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Smart indoor humidity and condensation control in the spring in hot-humid areas

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ABSTRACT

Continuous wet weather occurring in the spring in hot-humid areas causes many inconveniences and discomfort for building occupants. Techniques that control indoor environments well under continuous wet weather are still lacking. A smart, indoor humidity and condensation control logic was proposed based on condensation prevention logic and the adaptations of local people in hot-humid areas. The smart control system was established, and the field test was conducted in an office building in Guangzhou, China, during typical continuous wet weather in 2017. The test confirmed that the expected targets were successfully achieved by the control system with a fault rate of 5%. Compared to the conventional control (dehumidifiers always running and windows freely opened), under the smart control, the indoor air temperature and MRT increased by 0.6–2.1 °C and 0.4–2.1 °C, respectively; the indoor relative humidity and CO_2 concentration were similar; the occupants perceived the indoor environment as slightly cooler and wetter and as acceptable in terms of the thermal environment, humidity and air quality; and the daily mean energy consumption on regulating the environment decreased by 90%. The smart control shows great advantages for energy savings by proposing the control logic based on the adaptations of local people, integrating operable windows with dehumidifiers, and fully utilizing natural heat sources.

1. Introduction

Continuous wet weather (hereinafter referred to as CWW), the so-called back-to-south day, is a common phenomenon in the spring in the hot-humid areas of south China. In February to April, after the cold air has been driven out, the area experiences the warm and humid air from the South China Sea. The outdoor air temperature and humidity both increase, even becoming close to the saturation point. The increase is so rapid that the temperature of the indoor surfaces of buildings remains low and may be lower than the outdoor air dew point, which results in condensation [1]. CWW occurs less than 10 times a year and mostly lasts one to three days each time. Table 1 shows the records of CWW's occurrence in Guangxi Province in south China from 2005 to 2013. Though CWW last short time each year, it causes many inconveniences and discomfort in daily life. Floors and stairs are too slippery to be used. It is hard to dry washed clothes. Occupants of buildings are uncomfortable in the damp indoor environment, and some even experience disorders such as rheumatism. Meanwhile, mold breeds on the wet surfaces and damages buildings and furniture. In this sense, it is important to take measures in the hot-humid areas to reduce indoor air humidity and prevent condensation on indoor surfaces in the spring season, especially during the period of CWW.

Dehumidifiers are the most common equipment for indoor humidity and condensation control. Galvin [3] confirmed that using a dehumidifier not only proved to be a very inexpensive way to solve the problem of condensation, presumably leading to far less mold, but also offered considerable energy savings compared to using a home heating system to achieve the same goal. Using an air-conditioner is an optional method. Nevertheless, as the outside air is cooler than the indoor air under the dehumidification mode, the lower air temperature may produce thermal discomfort for occupants. Aziz et al. [5] proposed a dual air handling unit system, in which a humidity-control unit removed the moisture and a temperature-control unit removed the remaining sensible heat. The result showed that the proposed system offered energy savings up to 13.2% compared to the conventional air-conditioning system, without compromising the thermal comfort of the occupants. Besides, some patents [4,6] have been proposed that would raise the supply air temperature under such conditions, which could

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Table 1
CWW's occurrence in Guangxi Province, China (2005–2013) [2].

Occurring Date	Lasting Days	Occurring Date	Lasting Days	Occurring Date	Lasting Days
2005/2/4	1	2010/1/19	2	2011/3/20	2
2005/2/14	3	2010/1/28	1	2012/2/6	1
2005/3/27	2	2010/2/8	1	2012/2/14	2
2006/2/14	3	2010/2/24	1	2012/2/22	2
2006/3/16	3	2010/3/13	1	2012/3/5	2
2007/3/13	2	2010/4/5	2	2012/3/15	6
2007/3/23	3	2010/4/10	2	2013/2/17	2
2008/4/4	2	2010/4/18	3	2013/2/25	4
2009/3/10	2	2011/2/24	2		
2009/4/4	1	2011/3/13	2		

improve occupant comfort levels and save energy as well.

