Theoretical Analysis about Heat Pump Heat Recovery System for High School Bathroom

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Abstract: The heat pump system used for recycling and reusing waste heat in high school bathroom was minutely analyzed in its coefficient of performance, onetime utilization ratio of energy, economic property and so on. The results showed that this system has good economic property, can conserve energy and protects the environment. So there is a large room for it to be developed. Moreover, three projects about this system were presented and contrasted, which indicated that the joint system using both heat pump and heat exchanger to recycle waste heat is a preferable option.

Keywords: Heat pump technology; Recycling and reusing heat; Economic property; Onetime utilization ratio of energy

1 Introduction

Currently, the rapid development of China’s economic development is based on a large number of energy consumption, energy and the environment is the world's two prominent social issues. Heat pump technology has a very obvious advantage in recycling and reusing heat, the effective use of low-temperature energy, environmental protection and energy conservation, economic and other aspects of the operation. Therefore, it has good contribution to energy effective utilization and the social sustainable development. There must be a vast room for its growth and market prospects.

Relatively speaking, in colleges and universities, the open periods of bathroom is fixed, its water flow is large, the temperature (temperature of shower and drainage) is stable and moderate, so it is suitable for using heat pump technology to recycle and reuse the residual heat of drainage. But with a large temperature changes both in high-temperature flow fluid and in low-temperature flow fluid, and with a lag of low heat flow, bathroom residual heat recovery characteristics is distinct. Preliminary analysis and feasibility study shows that using heat pump technology in bathroom residual heat recovery has good economic property, good energy conservation and good environmental protection effects.

2 Cycle Conditions of Heat Pump And its Coefficient of Performance

2.1 Determining of Cycle Conditions and the Project Design

By surveying a bathroom meeting 6,000 students’ request of a college, we know that it opens 2 hours each day, its shower flow is 160 m³/h, the temperature of drainage is 31 °C. If the reusing quantity of heat, denoted by Qr, about bathroom drainage is from 31°C to 5°C, then it can be determined by (1):  

\[ Q_r = \phi \cdot c \cdot \dot{m} \cdot \Delta t \]  

Where \( \phi \) stands for flow coefficient of drainage, 0.93; \( \dot{m} \) stands for mass flow rate, kg/s, \( c \) is specific heat of water, kJ/(kg·K). By calculation, \( Q_r = 4495.2 \) kW, the equivalent of combusting about 378.8 kg 0# light diesel oil or 552 kg standard coal per hour, it can be seen that the quantity of heat flow which can be recycled is very enormous.

So, by integrating test results with relevant manual, determining some basic design datum of heat pump recovery system expressed as follows:  

a) shower temperature, 41°C; b) the temperature of waste drainage, 31°C; c) in winter, the temperature of tap water, 8°C; d) shower flow, 160m³/h; e) outlet temperature of hot water from heat pump, 46°C; f) flow coefficient of drainage, 0.93.

R22 is selected for heat pump cycle. In order to simplify the calculation process, calculation and analysis are based on basic cycle[1], and the lag of low heat flow is not considered too.

In order to recycle and reuse the heat of drainage better, firstly, some projects fitting for the system are worked out as following.

2.1.1 Project I

Waste water were directly pumped into the heat units, its outlet temperature is 5°C when it is exported from the evaporator; outlet temperature of hot water from the
condenser of heat pump is 46 °C, the flow chart as shown in Figure 1.

2.1.2 Project Ⅱ
Adding a heat exchanger into the recycle system based on project Ⅰ. In the system, waste water is firstly pumped into the heat exchanger before being pumped into evaporator. Its outlet temperature is approximate 20 °C when it is exported from the heat exchanger. The flow chart is shown in Figure 2.

2.1.3 Project Ⅲ
Adding a fuel boiler (or using inhere boiler) supplying assistant heat sources into the recycle system based on project Ⅱ. The capacity of the boiler is 1195.4 kW.

