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Complementary Cooling, Heating and Power Generation System Based on Sustainable Improvement of Solar Energy and Biomass Energy

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Abstract: The increasingly severe energy and environmental problems make the transformation of the world's energy structure imminent. Energy production and consumption according to local conditions, technology research and improvement of advanced energy power systems with complementary multi-energy and system integration innovation are the current key research and improvement directions. Combining the energy properties of solar energy and biomass, thermochemical complementary utilization is an efficient and stable complementary utilization method, that is, using concentrated solar thermal energy to provide the heat required for biomass gasification to generate hydrogen-rich gas fuel. The research purpose of this paper is based on the theory of sustainable improvement, the complementary utilization of solar energy and biomass energy, and the research on the cogeneration system of cooling, heating and power. The electrical load rate and solar radiation intensity. In this paper, solar energy and biomass energy are combined, and a combined cooling, heating and power supply system based on solar energy and biomass energy is proposed, which provides some new ideas for promoting the rational conversion of my country's energy structure.

1. Introduction

With the deepening of research on cogeneration of cooling, heating and power, making full use of the resource complementation between "source-grid-load" has gradually become a hot spot. The system has the characteristics of equipment coupling, information sharing, and energy complementation. Compared with the traditional energy supply structure, it is more economical, more environmentally friendly and more efficient. The participation of the load side means that the equipment connection and benefit evaluation within the system are more complicated. Accurate short-term load forecasting and a perfect evaluation system will make the operation scheduling of the system more reasonable [1].

The use of solar thermal power system, combined with the energy properties of solar energy and biomass, and the use of thermochemical complementary utilization methods, can reduce energy consumption.Diab A A Z fundamentally believes that providing clean, reliable and affordable energy through the adoption of hybrid drives is essential for countries seeking to achieve the Sustainable Improvement Goals. A method has been proposed to increase the size of hybrid systems, including photovoltaics, wind turbines, and pumped hydro storage systems. A study was conducted between the optimal whale algorithm, the waterway algorithm, and the gray algorithm. In addition, system components was studied using information and data from the Egypt [2]. According to Mahalle N, current work focuses and analysis that can be used as non-standard energy sources. In this proposed work, a transport system was improved based on the principle of a "thermoelectric device". The unit is suitable for both the hot side and the cold side, the cold side of the electrical unit is used for cooling purposes, while the heat from the hot side of the unit is dissipated by heat sinks and fans [3].This complementary approach not only improves the quality and efficiency of solar energy, but also realizes the orderly release and cascade utilization of the chemical energy of biomass fuels.

This paper studies the research background and significance of solar energy and biomass energy and cogeneration of cooling, heating and power, and expounds the overview of cogeneration, solar energy and biomass energy and sustainable improvement theory. In the experiment, the power generation efficiency algorithm of the internal combustion engine under rated operating conditions is used, and the electrical load rate of the internal combustion engine and the irradiation intensity of solar energy are investigated and studied under the analysis of the thermal performance of the system under the combined cooling, heating and power generation.

2. Sustainable Improvement of Solar Energy and Biomass Energy Complementary and Cogeneration System Research

2.1 Research Background and Significance

China's energy structure is dominated by coal, and China is the world's largest coal producer and consumer. Considering the special national conditions of my country's large population, my country's energy crisis is relatively more severe. We must realize that my country's existing energy structure must be changed, and should gradually transition to the future energy structure [4]. Although China has been actively building nuclear power plants and improving various sources, coal power will continue to dominate.

Solar energy is a widely distributed, sustainable source, and its applications are generally environmentally friendly. However, it has a series of serious disadvantages: relatively low energy density, intermittent and uneven distribution [5]. If it is to become one of the main energy suppliers, solar energy must be converted into other forms, such as electricity or heat.

Cogeneration of cooling, heating and power refers to the combined production of three different forms of energy, heat, electricity and cooling. Slightly different from cogeneration systems [6]. In some literature, the CHP system is also referred to as a tri-generation system, and if used in a building, it is a building CHP system. In recent years, CCHP systems are often associated with distributed energy sources. The relationship between the three is as follows, but there is no very clear boundary between the two categories. Compared with large-scale centralized power stations and conventional on-site electric-driven air conditioners, the distributed system is popular due to its unique charm [7].

