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An experimental study on a novel direct expansion based temperature and humidity independent control air conditioning system

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Abstract

Direct expansion (DX) air conditioning (A/C) system are widely used in various buildings because they are simpler and more energy efficient, and generally cost less to own and maintain. However, it is often problematical for a conventional On-Off controlled DX A/C system to simultaneously control indoor temperature and humidity, since the cooling and dehumidification process of air are highly coupled, unless costly extra equipment or complicated control method to decouple the cooling and dehumidification are provided. Therefore, a novel DX based temperature and humidity independent control air conditioning (DX-THIC) system with two parallel-connected condensers and two electronic expansion valves is presented for improved indoor environmental control and energy efficiency. This paper reports on an experimental study on the operating performances of a prototype experimental DX-THIC system. The experimental results demonstrated that the proposed DX-THIC system can provide independent control of indoor temperature and humidity. The experimental results also demonstrated that the indoor air humidity could influence the operating performances of the DX-THIC system.

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Keywords: Direct expansion; Temperature and humidity control, Decouple; Air-condtioning system

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1. Introduction

Achieving a comfortable indoor air temperature in conditioned buildings may not be the sole goal for building air conditioning (A/C) installations [1, 2]. Appropriately controlling indoor air humidity at a suitable level is also essential for an A/C system, since indoor humidity directly affects building occupants' thermal comfort, indoor air quality (IAQ) and the operating efficiency of building A/C installations [3, 4].

Direct expansion (DX) A/C systems are one of the most widely used A/C systems in buildings, in particular in small- to medium-scale buildings. Compared to central chilled water based A/C systems, DX A/C systems have lower set-up and running costs, and have been proved to significantly improve a building's cooling and ventilation capacity with minimal energy use. However, it is often difficult and challenging for a conventional DX A/C system to provide both temperature and humidity control, especially for the humidity control. Poor humidity control was often found in various buildings. The reasons for the poor humidity control including the current system design trends for DX A/C systems to have a small moisture removal capacity to boost their energy efficiency ratings (EER), highly variable space load conditions throughout a year and commonly used On-Off control strategies for single speed DX A/C systems.

Traditionally, the principal method for indoor humidity control is via mechanical cooling and reheating. However, there is a cost penalty for overcooling the air and then reheating it. Therefore, extensive efforts have been put into the temperature and humidity control in various buildings in recent years. The relevant studies are based on providing extra A/C equipment or developing control algorithms [5]. For example, using a supplementary chilled ceiling or a radiant panel to realize temperature control and a DX A/C system humidity control was one of the options [6]. Incorporating thermally activated solid / liquid desiccant units into a DX A/C system to provide humidity control was also adopted in many applications [7]. Although these systems proved effective in providing both temperature and humidity control, they are inevitably bulky and complicated, thus not suitable for the residential utilization.

On the other hand, a DX A/C system may be modified, so that the heat rejected from its condenser which is usually air cooled, or the hot refrigerant gas discharged from its compressor may be used for reheating air [8, 9]. With these arrangements, the temperature and humidity control could be partially decoupled. However, in these systems, it is difficult to vary the reheating capacity from the reheating coil, unless a modulating three-valve or two modulating valve with variable openings is used. For a DX A/C system with cooling capacity no more than 12kW, it is hard to find such modulating valves with electric control in the existing manufactures. Furthermore, the costly of such valves were extremely high, thus also not suitable for the residential use.

Furthermore, the variable speed technology also pave the way for simultaneously controlling indoor temperature and humidity by varying compressor and supply fan speeds. However, the corresponding control logics often require a complicated mathematical model to support their developments [10, 11]. It was also noted that the output total cooling capacity and the sensible heat ratio from a VS DX system are also restrained in limited ranges [12, 13]. The decoupling effect of cooling and dehumidification was less significant but still existed.

Therefore, to reduce the complexity and the initial and operational costs for existing A/C systems, in this paper, a novel DX based temperature and humidity independent control air conditioning (DX-THIC) system was proposed and an experimental study on its operating performances was carried out to exam if it was able for this system to provide independent temperature and humidity control.

