

Theoretical Performance Analysis of a Liquid Desiccant Air-Conditioning System for Air Heating and Cooling

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Abstract

A novel concept is proposed for a liquid desiccant air conditioning system (LDAC) for low-energy residential and commercial buildings in central and southern European countries. The concept uses a simple air-handling unit usually applied in these buildings to provide the hygienically required air change rate. The absorber component of the LDAC is installed in series with an air to air heat recovery device in the return air stream. Two operation modes are investigated: heating in winter time and cooling during summer time. In a first step, the efficiencies of the absorber component of the LDAC are studied on the basis of detailed steady state simulations. For both operation modes the ratio of the air to desiccant flow rates are varied to match an optimal flow configuration. In a second step, the performance analysis consists of an annual system simulation. Here, the parameter variation aims at maximizing the storage capacity and the solar fraction.

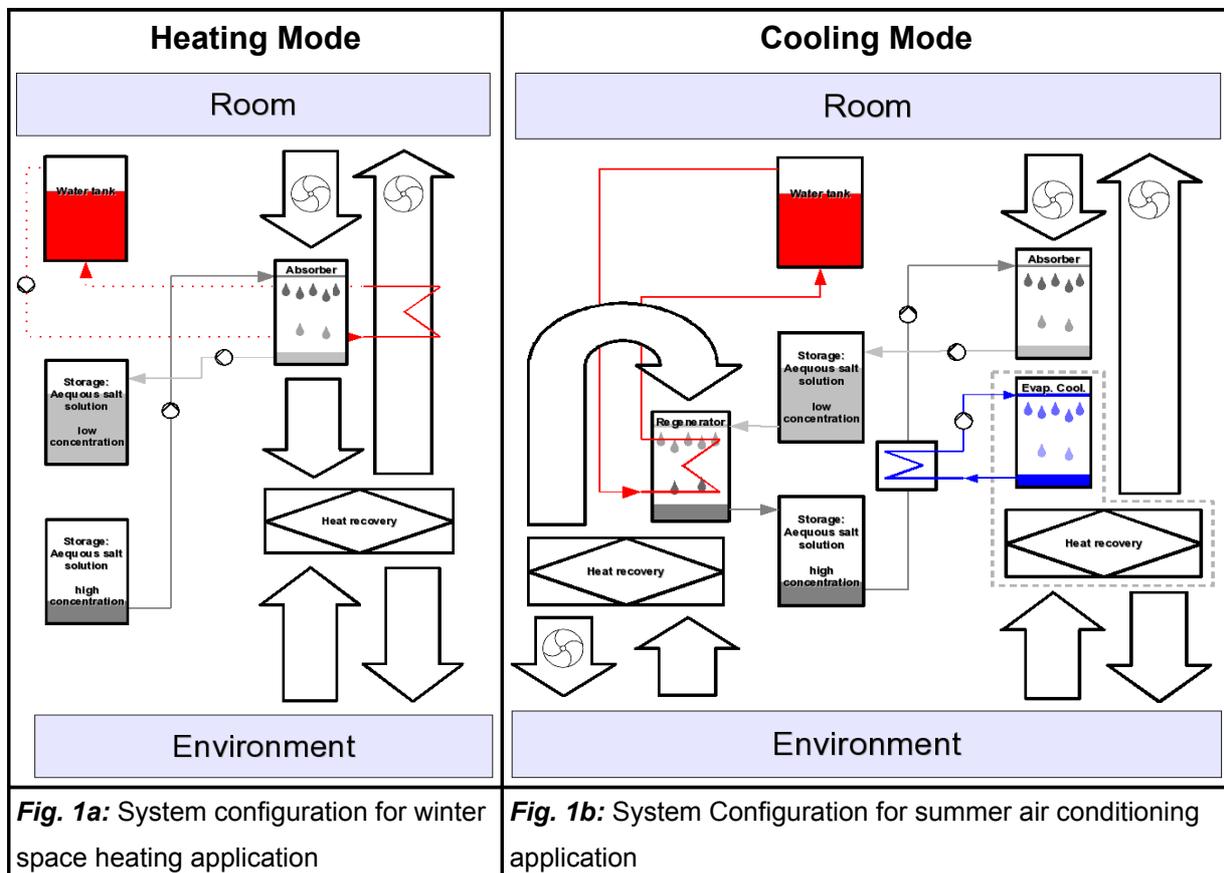
1. Introduction

Liquid desiccant air-conditioning components and systems have been investigated as direct air dehumidification systems [Lowenstein 2006], as cooling water generators [Lävemann 2005] or as assisting devices for increasing the potential of indirect evaporative coolers [Pietruschka 2006]. These application types include only the direct use of the liquid desiccant system in summer operation. During winter operation the liquid desiccant part is not used in the preceding concepts. The LDAC under investigation includes both operation modes.

In the presented study, a novel concept is proposed for a LDAC system to be applied in low-energy residential and commercial buildings in central and southern European countries. In this system a simple air-handling unit is used to provide the hygienically required air change rate. The absorber component of the LDAC is installed in the

return air stream in series with an air-to-air heat recovery device. Two operation modes i.e. heating and cooling are investigated:

- Figure 1a shows the heating mode. The aqueous salt solution used as desiccant e.g. lithium chloride or calcium chloride solution absorbs the moisture from the return air stream. Through the release of condensation and dilution enthalpy the air stream is heated. The heated exhaust air is then used in an air-to-air heat exchanger to heat the fresh air stream. The heating mode takes advantage of the system's lossless chemical heat storage [Kessling 1998]. The heat is stored by means of the concentration shift of the aqueous salt solution. The system acts as a seasonal heat storage as it concentrates and stores the aqueous salt solution during summer time using solar thermal energy for regeneration.



