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Method to control an air conditioner by directly measuring the relative humidity of indoor air to improve the comfort and energy efficiency

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HIGHLIGHTS

- Control logic is suggested considering relative humidity and temperature of air.
- New control logic was tested with an air-source heat pump.
- Thermal comfort and energy efficiency of an air conditioner are improved.

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ABSTRACT

In modern society, air conditioning systems are widely used in places where people tend to congregate, such as in homes, companies, schools and work sites. Both the dry-bulb temperature and relative humidity should be measured and controlled to achieve better comfort and to improve the energy efficiency of air conditioning systems. However, the current evaporation pressure control technique based on evaporator outlet pressure reading (EPCP) method only uses the dry-bulb temperature to control the evaporation pressure, making this method insufficient with regard to improving comfort. An evaporation pressure control approach based on the evaporator pressure and the relative humidity reading (EPCR) method is developed here. The *EPCR* method changes the evaporation pressure based on the dry-bulb temperature and the relative humidity of the air. The performance of an identical air conditioner is measured experimentally while switching the control method between the conventional EPCP method and the newly proposed EPCR method. The results demonstrate that the new EPCR method improves both the thermal comfort of indoor air and the energy efficiency.

1. Introduction

The development of science and technology has enriched the environments associated with human life. Today's air conditioners are necessary systems in all places where people congregate, such as homes, companies, schools and work sites. Air conditioners (A/C) are commonly used for the purpose of cooling our living spaces. A considerable amount of research on heat pumps has been conducted to improve their operational performance [1–3] and to reduce the amount of energy they use [4,5]. However, new demands such as thermal comfort and energy efficiency are gradually becoming more apparent [6]. As a result, it is crucial to improve the comfort delivered by air conditioners while also developing technologies that ensure greater energy savings.

Research on environments which are pleasant to humans has been done since Houghton and Yagloglou [7] presented their human comfort zone for thermal environments in the early 1920s. Nevins et al. [8] and Nevins [9] clarified that humans sense dry-bulb temperature changes seven to nine times more than they do humidity changes and reported that the comfort zone of humans ranged from 16.7 °C to 36.6 °C. Fanger [10] developed what was termed a predicted mean vote (PMV) formula to determine comfortable conditions in the thermal environments of humans. Since then, ASHRAE has constructed 21,000 databases with measured data on the comfort zones of thermal environments and has evaluated the applicability of the PMV model [11]. In the 2000s, Humphreys et al. [12] and Heidari et al. [13] suggested that the comfort zone according to Fanger's PMV model differs from actual comfort felt by humans. Olesen et al. [14] stated that comfort is an effect caused by direct heat exchanges between the human body and the environment. According to their results, in order to improve human comfort, it is necessary to control the state of the air in rooms where people frequently stay by maintaining comfortable levels of dry-bulb temperature

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Nomenclature

a	variable
ASHRAE	American Society of Heating Refrigerating and Air Conditioning Engineers
C	constant
DC	direct current
EEV	electronic expansion valve
EPCP	evaporation pressure control based on the evaporator outlet pressure reading
EPCR	evaporation pressure control based on the evaporator pressure and the relative humidity reading
EPCT	evaporation pressure control based on the temperature reading
e	residual of dry-bulb temperature
f	frequency, Hz
F	correction factor
g	correction value
ISO	international organization for standardization
K	gain
L	load
P	pressure
PCB	printed circuit board
PID	proportional integral derivative
r	residual of relative humidity
R	relative humidity,%RH
t	time, sec
T	temperature, °C

Subscripts

air	indoor air
comp	compressor
cond	condenser
D	derivative
E	entire air load
eva	evaporator
i	indoor
n	present step
n−1	previous step
o	outdoor
out	outlet
P	proportional
target	control target value

and relative humidity.

