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# Experimental study of a new multifunctional water source heat pump system

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ABSTRACT

A new multifunctional water source heat pump system is presented in this paper. The new technical program, consisting of the refrigerant system and water system, can achieve a variety of functions in its yearly work process. In the heating mode, hot water is produced by two-step heating. An experimental research on the program is implemented through the establishment of experimental platform, and the results are presented as follows: under the function of cooling and heat recovery, (15.4–57)% of the total condense heat can be recovered, when the inlet water of heat source heat exchanger is at a certain temperature, the refrigerating capacity remains about the same with the decrease of water flow in the heat source heat exchanger. Under the function of individual cooling, an added water-to-water heat exchanger stabilizes the operation of refrigerant system in the new technical program, increases the cooling coefficient of performance ($COP_c$) and at the same time reduces the scaling risk of heat source heat exchanger. When the new technical program is operated with the large temperature difference of hot water in the heating mode, the heating coefficient of performance ($COP_h$) and the heating capacity are elevated, the power of compressor reduced.



## 1. Introduction

With the development of economy and the improvement of living standards, there are demands for summer cooling, winter heating and annual domestic hot water in many buildings, such as residential houses, hotels, restaurants and hospitals. At present, the most common project to meet these needs is to adopt air conditioning equipment and domestic hot water heaters. The former is applied into summer cooling and winter heating, and the latter into the annual production of domestic hot water [1]. This project, however, is neither energy-efficient nor environment-friendly. In the summer cooling process, air conditioning equipment sends a huge amount of condense heat to the surroundings, which gives rise to both a waste of resources and thermal pollution of the environment. Besides, domestic hot water heaters are also needed to produce domestic hot water.

As the condense heat recovery in air conditioning equipment contributes to a dramatic decline in energy costs and the thermal pollution of the environment, the technology of condense heat recovery has been developing in recent decades [2–7]. Nowadays, the heat pump systems that can achieve summer cooling, winter heating together with the annual production of domestic hot water are referred to as multifunctional heat pump systems. In their annual working process, these systems are generally able to implement such a variety of functions as individual cooling, cooling and heat recovery, individual domestic hot water production, individual heating as well as heating and domestic hot water production [1].

According to the ways of switching between cooling and heating mode, multifunctional heat pump systems can be classified into two types. (1) The switch between the two modes is realized through the valve conversion of water system [2,3], which is applicable to a majority of ground source heat pumps but not suitable for the systems that ground water and surface water directly enter heat pump heat exchanger and for air source heat pumps. (2) The switch is achieved through the valve conversion of refrigerant system [4–7], which can be applied to all types of heat pumps.

This paper focuses on the second type of multifunctional heat pump systems. A typical program of this kind of heat pump systems consists of compressor, four-way valve, throttle valve, heat source heat exchanger, user heat exchanger and hot water heater. The hot water heater, installed on the pipe which is located between the compressor outlet and the four-way valve inlet, plays the role of a desuperheater. Under the function of cooling and heat recovery, it produces domestic hot water with the superheated refrigerant vapor from the compressor [7–10]. This typical program is defined

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**Nomenclature**

| | |
|---|---|
| $t_a$ | inlet water temperature of user heat exchanger (°C) |
| $t_b$ | outlet water temperature of user heat exchanger(°C) |
| $t_{h,i}$ | inlet water temperature of hot water heater (°C) |
| $t_{h,o}$ | outlet water temperature of hot water heater (°C) |
| $t_{c,i}$ | inlet water temperature of heat source heat exchanger (°C) |
| $t_{c,o}$ | outlet water temperature of heat source heat exchanger (°C) |
| $\Delta t$ | temperature difference between inlet and outlet hot water in the heating mode (°C) |
| $\rho_b$ | water density at the outlet water temperature of user heat exchanger (kg/m$^3$) |
| $\rho_{h,o}$ | water density at the outlet water temperature of hot water heater (kg/m$^3$) |
| $q_c$ | water flow of heat source heat exchanger (m$^3$/h) |
| $q_{ch}$ | water flow of user heat exchanger (m$^3$/h) |
| $q_h$ | hot water flow of hot water heater (m$^3$/h) |
| $C$ | specific heat of water (kJ/(kg °C)) |
| $Q_c$ | refrigerating capacity (kW) |
| $Q_r$ | heat recovery quantity under the function of cooling and heat recovery (kW) |
| $Q_h$ | total heating capacity in the heating mode (kW) |
| $Q_{h1}$ | first-level heating capacity in the hot water heater (kW) |
| $Q_{h2}$ | second-level heating capacity in the user heat exchanger (kW) |
| $S$ | second-level heating capacity's share of the total heating capacity (%) |
| $P$ | power of compressor (kW) |
| $COP_c$ | cooling coefficient of performance |
| $COP_h$ | heating coefficient of performance |
| COP | coefficient of performance under the function of cooling and heat recovery |

