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Development of temperature and humidity independent control (THIC) air-conditioning systems in China—A review

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ABSTRACT

A temperature and humidity independent control (THIC) system is a way to regulate indoor temperature and humidity separately through different approaches. Because of this distinction, THIC air-conditioning systems can satisfy the adjustment requirements of indoor temperature and humidity better than conventional systems can, and they show significant potential for energy conservation. In the past ten years, rapid improvements have been achieved in both theoretical research and the development of equipment related to THIC systems, and more and more applications are being put into use in non-residential buildings in China. This paper focuses on the development of THIC systems in China and reviews recent achievements and progress related to the main devices used for temperature and humidity control, including outdoor air handling dehumidification processors, sensible heat terminals, and high-temperature cooling sources. The energy performance of THIC systems is examined based on an analysis of established applications. Both the performance of key components and the energy consumption of entire systems indicate that THIC systems result in significant improvements in energy performance compared to conventional systems. Developmental trends and recommendations about design methodology, ways to improve the performance of handling devices, and feedback from applications of THIC systems are also discussed.

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Contents

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1. Introduction

Building energy consumption accounts for about 23% of the total energy consumed in China [1], and this proportion is predicted to increase as both the economy and society as a whole continue to develop rapidly. It is of great strategic significance to promote energy saving in buildings and pursue emission reduction. At the same time, non-residential buildings are developing very quickly in China. There was a total of approximately 7.8 billion m^2 of non-residential buildings in China in 2008, and about 4–5 million m^2 of new buildings are being built every year [1,2]. The energy consumption of air-conditioning systems represents a large proportion of the total energy consumption of non-residential buildings, usually 20–60% [3,4]. Thus, decreasing the energy consumption of air-conditioning systems is one of the main ways to save energy in non-residential buildings.

In conventional air-conditioning systems, the indoor sensible load and latent (moisture) load are handled by chilled water at the same time [5]. In other words, condensing dehumidification is used to regulate both indoor temperature and humidity. In fact, the required temperature of the cooling source is lower than the indoor air temperature and the dew bulb temperature in order to control the indoor temperature and humidity, respectively. Moreover, the sensible load is usually larger than the latent load, but even though the sensible load can be removed by a cooling source with a relatively higher temperature, it is typically handled by the same lower-temperature cooling source together with dehumidification, which leads to significant energy loss. Furthermore, conventional methods cannot effectively accommodate the large variances in sensible or latent loads in many buildings, resulting in indoor temperatures or moisture levels that exceed inhabitants' comfort ranges. Reheating is a possible solution in order to avoid such problems, but it can lead to unnecessary energy dissipation. Many researchers have attempted to address the shortcomings of conventional air-conditioning systems, and numerous solutions have been proposed. Regulating indoor temperature and humidity separately is one promising method, and this approach has becoming increasingly popular in recent years.

Dedicated outdoor air systems (DOAS) [6] have been proposed in the United States, and different devices have been adopted for humidity control and temperature control. These systems connect low-temperature air supply devices and sensible cooling terminals where the outdoor air is processed to a sufficiently dry state to satisfy the requirement of removing the indoor latent load [7]. DOAS conform to the ASHRAE standard for fresh air [8] in an energy-efficient manner, and operating cost savings can be achieved at the same time as significant improvements in indoor air quality and thermal comfort. DOAS are developing quickly, and several applications have been investigated [9,10]. However, conventional chillers are adopted in DOAS for both humidity control and temperature control; no special chillers supplying higher-temperature chilled water have been developed for temperature control, limiting further improvements in energy performance. Interestingly, radiant cooling terminals, which represent an effective way to extract sensible heat for temperature control, are appearing in systems in Europe [11,12]. If chilled water of an appropriate temperature is imported into the radiant terminals, indoor sensible heat can be extracted through radiant heat exchange and natural convection. Radiant terminals have become popular in Europe because a suite of terminals can be used for both cooling and heating, and the outdoor condition in most areas of Europe is dry enough to alleviate any concern about condensation on the surface of the radiant terminals in summer. Radiant terminals have been shown to be a good choice for low-temperature heating systems and high-temperature cooling systems, especially in research on low exergy systems in the Annexes [13–15] of the International Energy Agency's (IEA) Implementing Agreement on Energy Conservation in Buildings and Community Systems (ECBCS). In contrast to the dry outdoor climate in most parts of Europe, where there is little risk of condensation in radiant cooling, the outdoor air is humid in many areas of China. This means that if radiant cooling is adopted for temperature control in China, humidity control will be a more challenging task than it is in Europe [16].

Temperature and humidity independent control (THIC) air-conditioning systems, which consist of temperature control and humidity control subsystems, were first developed in China [17]. The basic idea of the THIC system is to regulate indoor temperature and humidity separately. A high-temperature cooling source is utilized for temperature control, and processed air with a relatively low humidity ratio is supplied into indoor spaces for humidity control. With the support of the 11th Five-year National Science and Technology Support Program of China (2006–2010), a number of organizations, including design institutes, research and development institutions, and equipment manufacturers, were involved in collaborative research and development of THIC systems. Newly developed handling devices and practical applications of THIC systems have been continuously promoted in recent years. In the early stages, THIC systems consisted of devices commonly used for conventional systems. Now, there are equipment components that are made especially for THIC systems, including high-temperature water chillers, dry fan coil units (FCUs), liquid desiccant outdoor air dehumidifiers, etc. Since 2006, almost 4 million m^2 of non-residential buildings have adopted THIC systems. With the rapid development of its particular devices and applications, the THIC system has been included in design handbooks and standards in China [18,19].

This paper focuses on the progress of THIC systems in China. Recent developments related to high-temperature water chillers, outdoor air handling devices, and sensible terminals are reviewed, and the energy performance of THIC systems in typical applications is investigated.

2. Operating principle of THIC systems

2.1. Independent control of indoor humidity and operating principle of THIC systems

The total cooling load of a building [20] includes both the sensible load from the outdoor air, building envelope, occupants, devices, lighting, etc., and the latent load (moisture load) from the outdoor air, indoor occupants, indoor wet surfaces, etc., as shown in Fig. 1. The main element of the indoor latent load in common non-residential buildings, such as office buildings, hotels, and shopping malls, is from occupants. In most cases, the sensible load accounts for a greater proportion of the total load than the latent load does. Air-conditioning systems are primarily responsible for

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