Nomenclature

C_{pa}	air specific heat at constant pressure, kJ/(kg·K)
h	specific enthalpy, kJ/kg
m	mass flow rate, kg/s
Q_{lat}	latent cooling capacity, kW
Q_{re}	reheating capacity, kW
Q_{sen}	sensible cooling capacity, kW
T	temperature, °C
RH	relative humidity, %

2. Detailed configuration of the proposed DX-THIC system

The proposed DX-THIC system was schematically shown in Fig. 1. In the refrigerant-side of the DX-THIC system, there are two condensers in the DX-THIC system, one acted as outside condenser (OC) and another a reheating coil (RC), which are parallel-connected. The RC is installed downstream of the EVA and the OC is installed at the outdoor environment. Correspondingly, there are two electronic expansion valves (EEVs), with the main-EEV (MEEV) connected to OC and associate-EEV (AEEV) to RC. In the air-side of the DX-THIC system, the return air from the conditioned space (R) is mixed with the fresh air (V) before being sent to EVA for cooling and dehumidifying. Then cooled and dehumidified air (II) will be reheated to an appropriate temperature and sent to the conditioned space.

With these arrangements, variable reheating capacity can be obtained from RC by adjusting AEEV opening, thus making it achievable to provide independent control of indoor air temperature and humidity. This was done by cycling compressor in respond to indoor humidity and AEEV to indoor air temperature. It is noted that the MEEV can response accordingly to the degree of refrigerant superheat (DS).

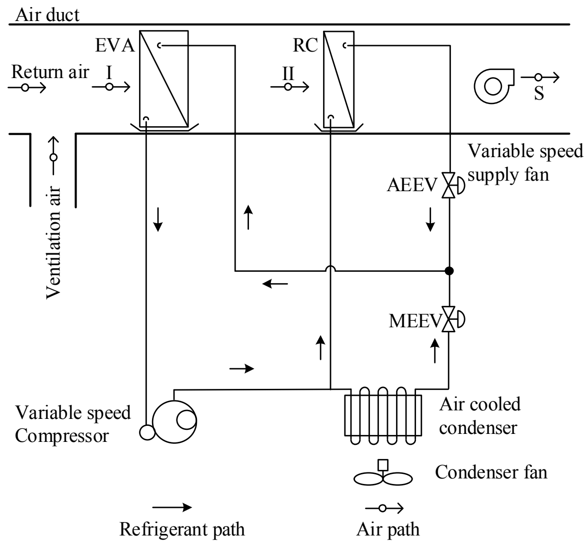

Fig. 1. Schematics of the detailed configuration for the proposed DX-THIC system

3. Experimental setup and cases

3.1. The prototype experimental DX-THIC system

The prototype experimental DX-THIC system was purposely established in a laboratory, in accordance with the schematics shown in Fig. 1. In the laboratory, there were two environmental chambers. One of the chambers was used as a simulated indoor space and the other a simulated outdoor space. The two chambers were conditioned by two existing air conditioning systems as shown in Fig. 2.

The prototype experimental DX-THIC system was mainly composed of two parts, i.e., a DX refrigeration plant (refrigerant-side) and an air-distribution sub-system (air-side). The schematic diagrams for both the DX refrigeration plant and the air-side of the experimental EDAC system are shown in Figs. 2 and 3, respectively. The EEVs, the solenoid valves and the compressor on the refrigerant-side and supply air fan, condenser fan on the air-side of the DX-THIC system were all connected to a control unit (C5) for manual or programed control.

The experimental DX-THIC system was fully instrumented for measuring all of its operating parameters. All the measurements were computerized, so that all the measured operating parameters can be real-time monitored and recorded for subsequent analysis.

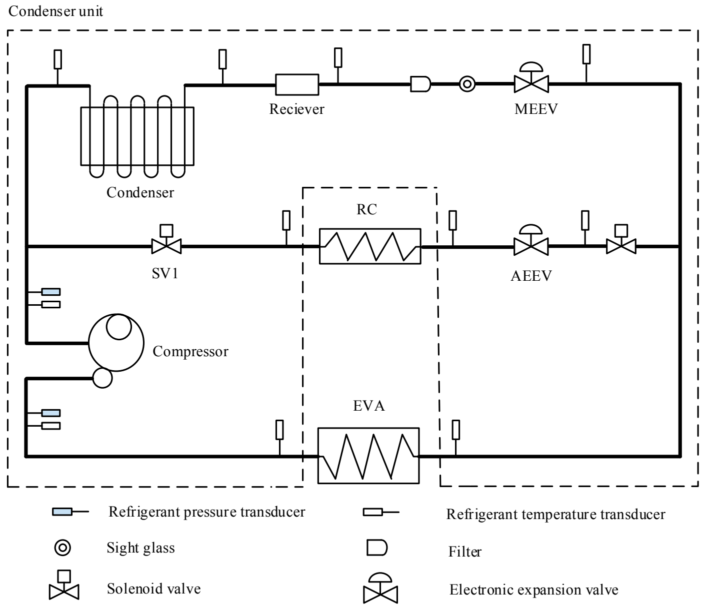

Fig. 2. The schematic diagram of the DX refrigeration plant in the prototype experimental DX-THIC system