(1) Save energy. On the one hand, compared with the 30-45% energy utilization rate of typical large-scale power stations, the tri-generation system can realize the cascade utilization of energy, which can be utilized according to the different temperatures of the medium, so as to reduce the available energy loss of the system as much as possible [8]. The final total energy utilization rate can reach 70% or even more than 90%. When obtaining the same amount of electricity and heat, the trigeneration system usually consumes less primary energy, which means relatively less fuel investment [9].

(2) Reduce emissions. On the one hand, some CCHP systems use more advanced technologies, such as fuel cells or micro-combustion turbines, and on the other hand, the triple-generation systems use clean energy, such as solar energy, biomass energy, geothermal energy, etc. [10] .

(3) Increase the reliability of the energy network. This feature is mainly associated with the advantages of distributed energy systems. The centralized system will cause the local power grid to collapse in the event of a climate disaster or terrorist attack, and the distributed energy system can make up for this shortcoming [11].

2.2 Overview of CCHP

Combined cooling, heating and power (Cooling, Heating and Power, CCHP) refers to the use of energy coupling equipment to meet the needs of users for three loads of cold, heat and electricity through the interaction between "source-grid-load" , through the active adjustment of equipment output and operation strategy by the supply side, to realize the cascade utilization of energy and promote sustainable improvement [12]. Common energy coupling devices include gas turbines, gas boilers, waste heat boilers, electric boilers, central air conditioners, and lithium bromide refrigeration units. At the same time, the CCHP system has been improved for a long time, the technology has become mature, the investment cost is low, and the construction is simple, etc., so that the CCHP system has been promoted and improved in more and more countries [13]. Compared with the traditional energy supply system, the economical high-efficiency advantages of the combined cooling, heating and power system have made it one of the important trends in national improvement in many countries around the world. Western countries improved earlier in this field, and after a series of power supply evolution processes, the technology is relatively mature. The improvement of my country's combined cooling, heating and power system belongs to an emerging industry, which is gradually being piloted and then promoted on a large scale [14]. The mutual complementation between energy sources is the focus of research on the CCHP system. Compared with the traditional energy utilization structure, the CCHP system has two main advantages: First, high energy utilization. The combined cooling, heating and power system realizes the cascade utilization of energy through the coupling between gas and electric energy, improves the comprehensive utilization efficiency of energy, effectively avoids the waste of resources, and has strong reliability of energy supply; secondly, low pollutant emissions. Different from the traditional energy supply structure, the CCHP system not only uses coal for energy supply, but also uses energy coupling equipment to meet various load demands of residents by mixing coal and natural gas [15]. As a clean energy, natural gas has the characteristics of zero pollutant emissions, and through the active optimization of the system, efficient energy utilization reduces the dependence on coal from another level, and reduces the emissions of carbides, nitrides and sulfides.

2.3 Solar Energy and Biomass Energy

The source of solar energy is the fusion of internal oxygen atoms to release huge nuclear energy

[16]. From the perspective of energy system, multi-energy complementation is beneficial to improve the energy conversion rate of the system. Solar energy is also a clean and renewable energy source with a large volume and flexible utilization. Therefore, the complementary utilization and biomass can greatly reduce the emission of pollutants. The independent utilization of solar energy is photothermal and photovoltaic [17]. The electric energy generated by photoelectric conversion can be directly used by users, but the integration form with the energy system is relatively simple. The most common one is photovoltaic power generation. Photothermal means that it is used in the heat to generate different grades of thermal energy (100 ℃~1500 ℃) without optical equipment. It is used in many forms complementary to biomass energy systems. Of course, solar energy can also generate electricity directly in the form of heat, such as CSP power generation systems and solar Stirling machine power generation systems.

The traditional gasification technology of biomass is simply integrated with solar energy, but it still stays at the level of solar heat utilization alone. Moreover, the cascade utilization of energy is only in the downstream process of the energy system, and the complementary utilization of fuel chemical energy is rarely studied from the initial stage of the energy source, resulting in a certain limitation of the utilization efficiency of biomass, and it is inevitable that the time-varying solar energy will stabilize the system. In order to improve the utilization efficiency of biomass and the energy conversion efficiency complementary to solar energy, solar thermal chemistry is one of the most potential methods.

