doi:10.1088/1742-6596/2835/1/012076

Research on waste heat utilization potential of data centers for agricultural greenhouse heating

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Abstract. The explosive growth of the data center computing business has caused the problem that the operation energy consumption is too high and the waste heat of equipment heat dissipation is discharged into the atmosphere without utilization. How to utilize data center waste heat economically and effectively has become the focus of research in recent years. At the same time, as a large agricultural country, China is promoting agricultural modernization, and the number of agricultural greenhouses is also increasing year by year. Ensuring that agricultural greenhouses can use more green, efficient, and cheaper heat sources in winter is also an urgent problem to be solved. In this paper, based on the characteristics of large, stable, temperature matching and combined with the winter demand for agricultural greenhouses, a scheme of using data center waste heat for agricultural greenhouses is proposed. Firstly, this paper defines the waste heat collection from the hot channel of the machine room and the backwater of the cooling unit, establishes the waste heat calculation model of the data center, and calculates the hourly heat generated by the equipment in the machine room and the hourly waste heat change of the water cooling unit according to the hourly change of the electrical load of the data center. At the same time, the heat generated in the machine room is collected in the hot channel and replaced by the heat pipe heat exchanger, and the residual heat of the hot channel is calculated in this part. Then, the heat load model of agricultural greenhouses is established to match the waste heat of data centers, and heat pump heating equipment is selected to heat agricultural greenhouses. Finally, the equipment is optimized according to the waste heat extracted from the hot channel.

1. Introduction

In the literature research on data center waste heat utilization and greenhouse thermal insulation heating, the following problems are summarized: there are few waste heat utilization cases in data centers [1]; With low energy quality, the data center is far from the urban area, and there may be no heating buildings nearby to use the waste heat [2]; In terms of agricultural greenhouses, these several greenhouse temperature control and energy saving methods [3] have shortcomings in improving and optimizing the greenhouse itself structure and increasing the form and materials of the greenhouse envelope structure [4], which will be trapped in the material and technical limitations [5]. In terms of heat sources, they have high operation and maintenance costs and are easy to produce safety problems and other hidden dangers, while biological heating is rarely used due to insufficient heat production and high labor costs [6]. In terms of new energy, there will be new greenhouse heating energy systems that are not stable enough [7]. The heat source supply of solar heat utilization technology will be affected by weather and its reliability is low. Ground source heat pump has the problem of soil heat exhaustion and covers a large area [8]. The waste heat of power plants has the problem that the land near the power plant is too polluted, which is not conducive to the establishment of agricultural facilities [9]. To sum up the above problems, the center and agricultural greenhouses are both large carbon emitters and better methods need to be proposed to make them more energy-efficient [10].

This paper designed a data center waste heat collection and utilization system. The waste heat collected from the hot channel of the data center computer room and the return water of the water cooling unit of the refrigeration system heated the agricultural greenhouse, and optimized the system waste heat collection through the comprehensive performance optimization objective of the system, to obtain the best operating conditions and improve the system energy efficiency. We solve the problem of high energy consumption of data centers and agricultural greenhouses and achieve energy saving and efficiency on both sides.

2. Theories and methods

(1) Rack heat production calculation model

$$Q_{IT}^{t} = P_{IT}^{t} \times h_1 \times h_2 \times h_3 \tag{1}$$

(2) Calculation model of residual heat of the cooling system

$$Q_{CT}^{t} = c_w G_w \rho_w (t_{rs,2} - t_{out}) \tag{2}$$

(3) Prediction model of agricultural greenhouse heat load

$$Q_{house} = Q_{wall} + Q_{window} + Q_{soil} - Q_{solar} \tag{3}$$

(4) Objective Function

First, we determine the impact of the ratio of waste heat collected by the machine room and the cooling system on the system operation and select the optimal ratio of waste heat collected. Then, the comprehensive performance efficiency of the system η_i is:

$$\eta_{DC} = \frac{Q_{CT}^{t} + Q_{air}^{t} - Q_{EO1}^{t} - Q_{EO2}^{t}}{E_{wp} + E_{hp} + E_{hx}} \tag{4}$$