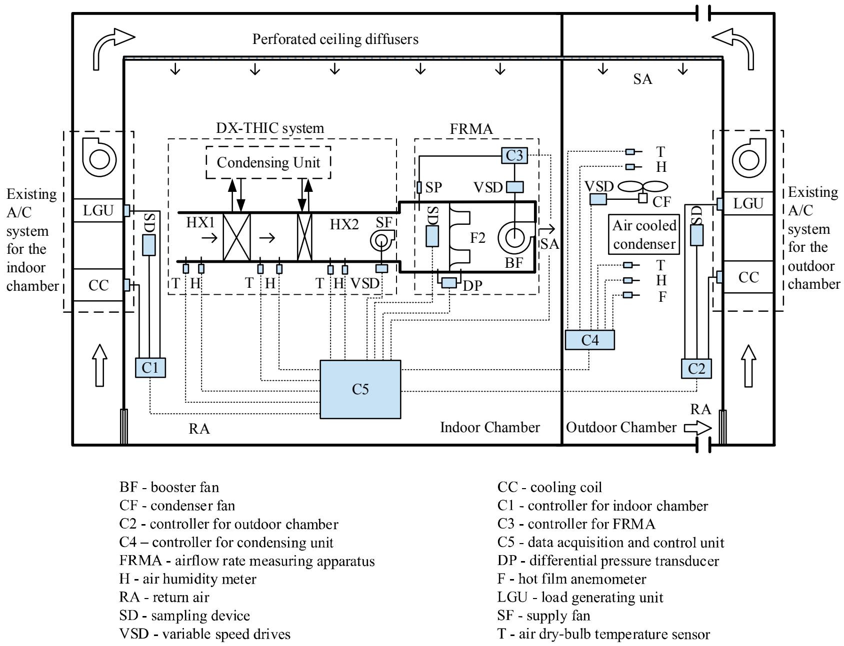

Fig. 3. The schematic diagram of the air side for the prototype experimental DX-THIC system

3.2. Experimental procedures and data interpretation

Two Sets of experiments were purposely carried out to evaluate the operating performance of the DX-THIC system, as shown in Tables 1 and 2, respectively. In order to simplify the experimental procedure, no fresh air was introduced to the experimental DX-THIC system in each case. For all the experimental cases, using the measured operating parameters, the output sensible cooling capacity, reheating capacity, total cooling capacity and latent capacity of the experimental DX-THIC system was evaluated using Eqs. (1-4), respectively.

$$Q_{\mathrm{sen}} = m_{\mathrm{a}} C_{\mathrm{pa}} (T_{\mathrm{aI}} - T_{\mathrm{aS}}) \tag{1}$$

$$Q_{\mathrm{re}} = m_{\mathrm{a}} C_{\mathrm{pa}} (T_{\mathrm{aS}} - T_{\mathrm{aII}}) \tag{2}$$

$$TCC = m_{\mathrm{a}} (h_{\mathrm{aI}} - h_{\mathrm{aS}}) \tag{3}$$

$$Q_{\mathrm{lat}} = TCC - Q_{\mathrm{sen}} \tag{4}$$

Where m_{a} is the air mass flow rate of the DX-THIC system; T_{aS} the supply air temperature from the DX-THIC system and T_{aI} the inlet air temperature to the DX-THIC system; T_{aII} the outlet air temperature from EVA or inlet air temperature to RC; h_{aS} is the specific enthalpy of the supply air from the DX-THIC system and h_{aI} that of the inlet air to the DX-THIC system.