- Figure 1b shows the cooling mode. The absorber acts as an assisting device to increase the power of an indirect evaporative cooler, as proposed by [Pietruschka 2006]. An evaporative cooler is added in the exhaust air stream between the absorber and the heat recovery device. First, the exhaust air is dehumidified in

the absorber with a quasi-isothermal process. The desiccant is cooled with the circulating water of the evaporative cooler. In a second step, the dry exhaust air is saturated and cooled in the evaporative cooler. In the heat recovery device the warm fresh air can be cooled to the desired conditions.

2. Modelling and Parameter Variation for Absorber

A new design for the absorber component is proposed employing a porous layer as the condensation area of the absorber. The advantages of a parallel plate heat exchanger are preserved i.e. homogenous air flow cross section to prevent carry-over of the aqueous salt solution into the air [Lowenstein 2006], high specific heat and mass exchange area, low pressure drop and compact design. In addition, the distribution of the liquid desiccant is expected to be more even.

In order to predict the heat and mass transfer performance of the absorber component, a semi-empirical model was implemented. The model is based on the effectiveness model proposed by [Stevens 1989]. It assumes an adiabatic reaction zone and calculates the heat transfer coefficient based on a Nusselt correlation taking into account the reaction zone geometry. The Lewis-Number correlation is used to relate the heat and mass transfer coefficients. The model assumes that convection effects dominate the general heat and mass transfer in the absorber. For the assumption of a neglectable change in the desiccant and air mass flow rate, the model calculates the output temperatures, humidities, concentrations and mass flow rates of air and desiccant with the effectiveness of a counter flow heat exchanger. This assumption could be validated up to a mass flow ratio between air and desiccant of 40. For higher mass flow ratios the model was extended to a one-dimensional multi-node model. The number of nodes are adjusted so that for each node the change in desiccant mass flow rate is within the model validity. The advantage of this model over finite difference models is a much faster calculation time that makes the effectiveness model more suitable for system simulations with TRNSYS. The effectiveness model was validated with the finite difference model by [Mesquita 2004].

Figures 2a-d show simulation results calculated with the effectiveness model. The model is used to dimension the absorber component and to predict its heat and mass transfer performance. The calculations are performed for three different desiccant flu-

ids: Calciumchloride (CaCl_2), lithiumchloride (LiCl) and a mixture of calciumchloride and calciumnitrate ($\text{CaCl}_2\text{-Ca}(\text{NO}_3)_2$, formerly known as Klimat3930). The physical properties for these desiccants are taken from [Conde 2004 and Waldenmaier 1998].

