

Heat Pumps for Improving the Energy Efficiency of Heating Water

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Abstract: This paper analyzes the energy consumption situations of heating sanitary water in various buildings and the insurmountable shortcoming of inefficient energy consumption of the conventional water heaters, and investigates the progress and problems of developing heat pump water heaters. It is pointed out that deepening development of heat pump water heaters is one of the efficient approaches to improve the energy efficiency of sanitary hot water.

Keywords: Heating water, energy efficiency, heat pump

1. INTRODUCTION

With the fast development of economy and urbanization of villages, the lifestyle of people is increasingly abundant and multiplex, and the proportion of energy consumption of hot water to that of buildings increases correspondingly, thus, much more attention is paid to saving energy of heating water. At present, the supply of hot water mostly comes from coal, oil, gas and electric water heaters or boilers, and the use percentage of solar water heaters is less than 5% in urban houses. Energy efficiency is a forever subject in developing water heaters. Technologically consummating electric or gas water heaters are essentially high-grade kettles with an insurmountable shortcoming of unsatisfactory efficiency. Deepening development of heat pump water heaters is one of the efficient approaches to improve the energy efficiency of heating sanitary water.

2. CONSERVING ENERGY — A FORVER SUBJECT IN THE DEVELOPMENT OF WATER HEATERS

2.1 The status of energy consumption of sanitary hot water

The energy consumption of various buildings accounts for approximately 30% of the gross energy consumption, and is increasing continuously in China. The energy consumption of sanitary hot water for bath in civil and commercial buildings approaches 20% and 10~40% among the total, respectively, so saving energy of buildings hot water becomes increasingly important.

The cost of energy consumption, including that of sanitary hot water, in commercial buildings approached 22.5 billions yuan per year, which has become the main management cost according to an investigation on energy consumption of commercial buildings in 2000. It was reported that the percentage

of energy consumption of sanitary hot water in office building, supermarket, restaurant and hospital is 2.7%, 10.7%, 31% and 41.8% among those of commercial buildings, respectively^[1].

With the development of urbanization in China, the urban population reaches already 5 hundred millions or so, and the utilization percentage of water heater approaches above 70% in urban houses and also some rich rural family begins to use water heater. A survey in Greece pointed out that the consumption of 42°C sanitary hot water of 74% family is less than 40 L/d, 64% family less than 35 L/d, the average consumption of a rural house 25-30% L/d, and the consumption of a family with 4 populations is the most per person per year^[2]. The consumption of hot water is influenced obviously by custom of region and individual, the related research has not been reported up to now in China. Based on this survey and the differences of region and season, the energy consumption of sanitary hot water of the city residents is $1.75 \sim 2.45 \times 10^{11}$ kWh calculated with 12°C tap water and 90% energy efficiency of conventional water heater.

In addition, large quantity of hot water is consumed in food process, natatorium, aquaculture and farm produce process, and so on.

2.2 Insurmountable shortcoming of unsatisfactory efficiency of conventional water heaters

At present, the supply of hot water of commercial buildings mostly derives from coal, oil, gas and electric boiler, and the use of heat pump is highly limited. The supply of hot water of civil buildings mainly comes from electric and gas water heater, and the use percentage of solar water heaters is less than 5% in urban houses.

Electric and gas water heater possesses rather perfect technique and is farther developing in the direction of facility, safety, aptitude, minitype, integration and centralization. However, conventional and gas water heater is essential *high-grade kettle* in

terms of the energy consumption. According to the standard, the thermal efficiency of conventional electric and gas water heater should not be less than 80%, water-storage electric water heater not be less than 85%, which is exceeded by those of most produces in the supermarket, however, up to now, the thermal efficiency can not exceed 95% and reach the limit of 100%. Thereby, high energy consumption is an insurmountable shortcoming of the conventional water heater.

