Heat Pump for High School Bathroom Heat Recovery

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Abstract: The heat pump system used for recycling and reusing waste heat in s 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. Therefore, there is a large potential for its development. In addition, three projects using this system are presented and contrasted, which indicate that a joint system that uses both the heat pump and heat exchanger to recycle waste heat is a preferable option.

Key words: 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 m^3/h, the temperature of drainage is 31℃. If the reusing quantity of heat, denoted by Q_r, about bathroom drainage is from 31℃ to 5℃, then it can be determined by the Eq.1:

$$Q_r = \phi \cdot c \cdot \dot{m} \cdot \Delta t \qquad (1)$$

Where ϕ 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,

$Q_r = 4495.2 \quad kW$, 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 as following :

a) shower temperature, 41℃; b) the temperature of waste drainage, 31℃; c) in winter, the temperature of tap water, 8℃; d) shower flow, 160m^3/h；e) outlet temperature of hot water from heat pump, 46 ；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.

Project Ⅰ Wastewater were directly pumped into the heat units, its outlet temperature is 5℃ when it is exported from the evaporator; outlet temperature of hot water from the condenser of heat pump is 46 , the flow chart as shown in Fig. 1.

Project Ⅱ Adding a heat exchanger into the recycle system based on projectⅠ. In the system, wastewater is firstly pumped into the heat exchanger before being pumped into evaporator. Its outlet temperature is approximate 20℃ when it is exported from the heat exchanger. The flow chart as shown in Fig.2.

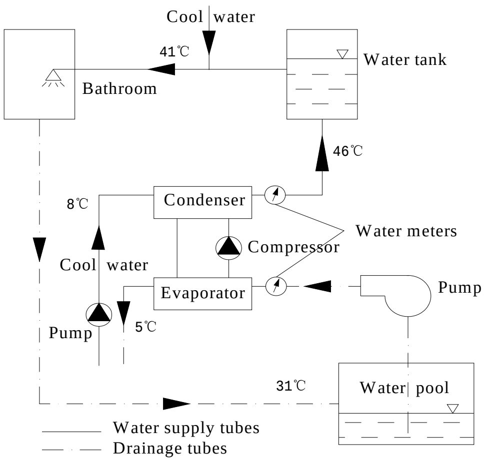

Fig. 1 The flow chart of project Ⅰ

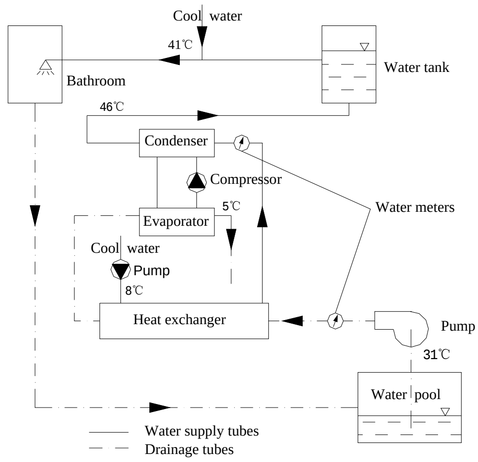

Fig. 2 The flow chart of project Ⅱ

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 0.50 yuan /(kW·h), the lower heating value of oil for 42700 kJ/kg, its price for the 4 yuan/kg and the efficiency of oil boiler for 0.9. The performance 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, but the lag of low-temperature heat source of the system is not be settled; c）In project Ⅲ, the equipment investment is least. By using additional heat-supplying equipment, the capacity demanded of heap pump is reduced and the lag of low-temperature heat flow is resolved. The intrinsic heating equipment also can be taken full advantage of to supply the assistant heat. So, with a great advantage, the project Ⅲ is a preferable option.

