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Performance investigation on a multi-unit heat pump for simultaneous temperature and humidity control

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HIGHLIGHTS

- A multi-unit heat pump is proposed for simultaneous temperature and humidity control.
- Condensation heat is non, partly or fully recovered for temperature regulation.
- Highly integrated heat pump for residential cooling, dehumidification and heating.
- High energy saving potential for all-year-round operation in wet and warm regions.

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ABSTRACT

A multi-unit heat pump is presented for simultaneous humidity and temperature control to improve the energy efficiency and the thermal comfort. Two parallel connected condensers are employed in the system, locating at the back of the indoor evaporator and the outdoor unit, respectively. The heat pump can operate in four modes, including heating, cooling and dehumidification without and/or with partial or total condensing heat recovery. The experimental investigation shows that the temperature control capacity is from 3.5 kW for cooling to 3.8 kW for heating with the cooling and heating efficiency higher than 3.5 kW kW^{-1}, and the dehumidification rate is about 2.0 kg h^{-1} with the efficiency about 2.0 kg h^{-1} -kW^{-1}. The supply air temperature and humidity can be simultaneously regulated with high accuracy and high efficiency by adjusting the indoor and/or outdoor air volumes. It provides an integrated and effective solution for simultaneous indoor air temperature and humidity control for all-year-round operation in residential buildings.

1. Introduction

A heat pump with vapor compression cycle is an efficient way for space cooling, heating, dehumidification, and water heating [1–10]. The evaporator can remove moisture from the air and decrease air temperature when the evaporating temperature is lower than the dew-point temperature of the air, while, the condenser can increase the air and/or water temperature because the condensing temperature is higher than that. As shown in Fig. 1, the heat pump, when applied as a residential or commercial air conditioner, can operate in the cooling mode or the heating mode by a four-way valve for all year round operation. Indoor air is cooled and dehumidified by the evaporator (HE1) in the cooling mode and is heated by the condenser (HE1) in the heating mode. It makes the air handling equipment accessible and easy operation by simultaneous cooling and dehumidification in the evaporator. However, in most conditions, the humidity load cannot match the cooling load very well. For example in South China, both the cooling load and the humidity load are high in summer, the humidity load is high while the cooling load is low in spring and autumn, while the heating load is moderate in winter. Furthermore, the cooling load and humidity load vary with the indoor and outdoor condition changes hour by hour [11]. So it is extremely hard to get to the desired air temperature and humidity simultaneously. Therefore, some devices are installed to reheat the air, which will increase the energy consumption and make the equipment more complex.

Some new air conditioning systems are proposed for independent temperature and humidity control, especially with the integration of heat pump with solid or liquid desiccant dehumidification [12–16]. Under different cooling and humidity load, the heat pump system controls the air temperature by cooling and heating while the desiccant controls the air humidity by dehumidification, respectively. The liquid/solid desiccant can be thermally regenerated by the heat source about 60–80 °C, which

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Nomenclature

d	air moisture content (g kg^{-1})
$d_{a,i}$	indoor air moisture content (g kg^{-1})
$d_{a,o}$	outdoor air moisture content (g kg^{-1})
$d_{a,s}$	supply air moisture content (g kg^{-1})
EER_c	cooling efficiency (kW kW^{-1})
EER_d	dehumidification efficiency (kg h^{-1} kW^{-1})
$G_{a,i}$	indoor air volume (m^3 h^{-1})
$G_{a,o}$	outdoor air volume (m^3 h^{-1})
H	air relative humidity (%)
$H_{a,i}$	indoor air relative humidity (%)
$H_{a,o}$	outdoor air relative humidity (%)
$H_{a,s}$	supply air relative humidity (%)
M_w	dehumidification rate (kg h^{-1})
P	power input (kW)
Q_e	cooling capacity (kW)
T	temperature (°C)
$T_{a,i}$	indoor air temperature (°C)
$T_{a,o}$	outdoor air temperature (°C)
$T_{a,s}$	supply air temperature (°C)
T_d	dry-bulb temperature (°C)
T_w	wet-bulb temperature (°C)

makes it efficient when the regeneration of desiccant is driven by the recovery of waste thermal heat or the utilization of renewable energy such as solar energy. However, if there is no waste heat or solar energy available, the regeneration of desiccant is energy consuming. Some new regeneration technologies such as ultrasound regeneration [17] and electric-oscossme regeneration [18] are being investigated. Although the experimental results showed the feasibility and efficiency of these regeneration technologies, it is still a little far away from real application. Furthermore, the integrated heat pump and desiccant system is complicated and space occupied, which make it difficult to be applied in the high-density residential buildings with limitation of using waste heat and solar energy.

