Exergy analysis of large temperature difference series air conditioners in subway stations

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Abstract. In view of the large difference in the heat and humidity ratio of each air-conditioning zone in the subway, the unified cooling and dehumidification method is adopted, which changes the traditional connection mode of air-conditioning terminal in parallel. A cooling system of air-conditioning terminal surface cooler in series, i.e. large temperature difference series cooling system, is applied to the subway station. The large temperature difference series cooling system is divided into three subsystems: cooling water system, chilled water system and end refrigeration system. The second law of thermodynamics, namely the law of exergy equilibrium and thermoeconomics, is used to analyze the feasibility and economy of the large temperature difference series system and its subsystems. After comparing energy consumption and economy with the conventional air conditioning system, it was found that the exergy efficiency of the chilled water system using the large temperature difference series cooling system was reduced. However, the exergy efficiency of the end refrigeration system in the subway equipment area has been significantly improved, saving electricity costs, and the investment can be recovered in 3.7 years, and the exergy cost has dropped significantly. The use of a large temperature difference series cooling system in a subway station can achieve the effect of energy saving and cost reduction.

1 Introduction

In recent years, China's urban rail transit has achieved rapid development, and the number of subway stations will continue to increase. The functional division of subway stations is clear, and the cooling load characteristics of each area are quite different. At the same time, due to the long operating time and the high energy consumption of the air conditioning system, the energy consumption of the air conditioning system has become an important part of the energy consumption of subway stations. Most of the previous researches and designs have dealt with the air-conditioning system in each room in a unified manner, without considering the load characteristics of each room. At the same time, the equipment is under partial load conditions and cannot effectively use the cooling capacity provided by the air-conditioning chilled water, which will also affect the efficiency of the refrigeration unit and the cooling end. These conditions are often caused by irrational design of the air-conditioning system or mismatch of energy supply and actual load. It can be seen that there is room for further optimization in the form of air conditioning systems in subway stations, which has certain energy saving potential.

Japan's research mainly focuses on chilled water with large temperature differences, and the United States main research focuses on the low-temperature air supply. In summary, there are more economic analysis reports and guidelines in both countries, and there are fewer technical

reports on practical applications^[1-3]. In China, the plan of using a series cooler with a new fan unit for the International Finance Building, and a plan of using a series cooler with a dry coil in the terminal of Xianyang International Airport have certain reference significance^[4-5].

The subway station public area has a high density of people, a lot of electrical equipment, and a large latent heat load. The air-conditioning load in the office equipment area mainly comes from electrical equipment, that is, the sensible heat load^[6]. The effect of chilled water inlet temperature on the latent heat load of the surface cooler is greater than that of the sensible heat load. As the temperature of the chilled water inlet increases, the ability of the surface cooler to handle latent heat load decreases more significantly^[7]. The pipes of the large temperature difference tandem cooling system are connected in series, and it is more suitable to use the combined air conditioner with centralized air supply in the subway public area and office equipment area^[8]. This paper uses a large temperature difference end series cooling system in a medical subway station, which can fully utilize the characteristics of different end loads to achieve the cascade utilization of chilled water cooling, reduce the amount of chilled water, and maximize the utilization of chilled water. This paper uses thermodynamic laws and thermoeconomics to analyze the suitability and economics of the system, and proposes a new form of air conditioning system suitable for subway stations, which has important

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theoretical significance and practical value for the economic and energy saving of subway station air conditioning systems.

2 Large temperature difference series cooling system scheme

2.1. Load Analysis of Room in Each Air Conditioning Subway Station

The load analysis in this article takes a standard subway station in Chengdu Metro as an example. The air-conditioning zone of the public area is B, and the air-conditioning zone of the office equipment area is B1, B2, B3. Zone B includes the station hall floor and the platform level. Zone B1 mainly includes rooms such as offices and watch rooms. Zone B2 mainly includes the electromechanical control room and equipment rooms. Zone B3 includes the power supply room, power

distribution rooms, and substations. After calculation, the cooling load of zone B (including fresh air load) is 362.74kW, the cooling load of zone B1 (including fresh air load) is 20.75 kW, the cooling load of zone B2 (including fresh air load) is 189.71kW, and the cooling load of zone B3 (including fresh air load) is 217.39kW. The load structure of each zone is shown in Figure 1. In Figure 1, the latent heat load of air conditioning zone B accounts for more than 56%, the latent heat load of air conditioning zone B1 accounts for approximately 27%, the latent heat load of air conditioning zone B2 accounts for approximately 21.6%, and the latent heat load of air conditioning zone B3 accounts for approximately 11.5%. Therefore, in the air conditioning zone B, the dehumidification requirements are high. You can use low-temperature chilled water to enter the surface cooler of the air conditioning zone B to dehumidify and cool down; other air conditioning zones have a small proportion of latent heat load, small wet load, high cooling demand, and high use temperature. The chilled water can be fed into the relevant surface cooler to meet the demand [7].

