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Energy conservation benefit of water-side free cooling in a liquid desiccant and evaporative cooling-assisted 100% outdoor air system

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ABSTRACT

The main purpose of this research was to experimentally investigate a liquid desiccant and evaporative cooling-assisted 100% outdoor air system. The proposed system was integrated with water-side free cooling in the desiccant solution and process air cooling to enhance its energy performance. The experimental results show that the required cooling water temperature for the desiccant solution is higher than the conventional cooling water supply temperature; that is, approximately 22–27 °C. Consequently, water-side free cooling was applied to produce the cooling water for the desiccant solution. The operation of the proposed system with the water-side economizer showed a 40–70% effectiveness of the indirect evaporative cooler, while that of the direct evaporative cooler was greater than 95%, and the supply air temperature ranged between 17 and 20 °C. The energy coefficient of performance (COP) of water-side free cooling applied to cool the desiccant solution was 8–17, whereas that of the conventional air-cooled chiller was 1–3. Economic consideration indicated that the operating energy savings might offset the penalty in the initial cost of the proposed system.

1. Introduction

A liquid desiccant and indirect/direct evaporative cooling-assisted 100% outdoor air system (LD-IDECOAS) has been proposed as an energy-conserving air conditioning system [1,2]. According to the literature [3], a liquid desiccant and evaporative cooling system has significant energy-saving potential among the non-vapor-compression heating, ventilation, and air conditioning (HVAC) systems.

The major components of the LD-IDECOAS are the liquid desiccant (LD) unit, the indirect evaporative cooler (IEC), and the direct evaporative cooler (DEC). In a hot and humid climate, outdoor air (OA) is dehumidified by the LD unit, and then the IEC and DEC cool the supply air (SA) to achieve the target condition [4–6]. The dehumidification performance of the LD unit plays a significant role in enhancing the cooling potential of the evaporative coolers and in the system's energy-saving potential.

Absorption of moisture from the process air in the LD unit is an exothermic process, so the desiccant solution in the absorber should be cooled to maintain dehumidification. The desiccant solution temperature at the absorber inlet is an important control parameter affecting the dehumidification rate [7]. The operating temperature range of the desiccant solution in the absorber of a conventional LD system is 20–30 °C, suitable for use with the water-side free cooling approach.

Water-side free cooling commonly uses a cooling tower to produce cooling water delivered directly to the load [8,9]. The OA wet-bulb temperature (WBT) critically affects the cooling tower performance [10–12].

Theoretical and experimental studies have been conducted to assess water-side free cooling with an LD system. Katejanekarn and Kumar [13] conducted simulation research on OA pre-conditioning with a solar-regenerated LD system integrated with water-side free cooling. They assumed that the cooling tower effectiveness was 33%, and cooling water that passed through the LD system was re-used to cool the SA. Katejanekarn et al. [14] also conducted experimental research in which a 10-t cooling tower cooled the water to a temperature near the OA WBT. They oversized the cooling tower to sufficiently cool the SA. Gommed and Grossman [15] simulated an LD system with water-side free-cooling using the ABSIM [16] program and found that the water-side economizer maintained the desiccant solution around 29.5 °C. They conducted additional experimental research, and their results indicated that the desiccant solution in the absorber can reach 22–27 °C with water-side free cooling [17]. Jain et al. [18] conducted experimental research on an LD dehumidification system with a calcium chloride and lithium chloride solution. Their results showed that the desiccant solution temperature in the absorber can be maintained at

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Nomenclature

b_y	bias standard uncertainty
c_w	specific heat of water (kJ/kg °C)
c_p	specific heat of air (kJ/kg °C)
h	enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
Q	load (kW)
s_{X_i}	random uncertainty of the measured quantity X_i
s_y	random standard uncertainty
T	temperature (°C)
U_y	overall uncertainty
W	electric energy consumption (kW h)
w	humidity ratio (kg/kg)

Greek symbols

ε	effectiveness (%)
σ	standard deviation (%)

