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Experimental investigation on a novel temperature and humidity independent control air conditioning system – Part II: Heating condition

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HIGHLIGHTS

- A novel temperature and humidity independent control system is proposed.
- This proposed system is experimentally investigated on heating condition.
- This proposed system is compared with a traditional system.
- Energy saving and improved indoor thermal comfort can be achieved simultaneously.

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ABSTRACT

Air source heat pump is a widely adopted system for winter heating in Central China and South China due to its high energy efficiency and low maintenance cost. However, such systems cannot produce any latent capacity resulting in decreased indoor air quality. Newly developed temperature and humidity independent control system (THIC) provides a solution to this problem. In this study, a novel THIC system was introduced and experimentally investigated under heating condition, which consisted of a solid desiccant heat pump (SDHP) and a variable refrigerant flow (VRF) air conditioning system to handle the latent load and sensible load, respectively. An experimental setup of the joint SDHP and VRF system (JDVS) was established, and the system was evaluated by indoor air condition, energy consumption and system coefficient of performance (COP). In addition, the proposed JDVS system was compared with widely adopted joint heat recovery ventilator (HRV) and VRF system (JHVS). Experimental results show that JDVS can keep indoor humidity ratio at about 50%RH, however JHVS can only increase the indoor humidity ratio to around 30%RH. In addition, JDVS can achieve energy saving of 9.3%, while the COP of JDVS increases by 45.2% compared with JHVS.

1. Introduction

Vapor compression (VC) air conditioning system is an appliance which alters the properties of air to more favorable conditions. In China, VC system is widely adopted for summer cooling through the whole country, but different heating facilities are adopted according to different climatic conditions in winter. In North China, the coal-fired boiler is the primary heating source, because of the low ambient temperature leading to low efficiency or even impossibility for working of VC system. However, this kind of heating method has been causing severe atmospheric problems. Therefore, air source heat pump has been suggested to be widely adopted in Central China and South China. An ASHP can achieve heating in winter and cooling in summer by altering the reversible valve. With low initial cost, high efficiency and less pollution, ASHP has become a research hotspot ever since. So far, most of studies reported have posed their focus on increasing system coefficient of performance (COP) with use of inverter drives, improved refrigerants and new multi-functional heat pump cycles [1]. However, with the improvement of living standards, the demand for better indoor air quality especially improving indoor air humidity in winter has become more and more urgent. Therefore, humidification should be taken into account, since ASHP cannot supply any

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Nomenclature

Cap	system capacity, kWh
COP	coefficient of performance
h	refrigerant or air enthalpy, kJ/kg
HR	humidity ratio, g/kg
$\dot{m}$	refrigerant or air mass flow rate, kg/s
P	power consumption rate, kW
Q	system capacity, kWh
T	temperature, °C
t	time, s
w	humidity ratio, kg/kg
W	energy consumption, kWh

Subscripts and superscripts

g	saturated vapor
i	ith indoor unit
i,i	inlet of ith indoor unit
i,o	outlet of ith indoor unit
lat	latent
n	number of variables
sens	sensible

Abbreviations

SDHP	solid desiccant heat pump
HRV	heat recovery ventilator
VRF	variable refrigerant flow
JDVS	joint SDHP and VRF system
JHVS	joint HRV and VRF system
OA	outdoor air
SA	supply air
RA	return air
EA	exhaust air

latent capacity in winter. So far, auxiliary electric humidifier is widely used for residential use. But energy efficiency of the electric humidifier is very low, and the effective area is very limited.

Comparing with ASHP with low energy efficiency and weak thermal comfort, newly developed temperature and humidity independent control system (THIC) provides an attractive option. In a typical THIC system, a solid or liquid desiccant subsystem handles the latent load, while VC system deals with the sensible load. Originally, the THIC system has been proposed for summer cooling and dehumidification and lots of research work have been conducted under summer condition. So far, rarely work has been reported for winter heating and humidification. Recently, based on the principle of desiccant dehumidification, some researchers started to investigate the feasibility of utilizing THIC systems for winter heating and humidification. In this case, the dry cold ambient air can be humidified by the desiccant subsystem, while ASHP will control the indoor temperature respectively. Li [2] proposed a liquid desiccant total heat exchanger and small capacity refrigeration cycle combined with fresh air processor, the experimental results showed that the supply air can be improved to 21–23 °C temperature and 6 g/kg humidity ratio, while the energy efficiency ratio (EER) varied from 4.7 to 5.0. Then based on this liquid desiccant total heat recovery device, Liu [3] proposed a hybrid liquid system integrated with refrigeration/heat grid system and investigated the annual system performance. Some researchers got inspiration from desiccant wheel systems which were widely adopted for cooling and dehumidification. La [4] investigated a one-rotor two-stage rotary desiccant system driven by solar air collectors on winter. The experimental results indicated that desiccant humidification did have the potential for solving the dry indoor conditions in winter. Li [5] utilized a two-wheel two-stage rotary desiccant system, and the results showed that the supply air humidity ratio could be increased by nearly 4 g/kg under humidification mode. Although these studies testified that the indoor comfort could be improved under heating condition by desiccant desorption, the humidification capacity couldn't be controlled to desired condition. Because both the sorption and desorption process were not well controlled while sorption heat and regeneration heat remained as the two obstacles. A novel self-regenerating heat pump desiccant system (HPD) introduced by Aynur [6] could solve the above issues. In his study, the two heat exchangers in the heat pump cycle were coated by solid desiccant materials. In this case, adsorption could be improved while adsorption heat was taken away by evaporator and condensation heat can be used to regenerate enough moisture from desiccant. Based on the proposed HPD system, Aynur [7] addressed the field performance evaluation of variable refrigerant flow (VRF) system integrated with HPD in an existing office. The experimental results showed that the novel integrated system could achieve energy saving while provided the best thermal comfort, compared with the other two operation methods. Jiang [8] also introduced a solid desiccant heat pump (SDHP), and embedded the mathematical model of this SDHP into EnergyPlus [9]. Series of simulation study were conducted to evaluate the SDHP by using the established model.

In this study, a novel THIC system consisting of an SDHP and a VRF system was proposed and experimental investigated. Due to the high energy efficiency and the demand for fresh air, heat recovery ventilator (HRV) has been widely integrated with VRF to provide fresh air. Then experimental setup of both the proposed joint SDHP and VRF system (JDVS) and the traditional joint HRV and VRF system (JHVS) were established in an office room in Shanghai. Comparison study of the two THIC systems was conducted under heating condition.

2. Experiment setup

In this study, two hybrid desiccant systems, joint SDHP and VRF system, and joint HRV and VRF system, were built up in an office room in Shanghai. Both of the two hybrid systems consist of two separate subsystems. In JDVS, SDHP mainly deals with latent load and some sensible load from fresh air, while VRF system handles the left sensible load. In JHVS, HRV cooperates with another VRF system to control the space and supply fresh air.

2.1. System introduction

2.1.1. Solid desiccant heat pump

The schematic diagram of Solid desiccant heat pump (SDHP) is shown in Fig. 1. With two desiccant coated heat exchangers (DCHE), expansion valve, compressor and a 4-way valve, SDHP has four inlets and outlets in total, namely supply air (SA), outdoor air (OA), return air (RA), exhaust air (EA). In the heating/humidification condition, the system works almost same as the cooling/dehumidification condition as in Part I, except for the function of the two desiccant coated heat exchangers. On one hand, condensation heat regenerates the desiccant to release the moisture adsorbed, while OA flows through condenser to get heated and humidified. Then the warm humid fresh air is supplied into the conditioned space. On