2.2 Contrast of Projects and Choice
Firstly, some values must be assumed before analysis. In this analysis, electricity price for 0.60 yuan/(kW·h), the lower heating value of oil for 42700 kJ/kg, its price for the 8 yuan/kg and the efficiency of oil boiler for 0.9. The related parameters of the three projects are shown in table 1 [2] .

which can be known from table 1: a) In project Ⅰ, for heat exchanger are not being used, so the capacity of heat pump is largest, its investment costs are biggest, and the operating costs are not low too. Therefore this project has the worst economic property; b) In project Ⅱ, operating costs is smallest , its equipment investment is moderate; c) In project Ⅲ, the equipment investment is least. By using additional heat-supplying equipment, the capacity demanded of heat pump is reduced and the lag of low-temperature heat flow is resolved. But its operating costs is largest. So, with a great advantage, the project Ⅱ is a preferable option.

3 The Analysis About Economic Property of Recycling and Reusing Heat System

3.1 COP of Heat Pump Cycle
COP is one of major thermo-economic parameters of heat pump, denoted by the ratio of proceeds (the quantity of heat) to costs (mechanical energy, electrical energy or heat energy). As for vapor-compression heat pump consuming mechanical energy, its COP is denoted by the ratio of the quantity of heat $Q_1$ to input work $P$.

<table>
<thead>
<tr>
<th>Items</th>
<th>Project Ⅰ</th>
<th>Project Ⅱ</th>
<th>Project Ⅲ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have heat exchanger or not</td>
<td>...</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Have hot water supply or not</td>
<td>...</td>
<td>...</td>
<td>yes</td>
</tr>
<tr>
<td>Temperature of drainage / °C</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Cost of heat pump, thousand yuan</td>
<td>1895</td>
<td>1516</td>
<td>1137</td>
</tr>
<tr>
<td>Cost of heat exchanger, thousand yuan</td>
<td>...</td>
<td>114</td>
<td>104</td>
</tr>
<tr>
<td>Cost of oil boiler, thousand yuan</td>
<td>...</td>
<td>...</td>
<td>230</td>
</tr>
<tr>
<td>Total investment of equipments, thousand yuan</td>
<td>1895</td>
<td>1630</td>
<td>1471</td>
</tr>
<tr>
<td>Power of electromotor, kW</td>
<td>1706.4</td>
<td>1226</td>
<td>892.9</td>
</tr>
<tr>
<td>Cost of assistant heat supply, yuan/h</td>
<td>...</td>
<td>...</td>
<td>448.0</td>
</tr>
<tr>
<td>Total operating costs, yuan/h</td>
<td>1023.8</td>
<td>735.6</td>
<td>1431.7</td>
</tr>
</tbody>
</table>
for ideal Carnot cycle, its \(COP\) is defined in (2):

\[
COP_i = \frac{T_1}{T_1 - T_2}
\]

(2)

Where \(T_1\) is the condensation temperature, K, \(T_2\) is the evaporation temperature, K.

Usually, take all types of wastages into account, the actual \(COP\) is denoted by (3):

\[
COP = \eta \cdot \frac{T_1}{T_1 - T_2}
\]

(3)

Where, \(\eta\) denote the ratio about \(COP\) to \(COP_i\), \(\eta = 0.8 \cdot \eta_m \cdot \eta_e \cdot \eta_h\), \(\eta_m\) is efficiency coefficient of electromotor, \(\eta_e\) is efficiency coefficient of compressor, and \(\eta_h\) is efficiency coefficient of heat exchanger\(^{[3]}\).

Under the condition of keeping condensation temperature \(T_2\) and total efficiency coefficient \(\eta\) constant, the value of \(COP\) will be continuously increased as the evaporation temperature \(T_2\) increasing; Keeping condensation temperature \(T_1\) and evaporation temperature constant, the way to further increase the value of \(COP\) is to improve the total coefficient \(\eta\), namely try best to reduce all types of wastages. For \(T_1 = 323\) K, the relationship about \(COP\) to the evaporation temperature \(T_2\) and total coefficient \(\eta\) is shown in Figure 3.