Figure1. Air conditioning zone load composition

2.2. Scheme design of series cooling system with large temperature difference

Based on the analysis of the load composition, a preliminary scheme for a large temperature difference series cooling system is given. As shown in Figure2, the surface coolers of the air conditioning zone B are connected in series with the surface coolers of the air conditioning zones B1, B2, and B3, and the way of the surface coolers of the air conditioning zone B1, B2, and B3 remains in parallel. The surface cooler that the chilled water enters first is called the first-stage surface cooler, and the surface cooler that enters later is called the second-level surface cooler. The air supply temperature of the surface cooler of B1 and B2 is 16 °C, and the air supply temperature of the surface cooler of B3 is 20 °C. According to the design principle of the surface cooler, the chilled water outlet temperature should be lower than the supply air temperature [9]. In this paper, the secondary surface cooler's chilled water outlet temperature is

designed to be 15 °C. The chilled water flow rate of the first and second stage coolers is consistent. According to Formula (1), when the mass flow rate m is equal, the temperature difference Δt is proportional to the load Q , that is, the first and second stage coolers supply The ratio of the return water temperature difference is equal to the ratio of the cold load of the first and second surface coolers.

$$Q = c_p m \Delta t \quad (1)$$

According to Formula (1), Δt_1 is about 3.6 °C and Δt_2 is about 4.4°C. The chilled water at 7°C enters the first stage cooler, and after heat exchange, the frozen water leaves the first stage cooler at 10.6 °C. Then 10.6°C chilled water enters the secondary surface cooler. After heat exchange, 15°C chilled water returns to the refrigeration unit. Increasing the heat exchange temperature difference of the cooling water may cause an increase in energy consumption [10,11], so in this solution, keep the cooling water in and out temperature and heat exchange temperature constant.

Figure2. Preliminary scheme of large temperature difference series cooling system

3 Exergy analysis of large temperature difference series cooling system

3.1. Build Exergy Model

The exergy model of a conventional central air-conditioning system using an all-air system [12-15] can be divided into three subsystems: a cooling water system, a chilled water system, a terminal and a room system, as shown in Figure 3. The cooling water system is mainly composed of cooling towers, cooling water pumps, and cooling water pipes; the chilled water system is mainly composed of refrigeration units, chilled water pumps, and chilled water pipelines; the end refrigeration system is mainly composed of air handling units, air conditioning ducts, and rooms Make up. The flow direction of the exergy flow E_x is consistent with the flow direction of the cooling medium.

Figure3. Exergy model of conventional central air conditioning

When a large temperature difference series cooling system is used, the original end refrigeration system is divided into a first-stage end refrigeration system and a second-stage end refrigeration system according to the order in which chilled water enters. Exergy model of large temperature difference series cooling system is shown in Figure 4.

Figure4. Exergy model of large temperature difference series cooling system

3.2. Analysis and calculation of exergy models

3.2.1. Analysis and calculation of exergy model of conventional air conditioner

The exergy model of the system shown in Figure 3 above gives the exergy balance equation of each subsystem.

The input exergy of cooling water system includes mechanical exergy W_1 of cooling tower fan, mechanical exergy W_2 of cooling water pump, $E_{x,AG}$ of cooling tower air inlet exergy, $E_{x,CR}$ of cooling water return exergy; the output exergy of cooling water system includes $E_{x,AH}$ of cooling tower air inlet exergy, $E_{x,CR}$ of cooling water supply exergy. Exergy loss of cooling tower is $E_{x,L1}$.

Exergy balance equation of cooling water system:

$$E_{x,AH}-E_{x,AG}+W_1+W_2=E_{x,CR}-E_{x,CS}+E_{x,L1} \quad (2)$$

Exergy efficiency of cooling water system:

$$\eta_{ex1}=(E_{x,CR}-E_{x,CS})/(E_{x,AH}-E_{x,AG}+W_1+W_2) \quad (3)$$

The input exergy of the chilled water system includes the mechanical exergy W_3 of the refrigerating unit, the mechanical exergy W_4 of the chilled water pump, the $E_{x,CS}$ of the cooling water supply exergy, and the $E_{x,CHR}$ of the chilled water return water exergy. The output exergy of the chilled water system includes $E_{x,CHS}$ for chilled water supply and $E_{x,CR}$ for cooling water return. Exergy loss of chilled water system is $E_{x,L2}$.

