A Study of the Impact of Exhaust Heat Recovery on Public Building Energy Consumption in Seasonal Extreme Temperatures

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Abstract — Taking Yiyang meteorological parameters as an example, according to the enthalpy discriminant relation between fresh air and exhaust air, we assess the impact on public buildings using exhaust air total heat recovery in hot summer and cold winter area. Three typical buildings are taken to analyze the distribution of the building total cold (heat) load and the fresh air cool (heat) load, we calculate the reduced load after the fresh air is treated by the exhaust air total heat recovery unit (EATHRU) and analyze the economic efficiency of the fresh air exchange device. The results show that using the exhaust air total heat recovery unit, the total cooling load of the whole building can be reduced by more than 45% and the total heat load is reduced by more than 20%. Although the EATHRU price is more expensive, the return on investment of the fresh air system will increase, but the investment and operation cost of cold heat source unit and pump are all reduced, the total investment change is not big but can greatly save operating expenses.

Keywords - load; exhaust air; fresh air; energy saving

I. INTRODUCTION

With the rapid development of society's economy, people's working and life level are continuous improved and become more and more high, the air conditioning system and equipment has become parts of people's life. In order to ensure the air quality in the air conditioning area, the fresh air quantity is increasing, and the cold and heat source system should put more energy into the air conditioning system. The fresh air load of the summer is about 30% ~ 50% [1] of the total load in shopping malls, office buildings, hotels and etc. With the continuous development of building energy saving, the energy consumption of building maintenance structure is gradually reduced, and the proportion of fresh air load is increasing. Fresh air’s energy saving is becoming more and more prominent. In the conventional central air-conditioning system design, the exhaust air is discharged directly to the outside, which resulting in a large number of cold or heat waste. If this part of the cold (heat) can be used, it will bemoere energy saving. With the cold or heat in the exhaust air to treat the fresh air, not only can reduce the fresh air cool or heat load, but also can reduce the cold heat source total load and the water pump power. It is necessary to use the exhaust air’s cold (hot), which can not only avoid the release of heat pollution in the urban atmosphere, but also save the limited energy.

II. FEASIBILITY OF EXHAUSTAIR TOTAL HEAT RECOVERY

According to the form of the recovery heat, the fresh air exchange device can be divided into sensible heat and total heat exchanger. The former can only recover the sensible heat, but the latter which can not only recover the sensible heat, but also can recover the latent heat in the exhaust air. According to the calculation method of heat transfer efficiency and the heat transfer analysis, the energy recovery E1 of exhaust air total heat recovery unit (EATHRU) can be calculated by formula (1).

\[ E_1 = (-1)^m \rho G \alpha \varepsilon \alpha (h_1 - h_3) \]  

In which: 
- \( m \)—seasonal mode transformation parameter, the heating season: \( m=1 \), the cooling season \( m=-1 \);
- \( \rho \)—the density of air, \( \rho=1.2 \text{kg/m}^3 \);
- \( G \)—the fresh air volume, m3/h;
- \( \alpha \)—the ratio of the fresh air to exhaust air; \( \alpha=0.9 \varepsilon_h \)—the total thermal efficiency, \( \varepsilon_h=0.75 \) [2];
- \( h_1 \)—the outdoor fresh air enthalpy;
- \( h_3 \)—the indoor air enthalpy.

The fan power of EATHRU can be calculated by formula (2).

\[ W = (1 + \alpha)G \frac{\rho}{\eta} \]  

Where: 
- \( \eta \)—the total thermal efficiency of the heat exchanger.
In which: $P$ — the total pressure of EATHRU, $P=0.4$ kPa; $\eta$ — the total efficiency which contains the efficiency of the wind turbine, electric motor and transmission, $\eta=0.52$ [3].

If the air conditioning system consumes the same power $W$, the air conditioning refrigerating or heating capacity $E_2$ can be calculated by formula (3).

$$E_2 = W \cdot \varepsilon$$  \hspace{1cm} (3)

In which: $\varepsilon$ — the system coefficient of refrigeration (heating) performance [4].

If $E_1$ is greater than $E_2$, it is suitable for the exhaust heat recovery. According to the formula (1) to (3), we can get the energy saving discriminant formula (4) of the EATHRU.

$$h_1 > h_3 + \frac{(1+\varepsilon)\varepsilon}{\rho a F \eta}$$

Refrigerating season: $h_1 > h_3 + \frac{(1+\varepsilon)\varepsilon}{\rho a F \eta}$

Heating season: $h_1 < h_3 - \frac{(1+\varepsilon)\varepsilon}{\rho a F \eta}$  \hspace{1cm} (4)

According to the discriminant formula (4), if the outdoor air enthalpy greater than the discriminant reference value in refrigerating season or less than the discriminant reference value in heating season, it is suitable for the EATHRU.

Fig 1. Annual outdoor air enthalpy of Yiyang.