The production of electric power is mainly dependent on coal fired, the average convert efficiency of electric to heat of a coal fired power plant is 33%, which is 30% left in the end after transport loss. Related data showed that, by the end of 2000 in China, the average power consumption of 1064 kWh per person per year is 1/2 and 1/6~1/10 of those of the world and the developed countries, respectively, and there are 23 millions people who can not use electric power. In china, among the reserves of available chemical fuels, the average quantity of coal accounts for 1/2, oil 1/2, and natural gas 1/23 of that of the world.

In China, it is especially important to exploit renewable energy sources and to improve energy efficiency for the sustainable development. Deepening improvement of heat pump is one of the effective methods to lower the high energy efficiency of water heaters.

3 DEVELOPMENT OF HEAT PUMP TECHNIQUE

Saving energy is a forever subject of energy consumption and is referred as the fifth energy source which is the same important as coal, oil, natural gas and electric power. The methods in conserving energy of sanitary hot water of buildings are classified into three following categories:

- (1) The use of solar energy and other renewable energy sources;
- (2) The recycle of waste heat of buildings and other waste heats;
- (3) Developing new technique and improving management in order to improve the efficiency of production and utilization of sanitary hot water.

Deepening development of heat pump is one of the effective approaches in heightening use efficiency of energy, in recycling various lower-grade waste heats and lowering the high energy consumption of buildings.

3.1 Conventional Heat Pump Water Heaters

The conventional heat pump water heaters include heat pumps which use soil, water and air as energy sources and other mechanical compression pumps, and is popularized in the field of air-condition [3]. Heat-pump electric water heater supplies hot water using the energy resulting from soil, water and air through heat recycle. The run mechanism is essentially the same as that of refrigeration system, their differences are the range of temperature and effect, conventional refrigeration system transports low-temperature energy to the environment, whereas heat pump water heater supplies hot water through

absorbing environmental energy at the expense of consuming electric energy.

The conventional heat-pump water heaters are popularized in countries with high energy consumption such as the accident, and share 16% market of all water heaters in South Africa [4]. The application of heat-pump in big supply systems of hot water should be further improved and deepened in China [5,6].

The advantages of heat pumps are as follows: (1) obvious effect of saving energy; (2) integration of simultaneously supplying hot water, heating, cooling and thus high use percentage of energy; (3) facility in utilizing and recycling low-grade energy, such as, terrestrial heat and waste heat of buildings. There are some technological difficulties for the conventional heat pumps in supplying hot water with temperature > 55 °C, which is one of the reasons for its limited popularization. The application of an auxiliary heat source or a bunch heat pump can meet the need of supplying water with temperature ranging in 40~60°C.

It was reported that a terrestrial source heat pump, developed by institute of Guangzhou energy source, Chinese Academy of Science, could supply water with tiptop export temperature 75 °C and 80 t/a water with temperature 60°C, besides offer heat and air conditioning in the winter and summer, respectively. The system can save energy 70% and 50% than that of an electric and natural gas heating system, respectively, and save above 20% electric energy in summer compared with the conventional central air-condition and reduce above 80% energy consumption in supplying hot water than the conventional [7].

CO₂ possesses absolute environmental advantage (η GWP=1, η ODP=0) and obvious superiority in aspects of transferring heat, fluxion, compression, cooling mete per dimension and price [8], in addition, a trans-critical CO₂ single stage heat pump cycle best applied in the heat pump water heater can be used the most suitably as refrigerant with low inlet temperature and high temperature elevation, under which the system has small electric current loss, better temperature match. Petter Neksa et al. reported that the heating-COP of a trans-critical CO₂ cycle air-source heat-pump could achieve 4.3 when heating tap water temperature from 9°C to 60 °C at an evaporation temperature of 0 °C, and a year average COP 4.0 was achieved. The primary energy consumption can be reduced with more than 75% compared with electrical or gas fired systems. Compared to the conventional water heaters, the system could save energy 75% and hot water with temperatures up to 90 °C could be produced without operational difficulties [9].