2.4 Sustainable Improvement Theory

The concept of sustainable improvement is essentially a systematic theory, which contains many aspects including economy, society, energy, environment and so on. Here we divide these definitions into three categories for exposition. The first category emphasizes the protection of resources and the environment, and defines improvement that has less negative impact on it as sustainable improvement, such as “the net benefit of economic improvement on the premise of maintaining the quality of natural resources and the services they provide. increase to the maximum extent", "improve the quality of human life without exceeding the carrying capacity of the ecosystems that support the planet". The second category is to emphasize the fairness of human interests in the present and the future, such as "sustainable improvement is to give future generations equal or even more opportunities than the present", "meet the needs of the present, but not the ability of future generations to meet their needs. improvement that constitutes a hazard” [18]. The third category is to focus on balanced improvement and meet the interests of all parties. "Sustainable improvement is a improvement that seeks to achieve an organic balance between economic improvement, environmental protection and the improvement of quality of life."

3. Investigation and Research on the Combined Cooling, Heating and Power Generation System Based on Solar Energy and Biomass Energy

3.1 The Complementary Process of Solar Energy and Biomass Energy

The biomass gasification process is a continuous process in which many chemical reactions are crossed, including drying stage, pyrolysis stage, oxidation stage and reduction stage. The reduction reaction is an endothermic reaction without the participation of oxygen. In the conventional system, this part of the heat is provided by the combustion heat of biomass. In this system, the main research material is steam gasification. The main reaction is an endothermic reaction, which requires an external heat source to supplement, The solar dish collector is used to collect heat to supplement this part of the heat, which is different from the biomass combustion heat in the conventional system to provide heat, avoids the waste of fuel, and utilizes energy more rationally. Among the products of biomass water vaporization, hydrogen and methane account for a large proportion, and the generated gas is a gas with a medium calorific value, and the calorific value can reach 10~20MJ/m3. The water vapor required for water vapor gasification does not need to be produced by a steam generator, and the high temperature gasification gas generated by the gasification system is used to exchange heat with the heat pipe gas-liquid heat exchanger to produce the water vapor required for gasification.

3.2 Research Methods

In this paper, the internal combustion engine is used as the power system of the combined cooling, heating and power system, and its mechanical efficiency is about 35%~40% under rated operating conditions, which has good economic benefits, and is suitable for biomass gas power generation. After the internal combustion engine generates electricity, there are still two parts of waste heat (flue gas waste heat and cylinder jacket water waste heat) that can be used. In recent years, these two parts account for nearly half of the waste heat of the internal combustion engine fuel. For internal combustion engines, there is no special internal combustion engine that uses biomass gasification gas as fuel. Since biomass gas has a lower calorific value than natural gas, it is necessary to modify the model of the internal combustion engine. In the formula, $N_e^*(kW)$ represents the maximum power generation under the design condition of the internal combustion engine. $\eta_e(\%)$ represents the actual power generation efficiency of the internal combustion engine, and γ_e represents the coefficient used to correct the power generation efficiency. The power generation efficiency of the internal combustion engine under rated operating conditions is as follows:

$$\eta_e^* = 28.08(N_e^*)^{0.0563} \quad (1)$$

$$\eta_e = \gamma_e \eta_e^* \quad (2)$$

$$\gamma_e = 0.102\frac{LHV_f}{LHV_{NG}} + 0.897 \quad (3)$$

4. Analysis and Research on the Combined Cooling, Heating and Power Generation System Based on Solar Energy and Biomass Energy

The thermodynamic performance analysis of the system explores two aspects of variable working conditions, including changing the electrical load rate of the irradiation intensity of solar energy. The analysis of variable working conditions adopts the principle of control variables. When one of the parameters is changed, the other The parameters of the design conditions remain unchanged.