To make the operation of the unit more energy-saving, the objective function is established for the highest comprehensive performance efficiency of the system:

$$F = max(\eta_{DC}) \tag{5}$$

(5) Carbon emission

$$T_{DC} = \sigma_{hp} \sum_{s=1}^{S} \sum_{h=1}^{D} E_{hp} + \sigma_{air} E_{IT} + \sigma_{grid} E_{CT} + \sigma_{wp} E_{wp} \tag{6}$$

(6) Daily operating cost

$$F_{DC} = E_{wp}(1 - \delta_{g,s,h}) \rho_{wp} + \sum_{s=1}^{S} \sum_{h=1}^{D} E_{hp} \delta_{g,s,h} \rho_{hp} \tag{7}$$

(7) Constraint Conditions

1. Residual heat change range: $Q_{air,min} \le Q_{air}^{t} \le Q_{air,max}$;
2. Q_{EO1}^{t} decreases as Q_{air}^{t} goes up.

3. Case and result analysis

This paper takes a data center in Shanghai as an example to analyze the feasibility and effectiveness of the proposed waste heat utilization scheme and model. The park where the data center is located covers an area of 50,000 square meters, of which the office area is about 4,600 square meters, and the equipment room for recycling the waste heat of the greenhouse is 1,000 square meters. The office building of the park is equipped with a chiller to cool the office area in summer, and there is no unified municipal heating in winter. Figure1 shows the relevant parameters of the data center and the cooling system.

In this case, agricultural greenhouses of Venlo type were selected. Venlo-type greenhouses come from the Netherlands, which are small roof glass greenhouses. This type of greenhouse has been recognized by the world, as the world's most widely used glass greenhouse type. It has a small component section, simple installation, high light transmittance, a good sealing ventilation area, and other characteristics. The agricultural greenhouses are located 500 meters east of the data center.

The application period for agricultural greenhouses is from December to February in winter. Therefore, one day during this period is selected for numerical simulation. The typical daily outdoor temperature, radiation, and power load of data centers are shown in Figure 1, Figure 2 and Figure 3.

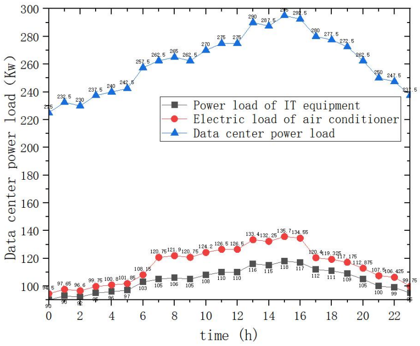

Figure 1. Data center power load.

As can be seen from Figure 4, the typical daily operating power load of data centers is relatively stable and has a small change range, but it can be divided into three sections: From 0 to 6, the power load of the data center is located in the lowest range between 225 Kw and 242.5 Kw, and the power load gradually rises from 6. The power load and cooling load reach the highest range from 14:00 to 17:00, which is about 290 Kw. It began to fall from 17:00 to 23:00, and reached its lowest point around the morning, at 237.5 Kw, when the outdoor temperature was also at its lowest point.

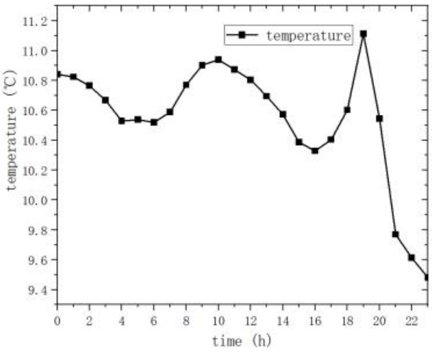

Figure 2. Outdoor temperature.

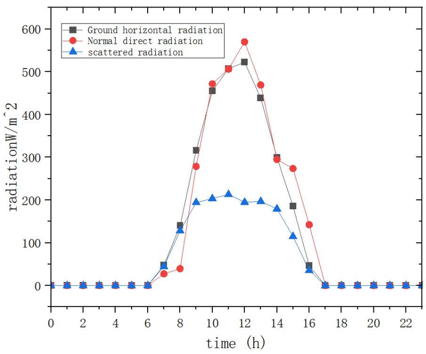

Figure 3. Outdoor radiation.