Taking Yiyang as an example, which is located in the hot summer and cold winter area, the outdoor air enthalpy and the discriminant reference value of refrigerating (heating) season are shown in fig 1. From Fig 1, the outdoor air enthalpy can meet the EATHRU energy saving discriminant value in refrigerating season and heating season.

III. FRESH AIR LOAD ANALYSIS

A. Fresh Air Requirements

The fresh air in the air conditioning system has two main uses [4]: The first is to dilute the concentration of harmful substances in the interior, meet the health requirements of personnel; the second is to complement the indoor air exhaust and maintain the positive pressure in the room. The central air conditioning system in the public building is mainly to meet the people’s comfort, the exhaust air volume is determined by the fresh air volume, the fresh air volume...
and the exhaust air volume should be maintained balance. In recent years, because of people's demands on the central air conditioning system in the work and living place becoming higher and higher, the demand of fresh air has been increasing.

B. Fresh Air Load per Unit Volume

Taking Yiyang of Hunan Province as an example, the winter and summer design parameters are assumed in Table 1, the sensible heat and latent heat load of fresh air per unit volume are calculated and the calculation values are also shown in Table 1.

Table 1 shows that: (1) Under the summer design conditions, the fresh air humidity is higher than the exhaust air, and the fresh air need to desiccant, and the latent heat load of fresh air accounted for 67.45% of total fresh air load; (2) Under the winter design conditions, the fresh air humidity is lower than the exhaust air, and the fresh air need to be wet, and the fresh air latent heat load is 40.63% of the total load; (3) In the design condition, the moisture content in the exhaust air, which can be used for the fresh air desiccant in summer and humidification in winter. Therefore, considered from the annual energy-saving of the building, those buildings which need temperature and humidity control in hot summer and cold winter area should choose total heat energy recovery equipment.

### Table I. The Load of Per Unit (m³/s) Fresh Air Volume Under Design Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor design temperature ℃</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>outdoor calculated temperature ℃</td>
<td>35.1</td>
<td>-1.6</td>
</tr>
<tr>
<td>indoor design humidity ratio (g/kg.dry air)</td>
<td>12.953</td>
<td>8.949</td>
</tr>
<tr>
<td>Outdoor humidity ratio (g/kg.dry air)</td>
<td>22.578</td>
<td>2.597</td>
</tr>
<tr>
<td>Sensible heat load kW</td>
<td>12.832</td>
<td>26.704</td>
</tr>
<tr>
<td>Latent heat load kW</td>
<td>26.588</td>
<td>18.277</td>
</tr>
<tr>
<td>moisture load (g/)</td>
<td>11.126</td>
<td>-7.511</td>
</tr>
<tr>
<td>Total cooling (heat) load kW</td>
<td>39.42</td>
<td>44.981</td>
</tr>
<tr>
<td>The proportion of sensible heat</td>
<td>32.55%</td>
<td>59.37%</td>
</tr>
<tr>
<td>The proportion of latent heat</td>
<td>67.45%</td>
<td>40.63%</td>
</tr>
</tbody>
</table>

### C. Fresh Air Load of Typical Public Buildings

In this paper, three kinds of public buildings are chosen to analyze the fresh air load. Building A is a Furniture Expo Center and all the floors on the ground are used for furniture stores; Building B is a company office building and the main uses are small single person office and conference room; Building C is an Exit Entry Inspection and Quarantine Building, the first floor to the third floor are mainly for the office and conference room and the other floors are laboratory test room.

In this paper, Hongye HVAC load calculation software 6.0 is used to calculate these three different types of public buildings’ design and calculation load, the maximum total cooling (heating) load and the fresh air load were calculated, and the values are shown in Table II.

Table 2 shows that: (1) For the public buildings, the fresh air cooling load accounts for more than 1/3 of the total cooling load in the summer and the heating load accounts for more than 1/2 in the winter.(2) In the public buildings, the more crowded places, the greater the proportion of fresh air load.

### IV. Energy Saving Calculation

When the EATHRU is used in the central air conditioning system, the building’s total cooling (heating) load and the total energy consumption are all reduced. The main energy-saving includes three parts: the cold and heat source equipment, the pump and the fan energy saving. Because of the fresh air and exhaust air remain constant in the air conditioning room, so the fan power consumption is constant, so the fan energy-saving is not considered. In this paper, only the power of the cooling heat source and the water pump are calculated.

### A. Cold and Heat Recovery of EATHRU

The public buildings generally use the fresh air ventilation device to recycle the exhaust heat (cold) to pretreatment the fresh air. According to formula (5), the energy saving of three different types of public buildings are calculated in Table III.

Table III shows that when the fresh air uses heat recovery device, the total cooling load of the building will be reduced by more than 20% in summer and the total heat load will be reduced by more than 1/3 in winter.
B. Energy Saving of Cold and Heat Source Equipment

When the EATHRU is used to deal with fresh air, the total cooling (heating) load will be reduced, and the power of the cold and heat source equipment also will be reduced. The rated energy-saving of cold and heat source equipment can be calculated according to formula (5) in the design conditions and is listed in Table IV.

\[ W = \frac{Q}{COP} \]  

(5)

In which: COP——the refrigerating (heating) coefficient of performance [4]. Q——the refrigerating (heating) capacity, KW.

