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Performance simulation of a joint solid desiccant heat pump and variable refrigerant flow air conditioning system in EnergyPlus

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ABSTRACT

Temperature and humidity independent control (THIC) system has become an attractive alternative to conventional HVAC systems for its merits of energy-saving. In this paper, a novel solid desiccant heat pump is introduced and integrated with a conventional variable refrigerant flow air conditioning system (VRF) to form a THIC system. A standalone module of the SDHP is developed and the integration of the proposed THIC system is established based on EnergyPlus. Performance of this joint SDHP and VRF system (JDVS) is investigated in an office room. Parametric investigation results show that performance of SDHP varies greatly with the change of ambient air condition and part load ratio. Then, performance of JDVS in terms of capacity, energy consumption and system coefficient of performance (COP) is studied under summer and winter conditions. Finally, comparison study with the conventional joint heat recovery ventilator (HRV) and VRF system (JHVS) is conducted. Simulation results show that JDVS could obtain a better indoor thermal comfort while consuming less energy compared to JHVS. Through the whole year, JDVS consumes 18.7% less energy compared to JHVS. In addition, 85.5% of the indoor condition provided by JDVS falls in the comfort zone, and 35.4% provided by JHVS falls in the comfort zone.

1. Introduction

Air conditioning load consists of sensible load and latent load, and then an air conditioner has to be designed to deal with these two parts of load. Conventional vapor compression (VC) system handles sensible and latent load together by cooling the air down below its dew point to condense out vapor. Since the dew point of process air is always lower than supply air, the required evaporation temperature is as low as about 5–8 °C, which results in relatively low COP of VC system. Besides, in a centralized air conditioning system with air duct, the dehumidified air is needed to be reheated to required supply air state, which results in additional energy waste [1]. Condensation of supply air on evaporator also causes bacterial growth.

Temperature and humidity independent control (THIC) system is proposed to overcome the problems of conventional VC system. Such systems consist of a desiccant cooling system and a conventional VC system, in which latent and sensible load are handled by desiccant system and VC system separately to achieve energy saving and better air conditioning. In the past years, numerous investigations have been conducted in this field. Based on a gas fired air conditioning system combining vapor compression machine with solid desiccant dehumidifier, Parsons [2] found that cooling capacity of hybrid system increased by 50% and COP based on gas consumption increased by 40%. Dhar [3] evaluated the performance of four hybrid cycles based on the analogy method, and the results showed substantial energy saving s of hybrid solid desiccant system. Yadav [4] simulated a liquid-desiccant hybrid system regenerated by solar energy, and the results showed more energy saving can be achieved under high latent load. Dai [5] developed a mathematical model to evaluate the liquid desiccant hybrid system, and the results showed that the hybrid system could achieve higher cooling capacity by 20–30% compared to traditional VC system. Researches on hybrid cooling system are also reported in reference [6–11]. A brief review on these works shows that THIC system is divided into solid desiccant system [2,3,6–8] and liquid desiccant system [4,5,9–11]. However, regeneration temperature of solid desiccant systems is relatively high, and liquid desiccant hybrid systems may cause corrosion problems.

In order to reduce regeneration temperature of solid desiccant cooling system, several researchers [12–19] proposed a novel solid desiccant equipment: desiccant coated heat exchanger (DCHE), in which desiccant material is coated to the surface of conventional heat exchanger. Yuan [12] proposed a cross-cooled DCHE and the simulation and experimental results indicated that dehumidification by silica gel with cooling can greatly improve its performance. Ge [13] proposed two types of DCHE with silica-gel and polymer coating on the fin tube of heat exchanger. Then, Ge [14,15]

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Nomenclature

COP	coefficient of performance
COP_{JDVS}	coefficient of performance of JDVS
$h_{i,o}$	enthalpy of outlet air of VRF indoor unit (kJ/kg)
$h_{i,i}$	enthalpy of inlet air of VRF indoor unit (kJ/kg)
HR	humidity ratio (g/kg)
$\dot{m}$	air mass flow rate (kg/s)
PLR	part load ratio
$P_{OutdoorUnit}$	electricity consumption rate of VRF outdoor unit (kW)
$P_{IndoorUnit}$	electricity consumption rate of VRF indoor unit (kW)
P_{SDHP}	electricity consumption of SDHP (kW)
$\dot{Q}_{i,VRF}$	capacity of indoor unit of VRF (kW)
$\dot{Q}_{Total,VRF}$	total capacity of VRF (kW)
$\dot{Q}_{SDHP}$	total capacity of SDHP (kW)
$\dot{Q}_{Total,VRF,sensible}$	sensible capacity of VRF (kW)
$\dot{Q}_{SDHP,sensible}$	sensible capacity of SDHP (kW)
RH	relative humidity (%)
SHR	sensible heat ratio
T	temperature (°C)
W	humidity ratio (g/kg)