4. Analysis of experimental results

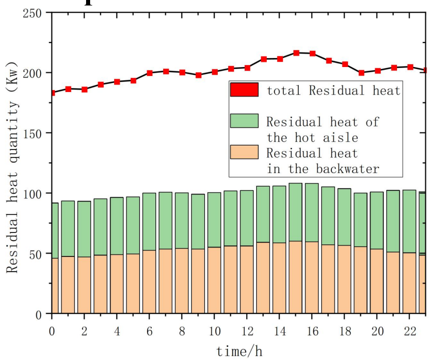

Figure 4. Relationship between the total amount of waste heat collected, the waste heat collected in the hot channel, and the waste heat at the return water of the

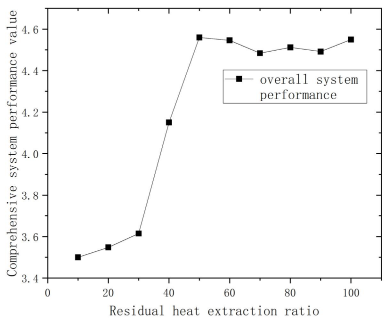

Figure 5. Influence of waste heat ratio on overall system performance.

water cooling unit.

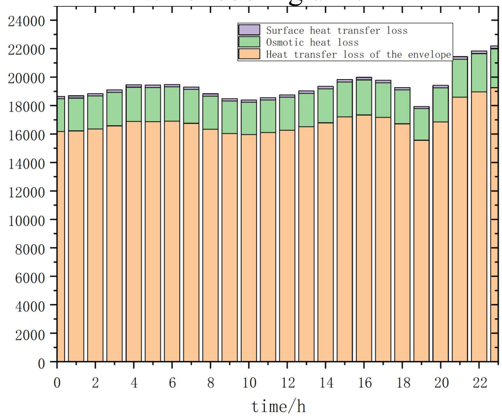

Figure 6. Greenhouse Greenhouse heat loss.

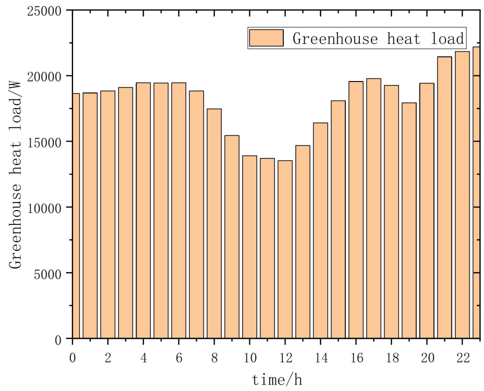

Figure 7. Greenhouse heat load.

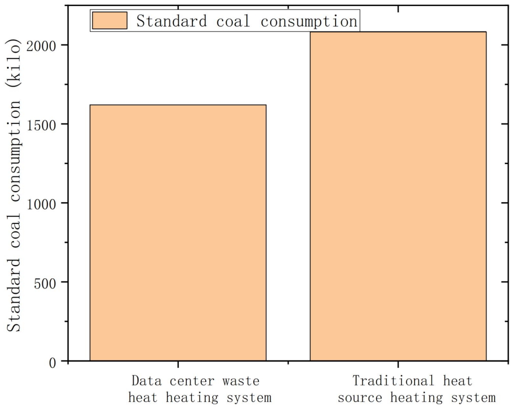

Figure 8. Carbon emissions saved by waste heat in data centers.

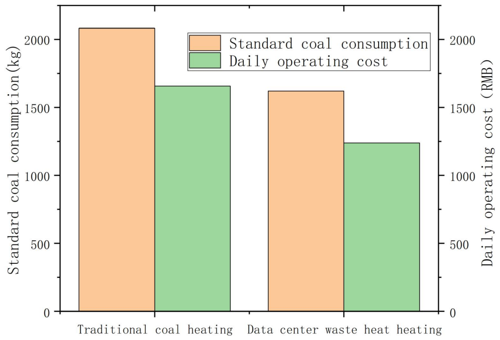

Figure 9. Compares operating costs.

