Applied Energy 138 (2015) 533–545

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Experimental assessment of the energy performance of a hybrid desiccant cooling system and comparison with other air-conditioning technologies

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HIGHLIGHTS

- Performance of a desiccant cooling system are investigated through energy analysis.
- Both the overall hybrid system and the desiccant rotor alone are analyzed.
- The effect of five operating variables on performance is analyzed.
- Suitable working range for each operating variable is defined.
- Energy and emissions comparisons with other air-cooling technologies are performed.

ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 2 September 2014
Accepted 24 October 2014
Available online 21 November 2014

Keywords:
Desiccant cooling
Air handling unit
Microcogenerator
Performance parameters
Energy analysis
Air-conditioning

ABSTRACT

Desiccant-based air handling units (AHU) can allow significant energy saving and emissions reductions with respect to conventional air-conditioning systems. In this work, experimental tests are used to investigate a hybrid desiccant cooling system (DCS) with desiccant wheel (DW), interacting with a small scale cogenerator.

Several new contributions are introduced by this study, such as the high number of operating conditions analyzed and of performance parameters used, the definition of a new COP and a comparison of the DCS with other air-conditioning options.

The performance were analyzed varying five operating conditions: regeneration temperature, rotational speed, volume air flow rates, outdoor air temperature and humidity ratio. Several performance parameters, based on electric, thermal and primary energy, are investigated.

Thermal performance of both the overall hybrid DCS and the DW reduce when regeneration temperature or flow rate increase, while electric and primary energy based parameters rise. Optimal operation is instead found for a narrow range of rotational speed.

The hybrid DCS with microcogenerator is compared with other thermal or electrical air-conditioning technologies. The investigated DCS performs better or at least equal than the other thermally-activated systems, while the result of the comparison with the conventional electric unit depends on the outdoor air conditions.

1. Introduction

Desiccant cooling systems (DCS), using either solid [1–3] or liquid [4,5] desiccant materials, are an interesting alternative to conventional systems with electrically-driven vapor compression cooling units, [6–9]. The main energy requirement is low temperature heat, which can be supplied by thermal wastes [10] or solar thermal energy [7,11], typically integrated with an auxiliary fossil-fuelled system. In a hybrid DCS an electric chiller contributes to balance the sensible load.

Desiccant dehumidification until now has been mostly used in niche markets (electronics, food and arms storage, pharmaceutical industry, hospitals). During last years, thanks to its benefits, this technology is also spreading in applications with high latent loads, such as supermarkets, ice arenas, restaurants, theatres, schools and museums, as well as in residential and tertiary sectors; nevertheless, this technique is still rarely implemented in Europe, due to several obstacles, such as high investment costs, low familiarity, lack of knowledge about performances and cost/benefit ratio.

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http://dx.doi.org/10.1016/j.apenergy.2014.10.065
0306-2619/

Nomenclature

COP	Coefficient of Performance, –
E	energy, MWh
F_{bp}	by-pass factor, –
h	enthalpy, kJ/kg
$\dot{m}$	mass flow rate, kg/s
N	rotational speed, rev/h
NE	net energy, MWh
P	power, kW
PE	primary energy, MWh
PER	primary energy ratio, –
t	temperature, °C
$\dot{V}$	volumetric air flow rate, m^3/h

Acronyms

ACH	absorption chiller
ADCH	adsorption chiller
AHU	air handling unit
CHP	Combined Heat and Power
DCS	desiccant cooling system
DW	desiccant wheel
HP	heat pump
HVAC	eating ventilation and air-conditioning
LDAC	liquid desiccant air-conditioning
MCHP	Micro Combined Heat and Power
SP	separate production
VCS	vapor compression system

Greek symbols

$\Delta CO_{2,eq}$	avoided equivalent CO_2 emissions, –
ε_{hc}	effectiveness of the heating coil, –
η	efficiency, –
μ	specific emission factor, $g_{CO2,eq}$/kWh
ω	air humidity ratio, g/kg
τ	time, s

Subscripts

conv	conventional
Cool	cooling
$CO_{2,eq}$	equivalent carbon dioxide
El	electric
Fuel	fuel primary energy
NG	natural gas
out	outdoor
PE	primary energy
proc	process air
ref	reference system
reg	regeneration air
s	saturated condition
sup	supply air
sorpt	sorptive
Th	thermal
tot	total

Superscripts

ACH	absorption chiller
ADCH	adsorption chiller
AHU	air handling unit
aux	auxiliaries
comp	chiller compressor
DCS	desiccant cooling system
fan	condenser fan
GB	gas boiler
MCHP	micro combined heat and power
ph	post heating
SP	separate production
VCS	vapor compression system

Energy performance assessment of DCS is a non-trivial task; several parameters have been used in literature to evaluate the energy performance of DCS, assessing the effect of several operating parameters. Exergy analysis of both solid and liquid DCS has also been performed, [12,13].

Actually, every DCS is very peculiar, and no standards exist about testing or performance coefficients definition. However, a reasonable and meaningful comparison between the different installations can be effectively carried out if several performance parameters are contemporary used, related to the overall system, to the air handling unit (AHU) only or to a part of it (such as the desiccant rotor). These performance parameters should allow to overcome the peculiarities of each system, taking into account the specific layout of the AHU, the energy requirements of the system (electricity, heat, primary energy) and the energy conversion devices used (based on either fossil fuels or renewables). Such performance parameters can also be used to compare a DCS with other air-conditioning technologies, in order to assess the more suitable system for a given application and climatic condition.

The COP is the commonly used parameter to characterize the performance of cooling equipment; it is the ratio between the useful cooling effect to the required energy input. For DCS, different COPs can be defined: the thermal COP considers heat input for regeneration, while the electric COP considers electric energy input, for auxiliaries and chiller, in the case of hybrid DCS. Furthermore, the COP can take into account the overall cooling effect, or only the amount which is not covered by the cooling coils, if any; in this case, it is usually defined as sorptive COP.

Henning et al. [2] presented the design of an advanced desiccant air handling unit using a high efficient combination of a vapor compression chiller and a desiccant wheel (DW). Electricity for the chiller was supplied by a CHP (Combined Heat and Power) system and thermal energy to regenerate the desiccant material was the recovered heat from the CHP. In order to compare the performance of the different layouts, several performance figures were defined. The sorptive COP varied in the range 0.41–1.34 and the electricity saving with respect to a reference system varied in the range 25.6–34.3%, depending on the system configuration.

Panaras et al. [14] identified the main design parameters of a solid desiccant air-conditioning systems, and investigated their effect on the performance of the systems. The air flow rate, the regeneration temperature, the operation cycle and the subsystems level of performance constituted the design parameters. The thermal COP reduced with both regeneration temperature and air flow rate, and it was higher for the ventilation cycle (maximum value of about 0.5) than the recirculation one (maximum value of about 0.4). The COP raised to 0.85 for the ventilation cycle in the case of high level performance of the desiccant rotor.

Heidarinejad and Pasdarshahri [15] developed a desiccant cooling model and applied it to different operating modes of the system. The effects of the regeneration temperature and rotational speed of the desiccant wheel on thermal COP were investigated. The COP reduced when regeneration temperature increased and when rotational speed decreased. Maximum values in the range 0.25–0.29 were found for the minimum regeneration temperature investigated (60 °C).