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Research Paper

Energy benefit of a dedicated outdoor air system over a desiccant-enhanced evaporative air conditioner

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HIGHLIGHTS

- The energy performances both DOAS and DEVap systems were compared.
- The sensible and latent cooling performances were analyzed using energy simulation.
- The DOAS showed 22% less annual primary energy consumption than the DEVap system.

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ABSTRACT

The purpose of this study is to comparatively evaluate the energy performances of a dedicated outdoor air system (DOAS) and desiccant-enhanced evaporative air conditioner (DEVap) in building applications. The DOAS effectively accommodates latent cooling loads and some of the sensible cooling loads of the space by introducing cooled and dehumidified ventilation air into a building while integrating a parallel system aimed at reducing the remaining sensible load.

The DEVap enhances the energy performance of a variable air volume system by reducing cooling coil loads through preconditioning of the supply air before it reaches a coil. The preconditioning is accomplished by using a liquid desiccant system and dew-point indirect evaporative cooler. In this paper, the operating and annual primary energy consumptions of both the DOAS and DEVap systems are compared based on detailed energy simulations. The results indicated the energy saving potential of DOAS to be greater than that of the DEVap. Specifically, a DOAS with ceiling radiant cooling panels experienced 20% less primary energy consumption compared to a DEVap.

1. Introduction

An air conditioning system should provide ventilation as well as sensible and latent cooling functions to maintain acceptable indoor air quality, temperature, and humidity set points for a conditioning zone. However, attempting to satisfy multiple air conditioning requirements by using one air conditioning system may result in problems due to inefficient control [1]. The concept of a decoupled system [1–3,5], which involves decoupling the ventilation function from the air conditioning function, or decoupling the sensible cooling from latent cooling, has been proposed for effective control and energy conservation of air conditioning systems.

A dedicated outdoor air system (DOAS) is a decoupled system solution that independently controls the latent and sensible air conditioning loads. The DOAS accommodates overall latent load and a certain amount of sensible load by treating outdoor air ventilation flow supplied to the conditioned zone with a total energy recovery component assisted by a cooling coil and sensible heat exchanger. Various configurations of DOAS, including desiccant systems for the allocation of humidification load of the cooling coil, have been produced. However, a typical dual wheel type DOAS, which is comprised of an enthalpy heat exchanger, cooling coil, and sensible heat exchanger, provided the highest energy conservation effect among various configurations [4,5]. Additional sensible cooling is conducted by a separate air conditioning system operated in parallel with the DOAS to maintain building space conditions [6].

Regarding the energy conservation of a DOAS with parallel cooling systems, Zakula et al. [7] investigated a low-lift cooling system that decouples thermally activated building surfaces (TABS) and a DOAS. Hallenbech [8] examined the DOAS with a fan-powered induction unit (FPIU) system. Both systems showed significant operating energy savings (i.e., approximately 50%) as compared to conventional variable air volume systems (VAV). A DOAS with

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Nomenclature

A	heat transfer area (m^2)
C	heat capacity rate (kJ/kg K)
CAPFT	capacity of a chiller
c_{pa}	specific heat of moist air (kJ/kg K)
DFR	driving force ratio
EIRFPLR	part-load efficiency of a chiller
EIRFT	full-load efficiency of a chiller
h	enthalpy (kJ/kg)
k	thermal conductivity (W/m K)
$\overline{K}$	enthalpy change to wet-bulb temperature change ratio on the wet side of the IEC
LG	liquid to gas ratio
L_c	liquid desiccant solution concentration (%)
$\dot{m}$	mass flow rate (kg/s)
NTU	number of heat transfer coefficients
P	power (kW)
PLR	part-load ratio
Q	load
Q_{CRCP}	sensible load accommodated by ceiling radiant cooling panel
Q_R	exhaust air to outdoor air flow rate
spd	rotation speed
T	dry bulb temperature (°C)
U	overall heat transfer coefficient (W/m^2 K)
V	face velocity (m/s)
$\dot{V}$	volume flow rate (m^3/s)
W	humidity ratio (kg/kg)

Greek symbols

$\alpha, \beta, F_p, F_s, n$	model coefficients
Δp	pressure drop in pump and fan (kPa)
ε	effectiveness
η	efficiency
$\varnothing$	relative humidity (%)

Subscripts

air	air stream
c	cold fluid
cws	chilled water supply
EA	exhaust air
eq	equilibrium
fan, design	design value of the fan operation
h	hot fluid
lat	latent
in	inlet
OA	outdoor air
out	outlet
max	maximum
p	primary air
r	ratio
RA	room air
ref	reference
s	secondary air
SA	supply air
SA, set	supply air set point
sen	sensible
t	target
w	water film

Superscript

wb	Wet bulb

Abbreviations

CC	cooling coil
CRCP	ceiling radiant cooling panel
DEVap	desiccant-enhanced evaporative air conditioner
DP-IEC	dew-point indirect evaporative cooler
DOAS	dedicated outdoor air system
DPT	dew point temperature
EW	enthalpy wheel
HC	heating coil
IEC	indirect evaporative cooler
LD	liquid desiccant
SW	sensible wheel
VAV	variable air volume system

ceiling radiant cooling panels (CRCP), as suggested in the literature [9–12], has also shown a relatively high operating energy conservation (i.e., over 40%) over conventional air conditioning systems. The decoupled systems that integrate desiccant dehumidifier and evaporative cooling system for separate latent and sensible load control are also proposed in several open literatures [2,3,13–16].

Dai et al. [13] introduced a hybrid air conditioning system that preconditions the process air through a liquid desiccant system (LD) combined with an evaporative cooling system. This hybrid system reduces the operating energy consumption of a conventional vapor compression-based air conditioning system. Experimental research on the energy conservation benefits of a desiccant rotor-integrated vapor compression air conditioning system are described in the literature [14].

An application of evaporative cooling and liquid desiccant in an air conditioning system has also been suggested in some experimental research. Kim et al. [2,15] suggested an application of LD, indirect evaporative cooling system (IEC), and direct evaporative cooling system supplied with 100% outdoor air. They experimentally showed their proposed system to use 68% less energy than a conventional VAV. Ham et al. [16] also suggested a non-vapor compression air conditioning system that operates an LD and dew-point evaporative cooling system in parallel. The results indicated that the system conserved primary energy over 12% compared with the conventional VAV system.

Woods and Kozubal [3] also suggested a desiccant-enhanced evaporative air conditioner (DEVap), which initially dehumidifies process air using a liquid desiccant dehumidifier and then cools the dry process air through a dew-point evaporative cooler close to its dew-point temperature [17]. Consequently, the cool and dry supply air meets the sensible and latent loads of the conditioned zone. The mass flow rate of the supply air in the DEVap can be modulated in a manner similar to that for a conventional VAV to meet the air conditioning load of the building.

Both the DOAS and DEVap are well known for their energy saving potentials. However, the performances of the systems have not been systematically compared. The two decoupled systems require different air conditioning strategies as the DOAS and VAV systems have different system configurations. Therefore, in this research, the energy performances of a DOAS with a parallel system and DEVap are estimated using a detailed energy simulation that simulates supplying conditioned air to a model office building. The potential energy savings of the two systems are then compared.