Tab.1 The performance parameters of projects

Items		Project Ⅰ	Project Ⅱ	Project Ⅲ
Have heat exchanger or not		…	yes	yes
Have hot water supply or not		…	…	yes
Temperature of drainage /℃		5	5	5
System investment	Cost of heat pump，thousand yuan	1895	1516	1137
	Cost of heat exchanger，thousand yuan	…	114	104
	Cost of oil boiler, thousand yuan	…	…	230
	Total investment of equipments, thousand yuan	1895	1630	1471
Operating costs	Power of electromotor，kW	1706.4	1226	892.9
	Cost of assistant heat supply，yuan/h	…	…	448.0
	Total operating costs，yuan/h	853.2	613.0	894.5

3 THE ANALYSIS ABOUT ECONOMIC PROPERTY OF RECYCLING AND REUSIG 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.

for ideal Carnot cycle, its COP_i is defined in Eq.2:

$$COP_i = \frac{T_1}{T_1 - T_2} \qquad (2)$$

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 Eq.3:

$$COP = \eta \cdot \frac{T_1}{T_1 - T_2} \qquad (3)$$

Where, η denote the ratio about *COP* to COP_i, $\eta = 0.8 \cdot \eta_m \cdot \eta_c \cdot \eta_h$, η_m is efficiency coefficient of electromotor, η_c is efficiency coefficient of compressor, and η_h is efficiency coefficient of heat exchanger[3].

At the condition of keeping condensation temperature T_1 and total efficiency coefficient η 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 η, 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 η is shown in Fig.3.

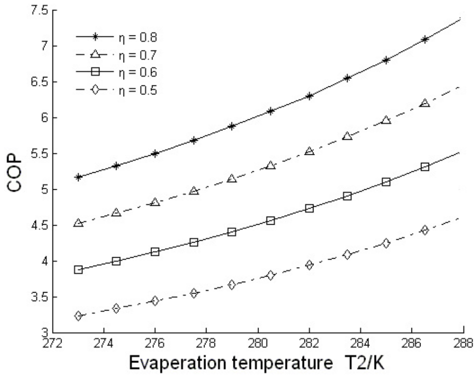

Fig. 3 The relationship of *COP* to the evaporation temperature T_2 and total coefficient η

3.2 Analysis About Utilization Coefficient of Energy

Heat pump's Utilization coefficient of energy *E* is its onetime utilization ratio of energy[4]. Although there are more than one heating coefficient of heat pump system, but the only way to judge its heating economic property is not enough. Utilization coefficient of energy should be analyzed, because it reflects the value of *COP* in addition to its onetime utilization ratio of energy. The equation to calculate heat pump's utilization coefficient of energy *E* is $E = \eta_1 \cdot COP \cdot \eta_2$, where η_1 denotes electricity-generation efficiency, η_2 denotes transmission efficiency of electricity, usually $\eta_2 = 0.9$. The relationship of *COP* and onetime utilization ratio of energy *E* is shown in Fig.4. As can be seen from Fig.4, with *COP* and electricity-generation efficiency η_1 improvement, heat pump's Utilization coefficient of energy *E* is a concomitantly increasing.

Heat pump's *COP* is usually bigger than 3.5 in this field, for *COP*=3.5, if the η_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 η_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.

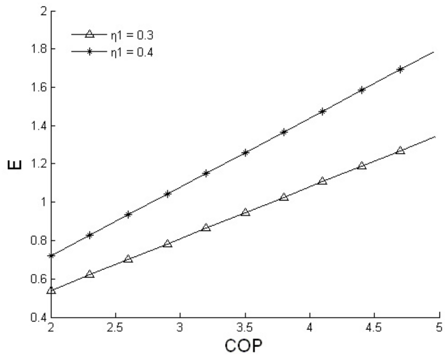

Fig.4 The relationship of *E* and *COP*

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.

Tab.2 Equipment investment and operating costs about every heating systems

Items	Heat pump system in recycling waste heat	Coal boiler heating system	Oil boiler heating system
Important equipments	Three heat pumps each for 1100 kW, heat exchangers, etc.	One four-ton coal-fired boiler, fans, water-treating equipments, etc	One four-ton oil-fired boiler, water-treating equipments, etc
Total cost of investments，thousand yuan	1241	400	490
Mostly consumed costs of energy	Consumed power： 892.9 kW	Consumed coal： 906.6 kg/h, consumed power：40 kW	Consumed oil: 463.2 kg/h
Operating costs per year，thousand yuan	321	340	1334
Onetime utilization ratio of energy *E*	Bigger than 1.26	0.7	0.90
The degree of contamination to environment	Least	Most	Moderate
Assistant operating costs	Least	Most	Moderate

The lower heating value of coal for 28053 kJ/kg, the efficiency of coal boiler for 0.9, its price for the

500 yuan per ton, the total open time of the heating system is 720 hours each year. Equipment investment and operating costs about every 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.

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 that the period of investment-callback is merely longer than one and half 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.

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