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

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HIGHLIGHTS

- A novel temperature and humidity independent control system is proposed.
- This proposed system is experimentally investigated on cooling 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

Temperature and humidity independent control system (THIC) has become a research focus for its merits of energy saving and improved indoor thermal comfort. In this paper, a novel THIC system was experimentally investigated, which consisted of a solid desiccant heat pump (SDHP) to handle the latent load and a variable refrigerant flow (VRF) air conditioning system to deal with the sensible load, respectively. An experimental setup of this joint SDHP and VRF system (JDVS) was established to measure the system performance under cooling condition. Meanwhile, an experimental setup of widely adopted joint heat recovery ventilator (HRV) and VRF system (JHVS) was also built up to make a comparison. Performances of both JDVS and JHVS were evaluated by indoor air condition, energy consumption and coefficient of performance (COP). Experimental results show that, JDVS can achieve energy saving of 17.2%, while COP of JDVS increases by 25.7% compared with JHVS. In addition, JDVS with indoor relative humidity stabilizing at 50%, can provide better indoor thermal comfort than JHVS.

1. Introduction

Nowadays, rapid economic growth leads to a large amount of energy consumption and CO_2 emission, which have drawn serious attention to sustainable and scientific development. Buildings account for a large part of energy consumption and environmental pollution in the whole society. Meanwhile, heating, ventilation, and air conditioning (HVAC) systems in buildings are estimated to consume about 50% of the total energy consumption in buildings. Therefore, developing high-efficiency HVAC system is crucial to realize energy-saving in buildings.

In air conditioning systems, latent load accounts for 30–50% of total thermal load in summer. In other words, dehumidification may consume 30–50% energy for summer cooling [1]. So far, traditional vapor compression (VC) air conditioning systems are widely adopted in buildings, which handle latent load by cooling down the air below its dew point (12–15 °C). As a result, the required evaporation temperature is about 5–7 °C, which leads to low coefficient of performance (COP) of VC system. In centralized air conditioning systems, auxiliary heaters are still required to reheat supply air to the required comfort air temperature, and thus more energy is consumed. In addition, indoor condition is either humid or cold, since indoor temperature and humidity can hardly be satisfied with only condensation dehumidification.

Temperature and humidity independent control system (THIC) is proposed to solve these problems in recent years. In a typical

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Nomenclature

Cap	system capacity, kWh
c_p	specific heat, J/(kg K)
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	energy 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

THIC system, a solid or liquid desiccant subsystem handles the latent load, while VC system deals with the sensible load. Since latent load is separately handled by the desiccant system, VC system can handle the sensible load at higher evaporation temperature resulting in higher system COP. Moreover, the cold–heat offset loss can be avoided and the desiccant can be regenerated with some low-grade heat sources (such as solar thermal energy). In the past years, a significant amount of investigations have been conducted in this field [2–8]. Burns [2] studied the performance of three possible configurations for solid desiccant hybrid systems and the results indicated 60% energy saving could be obtained compared with VC system. Worek [3] proposed a solid hybrid desiccant system integrated with heat pump utilizing condensation heat to regenerate the desiccant, thus system efficiency could be improved. Jia's study [4] showed that solid desiccant hybrid system could achieve low humidity ratio while achieving energy saving. Meanwhile, Yadav [5] combined liquid desiccant subsystem with VC system and utilized condensation heat to partially regenerate the liquid desiccant. The results showed significant energy saving compared with traditional VC system, especially under hot and humid climates. Dai [6] proposed a new liquid desiccant hybrid system integrated with evaporative cooling and the results indicated improvement of system COP compared with VC system. It can be seen that THIC system is an energy-saving alternative to VC system, however auxiliary heaters are necessary for desiccant regeneration, which increased the initial cost and system complexity.

It can be found from the reference review that condensation heat released from VC system provides a promising option for the required desiccant regeneration heat source. For a conventional VC system, condensation temperature is about 45 °C. Since 30 °C temperature rise has been demonstrated enough for the regeneration of some solid desiccants [9–11], thus adsorption temperature should be controlled at or below 15 °C. Otherwise, temperature of condensation heat is not high enough for desiccant regeneration when adsorption temperature is lifted due to the adsorption heat released during dehumidification. If the evaporator is adopted as an internal-cooled dehumidifier [12,13], the released heat from desiccant can be removed by cold refrigerant. In this case, condensation heat can be well utilized without using auxiliary heaters, while system COP can be improved when evaporation temperature increases to 15 °C compared with that of conventional VC system (7 °C). Based on this concept, several hybrid desiccant systems have been proposed recently. Lazzarin [14] introduced a novel self-regenerating liquid desiccant hybrid system with condensing heat utilized for desiccant regenerating and internal-cooled dehumidifier to enhance dehumidification. The simulation results showed that this novel hybrid desiccant system could ensure improved thermal comfort with relative humidity at 50% and achieve energy saving in the meanwhile. Aynur [15] introduced a self-regenerating air source heat pump desiccant (HPD) unit. In his study, the two heat exchangers in the heat pump were coated by solid desiccant materials, which were named desiccant coated heat exchanger (DCHE) by Ge [16]. In this case, adsorption could be improved while adsorption heat was taken away by evaporator and desiccant could be regenerated by condensing heat. The experimental results showed the HPD could supply a higher dehumidification capacity compared with heat recovery ventilator (HRV). Jiang [17] also introduced a novel solid desiccant heat pump (SDHP), and embedded the mathematical model into EnergyPlus [18]. By using the established model, series of simulation study were conducted to evaluate the proposed solid desiccant heat pump.

Since variable refrigerant flow air conditioning system (VRF) can't provide any fresh air, additional ventilation unit is usually necessary. Due to the high energy efficiency, HRV system is widely adopted to work with VRF, making up the joint HRV and VRF system (JHVS). In this study, a novel THIC system was proposed, which consisted of a SDHP and a VRF system. In order to evaluate the proposed joint SDHP and VRF system (JDVS), experimental setups of both the proposed JDVS and traditional JHVS were established in an office room in Shanghai. By analyzing the experimental results of these two THIC systems, comparison study was conducted under cooling condition.

2. Experimental setup

In order to evaluate system performance, two hybrid desiccant systems (joint SDHP and VRF system, joint HRV and VRF system) were built in an office room in Shanghai.

Both of the two hybrid systems consist of two separate parts. In JDVS, SDHP mainly deals with latent load. In addition, VRF system handles the left sensible and latent load. In JHVS, HRV cooperates with another VRF system to control the space.

2.1. Joint SDHP and VRF system

2.1.1. Solid desiccant heat pump system

The schematic diagram of solid desiccant heat pump (SDHP) is shown in Fig. 1. With two desiccant coated heat exchangers,