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Experimental investigation of a multi-function heat pump under various operating modes

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ABSTRACT

Heat pumps have been spotlighted as efficient building energy systems because they have great potentials for energy reduction in building air conditioning and reducing CO_2 emission. In this study, a multi-function heat pump which has the functions of heating, cooling, and hot water supply was designed and its performance was investigated according to operating modes. In the cooling-hot water mode, the capacity and COP were enhanced as compared to other modes because the waste heat from the outdoor heat exchanger was utilized as useful heat in the indoor heat exchanger. In the heating and hot water supply mode, the compressor speed should be increased to get appropriate heating and hot water capacities. For all operating modes, the system could be optimized by adjusting the superheat.

1. Introduction

With rising cost of fuel and global warming at the forefront of world attention, the interest in heat pump as a means of energy recovery appears to have been resurrected. Heat pumps offer one of the most practicable solutions to the greenhouse effect. It is the only known process that recirculates environmental and waste heat back into a heat production process. It also offers energy efficient and environmentally friendly heating and cooling in applications ranging from domestic and commercial buildings to process industries [1]. Especially, the heat pump systems with water source have been spotlighted as a key approach to improve energy efficiency, because it can recover very useful sources of waste heat and renewable energy such as geothermal energy, sewage water, river water, and so on [2,3]. The major focus in recent research has been on the development of the system to replace boiler. In this case, the heat pump system should have the functions of heating, cooling, and hot water supply [4].

Previous studies on heat pumps focused on the improvement of the system performance in heating and cooling operations. The technologies used in the development of heat pumps mainly focused on compressor capacity control, refrigerant flow rate control, and alternative refrigerants. Compressor speed control has been widely adopted in heat pumps to modulate capacity. In the early stage of compressor development, alternating current (AC) inverter technology was widely used for compressor speed control [5]. However, recently, the use of direct current (DC) inverter technology has become increasingly more common because of its energy saving efficiency and high control accuracy. The control of the refrigerant flow rate was remarkably improved by using the electronic expansion valve (EEV) [6], which can control the refrigerant flow rate precisely according to the variations of the operating conditions. The variable speed compressor and EEV are essential components in the development of heat pumps [7].

Even though many studies on heat pumps have been conducted, the researches on heat pump with multi-function which can execute heating, cooling, and hot water supply are very limited in open literature.

In this study, a multi-function heat pump was designed and its performance tests were executed in various operating modes. This study will provide a reference and guidelines for designing next-generation multi-function heat pump systems which will be able to replace the traditional air-conditioning system.

2. Experimental setup and test procedure

Experimental setup was designed to measure the performance of a multi-function heat pump under variable operating conditions. A schematic of the experimental setup is shown in Fig. 1. The test rig included heat pump and water flow loops simulating heat source

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and building load conditions. The nominal cooling capacity of the tested heat pump unit was 7.0 kW, and the working fluid was R134a. The heat pump unit consisted of a reciprocating compressor, three plate type heat exchangers (outdoor heat exchanger, indoor heat exchanger, and hot water heat exchanger), and an expansion device. The outdoor heat exchanger (OD HX hereafter), indoor heat exchanger (ID HX hereafter), and hot water heat exchanger (HW HX hereafter) had counter flow between refrigerant and water. The OD HX was used to exchange heat between the refrigerant and water flowing through heat source such as ground, sewage, and river water loops. The ID HX exchanged heat between the refrigerant and water flowing through building for heating and cooling, and the HW HX was adopted to exchange heat between the refrigerant and water for hot water supply to the bathroom and kitchen. The nominal capacities of ID HX, OD HX, and HW HX were 7 kW, 7 kW, and 3.5 kW, respectively. The secondary water flow rates of ID HX and OD HX were 10 LPM. The HW HX had a flow rate of 4 LPM. EEV was used as the expansion device in the heat pump unit. A stepping motor using 1–2 excitation method drove the EEV.

Table 1 shows five operating modes of the system: heating, cooling, hot water, heating-hot water, cooling-hot water modes. In the heating and cooling mode, the system operates in a common heat pump unit. In the hot water mode, the heat pump operates in the same way as in heating mode except that HW HX works as a condenser instead of ID HX. In the cooling-hot water mode, ID HX plays a role of evaporator, and the HW HX extracts heat. In the heating-hot water mode, heat is extracted from the ID HX and the HW HX.

The water flow loops were simulated by using constant temperature baths. Water was selected as a heat source and sink for the heat pump unit because of their simplicity of capacity measurements. Water flow loops (secondary flow loops) for the ID HX, OD HX, and HW HX were closed loops having magnetic pumps and constant temperature baths. Each water bath was equipped with a refrigeration system and electric heater.

