
STRATEGIES FOR THE LARGE-SCALE APPLICATION OF WATERWATER-LOOP HEAT- PUMP AIR-CONDITIONING SYSTEMS IN CHINA

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ABSTRACT

A water-loop heat pump air-conditioning (WLHPAC) system is energy efficient and environmentally friendly. However, the lack of internal cooling load, inadequate internal space, and/or little surplus heat gain in most buildings restrict it from being widely used in China. This paper discusses a number of strategies, based on the use of external low-grade heat sources, for the possible large-scale implementation of WLHPAC systems may become possible in China. A number of different types of low-grade heat sources available and their characteristics are discussed, as well as the strategies to use these low-grade heat sources in WLHPAC systems, with appropriate schematic illustrations. Compared to a conventional WLHPAC system, one that uses low-grade sources will be more energy efficient and therefore more environmentally friendly.

Keywords: *low-grade heat source, water loop heat pump, air conditioning, China.*

1 INTRODUCTION

The use of WLHPAC systems in commercial buildings has emerged since 1960s to provide heating and cooling in USA [1–2]. A WLHPAC system mainly consists of water/air heat pump units, a cooling tower, an auxiliary heat source, water piping network, etc. All these are connected together to form a closed water loop. The water/air heat pump units rely on the water loop as a heat sink to discharge heat when chilling and as a heat source to absorb heat when heating. Most WLHPAC systems are so controlled that the loop water temperature is maintained at between 13°C and 35°C, when a heat pump can be operated with a reliable performance and the thermal insulation on water piping network is not required [3]. When the heat discharged to the loop is more than that absorbed from the loop, the water temperature in the loop will rise. When the water temperature is higher than its preset value, the cooling tower starts operation to release excessive heat. On the contrary, the water temperature in the loop will fall, and when it is lower than its

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preset value, the auxiliary heat source starts operation. When the amount of discharged heat is approximately equal to that of absorption, the water temperature in the loop will approximately remain unchanged, neither the cooling tower nor the auxiliary heat source is operated, and the system operates at its highest efficiency.

WLHPAC systems can achieve cost saving by recovering excess heat from internal zones and moving it to perimeter zones of a building where simultaneous cooling and heating occur. This provides a simple method for individual room or zone temperature control, and provides a high level of reliability for both heating and cooling operating modes. They are flexible to install, with lower installation costs than central chilled water systems, and can be cost effective by allowing building operators to isolate and shut down unoccupied areas in a building. Therefore, WLHPAC systems are now widely accepted as a means of providing energy efficient heating and cooling in buildings [4]. There are increasing numbers of explored studies focusing on ground-coupled WLHPAC systems [5– 6], Hybrid geothermal WLHPAC systems [7–8] and variable flow pumping WLHPAC systems [9–10]. However, for ground-coupled WLHPAC systems, the high initial cost of underground heat exchanger and the technical requirement of installing such systems prevent them from being widely used in China [11].

WLHPAC systems were firstly introduced in China in 1980s. Currently more than fifty WLHPAC systems are being operated all over China. However, in most buildings in China, the internal cooling load is not considerably large, the internal zone area is small, and the surplus heat gain is negligibly small [12]. This impairs the energy saving potential of WLHPAC systems because much additional heat energy will be required in winter. In addition, most of conventional heat sources used in China are coal-fired boilers, which will be gradually pushed out in urban areas because of pollution. These actually restrict WLHPAC systems from being widely used. However, there are a number of external low-grade heat sources that may be suitably used as the heat source for a WLHPAC system in China. This paper presents strategies of using these external low-grade heat sources in WLHPAC systems so that their large scale applications in China will be become possible.

2 EXTERNAL LOW-GRADE HEAT SOURCES AND WATER LOOP HEAT PUMP AIR CONDITIONING SYSTEMS

2.1 Solar Energy and Water Loop Heat Pump Air Conditioning Systems

Solar energy has been known as the most promising type of energy in 21st century. There is abundance of solar energy resources in China. The regions where the annual sunlit time is more than 2000 hours cover two-thirds of the territory of China. For example, the average sunlit time of the north-western China and Qingzang Plateau is about 3000 hours. The weather data in 700 weather stations throughout China indicated that the annual averaged solar radiation density of in China ranged between 334.9kJ/cm^2 and 837.4kJ/cm^2 [13]. This places China in a favorable position to utilize solar energy.

