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A museum storeroom air-conditioning system employing the temperature and humidity independent control device in the cooling coil

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ABSTRACT

For conservation of cultural heritage, HVAC systems are often necessary for museums to maintain suitable indoor environment with precise control of indoor thermal-hygrometric parameters and air velocity. Large deviations of these parameters from the design values should be prevented, because they may cause degradation of artworks. So, more energy consumption is inevitable.

This paper presents a novel temperature and humidity independent control (THIC) device and its associated control method in a museum storeroom air-conditioning system. Compared with the conventional HVAC system with the cooling coil (*CC*), where the apparatus dew point is usually fixed, this system adopting the THIC device can achieve independent temperature and humidity control in an energy saving way. The experiment study shows that this system can reduce the energy consumption by 21.7%, compared with the conventional HVAC systems using reheat and humidify for an indoor thermal-hygrometric environment, and the temperature and humidity in the storeroom are also kept stable and at a higher precision level.

1. Introduction

Conservation of artworks requires precise control of the indoor microclimatic conditions. Thus, a suitable HVAC system with reliable control is often necessary for a museum, to maintain acceptable indoor thermal-hygrometric parameters and air velocity and also to minimize the deviations of these parameters from the design values. So it is indispensable for the museum air-conditioning system to comprise heating, humidifying, cooling, dehumidifying and automatic control units to control the temperature and humidity at the same time. Considering that the HVAC system in museum always has to be operated continually during all the year and 24 h per day, a suitable technique is necessary to obtain considerable energy saving [1], however, guaranteeing a good indoor thermal-hygrometric microclimate. It is shown by some literatures [2–5] that the energy consumption will be reduced by about 10–50%, if the HVAC system adopts a suitable energy-saving technique.

For conventional HVAC system, customarily, the dew point temperature is fixed on the cooling coil (*CC*) in the air-handling process, which makes the air after the *CC* be over-cooling to guarantee both the temperature and the humidity ratio are lower than the supply air parameters, and then results in much more energy compensation for reheating and re-humidifying. To reduce that compensation, it is necessary for the *CC* to reduce the over-cooling capacity, so the temperature and humidity independent control (THIC) technique has been studied in many literatures. Generally, substituting desiccant dehumidification for cooling dehumidification in the *CC*, the THIC technique uses solid desiccants [6–8] or liquid desiccants [3,9–11]. But how to realize independent control of temperature and humidity in the same cooling coil in HVAC system is a worthwhile problem, and there are few literatures about this THIC technique.

In this paper, an HVAC system employing the THIC device in the *CC* is proposed and designed. With the PID split-range control, only one of the two air thermal-hygrometric parameters after *CC*, i.e. temperature or humidity ratio, is to be controlled below the supply air, in order to make the over-cooling capacity as little as possible. And some experiment tests were done to validate the THIC device.

2. THIC device

The THIC device presented in this paper can be used in the *CC* of both existing and new conventional HVAC systems, as shown in Fig. 1.

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Nomenclature

C_p	constant pressure specific heat (kJ/kg K)
h	enthalpy (kJ/kg)
L	latent heat of vaporization (kJ/kg)
m	mass flow rate (kg/s)
Q	heat load (kW)
T	temperature (K)
ω	air humidity ratio (kg/kg)
Subscripts	
a	moist air
l	latent heat
i	indoor air; inlet
o	outlet
s	supply air; sensible heat
w	chilled water

Fig. 2 shows the schematic diagram of the THIC device. For temperature control, the *CC* adjusts the mass flow rate of the chilled water according to the sensible cooling load; and for humidity control, it adjusts the temperature of the chilled water according to the dehumidification load, or the latent load. Before and after the *CC*, an electric controllable three-way valve (CTV) is installed respectively. The CTV 1# adjusts the mass flow rate of the chilled water through the *CC* to control the leaving air temperature so that the sensible load is handled. The CTV 2# adjusts the flow rate of the recirculated water that leaves the *CC* and then returns to mix with the chilled water entering the *CC*. In this way, the apparatus dew point of the *CC* can be regulated and therefore the leaving air humidity can be controlled separately. In this device, the total mass flow rate of the chilled water ($m_w = m_{w,1} + m_{w,2} = m_{w,3} + m_{w,4}$) is determined by the pump, and the supply water temperature (T_w) is determined by the central chilling plant (CCP). Both of them can be considered as constants. The $m_{w,1}$ and $m_{w,2}$ is determined by the CTV 2#, while the $m_{w,3}$ and $m_{w,4}$ is determined by the CTV 1#.