Subscripts

act	actual
calc	calculated
elec	electricity
EA	exhaust air
lat	latent
min	minimum
max	maximum
OA	outdoor air
SA	supply air
RA	return air
sens	sensible
tot	total

proposed a novel solar driven solid desiccant air conditioning system using the DCHE and evaluated the performance of the system by simulation. William M. Worek [16] introduced a hybrid desiccant vapor-compression cooling system utilizing DCHE and results showed that the COP improved by 35%. Aynur [17] proposed a heat pump desiccant (HPD) unit and experimental results showed the HPD could supply a higher dehumidification capacity compared to heat recovery ventilator (HRV). Another study by Aynur [18,19] addressed the field performance evaluation of variable refrigerant flow (VRF) systems integrated with HPD systems in an existing office.

In this study, a novel solid desiccant heat pump (SDHP) utilizing DCHE is introduced, which is designed to cooperate with the traditional VRF system. The mathematical model of the proposed SDHP is inserted in the dynamic building energy simulation software EnergyPlus [20] as a new module. A novel THIC system with established SDHP module and existing VRF module is proposed as joint SDHP and VRF system (JDVS), and performance of the JDVS is analyzed and compared with the conventional system.

2. System description

Proposed THIC system in this study consists of a SDHP and a conventional VRF air conditioning system, in which SDHP is adopted to handle the latent load and the VRF is utilized to deal with the sensible load. As a result, sensible load and latent load can be handled separately, to achieve a higher COP and a better indoor thermal comfort.

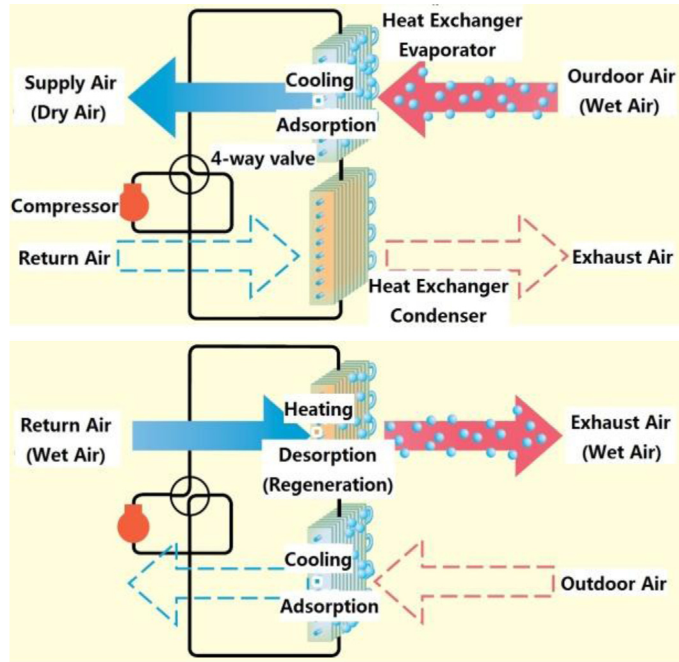

Fig. 1. Schematic diagram of SDHP working on two cycles.

2.1. Solid desiccant heat pump

In this study, a novel solid desiccant heat pump is introduced, which is designed to work with the VRF system. The schematic diagram of SDHP is shown in Fig. 1 [21]. There are two inlets and two outlets, namely supply air (SA), outdoor air (OA), return air (RA), exhaust air (EA), and four main parts like conventional heat pump system. However, traditional heat exchangers are replaced by desiccant coated evaporator and condenser, which are made by directly coating solid desiccant materials to the surface of fin tube type heat exchangers.

There are two conditions running on each heat exchanger simultaneously.

In the cooling/dehumidification condition, the upper heat exchanger acts as evaporator. Throttled refrigerant enters the evaporator at a very low temperature and cools down the desiccant material, so the desiccant material adsorbs the moisture from outdoor air. Meanwhile, in the air loop, outdoor air flows into the system through the cold dry evaporator and gets cooled down and dehumidified. As a result, hot humid outdoor air is processed into cool dry SA and supplied into the indoors.

Meanwhile, in the regeneration condition, discharged refrigerant enters the condenser at a very high temperature and heats the desiccant material, so the desiccant material desorbs the moisture. Meanwhile, in the air loop, RA flows through the hot humid condenser where it gets heat up and intakes the desorbed water vapor. As a result, the desiccant material completes regenerating and the hot humid EA is exhausted to the ambient.

After one cycle, the 4-way valve helps convert from cooling/dehumidification mode into regeneration mode by replacing the two heat exchangers by each other. Two air dampers are utilized to adjust the flow direction so that the whole system keeps nonstop working.

In the heating condition, the system works almost same as the cooling condition, except for the function of the two desiccant humidification/dehumidification heat exchangers. In this