The schematic diagram of a WLHPAC system using solar energy as low-grade heat source is shown in Fig.1. It consists of three parts: solar heat collection, a WLHPAC units, and hot water supply. In order to eliminate the intermittent and instable supply of solar energy, a water pool originally used for

fire-fighting can be used as a reservoir for heat storage. When water temperature in the loop is higher than 35°C, the motorized valves A, B, and C will be shut off, valves D and E will open, and cooling tower is operated. This disconnects the WLHPAC unit from the fire fighting pool, and the solar energy collected is used as the heat source for hot-water supply. When the water temperature in the loop is between 13°C and 35°C, the motorized valves A, B, D and the cooling tower will be shut off, and valves C and E will open, and the solar energy collected can still be used for hot-water heating. When the water temperature in the water loop is lower than 13°C, the motorized valves D and E will be shut off, and valves A, B and C will open. This would connect the WLHPAC to the fire-fighting pool, and solar energy collected can be used as low-grade heat source for WLHPAC. However, if there is still surplus of solar energy, it may be used for hot-water heating.

The WHLPAC system using solar energy would have the following characteristics:

- (1) The use of solar energy helps solve such problems as little surplus heat gain in buildings and the poorer energy efficiency of conventional WHLPAC systems. On the other hand, the use of solar energy decreases the operating time of auxiliary heating apparatus such as an electric boiler.
- (2) Not only the initial capital investment is low, but also the problem of intermittent and instable supply of solar energy can be solved by using the fire-fighting pool as a heat reservoir in this new system.
- (3) In transit seasons, the surplus solar energy stored in the pool can be utilized for hot-water heating.

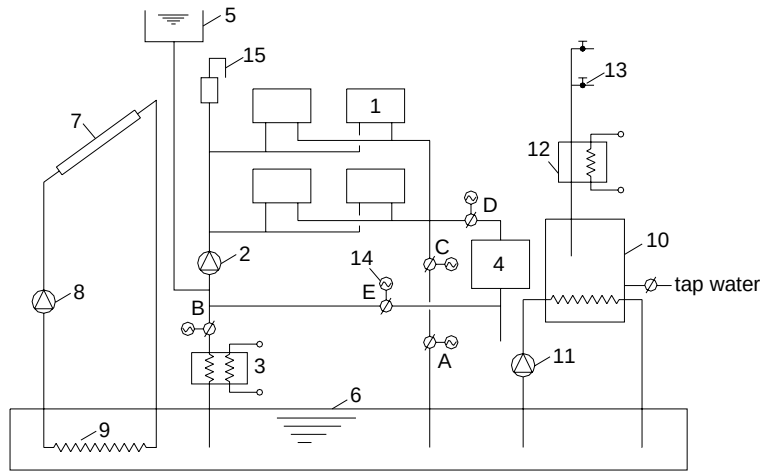


Fig. 1. Schematics of WHLPAC systems using solar energy as a low-grade heat source

1-water/air heat pump A/C units 2-water circulating pump 3-auxiliary heating source (e.g. electric boiler) 4-closed water cooling tower 5-water expansion tank 6-fire-fighting pool 7-solar energy collector 8-circulating pump of hot medium 9-heat exchanger 10-cubage heater 11-circulating pump of hot water 12-auxiliary heater of hot-water supply 13-hot water supplying points 14-motorized regulating valve 15-air vent

2.2 Underground Water and Water Loop Heat Pump Air Conditioning System

Underground water sources are also abundant in China. Either deep-well water or underground hot water may be used as a low-grade heat source for WHLPAC systems to achieve high energy efficiency.

The temperature of underground water, in particular of deep-well water is almost independent of climate changes. This makes it a favorable low-grade heat source for WLHPAC systems. However, the large scale utilization of underground water can lead to ground level going down, causing the water resource to dry up. Therefore, the method of “deep-well water recharging” has been effectively in place for many years to prevent the ground level from going down, through either “recharging in winter and using in summer” or “recharging in summer and using in winter.” The former is for the situation where the water cooled by a WLHPAC system in winter is reinjected to other deeper wells, so that the cooling energy is stored in under-ground water, which is used as a cooling energy source stored in for the WLHPAC system in summer. The latter operates in a reverse time-order to the former. With this method, both using underground water as a heat source for WLHPAC systems and the prevention of ground level from going down can be realized. However, attention should be paid to the impact on the change of underground water temperature when a WLHPAC system operates over a long period of time.

