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A new control algorithm for direct expansion air conditioning systems for improved indoor humidity control and energy efficiency

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Abstract

This paper presents an experimental study to develop a new control algorithm to replace the traditional on–off control algorithm widely used by direct expansion (DX) air conditioning (A/C) systems, which are widely used in small to medium sized buildings. The new control algorithm, which enables both the compressor and the supply air fan in a DX A/C system to operate at high speeds when the indoor air dry bulb temperature setting is not satisfied and at low speeds otherwise, is termed the H–L control. Extensive experiments have been conducted with an experimental DX A/C system at simulated different climates under both H–L and on–off control. The results suggest that the use of H–L control would result in better control performance in terms of an improved indoor humidity level and a higher energy efficiency of the DX A/C system when compared to the use of the traditional on–off control. The H–L control is also simpler, and its associated hardware cost is much lower than that of the control algorithms based on variable speed technology.

Keywords: Humidity control; Energy efficiency; DX; Air conditioning; High–low speed

1. Introduction

The use of DX A/C systems offers many advantages. They are simpler in configuration, more energy efficient and generally cost less to own and maintain than chilled water based large scale central A/C systems. Therefore, they find wider applications in buildings, in particular in small to medium size buildings. For example, in the US, according to the Department of Energy, packaged rooftop DX A/C systems consumed approximately 60% of the total amount of cooling energy used [1]. In Hong Kong, the annual total sales of DX residential A/C units were around 400,000 units in 1999 and 2000 [2].

However, most DX A/C systems are equipped with single speed compressor and supply fan, relying on on–off cycling as a low cost approach to maintain only the indoor dry bulb temperature, whereas the indoor air humidity is not controlled directly. Air dehumidification is usually only as a by product of the air cooling process. When a pre-set air temperature in a thermostat is reached, the compressor in an on–off controlled DX A/C system is stopped, and the dehumidification is also stopped. In a hot and humid climate like Hong Kong, the requirement for removing moisture from the air can often be more demanding than removing the sensible load. Therefore, indoor humidity may remain at a high level in the space served by an on–off controlled DX A/C System.

The situation may become worse when the supply fan in a DX A/C system runs continuously while its compressor is on–off operated. During an off-period, the air passing through the system's cooling coil may lead to re-evaporation of the residual moisture on the coil's finned surface (in the form of tiny water droplets), causing the indoor humidity to rise.

Khattar et al. [3] quantified the impact of on–off operation on the latent capacity of an A/C unit. It was demonstrated that moisture was added to the air stream when the unit was turned off. Henderson [4] also showed that a

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Nomenclature

c-p	power input to compressor (W)
COP_{com}	coefficient of performance based on power input to compressor
f-p	power input to supply fan (W)
RH	relative humidity (%)
total-p	total power input to DX A/C system (W)
T_d	indoor air dry bulb temperature (°C)
T_w	indoor air wet bulb temperature (°C)
ω	indoor moisture content (kg/kg dry air)

Abbreviations

A/C	air conditioning
DX	direct expansion
H-period	high speed period
LGU	load generating unit
L-period	low speed period
SHR	sensible heat ratio

cooling coil quickly became an evaporative cooler once the coil was deactivated, providing sensible cooling while the coil was still at a lower temperature, along with moisture addition, with no net enthalpy change across the coil.

Other related research work has also shown that even when a supply fan is cycled on and off with a compressor, there is a degradation of latent capacity at part load. Parken et al. [5] observed that at part load operation, the equipment sensible heat ratio (SHR), which was defined as the ratio of its sensible output cooling capacity to its total output cooling capacity for a DX A/C system, was not the same as that at full load operation.

A high level of indoor humidity can cause discomfort for occupants for at least two reasons: an uncomfortably high level of skin humidity and insufficient cooling of the mucous membranes in the upper respiratory tract by inhalation of humid or warm air [6]. Therefore, indoor humidity level should be properly controlled. Conventionally, accurate control of indoor temperature and humidity level may be accomplished by cooling the air to the required dew point and then reheating it to the required dry bulb temperature. This is obviously energy inefficient.

The introduction of variable frequency inverters has made the speed control of electric motors more practical. The use of variable speed supply fans and compressors in air conditioning systems for controlling simultaneously the indoor air temperature and humidity has been extensively investigated. Experimental results suggested that simultaneously varying the speeds of both the compressor and supply fan in a DX A/C system can help accurately control the indoor humidity [7–10]. However, the associated control systems and hardware are both complicated and costly, often requiring a dynamic mathematical model to support their development.

New control algorithms have been developed to address the control of indoor humidity using DX A/C systems. Zhang and Niu [11] showed that these algorithms can achieve both a better control of indoor humidity and higher energy efficiency when compared to the traditional on–off controlled DX cooling systems. However, they were expensive and, consequently, were not widely applied in actual buildings.

Therefore, a new control algorithm focusing on improving indoor humidity control for DX A/C systems should be developed. It is expected that the algorithm developed should be compatible with on–off control in terms of cost and complexity but would produce a better performance of indoor thermal environmental control and operating efficiency.

2. Development of the new control algorithm

As far as indoor humidity control is concerned, there are two main defects associated with the commonly used on–off control for DX A/C systems. Firstly, in hot and humid climates, during an on-period, the equipment SHR for an on–off controlled DX A/C system is always higher than the application SHR, which is defined as the ratio of the space sensible cooling load to the total space cooling load, for a conditioned space, leading to insufficient dehumidification. Secondly, during its off-period, if the supply fan is still operating, its cooling coil quickly becomes an evaporative cooler, causing the indoor humidity to rise. To address the former, there is no better way than varying the speeds of both the compressor and the supply fan. This will, however, definitely increase the control complexity and hardware cost.

On the other hand, much can be done to improve the operating performance of an on–off controlled DX A/C system during its off-period. The simplest way is to avoid an off-period. This is to say, when the set point of indoor dry bulb temperature is satisfied, the compressor in a DX A/C system is operated at a lower speed, rather than being completely shut down. Hence, its cooling coil will keep dehumidifying and prevent residual moisture from re-evaporation. This motivates the development of the H–L control algorithm. A DX A/C system under the proposed H–L control algorithm will be operated at a high speed or full speed when the indoor air dry bulb temperature setting is not reached, which is the same as the operating mode in the on-period for an on–off controlled DX A/C system. However, when the indoor air temperature setting is satisfied, instead of being completely shut down as in an on–off controlled system, the compressor in an H–L con-