Application of exhaust heat recovery in energy saving of HVAC

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Abstract: The research, development and application of energy-saving technologies are the basis of HVAC system energy saving. The recycling of the energy contained in exhaust air can achieve greater economic and environmental benefits. This article analyzes the waste heat recovery technology, and mainly analyzes the technical feasibility and energy saving of the application of fresh air and exhaust energy recovery system in the design stage of the HVAC system. From the setting of the sensible heat recovery system and the setting of the total heat energy recovery system, the energy consumption reduction of the HVAC system is analyzed, and it is proposed that the exhaust heat recovery technology has greater potential for energy conservation.

1. Preface
The HVAC system is one of the main energy sources for buildings, and its energy efficiency and economy are increasingly valued. The heat released from the air-conditioned room into the atmosphere causes both thermal pollution and waste of heat energy. Using the residual heat from the exhaust air to pre-treat the fresh air can reduce the energy required to handle the fresh air and reduce the unit load. In summer, the exhaust air temperature of air-conditioned buildings is lower than the outdoor fresh air temperature, and the indoor moisture content is also lower than the outdoor fresh air moisture content. Exhaust heat recovery can reduce the fresh air temperature and humidity. In winter, the exhaust air temperature is higher than the outdoor fresh air temperature, and the exhaust moisture content is higher than the outdoor fresh air moisture content. The waste heat recovery can preheat and humidify the fresh air. The specific method is to install a heat exchanger at the outlet of the exhaust air. Indirect contact heat exchange between the exhaust air and the fresh air will be realized to recover the waste heat of the exhaust air. At the same time, it can increase indoor fresh air and improve indoor air quality. Currently, heat recovery equipment that can be used is classified into sensible heat recovery type and total heat recovery type. The relevant experts have a high evaluation of the energy-saving significance of this technology, and their application prospects are optimistic.

2. Introduction of exhaust heat recovery system
The exhaust heat recovery system uses an air-air heat exchanger to recover the cold and heat energy in the exhaust air to pretreat the fresh air. According to the form of heat recovery, it can be mainly divided into sensible heat recovery devices (referred to as heat recovery) and total heat recovery devices (abbreviated as energy recovery). Typical heat exchangers are: heat pipe heat exchangers, plate-fin heat exchangers, rotary wheel heat exchangers. Our country has gradually applied it and achieved good results. Waste heat recovery can be applied to homes, offices, and commercial buildings. In particular, air quality requirements are high, air volume requirements are large, and new air systems have
outstanding energy-saving effects.

2.1 heat pipe heat exchanger
The heat pipe heat exchanger transfers heat through the evaporation and condensation of the working substance in the fully-sealed vacuum tube shell, and has the characteristics of large heat transfer coefficient, fast heat transfer rate, small temperature drop, simple structure and easy control, etc. In recent years, the air conditioner waste heat Recycling system has been widely used. Heat transfer efficiency factors mainly include heat transfer area, heat transfer distance and temperature difference.

2.2 plate-fin heat exchanger
The plate-fin heat exchanger is a cross-over of several corrugated plates made of a specially treated porous fibrous material. When there is a temperature difference between the fresh air and the exhaust air and the pressure difference between the steam and the wind, the fresh air and the indoor air exhaust flow through the heat exchanger in a positive crossover manner, respectively, to exchange heat and mass transfer processes. The heat exchange efficiency is related to factors such as the oncoming wind speed and the new exhaust air ratio. Through the energy recovery process, the system's new wind load is greatly reduced, that is, the total system load is reduced.