In order to maintain the humidity of indoor air at a level suitable for a comfort zone in a thermal environment, a heating, ventilation and air conditioning system (HVAC) has long been investigated. Busweiler [15] noted that a separate air dehumidification system is needed to handle the potential load of space to achieve better energy efficiency in existing air conditioning systems. In a study of air dehumidification, Jain et al. [16] presented an evaluation of various solid dehumidification cycles while Kinsara et al. [17] proposed an air conditioning system which uses a liquid dehumidifier. Calcium chloride ($CaCl_2$) when used as a liquid dehumidifying agent solution has the capability to hold water vapor. In addition, research which sought to change the air conditioning system was conducted. Dhar et al. [18] studied a solid-dehumidifier-based hybrid air conditioning system. Waste condenser heat was used to regenerate the solid dehumidifier. They demonstrated that using a hybrid air conditioning system based on a solid dehumidifier rather than a conventional system with only a refrigeration dehumidifier coil can achieve a significant energy savings effect. Niu et al. [19] studied the possibility of combining a solid dehumidifier with a ceiling air conditioning system. Zhang and Niu [20] introduced the problem of condensate on ceiling air conditioning panels when combining a solid dehumidifier and a ceiling air conditioning system in hot and humid areas. Jradi and Riffat [21] proposed a dew-point evaporative cooling system. They concluded that such a dew-point evaporative cooling system can provide the desired cooling demand and thermal comfort in buildings, especially those in hot climates. Keniar et al. [22] investigated the feasibility of using a solar regenerated liquid-desiccant membrane system and reported a decrease of 10% in the indoor relative humidity when the system was used to remove humidity from an office space. O'Connor et al. [23] used rotary desiccant wheels to regulate the relative humidity of air. These are commonly integrated into HVAC units to reduce the relative humidity of the incoming ventilation air. Xu et al. [24] developed a dew-point air cooler which utilized a wet material layer. They reported that their dew-point air cooler consumed much less electrical energy compared to that by existing air coolers of the same type. Development of HVAC systems is still required due to modern energy systems such as electric vehicles [25] and smart grid [26].

Currently, air conditioners are the most common means of controlling indoor air. Previously, the compressor rotation speeds of existing air conditioners were fixed, and the dry-bulb temperature of the room was controlled by the on-off method when the set dry-bulb temperature was reached. In this system, energy efficiency goals could not be met. In recent years, it has become possible to respond to multiple indoor load conditions [27] more actively by allowing the rotational speed of the compressor to vary [3]. In related studies, it was demonstrated that the efficiency is improved when the rotating speed of the compressor varies as compared to when it is fixed. Tassou et al. [28] reported that a partially variable compressor with 50% deceleration of the compressor speed could improve the energy efficiency by more than 10%. In addition, a fully variable compressor with a wider deceleration range is said to be able to provide high efficiency of around 30%.

In order to improve the levels of indoor air comfort and energy efficiency, various control strategies for air conditioners were also investigated [29,30]. Schmitz et al. [31] utilized fuzzy - proportional integral derivative (PID) control methods for air conditioners and Wang and Tang [32] investigated supply-based feedback control strategy. In addition, various control logic for direct expansion (DX) A/C system, such as genetic algorithm [33], direct digital (DDC)-based capacity controller for a variable speed DX A/C system [34,35], multi-input multi-output (MIMO) control [36], MIMO Linear Quadratic Gaussian (LQG) control strategy [37], artificial neural network based control [38], and hybrid steady-state model based control [39] were studied. Hamada et al. [40] proposed a method of evaporation pressure control based on the evaporator outlet dry-bulb temperature reading (EPCT), referring to the current evaporation dry-bulb temperature read via a dry-bulb temperature sensor at the outlet of the evaporator. The EPCT method calculates the evaporator pressure through the evaporation dry-bulb temperature and calculates the target evaporation pressure based on the room dry-bulb temperature and the set dry-bulb temperature. Subsequently, the evaporation dry-bulb temperature is controlled to match the target evaporation pressure through a change of the compressor, an electronic expansion valve (EEV), and a fan. However, it is difficult to control the evaporation pressure precisely and quickly, as the pressure is converted using the dry-bulb temperature sensor. Moreover, because the dry-bulb temperature sensor itself is exposed to the ambient temperature, there may be errors when attempting to take accurate measurements of the evaporation dry-bulb temperature. To solve this problem, Park et al. [41] proposed an evaporation pressure control scheme based on the evaporator outlet pressure reading (EPCP) method which measures the refrigerant pressure through a pressure sensor attached to the outlet end of the evaporator for the purpose of