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Experimental study on the performance of a simultaneous heating and cooling multi-heat pump with the variation of operation mode

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ABSTRACT

The cooling load in the winter season becomes significant in commercial buildings and hotels because of the wide usage of office equipment and improved wall insulation. In this study, a simultaneous heating and cooling multi-heat pump having four indoor units and an outdoor unit was designed and tested in five operation modes: cooling-only, heating-only, cooling-main, heating-main, and entire heat recovery. The performance of the system with R410a was optimized by adjusting the system's control parameters. In the cooling-main mode, the rate of the bypass flow to the heating-operated indoor unit was optimized by controlling the EEV opening of the outdoor unit. In the heating-main mode, the mass flow rate to the cooling-operated indoor unit was optimized by adjusting the EEV opening in the outdoor unit. In the entire heat recovery mode, the compressor speed was controlled to improve the system COP with appropriate heating and cooling capacities.

Etude expérimentale sur la performance d'un système à plusieurs pompes à chaleur assurant le chauffage et le refroidissement

Mots clés : Pompe à chaleur ; R410A ; Expérimentation ; Chauffage ; Réfrigération ; Optimisation ; Détendeur électronique ; Vitesse variable ; Compresseur

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Nomenclature

COP	coefficient of performance
CSR	compressor speed ratio
EEV	electronic expansion valve
h	enthalpy (kJ kg^{-1})
IDU	indoor unit
m	mass flow rate (kg s^{-1})
ODU	outdoor unit
P	pressure (kPa)
q	heat transfer rate (W)
rpm	revolution per minute
R	ratio
RH	relative humidity
W	power consumption (W)

Greek letters

Φ	opening

Subscripts

c	cooling
bp	bypass
h	heating
t	total

1. Introduction

A multi-heat pump, which has one outdoor unit and several indoor units, has been used to cover the cooling load of a building in the summer season and the heating load in the winter season. The operation mode of the multi-heat pump can be changed from the cooling to the heating mode by switching the direction of the refrigerant flow using a 4-way valve. A conventional multi-heat pump can provide either only-cooling or only-heating at any time. However, the cooling load in the winter season becomes significant in commercial buildings and hotels because of the wide usage of office equipment having high heat flux and because of the improved wall insulation. Therefore, the function of the multi-heat pump has to be extended to cover both heating and cooling loads simultaneously in different zones of a building. Currently, research continues to develop a highly efficient simultaneous heating and cooling multi-heat pump that can provide the required heating and cooling to different zones of a building at the same time. The major focus in recent research has been on the development of cutting edge technologies to realize optimum refrigerant flow control and high system efficiency and reliability.

Previous studies on multi-heat pumps focused on the improvement of the system performance in heating-only or cooling-only operation. The technologies used in the development of multi-heat pumps mainly focused on compressor capacity control, refrigerant flow rate control, and alternative refrigerants. Compressor speed control has been widely adopted in multi-heat pumps to modulate the compressor capacity. In the early stage of compressor development, alternating current (AC) inverter technology was widely used for compressor speed control (Nagatomo, 1998; Aprea et al., 2006). 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) (Qifang et al., 2007; Park et al., 2007), which can control the refrigerant flow rate precisely according to the variations of the operating conditions. The compressor inverter and EEV are essential components in the development of multi-heat pumps (Choi and Kim, 2003; Park et al., 2001).

Even though many studies on multi-heat pumps have been conducted, studies on simultaneous heating and cooling multi-heat pumps are very limited in open literature. Especially, the system optimization and flow distribution control of simultaneous heating and cooling multi-heat pumps according to the variations of the operation mode need to be studied more comprehensively to develop a highly efficient and reliable system.

In this study, a simultaneous heating and cooling multi-heat pump was designed and its performance was measured for five operation modes, namely the cooling-only, heating-only, cooling-main, heating-main, and entire heat recovery modes. The performance of the simultaneous heating and cooling multi-heat pump with R410a (Park et al., 2003; Kim and Bullard, 2001) was analyzed and then, improved by optimizing its control parameters such as the compressor rotation speed and EEV opening.

2. Experimental setup and test procedure

2.1. Experimental setup

Fig. 1 shows the schematic diagram of experimental setup. A simultaneous heating and cooling multi-heat pump using R410a was designed to have a cooling capacity of 8.0 kW in the cooling-only mode. The pump system consisted of an outdoor unit (ODU), a mode change unit (MCU), and four indoor units (IDU). The outdoor unit consisted of a blushless direct current (BLDC) type rotary compressor, an oil separator, a liquid–gas separator, an accumulator, a finned-tube heat exchanger and an EEV. Each indoor unit consisted of a finned-tube heat exchanger and an EEV. The heat exchangers for the indoor and outdoor units used micro-fin tubes and slit-fins. Each indoor heat exchanger had an evaporation capacity of 2.15 kW at the evaporating temperature of 7.2 °C and an air flow rate of 6.0 m^3/min. The outdoor heat exchanger had a condensation capacity of 11.34 kW at the condensing temperature of 54.4 °C and an air flow rate of 37.5 m^3/min.

For individual heating and cooling operations of the indoor units, an MCU was installed between the outdoor unit and the indoor units. It consisted of header pipes, branch pipes and solenoid valves. On/off operations of the solenoid valves were determined according to the operation mode of the indoor