![Figure 3. The relationship of COP to the evaporation temperature \(T_2\) and total coefficient \(\eta\)](image)

### 3.2 Analysis About Utilization Coefficient of Energy

Heat pump’s \(COP\) is usually bigger than 3.5 in this field, for \(COP=3.5\), if the \(\eta_1\) for coal-fired is 0.30, then \(E = 0.95\), bigger than the onetime utilization ratio of energy about coal-fired boiler (usually for 0.7); if the \(\eta_1\) for oil-fired is 0.40, then \(E = 1.26\), bigger than the onetime utilization ratio of energy about oil-fired boiler (usually for 0.9). Actually, considering the contribution of the heat exchanger in the recycling and reusing waste heat system, the total utilization coefficient of energy is higher than above. Therefore, heat pump system in recycling and reusing waste heat of high school bathroom has better environmental conservation results.

### 3.3 Economic Analysis of Recycling and Reusing Heat System

Currently, coal, oil and gas boilers heating are conventional heating model. Since gas prices are not the same everywhere, the gas boiler has not been considered at here. Taking into account store heat property of fuel boiler heating system, one four-ton boiler is used in the corresponding system. The relative expense to assistant heat equivalent is not considered. The lower heating value of coal for 28053 kJ/kg, the efficiency of coal boiler for 0.9, the price of coal for the 600 yuan per ton and the total open time of the heating system is 720 hours each year. Which about equipment investment and operating costs about each heating system are shown in Table 2.

### 4. Conclusions

The joint system using heat pump integrating with
Heat exchanger to recycle waste heat is a preferable option. The results showed that this system has good economic property, can conserve energy and protect the environment. So there is a large room for it to be developed.

<table>
<thead>
<tr>
<th>Items</th>
<th>Heat pump system in recycling waste heat</th>
<th>Coal boiler heating system</th>
<th>Oil boiler heating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Important equipments</td>
<td>Three heat pumps each for 1100 kW, heat exchangers, etc.</td>
<td>One four-ton coal-fired boiler, fans, water-treating equipments, etc</td>
<td>One four-ton oil-fired boiler, water-treating equipments, etc</td>
</tr>
<tr>
<td>Total cost of investments, thousand yuan</td>
<td>1241</td>
<td>400</td>
<td>490</td>
</tr>
<tr>
<td>Mostly consumed costs of energy</td>
<td>Consumed power: 892.9 kW</td>
<td>Consumed coal: 906.6 kg/h, consumed power: 40 kW</td>
<td>Consumed oil: 463.2 kg/h</td>
</tr>
<tr>
<td>Operating costs per year, thousand yuan</td>
<td>385.2</td>
<td>408.9</td>
<td>2668</td>
</tr>
<tr>
<td>One-time utilization ratio of energy $E$</td>
<td>Bigger than 1.26</td>
<td>0.7</td>
<td>0.90</td>
</tr>
<tr>
<td>The degree of contamination to environment</td>
<td>Least</td>
<td>Most</td>
<td>Moderate</td>
</tr>
<tr>
<td>Assistant operating costs</td>
<td>Least</td>
<td>Least</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Heat pump system used for recycling and reusing waste heat in high school bathroom has high one time utilization of energy $E$, and its effect of environmental protection and energy-conservation is evident.

According to Table 2, which can be obtained the period of investment-callback is merely longer than half of a year contrast to oil-fired heating model. Usually, the lifetime of heat pump system is between 15 years and 20 years. So, the economic benefit of this system is very considerable.

Taking into account the factors of operation, maintenance and the fuel supply, the assistant operating costs of coal-fired boiler heating system is the most, whereas, which of Heat pump system used for recycling and reusing waste heat is the least.

References