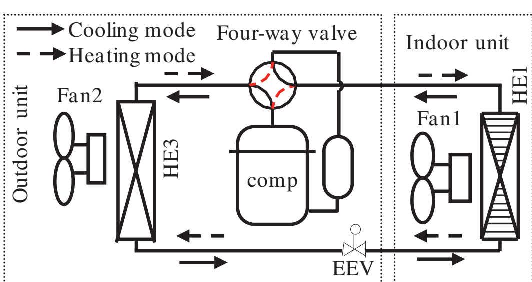

Fig. 1. Schematic diagram of the split-type air conditioner.

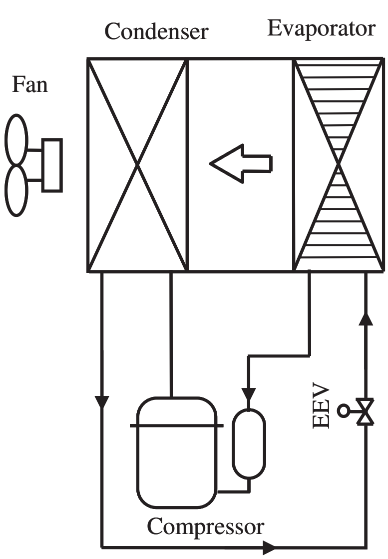

Fig. 2. Schematic diagram of the heat pump dehumidifier.

Heat pump is also applied for simultaneous utilization of its evaporator and condenser such as some multi-function heat pump systems [1–5]. The heat pump water heater can achieve space cooling and dehumidification with the evaporator and water heating with the condenser, which is an effective way for heat pump application in residential and commercial buildings. The heat pump dehumidifier is another efficient system, which is widely used in residential dehumidifying and industry drying for crops, papers, textiles, timbers, etc. [19–24]. In the traditional heat pump dehumidifier, the condenser is placed at the back of the evaporator, as shown in Fig. 2. Thus, the air is cooled and dehumidified by the evaporator and then is heated to a high temperature by the condenser. Usually, the condensing heat is larger than the evaporating heat in a heat pump, so the air is dehumidified and heated as the result.

Fig. 3 presents the air handling process in the air conditioner and the heat pump dehumidifier. The indoor air (point 1) is cooled and dehumidified (point 2) by the evaporator of the air conditioner or the dehumidifier and the air can be heated (point 3) by the condenser of the dehumidifier. Such a system controls the room air humidity by turning on and off the system, which leads to a large fluctuation of the air temperature and humidity in the room. For most applications, the cooling, heating, and dehumidification loads change as the outdoor environment changes either in a day or a year [11]. Hence, this system is neither efficient nor suitable for temperature and humidity control in all-year-round operations.

A multi-unit heat pump for simultaneous temperature and humidity control is presented by regulating the recovery ratio of condensing heat, and the experiments are carried out to analyze its performance and validate its feasibility for all-year-round operation.

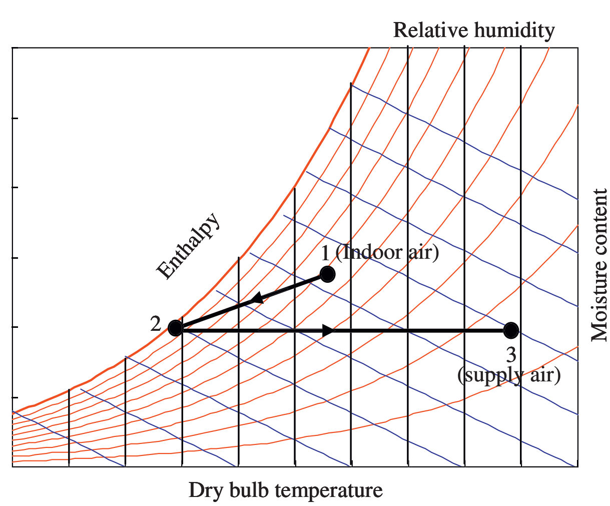

Fig. 3. Psychrometric chart for air handling process.