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A global optimized operation strategy for energy savings in liquid desiccant air conditioning using self-adaptive differential evolutionary algorithm

Xinli Wang [a,b], Wenjian Cai [b,*], Xiaohong Yin [c]

[a] *School of Control Science and Engineering, Shandong University, Jinan 250061, PR China*
[b] *EXQUISITUS, Centre for E-City, School of Electrical and Electronic Engineering, Nanyang Technological University, 639798, Singapore*
[c] *School of Automation & Electronic Engineering, Qingdao University of Science & Technology, Qingdao 266042, PR China*

HIGHLIGHTS

- Propose a global optimized operation strategy for energy saving in LDAC.
- SADE algorithm is employed to solve the presented optimization problem.
- 18.5% energy savings can be achieved by using the global optimized operation strategy.

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ABSTRACT

This study proposes a global optimized operation strategy to reduce energy consumption of a liquid desiccant air conditioning (LDAC) driven by chiller and electric heater. Energy models of chiller, electric heater, pumps and fans are developed to predict their energy consumptions under different operating conditions with different control settings. Heat transfer models of cooling heat exchanger, heating heat exchanger and recovery heat exchanger are established to analyze the heat transfer processes in these components. An optimization problem considering system constraints and interactions between components is built to optimize the energy usage of the whole liquid desiccant air conditioning and simultaneously maintaining the required indoor air quality (IAQ) level. Nine controllable variables related to the performance and energy usage of LDAC are selected as control settings. Self-adaptive differential evolutionary (SADE) algorithm with fast convergence rate is employed to solve the optimization problem to obtain optimal control settings and to develop optimal operation strategies. Compare study is carried out on a fabricated testing facility to show the energy saving performance of the proposed global optimized operation strategy. Compared with the conventional strategy, 18.5% energy saving can be achieved by using the proposed global optimized operation strategy. The proposed global optimized operation strategy is a valid operation strategy that is suitable for application in energy reduction of the existing LDAC system in building.

1. Introduction

In recent years, there have been extensive interests on liquid desiccant air conditioning (LDAC) as an alternative method to achieve air temperature and humidity control in occupied space due to its benefits of high energy efficiency and better Indoor Air Quality (IAQ). Compared with conventional cooling based method, LDAC can dehumidify the air energy efficiently by adopting low-grade thermal energy and natural substances with high affinity of water without cooling air below its dew point and reheating again to desired temperature, and can provide high quality air by better air humidity control and prevention of virus and bacteria breeding.

Currently, the main research topics of LDAC include the development of heat and mass transfer model [1–5], experimental investigation [6,7] and designing new types of system such as inner cooled/heated dehumidifier/regenerator [8,9], solar energy integrated dehumidification systems [10–13] and membrane based dehumidification systems [14–17]. Among these schemes,

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* Corresponding author.
E-mail address: ewjcai@ntu.edu.sg (W. Cai).