in the paper as the conventional multifunctional heat pump system, which has been studied by many researchers [4–10]. However, there is a schematic defect in the program. In the working process, if the outlet refrigerant of hot water heater is in the two-phase region, it will vaporize again when passing the four-way valve because of reduced pressure, which leads to a dramatic change in the pressure of the inlet refrigerant of four-way valve. In such a case, the four-way valve may fail to complete a normal conversion [11] or even be damaged under severe circumstances.

To address the problem mentioned above, Gong et al. [11] proposed a project in which the inlet connection position of the fluid bypass pneumatic control pipe of four-way valve was changed. This project, however, cannot eradicate the cause of refrigerant revaporization, so the drawback that the four-way valve is easy to be damaged still exists.

In order to improve the operational reliability of the conventional multifunctional heat pump system, a small hot water heater is adopted in practical applications at present, which only enables the sensible heat of the overheated steam exhausted by compressor to be reclaimed [3,5,12]. Although this project manages to improve the operating reliability of the conventional multifunctional heat pump system, it can only have a small amount of heat recovery, which accounts for a mere (10–25)% of the total condense heat [4,12]. Besides, with a small hot water heater, the system coefficient of performance under the function of individual domestic hot water production is extremely low [10,12].

As for the problems associated with the conventional multifunctional heat pump system discussed above, Ji et al. [13,14] proposed a program and conducted an experimental research. In this program, the hot water heater and heat source heat exchanger are connected in series, and the heat exchanger area of the hot water heater is not limited, so the system coefficient of performance can be improved in the function of cooling and heat recovery as well as individual domestic hot water production. Nevertheless, as the complicated program fails to achieve heating and the production of domestic hot water simultaneously in winter with an unused hot water heater, it does not have access to practical application. Byrne et al. [15–17] also put forward a project and carried out theoretical and experimental studies. The project focuses on the buildings with the demands of cooling and heating simultaneously. The differences between it and the conventional multifunctional heat pump system are that the four-way valve is replaced by magnet valves in refrigerant system, and the hot water heater and heat source heat exchanger are connected in parallel. Similar to the program proposed by Ji et al. [13,14], in some functions, the heat exchanger also exists in idle phenomenon, which causes an inevitable consequence that the running state of the system may undergo a drastic change during the conversion between different functions [12]. In addition, connected in parallel with the heat source heat exchanger, the hot water heater cannot provide the hot water with high temperature. Liu et al. [12,18,19] came up with an improved project of the conventional multifunctional heat pump system. With outdoor air and gray water as its low-temperature heat sources, the project can work under either or both of the heat sources. The experimental result, however, demonstrated that the negative effects a small hot water heater has on the conventional multifunctional heat pump system still exist in the improved project.

A new technical program [20,21] that is applicable to ground source heat pumps is proposed in this paper. It is composed of two parts of the refrigerant system and water system (as shown in Fig. 1). The new technical program is designed to realize a steady and simply structured refrigerant system and to switch through varied functions with the valve conversion of water system. Meanwhile, it is also hoped that the quantity of heat recovery is large under the function of cooling and heat recovery.

The main features of the new program are presented below:

(1) The operation of the refrigerant system has only two modes, namely, cooling mode and heating mode. These two modes interconvert through four-way valve, magnet valve #1 and magnet valve #2, which only occurs in the seasonal turnover of winter and summer. Besides, in whichever mode, the hot water heater, heat source heat exchanger and user heat exchanger of the refrigerant system are fully utilized, avoiding the situation where the heat exchanger is left unused. Therefore, in annual work process, the stability of the refrigerant system is to the maximum extent guaranteed.
(2) In cooling and heating modes, through the valve conversion of the water system, the new technical program can achieve such functions as individual cooling, cooling and heat recovery, individual production of domestic hot water, individual heating as well as heating and the production of domestic hot water in its annual work process.
(3) Compared with the conventional multifunctional heat pump system [4–10], there are three major differences. First, in cooling mode, connected with the heat source heat exchanger in series, the hot water heater plays the role of a desuperheater; however in heating mode, the user heat exchanger serves as a desuperheater when connected with hot water heater in series. Second, in heating mode, the hot water heater and the user heat exchanger are combined together to achieve the two stage heating of hot water. The former is responsible for the first step