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Performance analysis of the air-conditioning system in Xi'an Xianyang International Airport

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ABSTRACT

Reducing the energy consumption of air-conditioning systems is becoming increasingly important. This paper focuses on the air-conditioning system in Terminal 3 in Xi'an Xianyang International Airport, the first airport terminal to adopt radiant cooling in China. In the large spaces of this airport terminal, a temperature and humidity independent control (THIC) system has been adopted instead of a conventional nozzle air supply method, which significantly reduces the energy consumption of the air supply. The radiant floor is the main mechanism for indoor temperature control, while a liquid desiccant outdoor air processor combined with displacement ventilation is responsible for humidity control. Ice storage is adopted to reduce operating costs, and the supplied chilled water temperature can be as low as 3 °C. This paper examines the performance of the THIC system in detail. The indoor environment is determined through measurements to be comfortable, and the on-site performances of key components in both the airport terminal and the cooling plant are investigated. The outdoor air processor supplies air of appropriate temperature and humidity ratio; two kinds of radiant floors are used for temperature control, both with measured cooling capacities of about 30–40 W/m^2; and the energy efficiency ratio (EER) of the cooling plant is 2.62.

1. Introduction

The basic task of an air-conditioning system is to provide a suitable indoor environment with respect to temperature, humidity, fresh air, etc. With rapid economic development, the energy consumption of air-conditioning systems has increased dramatically, now accounting for about 30–40% of the total energy consumption of non-residential buildings in China [1]. Therefore, reducing the energy consumption of air-conditioning systems is an important way to conserve building energy use. In large spaces such as the check-in halls in train stations and airport terminals, nozzle air supply is the most common air-conditioning solution. However, distributing the air in such an all-air system consumes quite a lot of energy [1]. Therefore, many researchers have focused on improving the energy performance of air-conditioning systems for large spaces, and several studies designed to improve system performance have been beneficial [2–4].

Olesen [4] introduced a radiant floor application for cooling in an airport terminal in Thailand in which solar radiation entering through the building envelope could be extracted immediately by radiant cooling, thereby reducing the energy consumption of the air supply considerably. One of the challenges of adopting radiant panels is the issue of condensation [5–7]. In the airport terminal in Thailand, condensing dehumidification was used to handle the air to a sufficiently dry state to extract indoor moisture and prevent condensation. However, the dehumidified air had to be reheated before being supplied indoors due to condensing dehumidification. Inspired by Olesen's research in Thailand, radiant floors and displacement ventilation were employed to facilitate temperature and humidity independent control (THIC) in the large spaces of Terminal 3 of Xi'an Xianyang International Airport, which is the subject of this paper.

THIC air-conditioning systems, consisting of a temperature control subsystem and a humidity control subsystem, were first introduced in China [8]. Humidity control is realized by supplying sufficiently dry outdoor air, and both desiccant and condensing methods can satisfy the dehumidification requirement. As for temperature control, in contrast to conventional systems, a high-temperature cooling source (15–20 °C) is adopted, and radiant panels are often employed for this purpose. Previous studies focusing on applications of THIC systems in office buildings have demonstrated their superior energy performance compared to conventional air-conditioning systems [9,10].

In addition, ice storage technology is regarded as a feasible approach for peak-load shifting in the cooling season, as the price of electricity during off-peak hours is much lower than during peak

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Nomenclature

COP	coefficient of performance (dimensionless)
COP_{ideal}	ideal COP of the refrigeration cycle (dimensionless)
P	power consumption (kW)
Q	cooling capacity (kW)
t	temperature (°C)
Δt	temperature difference (°C)
TC	transport coefficient (dimensionless)

Greek symbol

η	thermodynamic perfect degree (dimensionless)

Subscripts

ch	chiller
chw	chilled water pump
ct	cooling tower
cw	cooling water
cwp	cooling water pump
e	evaporator
gl	glycol pump
i	ice

hours [11]. Although ice storage processes consume more power than conventional processes with the same cooling capacity, the operating costs of ice storage processes are much lower, and their applications in buildings have been on the rise in recent years [12–14]. Thus, ice storage was adopted in the system described in this study.

This paper focuses on the air-conditioning system in Terminal 3 in Xi'an Xianyang International Airport, the first airport terminal to adopt radiant floors for cooling in China. The operating principles of the terminal devices, distribution system, and cooling plant in this THIC system are described, and the performances of key components of the system are measured.

2. Description of the air-conditioning system in the airport terminal

Terminal 3 of Xi'an Xianyang International Airport (Fig. 1), located in China's Shaanxi Province, was designed by China Northwest Architectural Design and Research Institute. The terminal has been in use since May 2012, and it has a total building area of 258,000 m^2. Basic information about the building and the air-conditioning system is summarized in the remainder of this section.

2.1. Basic information

Terminal 3 has three floors: one underground floor and two that are above ground. As a typical airport terminal, the building includes a check-in hall, a departure hall, a baggage claim area, offices, etc. Fig. 1 gives a view of the check-in hall. The maximum height of the terminal is 37.0 m, and the underground depth is 8.6 m. The outdoor environmental conditions in Xi'an are shown in Fig. 2, including annual outdoor air temperature, relative humidity, and humidity ratio [15]. The average relative humidity of the outdoor air in summer is about 60%, and the humidity ratio is about 15–20 g/kg. The cooling season for Terminal 3 is from May 15th to September 15th; according to the daily operating time of the airport terminal, the air-conditioning system is run from 6:00 a.m. to 12:00 midnight.

Because of the extremely large spaces in this airport terminal, radiant floors and displacement ventilation were selected for the THIC system to conserve air distribution energy during operation. Moreover, since electricity prices in Xi'an vary tremendously (the off-peak price is only about one-third of the peak price), ice storage technology was utilized in order to maximize operating cost savings. The THIC air-conditioning system consists of specific devices based on these particular aspects of the airport terminal.

2.2. Air-conditioning system of Terminal 3

The indoor handling devices, distribution system, and cooling plant will be described in the following subsections.

2.2.1. Indoor terminals

The THIC air-conditioning system is employed in the large spaces of the airport terminal (i.e., the check-in hall and the departure hall), as shown in Fig. 3. The area adopting THIC system includes the check-in hall and the departure hall, with a total area of about 47,000 m^2. Fig. 4 shows the operating schematic of the THIC system in the airport terminal. In this THIC system, outdoor air is dehumidified by a heat pump-driven liquid desiccant processor, and high-temperature chilled water is used to precool the air. Displacement ventilation is utilized as the air supply terminal, and dry air is supplied into the indoor environment for humidity control. Dry FCUs (fan coil units) and radiant floors are used for temperature control in the THIC system, and dry FCUs with condensing plates

Fig. 1. Terminal 3 in Xi'an Xianyang International Airport (check-in hall).