Exergy balance equation of chilled water system:

$$E_{x,CR}-E_{x,CS}+W_3+W_4=E_{x,CHR}-E_{x,CHS}+E_{x,L2} \quad (4)$$

Exergy efficiency of chilled water system:

$$\eta_{ex2}=(E_{x,CHR}-E_{x,CHS})/(E_{x,CR}-E_{x,CS}+W_3+W_4) \quad (5)$$

The input exergy of the refrigeration end system includes mechanical exergy W_5 for air supply, $E_{x,OA}$ for fresh air exergy, $E_{x,R}$ for return exergy; the output exergy of the refrigeration end system includes $E_{x,RA}$ for air exergy. Exergy loss of refrigeration end system is $E_{x,L3}$.

Exergy balance equation of end refrigeration system:

$$E_{x,CHR}-E_{x,CHS}+W_5=E_{x,OA}+E_{x,RA}-E_{x,SA}+E_{x,L3} \quad (6)$$

Exergy balance equation of end refrigeration system:

$$\eta_{ex3}=(E_{x,OA}+E_{x,RA}-E_{x,SA})/(E_{x,CHR}-E_{x,CHS}+W_5) \quad (7)$$

Total exergy efficiency of conventional air conditioning systems:

$$\eta_{ex}=(E_{x,OA}+E_{x,RA}-E_{x,SA})/(E_{x,AH}-E_{x,AG}+\sum_{n=1}^5 W_n) \quad (8)$$

3.2.2. Analysis and calculation of exergy model for large temperature difference series air conditioner

According to the initial plan of the large temperature difference series cooling system, keep the chilled water supply temperature at 7 °C. According to Formula (1), the cooling load handled by the refrigeration unit remains the same, and the chilled water heat exchange temperature difference will increase, and the chilled water flow will be corresponding Reduced, at this time the performance of

the refrigeration unit and cooling system will hardly change^[10,11,16]. Therefore, the exergy model of the cooling water system of the large temperature difference series cooling system is the same as that of the conventional air conditioner, and the exergy efficiency of the cooling water system has not changed.

For the chilled water system of the large temperature difference series cooling system, the input power W'_3 of the refrigeration unit has not changed. Because of the change of the chilled water flow and the change of the branch head after the series cooler is connected in series, the pipe network must be redesigned to meet the existing air conditioning design specifications. In addition to the maximum head in the secondary surface cooler, the power of the pump can be calculated according to Formula (10)^[20].

$$H'/H=(m_{CHR}/m'_{CHR})^{0.4165} \quad (9)$$

$$W=mgH/1000 \quad (10)$$

Exergy balance equation of chiller water system of series cooling system:

$$E'_{x,CR}-E'_{x,CS}+W'_3+W'_4=E'_{x,CHR}-E_{x,CHS1}+E'_{x,L2} \quad (11)$$

Exergy efficiency of chilled water system of tandem cooling system:

$$\eta'_{ex2}=(E'_{x,CHR}-E_{x,CHS1})/(E'_{x,CR}-E'_{x,CS}+W'_3+W'_4) \quad (12)$$

It can be obtained from formulas (9) and (12) that the input power W'_3 of the refrigeration unit does not change; Exergy difference $(E'_{x,CR}-E'_{x,CS})$ between cooling water supply and return water does not change. ; The power W'_4 of the chilled water pump is reduced, but the exergy difference $(E'_{x,CHR}-E_{x,CHS1})$ of the chilled water supply and return water is reduced, so the chilled water system efficiency may increase or decrease.