The calculations are all done for constant input values:

$T_{\text{air}} = 20\text{ }^\circ\text{C}$, r.h. = 50% (relative humidity of the return air), $\dot{m}_{\text{air}} = 300\text{ kg/h}$, $T_{\text{des}} = 20\text{ }^\circ\text{C}$, $C_{\text{LiCl}} = 44\%$, $C_{\text{CaCl}_2} = 40\%$, $C_{\text{CaCl}_2\text{-Ca}(\text{NO}_3)_2} = 62\%$.

A sensitivity analysis was carried out for the mass flow rate of the liquid desiccant (with $\dot{m}_{\text{air}}/\dot{m}_{\text{des}} = 100$) and for the ratio of the air to the desiccant mass flow rates (with $\dot{m}_{\text{air}}/A_{\text{abs}} = 42\text{ m}^3/\text{h}-\text{m}^2$).

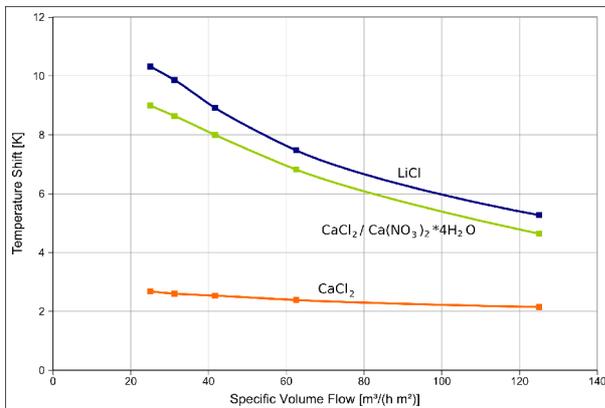


Fig. 2a: Temperature shift in the absorber over the specific volume flow rate.

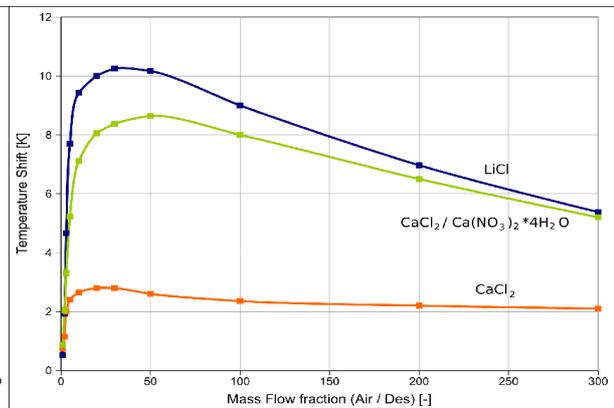


Fig. 2b: Temperature shift in the absorber over the mass flow rate ratio.

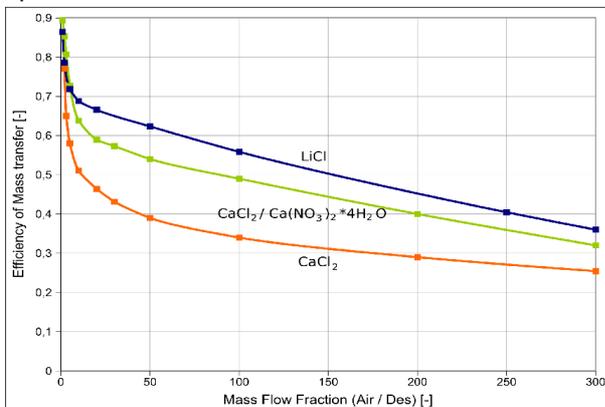


Fig. 2c: Efficiency of mass transfer in the absorber over the mass flow ratio.