2.3 Rotary heat exchanger
Rotary heat exchangers are rotary heat exchangers and consist of a rotating wheel, a drive motor, a casing and a control section. The middle part of the runner is divided by the partition plate to separate the exhaust side from the fresh air side. The packing in the runner is a heat storage body. When the exhaust air and fresh air flow backward through the runner, the heat storage body stores the energy in the exhaust air. Then release it to the fresh air. The runner can be made of hygroscopic material, and latent heat can also be recovered. The runner rotates slowly at a speed of 8-10 r/min, and performs heat and moisture exchange using the temperature difference between the runner material and the air and the differential pressure of the steam pressure, thereby transferring heat and moisture between the exhaust air and the fresh air. Adjusting the rotation speed of the rotor can adjust the heat recovery efficiency and can adapt to different chambers and internal and external air parameters. The main factors affecting the heat transfer efficiency are air flow speed, rotor speed, and specific surface area.

3. Energy-saving analysis

3.1 Analysis of Schematic Diagram of Air Conditioning System of Typical Air Heat Recovery Unit
Some of the air coming out of the air-conditioned room passes through the heat recovery device and exchanges heat with fresh air to pre-treat the fresh air. After the heat exchange, the exhaust air is discharged in the form of exhaust gas. After the pretreated fresh air is mixed with the return air, it is processed and delivered. The wind is sent into the room. As shown in Figure 1.

Fig. 1  Schematic diagram of exhaust air heat recovery air conditioning system
When the temperature difference between indoor and outdoor is small, open the bypass pipe set at the fresh air inlet. When the exhaust heat recovery system is insufficient to meet the cold (heat) load in the air conditioning area, turn on the auxiliary cooling (heating) equipment. In the figure, 1 point represents the fresh air inlet, 2 point represent the fresh air after the exhaust gas heat recovery pretreatment, 3 point represent the pre-pretreatment inlet, and 4 point represents the exhaust outlet. The efficiency of the exhaust heat recovery device can be expressed as follows:

Sensible heat recovery: 
\[ \xi_T = \frac{m_s(T_1 - T_2)}{m_{\text{min}}(T_1 - T_3)} \]  
(1)

Total heat recovery: 
\[ \xi_h = \frac{m_s(h_1 - h_2)}{m_{\text{min}}(h_1 - h_3)} \]  
(2)

Among them, \( m_s \) is the air flow rate of the air supply, \( m_{\text{min}} \) is the smaller air flow rate in the supply and exhaust air, \( T_1 \) and \( h_1 \) are the outdoor fresh air temperature and the enthalpy respectively, and \( T_2 \) and \( h_2 \) are the temperature and enthalpy after the new air is pretreated. \( T_3 \) and \( h_3 \) are the indoor exhaust temperature and enthalpy respectively.

From the above formula, it can be seen that the effect of heat recovery depends largely on the difference in temperature between indoor and outdoor. The greater the temperature difference, the higher the efficiency; the smaller the temperature difference, the lower the efficiency. Local climate conditions are a very important factor in the design and analysis of heat recovery systems.

3.2 Analysis of sensible heat recovery system

Assuming that the air-conditioner is operating throughout the year, the summer running time is \( t_1 \), the winter running time is \( t_1 - t_2 \), and the running period is a fresh air style. The fresh air and exhaust air volume are equal. According to Figure 2 from the sensible heat recovery efficiency formula can be obtained after passing the sensible heat exchanger \( T_2 = (1 - \xi_T)T_1 + \xi_TT_3 \). If there is no heat recovery system, the cooling load of the system is the amount of air to be treated from \( T_1 \) to \( T_3 \). After adding the heat recovery system, it is only necessary to treat the air from \( T_2 \) to \( T_3 \). In the following analysis, the design temperature \( T_3 \) in \( T_1 \), \( T_2 \), and \( T_3 \) is a constant value, \( T_1 \) and \( T_2 \) are seen as a function of time \( t \).