Table 1. Experimental conditions for Set A

	Fixed settings	Changed settings			
No	T_{aI} / RH_{aI} / AEEV	f1* (Hz)			
A1	26 ºC / 40% / 0	50	55	60	65
A2	26 ºC / 60% / 0	50	55	60	65

* compressor frequency

Table 2. Experimental conditions for Set B

	Fixed settings	Changed settings					
No	T_{aI} / RH_{aI} / f*	AEEV (%)					
B1	26 ºC / 40% / 60Hz	0	20	40	60	80	100
B2	26 ºC / 60% / 60Hz	0	20	40	60	80	100

* compressor frequency

4. Experimental results

4.1 The experimental results for Set A

The experimental results for Set A are shown in Figs. 4 and 5, respectively. As seen from the figures, at a fixed inlet air temperature and RH when the AEEV is fully closed, both the sensible and latent cooling capacities from the experimental DX-THIC system were increased with the increase in the compressor frequency, but at different magnitudes. This suggested that a variable dehumidification ability from the experimental DX-THIC system could be obtained by varying the compressor frequency. It was also found that the increase in the inlet air RH would lead to a higher total cooling capacity and a lower sensible heat ratio.

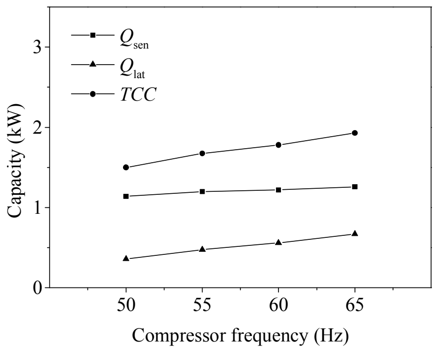

Fig. 4. The experimental results for A1

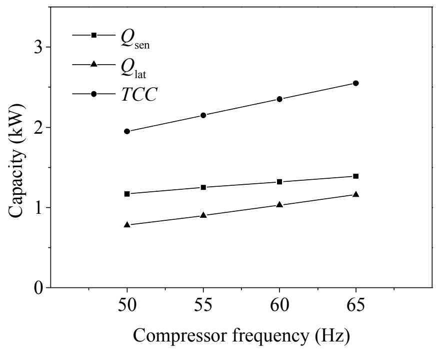

Fig. 5. The experimental results for A2

4.2 The experimental results for Set B

The experimental results for Set B are shown in Figs. 6 and 7, respectively. As seen from the figures, at a fixed inlet air temperature and RH, and a fixed compressor frequency, for the experimental DX-THIC system, the reheating capacity was increased accordingly with an increase in AEEV opening, but this increase became less significant after the AEEV opening was above 80%. Correspondingly, the sensible cooling capacity would experience a reverse variation trend. It was also noted that the latent cooling capacity was decreased with the increase in AEEV opening, but not significant. This suggested that an appropriate temperature control could be obtained while the humidity control was also achievable without significant influence. On the other hand, the inlet air RH would impact the sensible and latent cooling capacities, and the reheating capacity.

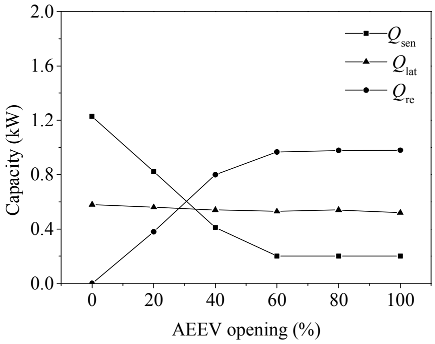

Fig. 6. The experimental results for B1

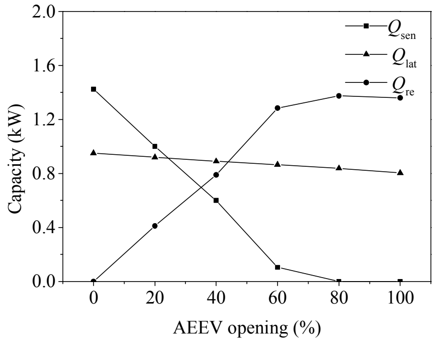

Fig. 7. The experimental results for B2

5. Conclusions

In this paper, an experimental study on a novel direct expansion based temperature and humidity independent control air conditioning (DX-THIC) system is reported. Based on the experimental study, the following conclusions could be obtained.

1) The DX-THIC is able to provide independent control of temperature and humidity by varying compressor frequency and AEEV opening.
2) Inlet air relative humidity can significantly influence the operating performance of the DX-THIC system.

Acknowledgements

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