Temperatures in the test setup were monitored at the selected locations using thermocouples according to ASHRAE Standard 41.1 [8], and refrigerant pressures were also measured according to ASHRAE Standard 41.3 [9]. A mass flow meter to measure refrigerant flow rate was installed at the inlet of expansion device. A volumetric flow meter was installed to measure water flow rate in the secondary flow loop. Each sensor was calibrated to reduce experimental uncertainties. The specification and accuracy of sensors are summarized in Table 2.

The first step of the test procedure was to determine optimum charge amount. Since the heat pump is normally charged in the cooling mode [10], the optimum charge amount in this study was determined in the cooling mode. Initially, the refrigerant was charged at water temperatures of 25 °C and 12 °C entering the OD HX and ID HX, respectively. The EEV regulated refrigerant flow rate by varying flow area in an orifice using a needle stem. For determining the optimum charge amount, the refrigerant was added into the heat pump unit in a 500 g increment until the maximum COP was obtained. Once the optimum charge was determined, the performance tests were conducted in various operating modes and

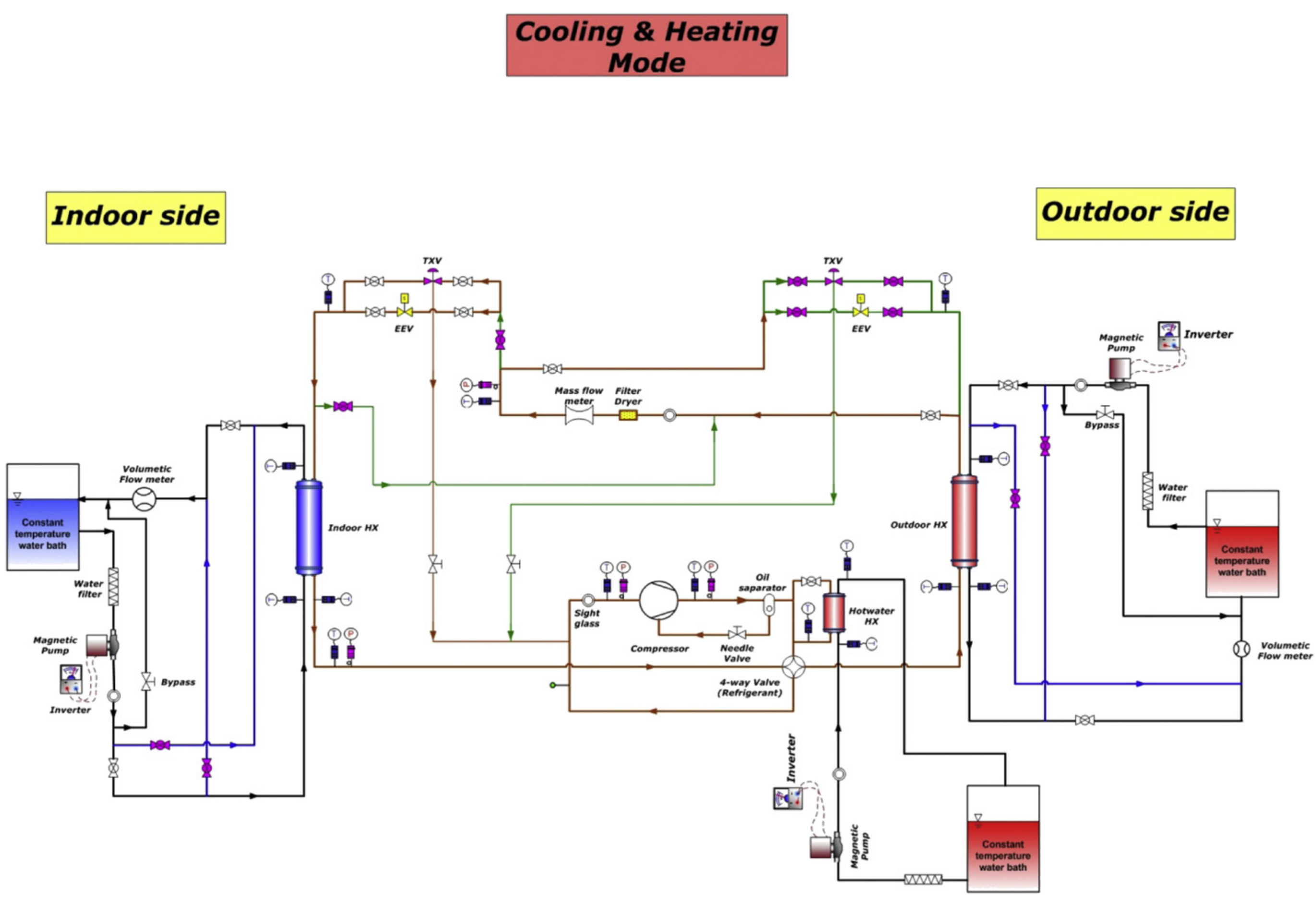

Fig. 1. Schematic diagram of a multi-function heat pump.