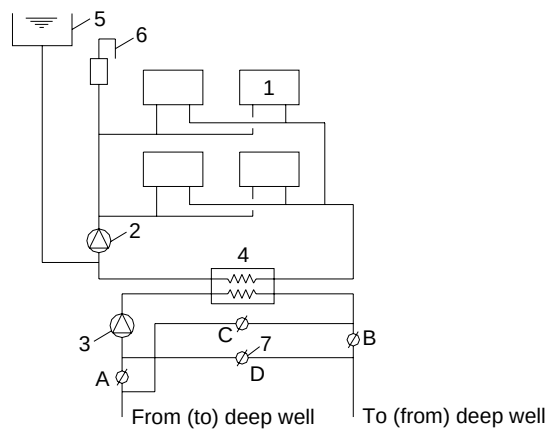


Fig. 2. Schematics of WLHPAC systems using deep well water as a low-grade heat source

1-water/air heat pump A/C units 2-water circulating pump 3-deep-well water pump 4-heat exchanger exchanger
5-water expansion tank tank 6-air vent 7-valves

The schematic diagram of WLHPAC system using deep-well water as low-grade heat source is shown in Fig.2. It consists of two parts: well water low-grade heat source and WLHPAC units. When the water temperature in the loop is between 13°C and 35°C, the surplus heat gain in internal zones is transferred to perimeter zones in buildings through the closed-water loop, minimizing using high grade energy for heating. In summer, when the water temperature in the loop is higher than 35°C, the valves A, B and deep-well water pump 3 are turned on, with valves C and D shut off. The heat discharged from WLHPAC units is transferred to well water through the heat exchanger 4. The warm well water after the heat exchanger is injected to other deeper wells so that the water temperature in the loop would be kept under 35°C. In winter, most heat pump units are in heating mode. When the water temperature in the loop is lower than 13°C, the valves A and B are closed, with the valves C and D opened, and deep well-water pump 3 turned on. The water in the loop absorbs heat from well water through the heat exchanger 4, and the cooled well water after the heat exchanger is reinjected to other deeper well. In this way, the so-called “recharging in winter and using in summer” and “recharging in summer and using in winter” are realized.

2.3 Discharged Waste Water and Water Loop Heat Pump Air Conditioning System

Discharged waste water includes domestic waste water and industrial waste water. The former includes the water from laundry, bathing pool, and hotel, etc.. Domestic waste water may be used as a low-grade heat source for WLHPAC systems because of its relatively high temperature at 24~29°C. However, the key issues include how to obtain an adequate amount of water to deal with the fluctuation of heating load, how to maintain heat exchanger clean and how to prevent the equipment used from being corroded. A number of engineering examples of heat pump systems using domestic waste water as a low-grade heat source can be found in Japan [14]. Industrial waste water, on the other hand, is characterized by various types, large quantity, and a higher temperature. Some types of industrial waste water may be used for heating directly, such as industrial cooling water in metallurgy and founding industry. Some may however be used as a low-grade level heat source for heat pump, such as cooling water from power generation plants. A WLHPAC system using cooling water from a power generation plant as the low-grade heat source has been successfully operated since 1999 in a building in Dalian, in North Eastern China [15]. Recently, an increasing attention has been paid to using waste water from oil fields, because of its high temperature at 31~45°C, large quantity and steady output. However, the key issue in using waste water includes, again, how to maintain heat exchanger clean and how to prevent the equipment used from being corroded. Currently, detailed studies are being carried by Tianjin University for using waste water in Shengli Oil Field, and by Harbin Institute of Technology in Daqing Oil Field [16].

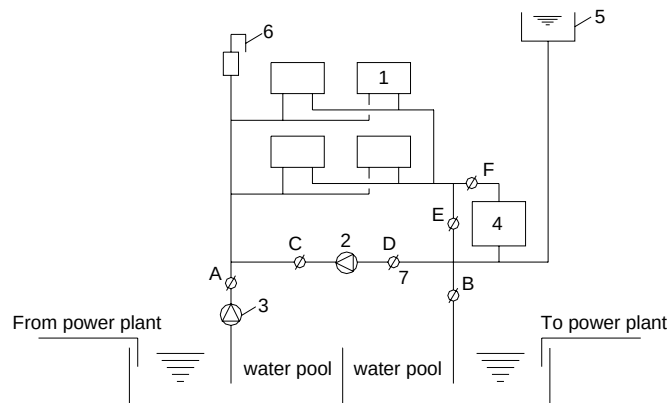


Fig. 3. Schematics of WLHPAC systems using cooling water from power plant as a low-grade heat source

1-water/air heat pump A/C units 2-water circulating pump 3-circulating pump of cooling water 4-closed cooling tower 5-water expansion tank 6-air vent 7-valves

The schematic diagram of a WLHPAC system using cooling water from power generation plants as the low-grade heat source is given in Fig. 3. In transit seasons, when the water temperature in water loop is between 13°C and 35°C, the valves C, D and E open, with valves A, B, F, water pump 3 and cooling tower shut off. The surplus heat gain in internal zones is transferred to external zones in a building through the closed water loop, achieving maximum energy saving. In summer, when the water temperature in water loop is higher than 35°C, the valves A, B, E and water pump 3 are shut off, with

valves C, D and F open, and the cooling tower turned on, so that the water temperature in loop remain under 35°C. In winter, most of heat pump units are in heating mode, the valves C, D, F and water pump 2 are shut off, with valves A, B and E open, and water pump 3 turned on. The cooling water from a power plant is used as the low-grade heat source for heating. Test results in Dalian city by the Chinese Institute of Air Conditioning demonstrated that in cold climates in northern China, it is reasonable and economical to use cooling water from power plants as a low-grade heat source for WLHPAC systems, if such a low-grade heat source is available [15].