Some researchers have proposed new ventilation systems to control indoor humidity and condensation, where their potential could be reclaimed through energy savings. Woloszyn et al. [7] proposed a relative-humidity-sensitive ventilation system combined with the moisture-buffering capacity of materials. Their study showed that the proposed ventilation system reduced the spread between the minimum and maximum values of the RH (relative humidity) in the indoor air, not allowing for the possible risk of condensation and generating energy savings. They also mentioned that one of the disadvantages of the system in that other indoor pollutants (such as CO_2) may exceed target values. Ge et al. [8] presented an integrated system that combined a DOAS (dedicated outdoor air system) with dry fan-coil units. This system was proven to be able to achieve the best indoor relative humidity on typical summer and spring days, while consuming almost the same amount of energy as the wet fan-coil unit system on the summer days and approximately 5% more energy on the spring days. Napp et al. [9] proposed an adaptive ventilation system with a heat pump, which introduced outdoor air when the outdoor air had lower water vapor content than the indoor air, and it had a potential to dry out the indoor environment. Their study showed that the adaptive ventilation performed well in high indoor humidity conditions when the annual energy consumption for conservation heating with a heat pump was the lowest, and dehumidification was most effective during the cold period. Other equipment such as heat pump was applied for the humidity control as well. For instance, Fan et al. [10] proposed a multi-unit heat pump for simultaneous humidity and temperature control to improve the energy efficiency and thermal comfort.

In summary, the above studies and relevant patents met the goal of indoor humidity and condensation control, and most of them were reported to be more energy efficient than traditional measures. However, they were focused on single equipment and limited aspects of indoor environmental quality. As Galvin [3] mentioned, although a dehumidifier was both a less expensive and more energy-efficient than the original heating system, developing a 'smart' dehumidifier system to reduce running costs to a minimum while achieving optimal moisture reduction was suggested. Indeed, single equipment has more potential for saving energy when combined with other equipment or auxiliary means, in other words, to be integrated into a holistic control system. In addition to energy efficiency and thermal comfort, occupant satisfaction with indoor humidity and air quality should also be taken into consideration.

So far, the studies on indoor humidity and condensation control systems have mainly focused on public buildings with substantial moisture evaporation such as an indoor swimming pool [11], equipment with a high risk of condensation such as radiant systems [12], and other special building spaces such as multi-enclosed thermal zone [13]. Only a few studies were conducted in residential or office buildings. Michael [14] proposed a room heating and moisture-proof system, mainly oriented to damp rooms such as a bathroom. This system was equipped with a heating unit, ventilation system and ultraviolet radiation emitter, and it prevented moisture and mold from forming. Huang et al. [15] proposed a moisture-proof system that was applied to a smart home. Windows and dehumidifiers were operated by this system according to indoor humidity. Occupants could operate the equipment manually from a distance and be informed about the actions of the equipment by message or voice broadcast. On the other hand, many studies have been conducted on indoor environment control systems. The early studies such as Refs. [16,17] were focused on control based on the PMV model since Fanger [18] proposed this model of thermal comfort in 1970 and later cases on thermal adaptation such as Ref. [19]. These studies were all designed to achieve thermal comfort for the occupants, and some of them focused on energy saving as well. However, a literature survey by Shaikh et al. indicated that among 121 literature themed on 'energy', 'comfort', 'control' and 'optimization' in 1995–2013, there were only 13 literature (appropriately 11%) including humidity as an optimization objective [20].

The purpose of this study is to provide a new indoor humidity and condensation control system to be used in the spring season in hot-humid areas and to test its performance in terms of indoor environmental quality, condensation prevention and energy efficiency. Our specific goals are 1) to propose a smart indoor environment control system based on condensation prevention logic and thermal and humid adaptations of local people in hot-humid areas; 2) to conduct comparative field tests on the smart and conventional controls in offices during the period of a typical CWW; and 3) to determine the performance of the smart control in terms of its environmental, subjective and energy aspects. This study provides an innovative solution for indoor humidity and condensation problems in the spring and has great practical application potential as smart indoor environment control technology for hot-humid areas.

2. Control logic and system

2.1. Control logic

The goals of the smart control, with a priority order from high to low, are thermal and humid comfort, condensation prevention, energy saving, and good air quality. The logic behind the smart control can be summarized by three criteria and two actions as Fig. 1 shows; they are the ventilation criterion related to the indoor and outdoor air temperatures and CO_2 concentration, the condensation criterion related to the difference between the temperature of the internal surface with a highest risk of condensation (hereinafter referred to as TS_{TRC}) and the outdoor air dew point, and the comfort criterion related to the indoor air temperature and relative humidity, as well as the acts of opening or closing windows and turning dehumidifiers on or off.

The criteria are judged step by step in the control logic, with a priority order following the control goals from low to high. The first criterion is the indoor CO_2 concentration. The control target is set as < 1000 ppm according to the Chinese national standard GB/T 18883 [21]. A margin of ± 100 ppm is used to avoid too-often acts. The