![Figure 2 sensible heat recovery energy-saving diagram](image)

As shown in Figure 2, before adding the exhaust heat recovery device, the cold (heat) load of the air conditioning system should be the sum of the shaded and shaded area; after the addition, the air conditioning system only needs to provide the slashed portion of the cold (heat). The amount of shadows is the recovered energy. There are three main factors influencing the recovery of cold (heat) from the air conditioning system of the exhaust sensible heat recovery device: the heat exchange efficiency \( \xi_T \) of the heat exchanger, the operating time \( t \) of the exhaust heat recovery device, and the temperature difference \( \Delta T \) between the indoor and outdoor.
3.3 Analysis of total thermal energy recovery system
The total heat energy recovery and sensible heat energy recovery are roughly the same, and the analysis is performed according to Figure 3 below.

For the total heat recovery system, there are mainly three factors affecting the heat transfer efficiency $\varepsilon_h$, the operating time $t$, and the indoor and outdoor enthalpy difference $\Delta h$. The enthalpy of the air is related to the temperature, and the humidity also affects its size. In places where the temperature difference between indoor and outdoor is large and the humidity difference is also large, the difference is large, and the application in other places will reduce the use effect.

4. The application potential of exhaust heat recovery system in Dezhou City

4.1 Meteorological parameters of Dezhou City
Dezhou City is located at 37°26’N latitude and 116°19’E longitude and is a cold area. The air conditioning outdoor design temperature in summer is 34.7°C, the wet-bulb temperature is 26.5°C, and the relative humidity is 73%; the air conditioning outdoor design temperature in winter is -11 and the relative humidity is 49%. The indoor design temperature in the summer is $T_3=24°C$, the relative humidity is 60%, the indoor enthalpy value $h_3=52$ kJ/kg, and the supply air temperature is $T_{dse}=15°C$. The indoor design temperature in winter is $T_3=20°C$, relative humidity 50%, indoor value $h_3=38.2$ kJ/kg, supply air temperature $T_{dse}=27°C$. Assuming that the project is an all-new air-conditioning system, the recovery efficiency of sensible heat recovery and total heat recovery will be 70%.

4.2 sensible heat recovery
The highest summer temperature in Dezhou is around July. The temperature of summer air conditioning design is 34.7°C; the minimum temperature in winter is about January, and the temperature is -11°C. Using $T_2=(1-\varepsilon_T)T_1+\varepsilon hT_3$ plus design parameters, you get:

Summer: $T_2=(1-\varepsilon h)T_1+\varepsilon h_3=0.3T_1+0.3T_3+16.8$

Winter: $T_2=(1-\varepsilon h)T_1+\varepsilon h_3=0.3T_1+0.3T_3+14$

According to the sensible heat recovery energy-saving diagram in Figure 2, the cold heat recovered and the cold and heat load brought by the temperature difference of the air supply are calculated. The calculated summer heat recovery ratio can reach 32% and the winter can reach 53%.

4.3 total heat recovery
The $h_2$ of the fresh air after pretreatment is obtained by using $h_2=(1-\varepsilon h_1)h_1+\varepsilon h_3$, available:

Summer: $h_2=(1-\varepsilon h)h_1+\varepsilon h_3=0.3h_1+36.4$

Winter: $h_2=(1-\varepsilon h)h_1+\varepsilon h_3=0.3h_1+26.74$
According to Fig. 3, the total heat recovery energy-saving map, the calculated cold heat and the cold and heat load brought by the temperature difference of the air supply, the calculated summer heat recovery ratio can reach 37%, and up to 50% in winter.

5. Conclusion
Exhaust heat recovery technology is an effective energy-saving method, has great potential for energy conservation, and has greater promotion value. Factors that affect heat recovery include heat exchange efficiency of the heat exchanger, operating time of the air exhaust unit, and the temperature difference between the interior and exterior (ambient difference). In the specific design and application, the actual temperature, humidity, air-conditioning operation time, etc. For achieving the best energy-saving effect, we can choose a reasonable recovery method, determine the time the device is running, etc. According to the weather conditions in Dezhou City, it belongs to a city with cold climate and low humidity, and it is more appropriate to use a sensible heat recovery system.

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