The exergy equilibrium equations of the primary refrigeration end system and the secondary refrigeration end system can be obtained according to Figure 4:

$$E_{x,CHS2}-E_{x,CHS1}+W_{5,1}=E_{x,OA1}+E_{x,RA1}-E_{x,SA1} \quad (13)$$

$$E_{x,CHR}-E_{x,CHS2}+W_{5,2}=E_{x,OA2}+E_{x,RA2}-E_{x,SA2} \quad (14)$$

Exergy efficiency of the end refrigeration subsystem of a tandem cooling system:

$$\eta_{ex31}=(E_{x,OA1}+E_{x,RA1}-E_{x,SA1})/(E_{x,CHS2}-E_{x,CHS1}+W_{5,1}) \quad (15)$$

$$\eta_{ex32}=(E_{x,OA2}+E_{x,RA2}-E_{x,SA2})/(E_{x,CHR}-E_{x,CHS2}+W_{5,2}) \quad (16)$$

In the scheme, the surface cooler is redesigned according to the design principle of the surface cooler^[9,21]. The supply air volume, return air volume and air temperature difference have not changed, so the exergy value difference $(E_{x,OA1}+E_{x,RA1}-E_{x,SA1})$, $(E_{x,OA2}+E_{x,RA2}-E_{x,SA2})$ between the supply air and the return air is consistent with the conventional air conditioner. According to the design principle of the surface cooler, redesigning the surface cooler For the first-level surface

cooler, the exergy value difference ($E_{x,CHS2}-E_{x,CHS1}$) of the chilled water supply and return water increases. If the heat exchange area is small, the power of the blower $W_{5,1}$ increases, and the exergy efficiency of the first-stage surface cooler decreases. For the secondary meter cooler, the difference in exergy value ($E_{x,CHR}-E_{x,CHS2}$) between the chilled water supply and the return water is significantly reduced, so the exergy efficiency of the secondary meter cooler will increase.

Total exergy efficiency of large temperature difference series cooling system:

$$\eta'_{ex} = [(E_{x,OA1} + E_{x,RA1} - E_{x,SA1}) + (E_{x,OA2} + E_{x,RA2} - E_{x,SA2})] / (E_{x,AH} - E_{x,AG} + \sum_{n=1}^5 W'_n) \quad (17)$$

From Formula (17), it can be seen that the exergy difference between the supply air and the return air has not changed. There is no change in the use of return air to the cooling tower, and there is no change in return exergy. The main reason is that the input exergy of the pump is significantly reduced, and the input exergy of the fan is slightly increased. So the exergy efficiency of the system is increased.

In the calculation process, the exergy calculation of wet air is calculated according to Formula (17) [22-24]. The enthalpy and entropy of water can be found in the enthalpy and entropy diagram of water, and then calculated according to Formula (18)

$$E_x = (c_{p,a} + dc_{p,v}) T_0 \left(\frac{T}{T_0} - 1 - \ln \frac{T}{T_0} \right) + (1 + 1.0608d) R_a T_0 \ln \frac{P}{P_0} + R_a T_0 \left[(1 + 1.608d) \ln \frac{1 + 1.608d_0}{1 + 1.608d} \right] + 1.608d \ln \frac{d}{d_0} \quad (18)$$

$$E_x = m(\Delta h - T_0 \Delta s) \quad (19)$$

3.3. Engineering example calculation

As an example, a standard station in the Chengdu Metro has an outdoor dry-bulb temperature of 30.9°C and a wet-bulb temperature of 26.5°C in summer air-conditioning in public areas; an outdoor dry-bulb temperature of 31.8°C and a wet-bulb temperature of 26.4°C in summer air-conditioning in office equipment areas. The exothermic calculated ambient temperature is 31.8°C, which is 304.95K. The design parameters of conventional air conditioning systems are shown in Table 1. After the surface cooler is connected in series, the redesigned series system design parameters are shown in Table 2. Surface coolers after series connection need to be redesigned. Table 3 shows the design parameters of parallel and series surface coolers. From Tables 1 to 3, it can be concluded that the cooling tower power, cooling water pump power, refrigeration unit power, surface cooler air volume and cooling capacity have not changed as mentioned above; the surface coolers are connected in series, the pipe network resistance increases, and the frozen water The flow rate is reduced, the power of the chilled water pump required is reduced; the temperature difference between the cold water heat exchange of the surface cooler is reduced, the heat exchange area is increased, and the fan power is only increased by the increase of the first surface cooler.

