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Further study on the inherent operating characteristics of a variable speed direct expansion air conditioning system

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HIGHLIGHTS

- Steady state experiments carried out under different inlet air states to a VS DX A/C system.
- Different inlet air states influenced the system inherent operational characteristics.
- A data processing method developed to estimate the ICs at non-test inlet air states with accuracy.
- It paved the way to developing advanced control strategy for DX A/C system.

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ABSTRACT

Further to a previous experimental study on the inherent operational characteristics of an experimental variable speed (VS) direct expansion (DX) air conditioning (A/C) system at only two inlet air states, an experimental study using the same experimental VS DX A/C system at six different inlet air states to the DX A/C system has been carried out and the study results are presented in this paper. The results suggested that different inlet air states to a DX A/C system influenced the operational characteristic of the system, in terms of the Inherent Correlation (IC) between its output total cooling capacity (TCC) and Equipment sensible heat ratio (SHR). Therefore, a further data processing method was developed using regression, by which the ICs of the VS DX A/C system at non-test inlet air states can be predicted with adequate accuracy. This has therefore paved way to developing advanced control strategies for indoor thermal environment (i.e., air temperature and humidity) based on the known or predicted ICs within the possible operating ranges of inlet air temperature and humidity to the DX A/C system, for better control accuracy and energy efficiency.

1. Introduction

In small to medium scale buildings located in the subtropics, such as Hong Kong, direct expansion air conditioning (DX A/C) systems are widely applied. These DX A/C systems are being constantly optimized with respect to operating efficiency. For example, recently, Chen et al. [1] and Xu et al. [2] developed a theoretical optimization method based on entransy theory and applied it to refrigeration systems.

For an air conditioned space served by a DX A/C system, to maintain the required indoor air temperature and humidity required matching not only the system's total output cooling capacity (TCC) with the space cooling load, but also the sensible heat ratio of the DX A/C system (E SHR) with the application sensible heat ratio of the conditioned space (A SHR) at all time [3]. This is however hardly possible with a single-speed compressor DX A/C system as its E SHR is very often between 0.7 and 0.8 which can well be larger than the A SHR of a conditioned space at 0.6 to 0.7 and even below 0.5 in wet seasons in sub-tropics [4,5].

To overcome the difficulties for simultaneous control of indoor air temperature and RH using a single speed DX A/C system, variable speed (VS) technology has been applied to DX A/C systems, paving the ways for more sophisticated control of indoor air temperature and humidity simultaneously. For example, Krakow et al. [6] developed experimentally a strategy to simultaneously control of indoor air temperature and humidity using a VS DX A/C system. The control strategy was to control indoor air temperature by varying compressor speed and humidity by varying supply air fan

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Nomenclatures

A, a, b, c, d, e	regression factors
A_F, K	scale factors
C	percentage of the maximum compressor speed, %
F	percentage of the maximum supply air fan speed, %
m_a	mass flow rate of air through the evaporator, kg/s
C_{pa}	air specific heat at constant pressure, kJ/kg K
h_a	air enthalpy, kJ/kg
Q_s	sensible output cooling capacity of a DX A/C system, kW
T_{db}	air dry-bulb temperature, °C
T_{wb}	air wet-bulb temperature, °C
W	indoor air absolute humidity, g/kg

Subscripts

i	inlet of an evaporator
o	outlet of an evaporator
r	relative
s	sensible

Abbreviations

A/C	air conditioning
A SHR	application sensible heat ratio
DX	direct expansion
EEV	electronic expansion valve
E SHR	equipment sensible heat ratio
IC	inherent correlation
IC′	relative inherent correlation
IC″	revised relative inherent correlation
LGU	load generating unit
RH	relative humidity
SHR	sensible heat ratio
TCC	total cooling capacity

speed, respectively, using a proportional-integral-derivative (PID) control algorithm. The experimental study proved the feasibility of the PID control strategy for the simultaneous control of indoor temperature and humidity. Other related developed work included a DDC based controller of a DX A/C system for simultaneous indoor temperature and humidity control [7,8], and a Multi-input-Multi-output based controller for a DX A/C system [9]. However, in these previous developments, inherent operating characteristics of a VS DX A/C system were not utilized, and all these previous controllers had their own inadequacies such as poor control sensitivity, and limited control ranges, etc.