### Table III. The Exhaust Air Heat Recovery Calculation of Three Different Kinds of Typical Building

<table>
<thead>
<tr>
<th></th>
<th>Summer cooling condition</th>
<th>Winter heating condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest heat recovery (KW)</td>
<td>The total cooling load after EATHRU (KW)</td>
<td>Energy saving rate (%)</td>
</tr>
<tr>
<td>Building A</td>
<td>4842.7</td>
<td>11327.3</td>
</tr>
<tr>
<td>Building B</td>
<td>121.6</td>
<td>298.0</td>
</tr>
<tr>
<td>Building C</td>
<td>170.6</td>
<td>542.1</td>
</tr>
</tbody>
</table>

### Table IV. The Cold and Heat Source Equipment Rated Energy-Saving at Design Conditions

<table>
<thead>
<tr>
<th></th>
<th>Building A</th>
<th>Building B</th>
<th>Building C</th>
</tr>
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<tbody>
<tr>
<td>Total cooling (heating) load (KW)</td>
<td>16170.0</td>
<td>11443.8</td>
<td>419.6</td>
</tr>
<tr>
<td>Original power / gas consumption (KW/ m3/h)</td>
<td>2740.7</td>
<td>1377.1</td>
<td>85.6</td>
</tr>
<tr>
<td>Total cooling (heating) load after setting EATHRU (KW)</td>
<td>11327.3</td>
<td>5917.9</td>
<td>298.0</td>
</tr>
<tr>
<td>Power /Natural gas consumption (KW/m3)</td>
<td>1919.9</td>
<td>712.1</td>
<td>60.8</td>
</tr>
<tr>
<td>Power / gas saving in design condition (KW/m3)</td>
<td>820.8</td>
<td>665.0</td>
<td>24.8</td>
</tr>
</tbody>
</table>

Note: Building A uses the water cooling centrifugal chiller and the others use the screw chiller in summer; all the boilers are gas-fired water boiler and the natural gas low calorific value is 33.24MJ/m3.

C. Pump Energy-saving

Because of the indoor cooling (heating) load decreases, the conveying energy consumption of the water pump will be reduced in the same cold (hot) water temperature difference. The pump shaft power can be calculated according formula (6) in different conditions, and the specific calculation data are shown in Table V.

\[ W = Q \cdot [ER] \]  

(6)

In which: ER——the ratio of axial power to transferred cooling (heat) quantity [5]. Q——the total cooling (heating) load, KW.

### Table V. The Energy-Saving of Water Pump in the Design Condition

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<td>Original water pump shaft power (KW)</td>
<td>480.1</td>
<td>188.7</td>
<td>10.1</td>
</tr>
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<td>11327.3</td>
<td>5917.9</td>
<td>298.0</td>
</tr>
<tr>
<td>Water pump shaft power (KW)</td>
<td>336.3</td>
<td>97.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Power saving of the pump in design condition (KW)</td>
<td>143.8</td>
<td>91.1</td>
<td>2.9</td>
</tr>
</tbody>
</table>

V. Cost Analysis

A. Operating Expenses

In the hot summer and cold winter area, the cooling period is generally from June to September and the heating period is generally from December to February of the following year, the cooling time is 120 days and the heating time is 90 days, the daily running time is 10 hours, the equivalent full load coefficient is 0.7, the commercial electricity price is ¥1.2/KWH and the natural gas price is ¥3.88/Nm3. From the above data, the annual operating cost saving of cold and heat source equipment and pump can be calculated in Table VI.
In this paper, the three kinds of typical construction have no internal and external partition. If there is internal and external partition, the actual reduced cold (heat) consumption should be hourly calculated before and after setting heat recovery device [7]. The energy saving and economy of heat recovery device is analyzed in the design conditions, and we have neglected the difference of the exhaust system, the difference between the transmission line and the terminal equipment, and the equipment price comes from the equipment manufacturer, therefore, the actual investment should be based on the actual price.

In this paper, the application of exhaust air heat recovery in air conditioning system is discussed in the design condition in public buildings. The feasibility is analyzed from the aspects of the cold (heat) recovery of exhaust air, the investment of equipment and operation cost, and the following conclusions are obtained:

(1) After the EATHRU is used, the total cooling load of the whole building can be reduced by more than 45% and the total heat load will be reduced by more than 20%.

(2) Because of the reduction of the total cooling (hot) load, the installed capacity of cold heat source unit becomes small, and the investment and operation cost are reduced; Because of the reduction of water, the pump investment and operation cost are also reduced.

(3) When the EATHRU instead of fresh air handling unit, because the EATHRU price is more expensive, the investment of the fresh air system will increase, but the cold and heat source and water pump investment are reduced, so the total investment change is not big but saving operating expenses.

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