From Figure 5, we can deeply understand the impact of the waste-heat ratio on the comprehensive performance of the system. It is expected that the waste heat recovery capacity of the system will vary under different conditions. The maximum is 108 Kw and the minimum is 91 Kw.

Based on the study of the influence of waste heat collection ratio on the comprehensive performance of the system in Figure 6, it is found that when the proportion of waste heat in the hot channel is set between 10% and 30%, the comprehensive performance of the system fluctuates between 3.5 and 3.6, and the change is relatively small. However, when the proportion of waste heat in the hot channel is gradually increased from 40% to 50%, the overall performance of the system is significantly improved, reaching 4.15 and 4.56 respectively. Subsequently, system performance remained at a high level and fluctuated around 4.5.

Figure 7 shows the variation of typical daily hourly heat loss in agricultural greenhouses. According to the analysis in Figure 7, we know that in greenhouses, the highest proportion of heat loss mainly comes from the enclosure heat loss, which accounts for 86%. It is followed by heat loss from cold infiltration, and the change of heat loss from cold infiltration is relatively stable. In contrast, ground heat transfer losses are minimal.

Figure 8 shows the influence of extraction of waste heat ratio on carbon emissions saved by waste heat energy in data centers, and Figure 9 shows the comparison of operation conditions between traditional coal heating and data center waste heat heating. According to the detailed analysis of the proportion of waste heat extraction in Figure 8 and Figure 9, we know the carbon emission and economic impact under different waste heat supply strategies. The following analysis results can be obtained. Waste heat utilization at the backwater, if only the waste heat at the backwater is used, that is, the waste heat of the collection hot channel is 0, the standard carbon emission of the system can be reduced by about 659.83 kg. As the proportion of waste heat extraction increases, more standard carbon can be saved, and 1438.78518 kg of standard carbon can be saved if the data center's waste heat is fully utilized. Considering the energy saving and carbon reduction and the operation economy of the equipment, the proportion of waste heat in the hot channel selected by the system is about 50%. In this case, the carbon emissions of the system are still significantly reduced, approximately within the range of 951.15 to 1146.54 kg of standard carbon. This choice is more reasonable economically, because it can take into account the green and energy-saving operation of the data center without causing further waste, and the equipment can run at rated power without causing waste of equipment performance. As shown in Figure 9, the daily operating cost of the waste heat heating system of the data center is 1237.5207 yuan and the standard coal energy consumption is 1620.87 kg. Regardless of the daily operating cost and the standard coal energy consumption, the waste heat heating system of the data center is lower than the traditional coal heating. Because data center waste heat heating consumes more energy is electricity, compared to coal costs are lower, more energy saving. Finally, Figure 9 shows the waste heat benefit of the data center. It can be seen from the table that the annual charge for the waste heat supply of the data center is 289,580 yuan, the annual operating cost is 160,190 yuan, and the annual net income can reach 132,840 yuan. This is a significant economic advantage, but also has a lower level of carbon emissions, to achieve the dual effect of economy and energy conservation and emission reduction. The comprehensive research results show that under the consideration of balancing carbon emission reduction and equipment economy, choosing about 50% waste heat extraction ratio is the optimal strategy. Datacenter waste heat supply can not only reduce the energy consumption of greenhouses but also show obvious advantages in the economy, providing strong support for sustainable development.

5. Conclusion

This paper proposes an innovative scheme to improve system energy efficiency, reduce energy consumption costs, and achieve green sustainable development by using waste heat from data centers to heat agricultural greenhouses. Firstly, the system is modeled to provide heating services for agricultural greenhouses by collecting waste heat from the hot channel of the data center machine room and the return water of the water cooling unit. Then, to optimize the performance of the system, the paper uses Matlab software for numerical simulation analysis, and obtains the optimal proportion of the hot channel of the data center through the algorithm, which will not have any negative impact on the operation of the data center after the utilization of the waste heat of the data center. Under the best operating conditions, the comprehensive performance of the system can be significantly improved, carbon emissions can be reduced, and compared with traditional coal heating, it has better economic benefits.

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