Table1. Design parameters of conventional air conditioners

Cooling tower power (kw)	Refrigeration unit power (kw)	Cooling water pump			Chilled water pumps		
		Head (m)	Flow (kg/s)	Powr (kw)	Head (m)	Flow (kg/s)	Powr (kw)
1.22	143.4	23	45.2	12.7	32	37.7	14.8

Table 2. Design parameters of tandem air conditioner

Cooling tower power (kw)	Refrigeration unit power (kw)	Cooling water pump			Chilled water pumps		
		Head (m)	Flow (kg/s)	Powr (kw)	Head (m)	Head (m)	Flow (kg/s)
1.22	143.4	23	45.2	12.7	35.9	24.3	10.7

Table3. Design parameters of surface cooler

surface cooler	Air volume (m ³ /h)	Refrigerating capacity (kw)	Conventional air conditioning			Series air conditioning		
			Water flow (T/H)	Heat transfer area (m ²)	Fan power (kw)	Water flow (T/H)	Heat transfer area (m ²)	Fan power (kw)
B	62650	360.9	62.1	265.2	1.00	87.3	244	1.00
B1	4103	20.7	3.6	43.4	0.08	4.0	57.4	0.12
B2	37518	189.7	32.3	283.7	0.79	36.9	399.6	0.79
B3	4950	217.4	37.6	223.8	1.31	42.3	268.5	1.31

According to the design parameters of Formula (2) ~ (18) and Table 1~3, calculate the exergy efficiency of cooling water system, chilled water system and end refrigeration system and the exergy flow of each subsystem. See Table 4-6 for the results. Since the cooling water system is not affected by the system change, the exergy efficiency has not changed. Although the power of the chilled water pump in the chilled water system has decreased, the exergy value of the chilled water has

decreased significantly, resulting in a decrease in the exergy efficiency of the system; in the end cooling system, except for the decrease in the exergy efficiency of the surface coolers in zone B, the exergy efficiency of the surface coolers in other zones has increased significantly, and the exergy efficiency of the end cooling system has increased. After the final calculation, the total exergy efficiency of conventional central air conditioning is 14.37%, and that of series central air conditioning is 14.73%, up 0.36%

Table 4. Calculation results of exergy value of cooling water system

cooling water exergy (kw)	Cooling tower power (kw)	Pump power (kw)	Intake and return air Exergy difference (kw)	exergy efficiency
9.22	1.22	12.70	8.31	41.48%

Table 5. Calculation results of exergy value of Chilled water system

	Chilled water exergy (kw)	Power of refrigerating unit (kw)	Pump power (kw)	cooling water exergy (kw)	exergy efficiency
Conventional air conditioning	65.11	143.40	14.80	9.22	38.89%
Series air conditioner	58.75	143.40	10.70	9.22	35.97%

Table 6. Calculation results of exergy value of terminal refrigeration system

Surface cooler	Intake and return air Exergy difference (kw)	Chilled water exergy (kw)	Fan power (kw)	exergy efficiency	System exergy efficiency
B	12.31	29.82	1.00	39.93%	36.88%
B1	0.84	1.73	0.08	46.61%	
B2	7.76	15.51	0.79	47.63%	
B3	4.28	18.05	1.31	22.09%	
B (Series)	12.31	33.17	1.00	36.02%	40.70%
B1(Series)	0.87	1.23	0.12	64.92%	
B2(Series)	7.76	11.34	0.79	63.97%	
B3(Series)	4.28	13.00	1.31	29.87%	

4 Thermoeconomic analysis of series cooling system with large temperature difference

4.1. Basic concepts of thermoeconomics

Thermoeconomics, also known as exergy economics, is an interdisciplinary subject combining thermodynamic analysis with economic factors. It is based on the first law and the second law of thermodynamics. It combines the principle of thermodynamics with the concept of economics. It studies the rationality of energy use process, the feasibility of scheme and the optimality of system by using the thought of system engineering. It is a thermodynamic analysis the method can be used as a useful supplement. [27~30]

In the thermoeconomic analysis of energy system, the unit price or value of various exergy must be involved.

Therefore, in the thermal economic analysis of energy system, in addition to mass conservation equation, energy conservation equation and exergy balance equation, an economic balance equation, also known as exergy cost equation, needs to be added. The so-called exergy cost equation is to list the capital balance mode of product cost for any energy system (unit, equipment), that is, the cost of all production outlets, including one-time investment and operation costs (energy consumption, maintenance, wages and management costs). In fact, the exergy cost is expressed in terms of annual expenses. Only when establishing the exergy cost equation, the decision variables that affect various expenses must be considered [X]. The exergy cost equation can be established as Formula (20). Let C_F be the fixed investment cost of the equipment, C_f be the energy cost and C_{qt} be the other operating costs

$$c_{pc} = \frac{C_F}{E_{x,pc}} + \frac{C_f}{\eta_{ex}} + \frac{C_{qt}}{E_{x,pc}} \quad (20)$$

As can be seen from the above formula: the average unit price of the exergy of the product must be greater than the average unit price of the input energy consumption exergy, because $\eta_{ex} < 100\%$, and it also costs energy consumption C_f and other operating costs C_{qt} . If the energy cost C_f and other operating costs C_{qt} remain unchanged, c_{pc} will decrease; if the increase of η_{ex} causes an increase in energy cost C_f or other operating costs C_{qt} , c_{pc} may not necessarily decrease.