The energy conservation Eq. (1) shows that the mixed temperature $T_{w,1}$ is determined by $m_{w,1}$ and $m_{w,2}$, which is controlled by the CTV 2# only. And the flow rate $m_{w,3}$ of the chilled water into the *CC* is only controlled by CTV 1#. Thus the system controls the temperature and humidity independently.

$$T_{w,1} = (T_w \cdot m_{w,1} + T_{w,2} \cdot m_{w,2})/m_w \tag{1}$$

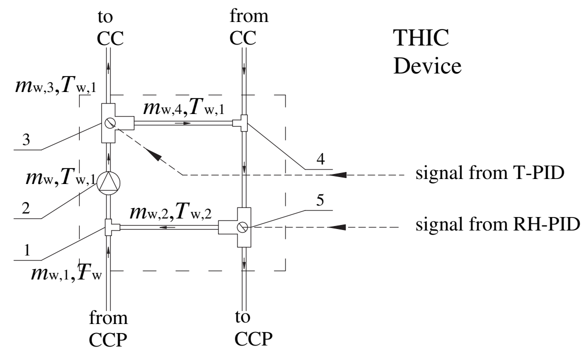

Fig. 2. Schematic diagram of the THIC device in the CC (1 Three-way valve 1#; 2 Pump; 3 CTV 1#; 4 Three-way valve 2#; 5 CTV 2#).

For satisfying different thermal-hygrometric loads of different seasons, the system is controlled by two split-range PID conditioners. As shown in Fig. 2, the PID conditioner for temperature (named as T-PID) controls the CTV 1# and the heater, while the PID conditioner for relative humidity (named as RH-PID) controls the CTV 2# and the humidifier. The two PID conditioner work together to decide how the *CC*, the heater and the humidifier works, as shown in Figs. 3 and 4.

As shown in Fig. 3, when the T-PID signal for temperature increases from 0.0 to 0.5, the signal for CTV 1# which represents the mass flow rate of the chilled water decreases from 1.0 to 0.2, while the signal for heater remains at zero; and when the T-PID signal increases from 0.5 to 1.0, the signal for CTV 1# remains at 0.2 which guarantees the minimum flow rate of chilled water going through *CC*, while the signal for heater increases from 0.0 to 1.0. So, generally, with the increase of the value of T-PID signal for temperature, the outlet air temperature of AHU increases.

Similarly, in Fig. 4, the outlet air relative humidity of AHU increases, when the value of RH-PID signal for relative humidity increases. To avoid sending back all of the recirculated water that leaves the *CC*, the signal for CTV 2# remains at 0.8 when the RH-PID signal increases from 0.5 to 1.0.

3. Experiment setup

An HVAC system employing the TIHC device was manufactured and installed to air-condition a museum storeroom, the main parameters are listed in Table 1. It comprises the following subsystems: (1) AHU with a *CC*, a heater, a humidifier and a constant flow rate fan, and the details of the *CC* are listed in Table 2; (2) Air

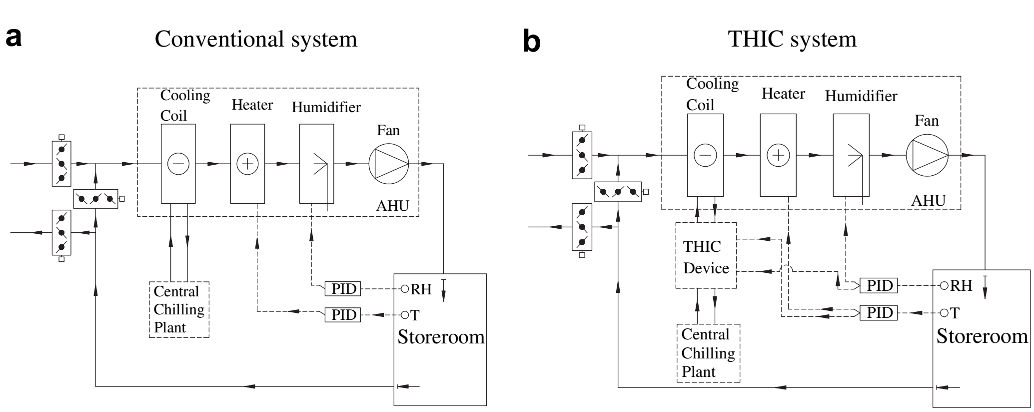

Fig. 1. Comparison of the conventional and THIC system.