Subscripts

cw	cooling water
ct	cooling tower
e	equilibrium
hw	hot water
in	inlet
out	outlet
pri	primary
sec	secondary
s	supply
SC	solution cooling
SH	solution heating
r	return
w	dehumidification
wt	water

Acronyms

COP	coefficient of performance
CT	cooling tower
DBT	dry-bulb temperature (°C)
DEC	direct evaporative cooler
EA	exhaust air
HEX	heat exchanger
HVAC	heating, ventilation, and air conditioning
HC	heating coil
IEC	indirect evaporative cooler
LD	liquid desiccant
LD-IDECOAS	liquid desiccant and evaporative cooling-assisted 100% outdoor air system
LPG	liquefied petroleum gas
MRC	moisture removal capacity
OA	outdoor air
PP	process pump
RA	return air
RF	return fan
RGF	regeneration fan
RGP	regeneration pump
RH	relative humidity (%)
SA	supply air
SF	supply fan
SHE	sensible heat exchanger
WBT	wet-bulb temperature (°C)

26.0–31.7 °C using water-side free cooling. Alizadeh [19] conducted small-scale experimental research on a solar-assisted LD air conditioner and found that the desiccant solution, which was heated to 70 °C for regeneration, could be effectively cooled to 23 °C by water-side free cooling. Several studies have been conducted on the use of a cooling tower in an LD system; however, there is insufficient research to determine the energy-saving potential of the proposed system integrated with a cooling tower over a conventional air-cooled chiller.

The main purpose of this research is to experimentally investigate the effect of water-side free cooling in LD-IDECOAS operation during the cooling season with hot and humid OA conditions. The energy-saving potential of water-side free cooling in LD-IDECOAS is also evaluated by comparing the proposed system's operating energy consumption with that of a conventional air-cooled chiller, and the initial cost breakdown of the LD-IDECOAS pilot system is provided.

2. Pilot system overview

2.1. System configuration

The LD-IDECOAS pilot system serves a 6 × .2 × 2.4 m^3 office. The office is in an interior zone and does not have a window. Physical information about the conditioned space is presented in Table 1.

As shown in Fig. 1, the main components of the proposed system are an LD unit, an IEC, and a DEC on the upstream and a heating coil and a sensible heat exchanger are located downstream. Depending on the thermal load variation, the SA flow rate is modulated to achieve the indoor condition setpoint. Only OA is handled by the proposed system, without recirculation of the room return air (RA). The nominal airflow rate is 2000 m^3/h.

In this research, a honeycomb-structured packed tower was used as an absorber and regenerator. The internal diameter was 0.01 m packed to a volume of 0.315 m^3 with wood fiber-structured packing of a specific surface area (223 m^2/m^3). Lithium calcium (LiCl) solution was used as a desiccant and was sprayed at the top of the column from the sump and distributed over the packing.

Fig. 2 shows a schematic of the water-side free cooling and evaporative coolers in the LD-IDECOAS, and the schematics are listed in Table 2. The solution cooling system before the absorber was composed to enhance the dehumidification rate. The system for desiccant solution cooling consists of a cooling-water storage tank, a cooling tower, and an air-cooled chiller (Fig. 2(a)). The cooling tower and air-cooled chiller are connected, in parallel, to a water storage tank. The cooling tower is managed by the free cooling operation. The air-cooled chiller is operated only to compare its energy performance with that of water-side free cooling. The solution cooling water was supplied to the absorber and distributed to the solution-to-water heat exchanger (HEX1) and the air-to-water heat exchanger (HEX2). In HEX1, the desiccant solution is cooled by the cooling water, and the process air in HEX2 transfers heat from the air to the cooling water.

The wet-coil IEC was divided into two channels: the process air was cooled as it passed through the primary channel;

Table 1
Conditioned space.

Location		Incheon, Republic of Korea	
U-value		Exterior wall	1.779 W/m^2 K
		Roof	2.074 W/m^2 K
Room		6 × 7.2 × 2.4 m^3	
Heat gain	People	1 person	
	Lights	4 lighting fixtures (560 W)	
	Computers	2 (460 W)	