4.1 Transformer load rate

When the electric load of the internal combustion engine of the combined cooling, heating and power subsystem runs from low load to full load within 20-90kW, the input energy of the whole system changes with the change. The change analysis is shown in Figure 1 and Table 1. Show:

Table 1. Energy input in summer and winter during the substation load rate

Electric load rate: (%)	Energy input (kW)			
	Solar energy used in winter	Biomass energy in winter	Solar energy used in summer	Biomass energy in summer
25	92	84	95	86
55	162	154	168	156
85	268	251	274	255

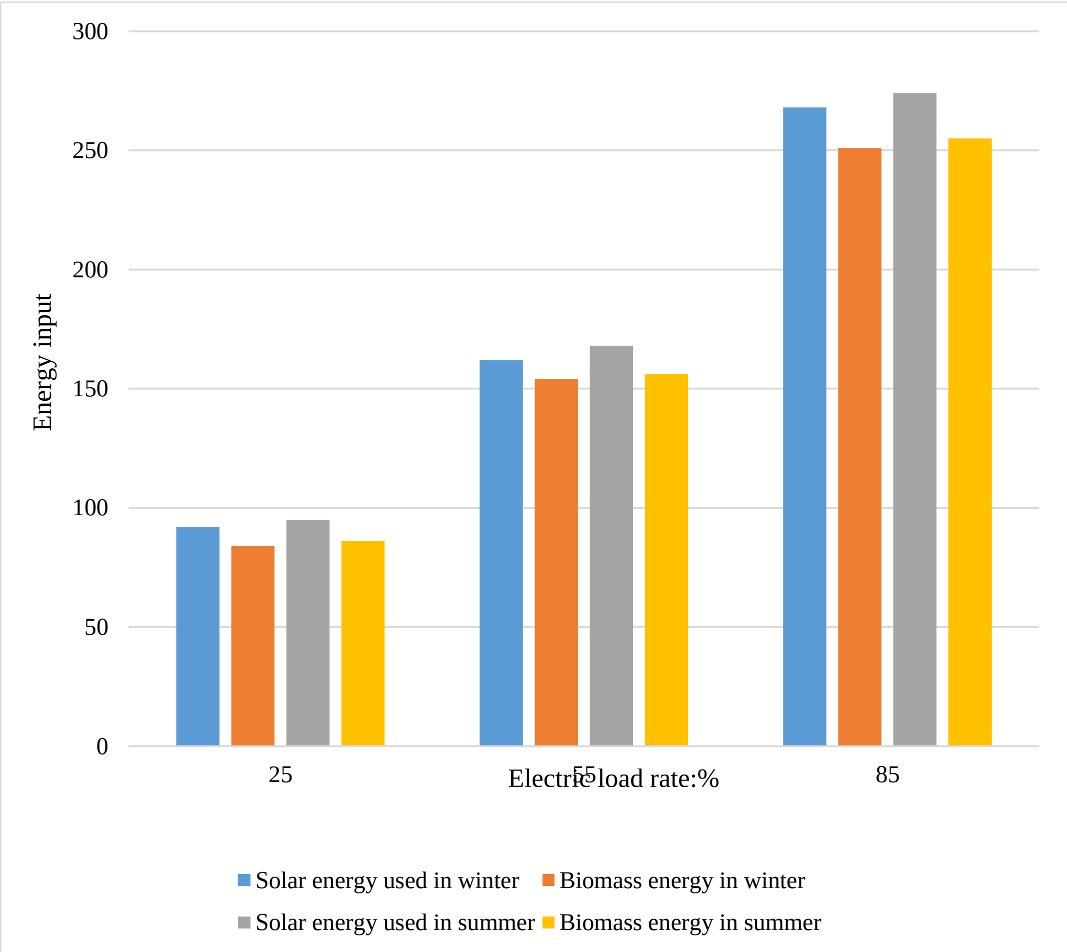

Figure 1. Comparison diagram of energy input data at substation load rate

When the electric load of the internal combustion engine of the combined cooling, heating and power subsystem runs from low load to full load in the range of 20-90kW, the input energy of the whole system changes with the change. The change analysis is shown in Figure 2 and Table 2. 2 shows:

Table 2. Energy output from winter and summer under substation load rate

Electric load rate: (%)	Energy output (kW)			
	Electricity in winter	Electricity in summer	Hot water in winter	Cool water in summer
25	25	28	46	52
55	56	58	106	96
85	105	108	194	173