A two-stage compressing heat-pump system could first preheat tap water to 30~40 °C via a heat exchanger with low grade condensing temperature 35~45 °C, then heat the water to 65 °C through another heat exchanger with high-grade condensing temperature 70 °C. This system could reduce the energy consumption of the drive compressor on the one hand, and on the other enhance the efficiency via twice preheat through the primary and second

subcooler and the COP 3.73 was achieved at import water with temperature 65 °C^[10].

3.2 Solar energy auxiliary heat pump water heaters

Solar energy auxiliary heat pump water heaters on sale in the supermarket of foreign countries include 3 kinds: fission single or double cycle type and integration type, which were studied early in foreign countries and on sale in the market whereas scarcely reported in China^[11-14].

The fission double cycle type consists of refrigerant and water cycles, and its commercial popularization is difficult owing to the intricate structure, inconvenient installation and high cost.

The fission single cycle type with only refrigerant cycle is the integration of evaporator and collector of solar energy, its condenser is the radiator immersed in the water tank and the condensation heat directly supplies hot water. This type with simple structure and high efficiency can be purchased in the supermarket, however, its installation is very inconvenient owing to locale perfusion of refrigerant. Hawlader et al. reported that the average values of COP of a solar assisted heat pump water heating system ranged from 4 to 9 and solar collector efficiency was found to vary between 40% and 75% for water temperatures in the condenser tank varying between 30 °C and 50 °C. An economic analysis indicates a minimum payback period of about two years for the system^[15].

A packaged solar energy auxiliary heat-pump water heater consists of heat collector or evaporator,

the temperature difference of water 38.6-52 °C and 24.6-35.1 °C, the highest/average COP of an integral-type solar-assisted heat pump water heater obtained is 2.54 and 3.83, respectively^[17].

3.3 Thermoelectric heat pump water heaters

The cooling COP of the existed thermoelectric system is undesirable at near room temperature, however, this system can reduce energy consumption compared to electric heating devices. Furthermore, it possesses following advantages: without refrigerant and running parts, simple structure, precise control, safe and friendly to environment^[18].

An integration system of thermoelectric air condition/water heater uses simultaneous solar energy and heat exhausted by air condition. It major parameters are as follows: 30 pieces TECI-12704 type thermoelectric module, 120 L water tank. When the velocity of flow on hot and cold side radiator is 10-15 L/min and 2.5-5 m/s, respectively the unit could heat 120 L tap water to near 50 °C in 2 hours and the average COP is 3.12 in Bangkok^[19].

A thermoelectric heat pump water heater by recycling waste heat through cycle water on the cold side was developed in Hunan University. The prototype contains 120 pieces TE module (type TECI-12706). Its COP value reaches 2.0 at import water temperature below 50 °C and flux 6 L/min, and thus offer a new idea for saving energy in buildings hot water, recycling waste heat and the application of low grade energy sources^[20].

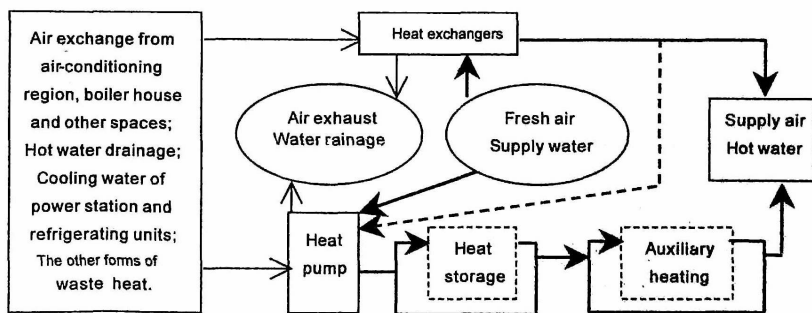


Figure 1: The cycle pattern of waste heat of buildings

compressor, condenser and water tank, and so on^[16]. This system possesses some advantages as follows: compact structure, small size, without cycle water pump, all parts assembled once in the factory, convenient and flexible installation. On rainy day, it runs via the model of air heat pump, thus, supplies hot water the whole day, however, its COP is lower than that of fission type due to the limitation of its structure and lighting area.