4.2. System Exergy Analysis

The unit price of each device is shown in Table 7.

Table 7. Unit price of equipment

Device name	Unit Price
Unit cooling capacity price of chiller	460 (yuan/kw)
Pump unit water flow price	50 (yuan / (m ³ /h))
Cooling tower unit water flow price	440 (yuan / (m ³ /h))
Fan unit air volume price	0.8 (yuan / (m ³ /h))

The cost of surface cooler equipment is calculated

according to Formula (21). a and b are correction coefficients, refer to Table 8; U is unit price of air volume, 2.2 yuan / (m³ / h); W is air volume, m³ / h.

$$P = abUW \quad (21)$$

Table 8 Surface cooler price correction factor

Row number	4	6	8
a	1	1.1875	1.3751
b	$B = 1.4711V_y^{-0.4212}$		

The above design principles are only suitable for surface coolers with a temperature difference between inlet and outlet water of 5 ° C. According to the design principles of the surface cooler, the heat exchange area of the new surface cooler is increased, but the cost of the new surface cooler equipment is the same as the original price the situation is not realistic. Therefore, a correction factor c is added to the basis of Formula (21) to obtain Formula (22). The correction factor c is the ratio of the heat exchange area of the new surface cooler to the heat exchange area of the original surface cooler.

$$P = abcUW \quad (22)$$

According to the formula and reference parameters given above, the calculation of equipment costs was performed, and the results are shown in Table 9.

Table 9. System equipment costs

	Fan (yuan)	Surface cooler (yuan)	Pump (yuan)	Refrigerator (yuan)	Cooling Tower (yuan)	Total (yuan)
Conventional system	146221	377609.2	14922	65964	71355.68	676071.88
Series system	146221	433385.5	12510	65964	71355.68	729436.18

It can be found from Table 9 that the increase in equipment costs is mainly because although the cost of the pump has been reduced, the surface cooler has increased the heat exchange area and the cost has increased. The fixed investment cost of the equipment has increased by 53364.3 yuan.

The subway runs from 5:00 to 23:00 every day. The air-conditioning system generally starts cooling from May and ends at the end of October for a total of 185 days. As shown in Figure 5, the change of outdoor enthalpy in typical working conditions and the change in passenger flow coefficient of a subway station as shown in Figure 6 can be calculated as shown in Figure 7. After calculation, the daily power consumption of conventional air-conditioning systems is 2449.87 kW·h; the daily power

consumption of serial air-conditioning systems is 2353.35 kW·h; the annual power consumption of conventional air-conditioning systems is 453225.37 kW·h; Chengdu's electricity bill is 0.8 yuan / kW·h. Finally, the annual electricity bill for conventional air-conditioning systems is 362580.3 yuan, and the annual electricity bill for series air-conditioning systems is 348295.5 yuan. The use of a series air-conditioning system can save electricity costs of 14284.79 yuan, and recover the equipment investment cost in about 3.7 years. According to Formula (20), it is assumed that the other operating costs C_{qt} are 10% of the initial equipment investment. After calculation, the exergy cost of the conventional air-conditioning system is 2552698 yuan / kW; the exergy cost of the series air-conditioning system is 2396385 yuan / kW.

Figure 5. Change of outdoor enthalpy in typical working conditions

Figure 6. Passenger flow coefficient at subway stations

Figure7. System energy consumption in typical working days

5 Conclusion

According to the research in this paper, it can be found that because the heat transfer temperature difference of the chilled water in the series system increases and the flow rate decreases, the exergy efficiency of the chilled water system decreases. Increasing the flow rate reduces the exergy efficiency; the chilled water inlet temperature of the secondary end refrigeration system increases, the flow rate decreases, the exergy efficiency significantly increases, and the total exergy efficiency of the end refrigeration system slightly increases; the exergy efficiency of the series system has been calculated to have it is slightly improved but not obvious; analysis using thermoeconomic principles can find that the initial investment of the series system has increased, but the

saved electricity costs can be recovered within 3.7 years; the exergy cost of the series system is significantly reduced. Therefore, the application of series air conditioning systems in subway stations has the advantages of saving energy and reducing costs.

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