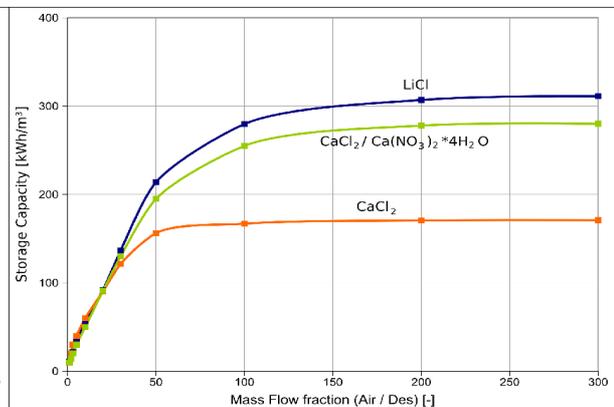


Fig. 2d: Storage capacity over the mass flow ratio.

Figure 2a shows the increase in air temperature of the exhaust air in the absorber over the specific air volume flow rate at a constant air to desiccant mass flow ratio of 100. By increasing the absorber's exchange area (shown from right to the left in figure 2a), the temperature shift increases for LiCl and $\text{CaCl}_2\text{-Ca}(\text{NO}_3)_2$ from about 5 to about 10 K. CaCl_2 has a very low performance as it increases only about 3 K.

Figure 2b shows the temperature shift in the absorber over the air to desiccant mass flow ratio. A mass flow ratio of 50 yields a maximum temperature shift of 10.1 K for LiCl, 8.2 K for CaCl₂-Ca(NO₃) and for CaCl₂ to 2.7 K. Mass flow ratios between 20 and 100 turn out to be most sufficient for the heating mode. For the cooling mode mass flow ratios of about 1 are more favourable (temperature shift < 0.5 K).

In figure 2c the efficiency of the mass transfer is shown over the air to desiccant mass flow ratio. The efficiency decreases fast with an increasing mass flow ratio for small values of the mass flow ratio, but it reaches a reasonable result of about 58% for LiCl and of about 50% for CaCl₂-Ca(NO₃) at a mass flow ratio of 100. For the cooling mode the efficiencies result to values near to 90% for all desiccants. The higher the air to desiccant mass flow ratio, the higher the concentration shift of the desiccant solution and therewith the storage capacity turn out.

Figure 2d illustrates the storage capacity over the air to desiccant mass flow ratio. An air to desiccant mass flow ratio of 100 yield a reasonable storage capacity of about 250 kWh/m³ for both, LiCl and CaCl₂-Ca(NO₃).

Generally, the study reveals that CaCl₂ is not useful for this application. In opposite, LiCl and CaCl₂-Ca(NO₃) show a very similar and good performance.

3. Annual Simulation Results

The performance of the whole LDAC system is examined in an annual TRNSYS simulation. The simulation project consists of a solar flat plate collector cycle with 20 m² aperture area, a hot water combi storage with a volume of 1000 ltr, an auxiliary gas heater with 10 kW power, a dynamic building model for a single family house of 140 m² floor area and an annual space heating demand of 30 kWh/m² a. Furthermore the air conditioning system was implemented as shown in figure 1b. In the desiccant cycle a 4m³ tank was utilized filled with CaCl₂-Ca(NO₃) at an initial concentration of 62%. The project was examined under the climatic conditions of Zurich.

The control of the air conditioning system has three modes for cooling operation: a) controlled ventilation, b) indirect evaporative cooling and c) indirect evaporative cooling with assisting pre-absorption. The heating control consists also of three modes: a) controlled ventilation with heat recovery, b) heating by the absorber, and c) auxiliary heating by solar thermal system or gas burner.

The simulation results reveal that active cooling was used during 819 h/a. At 28% or 230 h/a of this time the air conditioning system operated in mode c). The cooling load could be covered at 96% of the total active cooling time.

For the heating operation the calculations reveal the following results: The total space heating demand of the building amounts to 4223 kWh/a. It was partially covered by the absorption storage by contributing 1097 kWh/a. The solar thermal system contributed directly with 1922 kWh/a. The auxiliary gas burner added the remaining 1204 kWh/a. Hence, the achieved annual fractional savings result to 69.3%.

4. Conclusion and Outlook

The simulation studies showed that the novel system concept of a liquid desiccant air conditioning unit combined with an indirect evaporative cooler, used for combined heating and cooling applications is very promising. Further simulation studies have to be conducted to find optimal system configurations. Furthermore, prototypes of the components are being developed in order to test the concept in laboratory scale and validate the numerical component models.

5. References

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