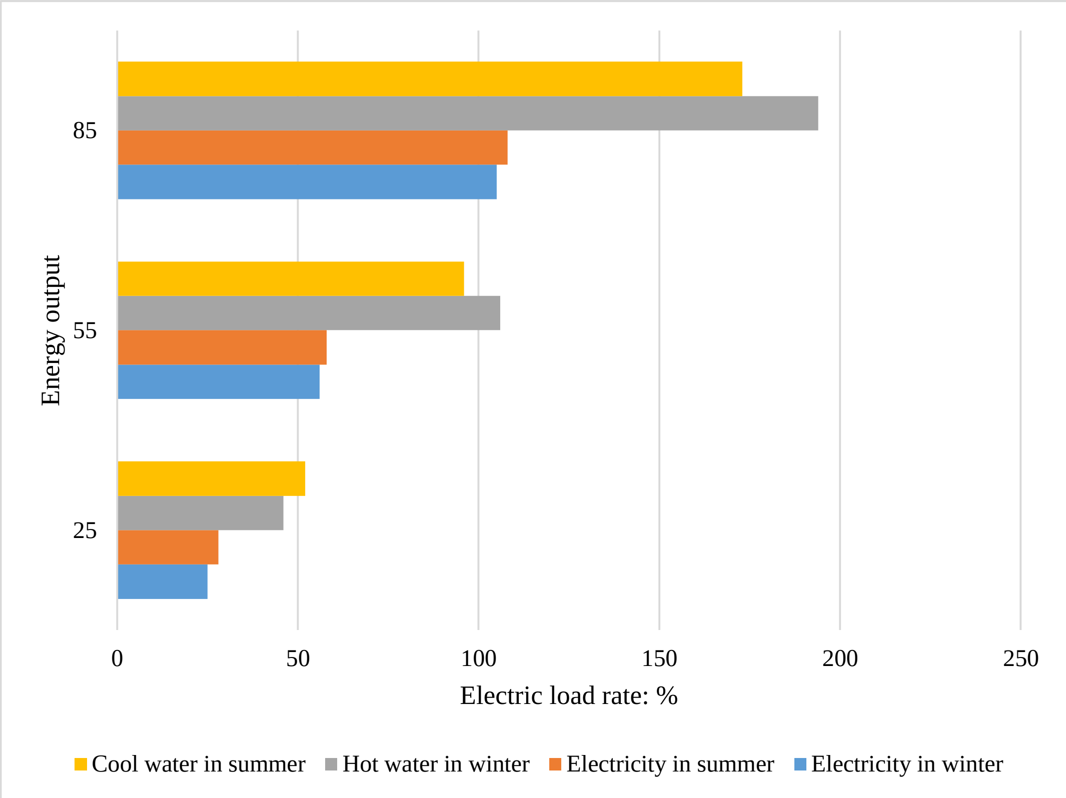

Figure 2. Comparison diagram of energy output data at substation load rate

With the gradual increase of the electrical load rate to the full load operation of the internal combustion engine, the biomass energy and solar energy at the energy input, cooling/heating at the energy output end of the entire system under the working conditions in summer and winter all increase with the electric load. This is due to the increase in the consumption of biomass gas required for the increase in power generation. The biomass gas generated in the solar gasifier is accompanied by solar energy to provide heat to drive gasification. The demand for biomass gas increases and the consumption of solar energy increases. The amount also increased. In general, the energy ratio of the output end fluctuates slightly with the change of the electrical load rate in winter and summer, but basically remains at the same level.