B. J. Huang reported that in China when radiant intensity of sun reaches the highest and middle value 5581.9 kJ/m².d and 1285.5 kJ/m².d, the environmental temperature 30.7 °C and 21.3 °C and

3.4 Recycling waste heat of buildings by heat pump

Complex commercial buildings can discharge lots of waste heat, and thus strengthen "heat island effect". Recycling waste heat is adopted in more and more buildings with high energy consumption and benefit have been achieved obviously^[21,22]. The recycle pattern of waste heat of buildings is shown as figure 1.

In the summer the most convenient and abundant heat source for sanitary hot water is the condensing heat from the refrigerator and in the winter is the waste heat of sewage, waste water and gas discharged from boiler, transformer room and wash house. In summer, the condensation heat emitted by

refrigerating system of commercial buildings is 1+COP fold of the refrigeration load, and for hotel, supermarket and other commercial buildings, the condensing heat is several times of the energy consumption of sanitary hot water. However, the outlet temperature of water cooled condensator with a conventional low pressure refrigerant is about 35~37°C, which must be heated to meet the need of the temperature 40~60°C of sanitary hot water. Recycling waste heat via heat pump for heating sanitary water can eliminate heat pollution to environment and reduce some boiler devices on the one hand, and on the other can lower the import water temperature of cycle cooling water of the refrigerating unit and thus the condensing temperature of the compressor, and enhance the efficiency.

Because the discharge of the waste heat of buildings can not be in phase with the use of sanitary hot water, two problems should be solved in the construction engineering.

For the balance between the supply heat and the available waste heat, besides a sanitary hot water tank, a sewage reservoir should be installed for conserving waste heat of large amount of sewage. Taking into account of the fluctuation of consumption of hot water, devices with the least capacity for reducing the first cost should be selected and assisted heating devices for complementing heat should be needed.

In the winter, if the tap water is heated directly to 40~60°C by the waste heat recycled by heat pump, the COP will drop, and under this conditions, an auxiliary heat source or bunch heat pump can be used to meet the need of import water temperature.

3.5 The economic performance of heat pumps

The economic performance (the ratio of the first cost to running cost) of heat pump hot water system varies with the changes of the price of energy source and the tax rate for environment protection, etc. In terms of the current price system of energy, the first invest of heat pump is the most, and its running cost is obvious lower than those of electric, oil fired or gas fired boilers and whereas higher than the coal fired boiler^[3,4].

The economic performance of soil-source heat-pump system is much more complex due to the difference in the soil factors such as soil drilling condition, diathermancy, and so on.

Thermoelectric heat pump system generally does not possess economic superiority due to the limitation of high price of thermoelectric materials.

Since the beginning of 1990's, the developed countries strengthened support to heat-pump water heaters which has shared much market. From the viewpoint of sustainable development, the government should pay much more support to establish policy and market stimulations for developing heat-pump water heaters.

4. CONCLUSION

(1) Energy consumption of sanitary hot water accounts for 10~40% of total quantity of commercial buildings, and 30% of that of civil buildings, so it is

increasingly important to save energy for heating water of architecture.

(2) Heat pumps present double advantages: energy efficient and friendly to environment. Water and air sources heat pumps present better economic performance. The economic performance of soil-source heat-pump system is much more complex due to the difference in the soil factors such as soil drilling condition, diathermancy, and so on. Thermoelectric and solar assisted heat pump system generally do not possess economic superiority.

(3) It is an efficient way of saving energy of heating water to renew waste heat by heat-pumps. Two problems should be solved: maintaining the balance between heat supply and available waste heat, meeting the need of the temperature of hot water.

(4) From the viewpoint of sustainable development, the government should pay much more support to establish policy and market stimulations in order to develop heat-pump water heaters with higher efficiency and lower cost than that of conventional water heaters.

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