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# Hybrid liquid desiccant air-conditioning systems: A conceptual study with respect to energy saving potentials

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ABSTRACT

In conventional air-conditioning systems with vapour compression cycles the dehumidification is realised by cooling the air below the dew point of the supply air. One possibility to avoid cooling the air below the dew point and thus to reduce the electric energy demand of air-conditioning systems is hybrid liquid desiccant air-conditioning systems (HLDACS) which use an open absorption cycle for dehumidification of the air. This conceptual study examines four different HLDACS with respect to their electric energy demand and shows energy saving potentials compared to a conventional air-conditioning system for three different climatic design conditions. All considered systems consist of an open absorption system in combination with either a vapour compression system (VCS) or an indirect evaporative cooling system. The results show that electric energy savings of 30–60% depending on the HLDACS and climates are possible.



# Systèmes hybrides de conditionnement d'air à déshydratant liquide: Une étude conceptuelle selon les potentiels d'économie d'énergie

*Mots clés :* Système hybride de conditionnement d'air ; Économie d'énergie ; Déshydratant liquide ; Déshumidification

## 1. Introduction

The energy demand for heating, ventilation and air-conditioning of buildings represents an important share of the worldwide energy consumption. The electricity demand for the cooling of buildings is still increasing and scenarios assume that the worldwide electricity consumption of cooling will increase to about 4000 TWh in the year 2050 and will further increase up to 10,000 TWh in the year 2100 (Isaac and van Vuuren, 2009).

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**Nomenclature**

| | |
|---|---|
| $c_p$ | specific heat capacity [kJ kg$^{-1}$ K$^{-1}$] |
| $h$ | specific enthalpy [kJ kg$^{-1}$] |
| $\dot{m}$ | mass flow rate [kg s$^{-1}$] |
| $P_e$ | electric power [kW] |
| $\dot{Q}$ | thermal power [kW] |
| $\dot{Q}_0$ | cooling capacity [kW] |
| $\dot{Q}_c$ | condenser capacity [kW] |
| $T$ | temperature [°C] |
| $T_0$ | evaporation temperature [°C] |
| $T_C$ | condensing temperature [°C] |

*Greek symbols*

| | |
|---|---|
| $\eta_i$ | isentropic efficiency |
| $\eta_{mech}$ | mechanical efficiency |
| $\omega$ | absolute humidity [$g_{H2O}$ kg$^{-1}_{a,dry}$] |

*Subscripts*

| | |
|---|---|
| a | air |
| dil | dilution |
| dry | dry |
| abs | absorber, absorption |
| d | (liquid) desiccant |
| evap | evaporator |
| heat | heating |
| in | inlet |
| out | outlet |
| ref | refrigerant |
| reg | regeneration, regenerator |
| tot | total |
| vap | vapour |

*Abbreviations*

| | |
|---|---|
| ACS | air-conditioning system |
| COP | coefficient of performance |
| EER | energy efficiency ratio |
| EHA | exhaust air |
| ETA | extract air |
| FDM | finite difference model |
| HLDACS | hybrid liquid desiccant air-conditioning system |
| HRU | heat recovery unit |
| ODA | outdoor air |
| R | reference |
| SUP | supply air |
| VCS | vapour compression system |

The reduction of the electricity consumption in air-conditioning systems (ACS) is therefore a major concern with respect to worldwide energy efficiency goals.

In conventional ACS with a vapour compression system (VCS) the dehumidification of the air is realised by cooling the air below the dew point of the supply air. As a result the air needs to be reheated after dehumidification before entering the rooms. The conventional dehumidification and reheating of the air is very energy-consuming. The energy demand can be reduced by the separation of the dehumidification process from the cooling process for example by hybrid liquid desiccant air-conditioning systems (HLDACS). Such a system consists mainly of a cooling unit and an open absorption system which includes a dehumidifier (absorber) and a regenerator. There are various options of the technical design of the components. The absorber and regenerator can be realised e.g. as packed column, flat plate or tube bundle heat and mass exchangers (Mei and Dai, 2008). The most widespread type for the cooling unit is a VCS which either supplies chilled water or cools the air directly. Other possible types of cooling units can be a vapour absorption system or an evaporative cooling system.

During the last decade a lot of research related to HLDACS has been carried out. Dai et al. (2001) for instance examined a system which contains an open absorption system combined with a VCS and evaporative cooling. They developed a mathematical model to predict the performance of the system and validated the model with experimental data. It was concluded that the electric power required by the VCS of the hybrid system could be reduced by about 43% compared to a conventional ACS. Yamaguchi et al. (2011) developed a HLDACS which integrates absorber and evaporator as well as condenser and regenerator. This system was simulated with Simulink and afterwards compared with experimental data. They focussed on parameters which influence the COP of the HLDACS. The HLDACS developed by Chen et al. (2014) uses the condenser heat for regeneration. The COP of the hybrid system was more than twice as high as for a conventional system for a sensible to latent heat load ratio of 1:2. However they pointed out that with increasing latent heat the COP of the hybrid system decreases due to the increase in required condensation heat for the regeneration.

Several reviews are available (Daou et al., 2006; Mei and Dai, 2008; Mohammad et al., 2013) which summarize previous research with respect to the combination of liquid desiccant systems with vapour compression systems. These reviews give a good overview about different systems. However the various systems are hardly comparable since the technical conditions as well as the climatic conditions are quite different. A single comparison of one HLDACS with a conventional VCS can be found quite often in literature (Bergero and Chiari, 2010; Dai et al., 2001; Yadav, 1995) but a comparison of more than two HLDACS for different climatic conditions is not available. Dai et al. (2001) for instance studied two HLDACS: An open absorption system combined with VCS on the one hand with an open absorption system combined with VCS and evaporative cooling on the other hand. Capozzoli et al. (2006) analysed in a case study a liquid desiccant system and a hybrid system with a desiccant wheel for supermarket applications for three different cities in Italy. They studied the performance and operating costs of the hybrid systems compared to a conventional system with the result that operating cost savings between 5 and 13% are possible. Furthermore they concluded that electric power savings for air-conditioning are between 27 and 46%. Ronghui et al. (2014) examined by a simulation the cooling