4.2 Variable solar radiation intensity

In the complementary subsystem of solar energy and biomass energy, the solar radiation intensity varies in the range of 250~850W/m2. With the change of solar radiation intensity, the solar energy and biomass energy at the input of the entire system and the power generation, cooling/heating at the output of the system will also change. The changes are shown in Table 3 and Figure 3:

Table 3. Energy input data in winter and summer

Solar energy irradiation intensity (W/m2)	Energy input (kW)			
	Solar energy used in winter	Biomass energy in winter	Solar energy used in summer	Biomass energy in summer
250	120	132	124	133
550	330	341	331	344
850	354	376	357	381

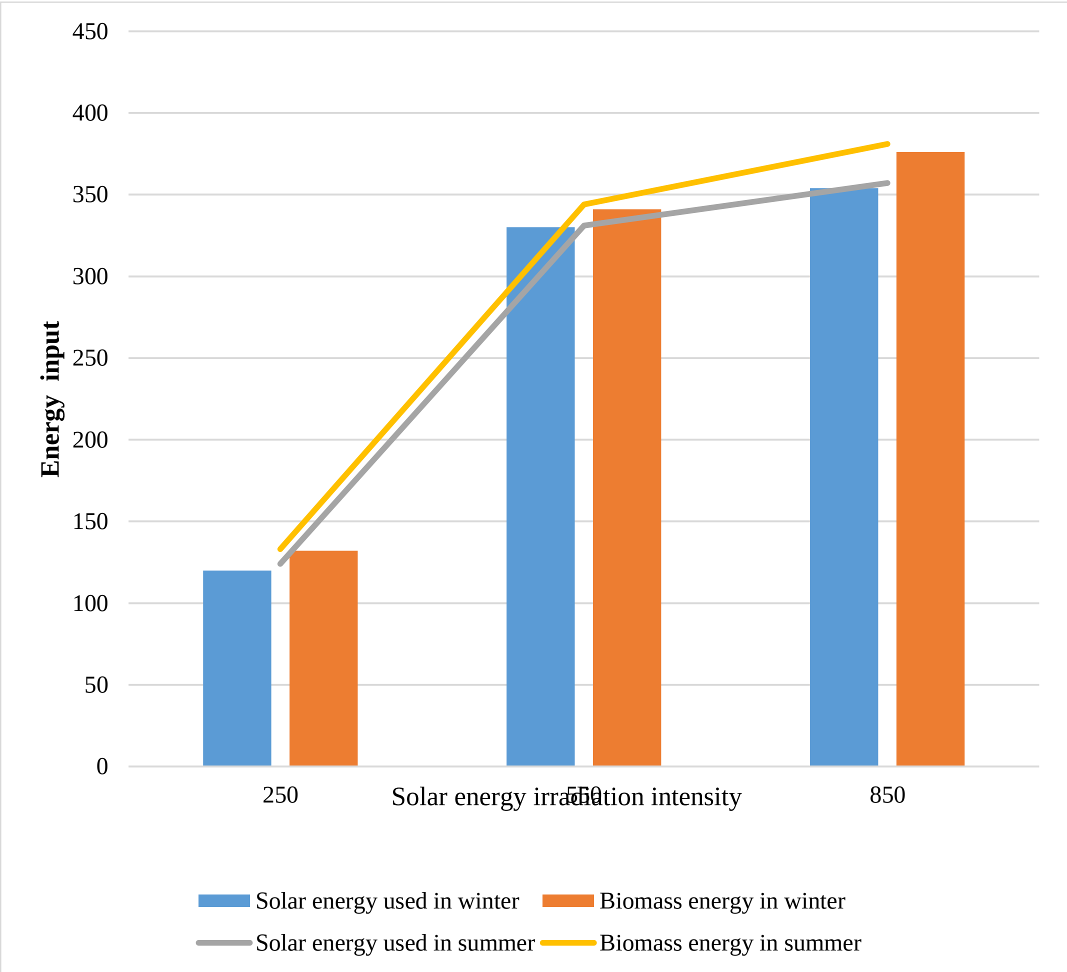

Figure 3. Comparison diagram of energy input data under variable radiation intensity

In the complementary subsystem of solar energy and biomass energy, the solar radiation intensity varies in the range of 250~850W/m2. As the solar radiation intensity changes, the power generation, cooling/heating at the output of the entire system will also change, and the changes are shown in Table 4 and Figure 4:

Table 4. Energy output data in winter and summer

Solar energy irradiation intensity (W/m2)	Energy output (kW)			
	Electricity in winter	Electricity in summer	Hot water in winter	Cool water in summer
250	35	37	88	78
550	103	105	148	136
850	114	119	236	241