2.4 Air and Water Loop Heat Pump Air Conditioning System in Cold Climate

Air, an inexhaustible low-grade heat source, contains abundant energy, and is available everywhere at any time. Unlike waste water, air will not cause any damage to heat exchange equipment, and therefore, becomes a primary low-grade heat source for heat pump units. Currently, air source heat pump water heater/chiller, air source heat pump domestic air conditioner, etc., dominate the air conditioning heat pump market. However, when outdoor air temperature drops, evaporating temperature will be lower, the difference between the evaporating temperature and condensing temperature will increase. This will lead to an increase in compression ratio and consequently the operating efficiency of a heat pump unit will fall. Experimental results showed that a single stage compression heat pump can be operated at temperature between -13°C and -20°C, however its COP will greatly be significantly low, with its actual output heating being below 50% of its rated capacity [17]. In order to solve the problem, an additional air/water heat pump unit can be used to heat water in the loop of a WLHPAC system, maintaining it remain not less than 13°C. Because of relatively low compression ratio, the operating efficiency of the additional air/water heat pump unit is greatly increased. With the help of the additional air/water heat pump unit, the water /air heat pump units in the WLHPAC system can be efficiently operated in heating mode. Based on this method of using series heat pump, operating WHLPAC systems using air as a low-grade heat source in cold climate is possible, and the operational principle is illustrated in Fig. 4.

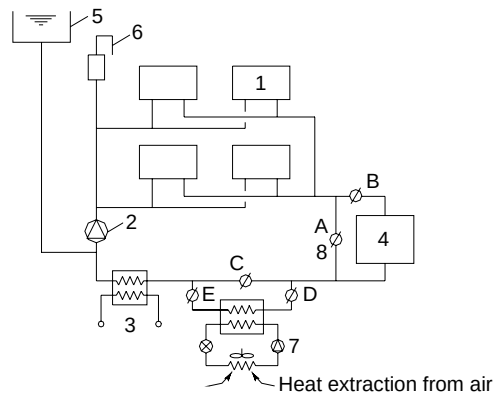


Fig. 4. Schematics of WLHPAC systems using air as a low-grade heat source

1-water/air heat pump A/C units 2-water circulating pump 3-auxiliary heater (e.g. electric boiler) 4-closed cooling tower 5-water expansion tank 6-air vent 7-additional air/water heat pump unit 8-valve

As seen in Fig. 4, a WLHPAC system using air as a low-grade heat source consists of two parts:

WLHPAC units and an additional air/water heat pump unit used for extracting heat from air. In transit seasons, when the water temperature in the loop is between 13°C and 35°C, the valves A and C open, with the valves B, D, E and cooling tower 4 shut off. The surplus heat gain in internal zones is transferred to external zones in buildings through the closed water loop, maximizing energy saving. In summer, when the water temperature in water loop is higher than 35°C, the valves A, D and E are shut off, with the valves B and C opened and the cooling tower operated, so that the water temperature in the loop is maintained at below 35°C. In winter, most of heat pump units are in heating mode. The valves B and C are shut off, with the valves A, D and E opened, and the WLHPAC system uses air as a low-grade heat source by the use additional air/water heat pump unit which extracts heat from air. In extremely cold climates regions, an auxiliary heater may be used for heating. Currently, the investigation made by Wang [18] have verified that its technical feasibility, economical viability and its energy efficiency of such a system, and a practical engineering using this system has been operated in Beijing, China for two years.

From the above analysis on the characteristics of a number of types of low-grade heat sources and the various WHLPAC systems using these types of low-grade heat sources, the following conclusions may be drawn.

- (1) A WLHPAC system operating on solar energy, underground water, industrial waste water as the low-grade heat source can achieve energy saving, and is therefore promising for large scale applications. The use of low-grade heat sources from outside buildings (e.g. solar, waster water) would make the application of such an energy efficient system in buildings with negligibly small heat gain possible, thus effectively extending the ranges of application for WLHPAC systems.
- (2) The proposed use of series heat pumps utilizing air as a low-grade heat source further increases the ranges of the application of WLHPAC systems. This is particularly effective in cold climates.
- (3) The use of conventional auxiliary heat source can be reduced, or even avoided, with the utilization of these low-grade heat sources. This not only helps preserve primary energy sources, but also reduces the quantity of CO₂ discharged, contributing to sustainable development.

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