \[ Q = A \cdot J_T \cdot \eta_{cd} \cdot (1 - \eta_L) \] (1)

Where: \( Q \) is the heat which collector collect, \( J_T \) is local collector surface lighting average of daily amount solar radiation, Jinan for 13.95MJ / (m²⋅d), \( \eta_{cd} \) is based on the total area of the collector the average collection efficiency (%), take 80%, \( \eta_L \) is pipe and tank heat loss (%), take 10%.

- \[ B = \frac{Q \cdot P}{Q \cdot \eta} \] (2)

Where: \( B \) is the cost savings (yuan), \( \eta \) is the average boiler efficiency, \( P \) is the gas price (yuan / m³).

Simultaneous (1), (2), two type can get the relationship between the saving and the solar energy collector area.
The following to compare the relationship between the saving and the solar energy collector area in the entire heating season, the results shown in figure 2. With the fuel prices increasing year by year, the same collector area fuel saving costs will increase.

![Figure 2. collector area and cost savings graph](image1)

![Figure 3. Relationship between collector area and the income](image2)

How to obtain maximum benefits in life period is an important indicator to evaluate solar energy heating efficiency, it is affected by the building type, the size of the initial investment, annual cost savings, fuel prices, local weather conditions and many other factors. The total revenue is the difference between the overall cost savings and the initial investment of solar collector system in the life, investment is consider as compound interest, the life of 15 years. Namely:

\[
F = F_i (1 + \frac{r}{n})^n
\]

\[(4)\]

\(F_c\) is the total increased investment compared combined heating to boiler heating (yuan), \(F_i\) is the initial increased investment compared combined heating to boiler heating (yuan), \(r\) is the interest rate, lending rate to take 6%, \(n\) for the system life (years).

Simultaneous utilizing (1), (3) and (4), we calculate in accordance with the residential heat load. Life of the net income and collector area curve is shown in figure 3. It can be seen from the figure, with the collector area increases, revenue increases. When the collector area is 18 m², we can get the maximum gain.

4. Economic Analysis of operation mode

This paper selects a residence in Jinan to analyze and compare the economic situation of three weather conditions: high temperature, medium and low temperature. The economy of solar heating alone, boiler heating alone and combined solar heating with boiler heating are compared respectively. According to the three conditions of temperature, radiation intensity, the solar collector area, the collector heat and the residential heat hourly load are calculated.

4.1. Higher temperature conditions

The optimal collectors area are 18 m² for this residence, this collector area can satisfy independent heating in late November and the beginning of March next year. The circulating pump only uses a small amount of power energy in this operation time, and no fossil fuel waste is the most economical operation mode.

4.2. Moderate temperature conditions

Under this condition, the solar collector can meet part of the room load and the energy gap provided by the auxiliary heat source. Floor radiant heating system has strong heat storage capacity, so the indoor temperature can be stable when the gas boiler stops running for a period of time. Choosing non-
condensing boiler or condensing boiler as auxiliary power is more economical. In addition, the operation economy of non-condensing boiler and condensing boiler are considered.

Figure 4. Boiler operating efficiency in various operation modes

Figure 5. The accumulation of natural gas consumption for various operation modes

Figure 4 and figure 5 are boiler operating efficiency and the accumulation of natural gas consumption for various operation modes. From the figure we can see the condensing boiler efficiency more than 15% compared to the non-condensing boiler. Solar combined with the gas boiler heating have the most energy efficient, it can save more than 50% fuel compared to the gas boiler which run alone.

4.3. Low temperature conditions
When the temperature of the room is low and the load needed is large, and the solar radiation energy is minimum, the room is completely dependent on the gas boiler for heating.

Figure 6. Boiler operating efficiency in the operation modes

Figure 7. The accumulation of natural gas consumption in the operation modes

Figure 6 is the gas boiler load and room hourly load relationship respectively. Figure 7 is the natural gas consumption accumulation for the gas boiler. As can be seen from the figure, the efficiency of the condensing boiler is about 20% higher than that of the non-condensing boiler during the cold running time. The condensing boiler energy saving effect is obviously.

5. Conclusion
The system ensures the stability of the heating temperature through the water mixing valve and regulates the flow and pressure with a three-speed pump. At the same time, it can reach the appropriate value uniformly in the compound operation and make full use of the heat storage. There are several ways to run in the system, which can satisfy winter heating demand at any moment.
Through the calculation model, we can get the most economic collector area are 18 m² which can be used as reference for Jinan areas of energy-saving building living space for 250 m² around in residential buildings when combined heating.

By comparing several typical working conditions, the economy of the whole heating season is obtained. The efficiency of condensing boilers is more than 15% higher than that of non-condensing boilers. Solar heating combined with the gas boiler have the most energy efficient heating, more than 50% fuel can be save compared to the boiler run separately.

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