It therefore came to realize that knowing the inherent operating characteristics of a VS DX A/C system in terms of its TCC and E SHR at various speed combinations of its compressor and supply fan would help achieve accurate control over indoor air temperature and humidity simultaneously using the VS DX A/C system. In view of this, experimental studies were previously carried out [3,10]. Li and Deng [3] studied TCC and E SHR of an experimental VS DX A/C system under different combinations of compressor and supply fan speed. However, TCC and E SHR at a fixed inlet air state versus the different speeds of compressor and supply air fan were presented separately. Such a presentation could only reflect the influence of speeds variation on TCC or E SHR separately, but not the inherent correlation between these two representative operating characteristics. Furthermore, the study was conducted only at one set of inlet air state to the VS DX A/C system, so that the influences on the operating characteristics due to different inlet air states were not included. On the other hand, Xu et al. carried out a related experimental study using the same experimental DX A/C system [10], but presented the obtained operating characteristics in a different way by X–Y plotting TCC and E SHR on the same diagram as shown in Fig. 1. It was consequently suggested that TCC and E SHR of the VS DX A/C system were correlated but mutually constrained within a trapezoid A–B–D–C, within their possible maximum values as represented by the rectangle W–X–Z–Y. Furthermore, in this study [10], two sets of the operating characteristics at two different inlet air states were obtained, and it was revealed the trapezoid would shift its position at different inlet air states, although retaining similar shape.

It can be seen, therefore, that while Xu et al. [10] considered the influences caused by the different inlet air states on TCC and E SHR of the same experimental DX A/C system, the sets of inlet air state were limited to only two, which was considered as being inadequate in both fully comprehending the inherent operating characteristics of a VS DX A/C system and using them as a basis to develop advanced control strategies for simultaneous control over indoor air temperature and humidity using a VS DX A/C system. Therefore, a further experimental study on the inherent operational characteristics in terms of the TCC and E SHR under different speed combinations of compressor and supply air fan but at a wider range of inlet air states has been carried out using the same experimental DX A/C system and the study results are reported in this paper. The range of indoor air states adopted in this study corresponded to typical indoor settings of 22–26 °C (dry-bulb temperature) and 40–70% RH.

This paper is organized as follows. Firstly, the experimental setup, where all experimental works were carried out, is described. This is followed by presenting the experimental results and their related analysis and discussions. Finally, conclusions are given.

2. Experimental setup

2.1. The experimental VS DX A/C system

All the experimental works were carried in an experimental VS DX A/C system which was previously setup and used in previous

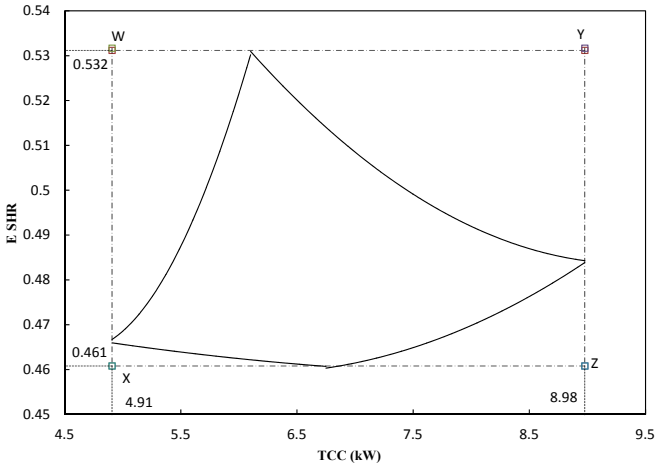

Fig. 1. The measured inherent correlations between output TCC and Equipment SHR with reference rectangle [10].