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Nomenclature

A_i	heat transfer area of CHE, HHE or RHE (m^2)
$b_{1,j} - b_{4,j}$	parameters for energy models of pumps or fans
$c_{1,D/R} - c_{3,D/R}$	parameters for heat transfer models in dehumidifier or regenerator
$c_{4,D/R} - c_{7,D/R}$	parameters for mass transfer models in dehumidifier or regenerator
COP	coefficient of performance
c_s	specific heat of desiccant solution (kJ/(kg °C))
E_{total}	total energy consumption by LDAC (kW)
E_C	energy consumption of cooler (kW)
$E_{Chiller}$	energy consumption of chiller (kW)
E_{CWP}	energy consumption of chilled water pump (kW)
$E_{Electric\ Heater}$	energy consumption of electric heater (kW)
$E_{F,D}$	energy consumption of dehumidifier fan (kW)
$E_{F,R}$	energy consumption of regenerator fan (kW)
E_H	energy consumption of heater (kW)
E_{HWP}	energy consumption of hot water pump (kW)
E_j	energy consumption of pumps or fans (kW)
$E_{j,nom}$	nominal energy consumption of pumps or fans (kW)
$E_{P,D}$	energy consumption of dehumidifier pump (kW)
$E_{P,R}$	energy consumption of regenerator pump (kW)
J	cost function to be optimized (kW)
$k_{c,i}$	heat transfer coefficient for cool side of CHE, HHE or RHE (kW/(m^2 °C))
$k_{h,i}$	heat transfer coefficient for hot side of CHE, HHE or RHE (kW/(m^2 °C))
$m_{a,D/R}$	mass flow rate of air in dehumidifier or regenerator (kg/s)
$m_{a,req}$	indoor required supply air flow rate (kg/s)
$m_{c,i}$	mass flow rate of cooling fluid in CHE, HHE or RHE (kg/s)
$m_{h,i}$	mass flow rate of hot fluid in CHE, HHE or RHE (kg/s)
$m_{j,cur}$	current mass flow rate of pumps or fans (kg/s)
$m_{j,nom}$	nominal mass flow rate of pumps or fans (kg/s)
$m_{s,D}$	desiccant solution flow rate in dehumidifier (kg/s)
$m_{s,D/R}$	mass flow rate of desiccant solution in dehumidifier or regenerator (kg/s)
$m_{s,R}$	desiccant solution flow rate in regenerator (kg/s)
$N_{D/R}$	mass transfer rate in dehumidifier or regenerator (kg/s)
p_a	water vapor pressure of air (kPa)
$p_{a,in,D/R}$	water vapor pressure of inlet air in dehumidifier or regenerator (kPa)
$p^*_{s,in,D/R}$	equilibrium water vapor pressure of inlet desiccant solution in dehumidifier or regenerator (kPa)
$Q_{c,cur}$	chiller current cooling capacity (kW)
Q_{CHE}	cooling requirement of CHE in dehumidifier (kW)
$Q_{c,nom}$	chiller nominal cooling capacity (kW)
$Q_{D/R}$	heat transfer rate in dehumidifier or regenerator (kW)
Q_{HHE}	heating load of heater in regenerator (kW)
Q_i	heat transfer rate of CHE, HHE or RHE (kW)
r_c	chiller part load ratio
$RH_{a,out}$	outdoor air relative humidity (%)
$RH_{a,req}$	indoor required air relative humidity (%)
r_j	part load ratio of pumps or fans
T_a	temperature of air (°C)
$T_{a,in,D/R}$	inlet temperature of air in dehumidifier or regenerator (°C)
$T_{a,out}$	outdoor air temperature (°C)
$T_{a,req}$	indoor required air temperature (°C)
t_c	condensing temperature of chiller (°C)
$T_{c,in,i}$	inlet temperature of cooling fluid for CHE, HHE or RHE (°C)
t_e	evaporating temperature of chiller (°C)
$T_{h,in,i}$	inlet temperature of hot fluid for CHE, HHE or RHE (°C)
$T_{s,bot,D}$	temperature of desiccant solution in bottom of dehumidifier (°C)
$T_{s,bot,R}$	temperature of desiccant solution in bottom of regenerator (°C)
$T_{s,in,CHE}$	desiccant solution temperature of inlet CHE in dehumidifier (°C)
$T_{s,in,D}$	desiccant solution temperature of inlet dehumidifier (°C)
$T_{s,in,D/R}$	inlet temperature of desiccant solution in dehumidifier or regenerator (°C)
$T_{s,in,HHE}$	desiccant solution temperature of inlet HHE in regenerator (°C)
$T_{s,in,R}$	desiccant solution temperature of inlet regenerator (°C)
$T_{wall,i}$	average wall temperature of heat transfer surface for CHE, HHE or RHE (°C)

Greek symbols

λ, γ	parameters for heat transfer models of CHE, HHE or RHE
$\omega_{s,bot,D}$	concentration of desiccant solution in bottom of dehumidifier (%)
$\omega_{s,bot,R}$	concentration of desiccant solution in bottom of regenerator (%)

LDAC driven by chiller and hot water is one of the typical applications used in building air cooling and dehumidification [18]. Experimental and theoretical studies were carried out by Bouzenada et al. [19] to analyze performance of LDAC driven by evacuated-tube (ETC), flat-plate (FPC) and hybrid solar thermal arrays under different climates. They concluded that cost savings and design flexibility can be improved by adopting a ratio of 30% FPCs and 70% ETCs. Zhao et al. [20] developed a LDAC system driven by heat pumps and chilled water to be implemented in an office building to achieve air temperature and humidity independent control. Compared with the conventional air conditioning system, the testing results demonstrated big energy saving potential with accepted comfortable indoor environment as well. Qi et al. focused on the energy performance of solar-assisted LDAC systems in commercial buildings for four main climate regions [21]. Simulation results showed that building sensible and latent load ratio seriously impacts energy performance of solar assisted LDAC and best performance can be achieved in humid areas.

There is no doubt that LDAC is with the benefits of high energy efficiency compared with conventional air conditioning system. However there is still considerable space to improve the system control, efficiency, capacity, and economics of LDAC by suitable system optimal control and energy management [22]. Optimal control technologies have been widely studied for Heating, Ventilation and Air Conditioning (HVAC) systems based on Genetic Algorithm (GA) [23], Particle Swarm Optimization (PSO) [24,25] and evolutionary computation algorithm [26]. To further explore the energy saving potential of LDAC systems, more and more attentions have been paid on the research of optimization technologies for LDAC systems to get a better application in building HVAC area with improved comfort and economic benefits. Ge et al. [15] developed an optimal control strategy for liquid desiccant based Dedicated Outdoor Air-Chilled Ceiling system (DOAS-CC) by employing Genetic Algorithm to improve the system energy performance and indoor thermal comfort. Qi et al. [27] optimized system control parameters of a solar assisted LDAC system for buildings in different climates with multi-population GA to obtain maximum energy savings with a minimum cost payback year. Audah et al. [28] indicated the feasibility of supplying both building cooling capacity and fresh water needs with minimal energy