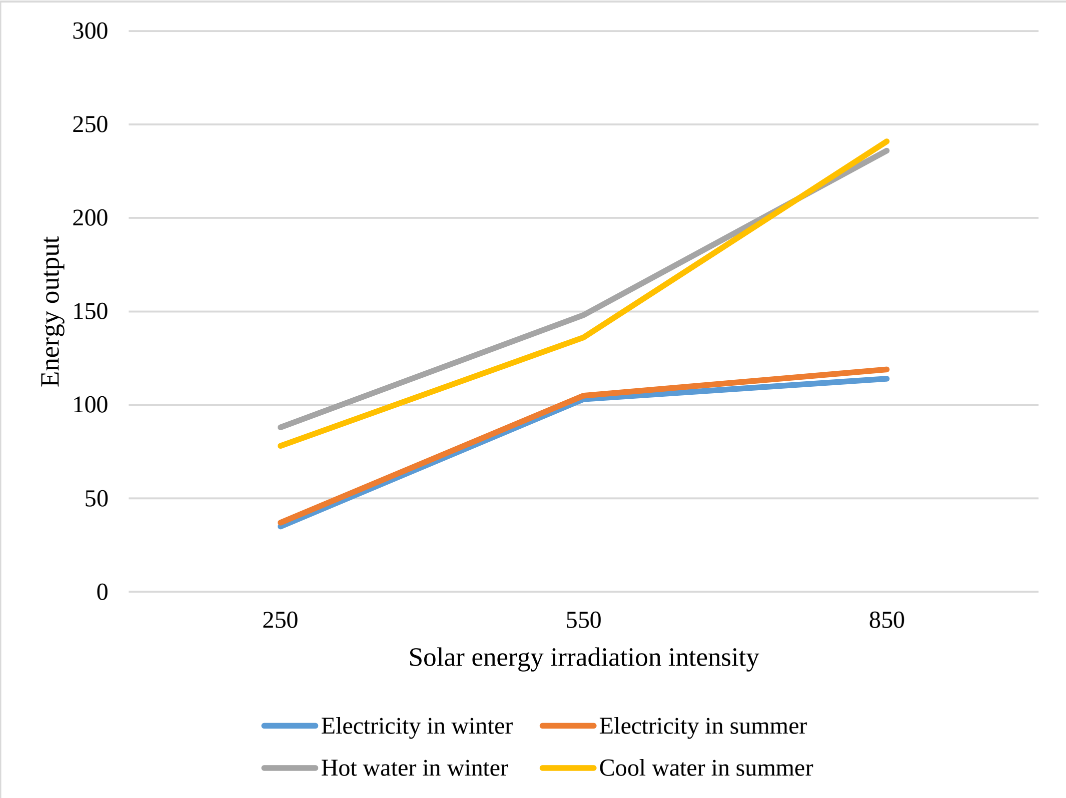

Figure 4. Comparison chart of energy output data under variable irradiation intensity

The figure shows the energy input and output of the combined cooling, heating and power system in which solar energy and biomass energy complement each other. With the increase of solar radiation intensity, the heat collection increases, and the increased heat collection helps more biomass gasification, but when the intensity is greater than 550W/m2, that is, it exceeds the design parameters of the system, Due to the limitation of system capacity, when the solar radiation intensity is increased again, the solar energy will not be fully utilized, and excess solar energy will be generated. When the radiation intensity is 550W/m2, the power as reached 100kW, and then the radiation intensity is increased to generate electricity. In winter, the ratio of domestic hot water and electricity output to the total output energy is decreasing, and the ratio of air-conditioning hot water to the total output energy is increasing.

5. Conclusions

The combined cooling, heating and power system is based on the interaction between equipment and equipment, load and load, and can provide three energy forms of heat, electricity and cold to a certain area at the same time. The principle of "cascade utilization" can meet the diversified load demands of users, and it has also become an important improvement direction of energy conservation and emission reduction. In fact, the application technologies of thermal energy storage and cold energy storage in CCHP systems are relatively mature, such as heat storage tanks, cold storage tanks, and phase change energy storage technologies are widely used. Therefore, follow-up research work Considering the influence of various energy storage methods on the operation optimization of the system will be one of the future learning directions.

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