Regenerator Design for Open Cycle Liquid Desiccant Systems –

Theoretical and Experimental Investigations

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1.   System Concept

In Australia, almost every residential and commercial space heating system is air-based. About half of these systems use electrical reverse cycle air-conditioners to provide the heat, whereas the others are based on natural gas. These air based heating systems, which are mainly recirculation systems, represent a good opportunity to integrate open cycle air conditioning concepts into domestic air conditioning using a single heating and cooling distribution system.
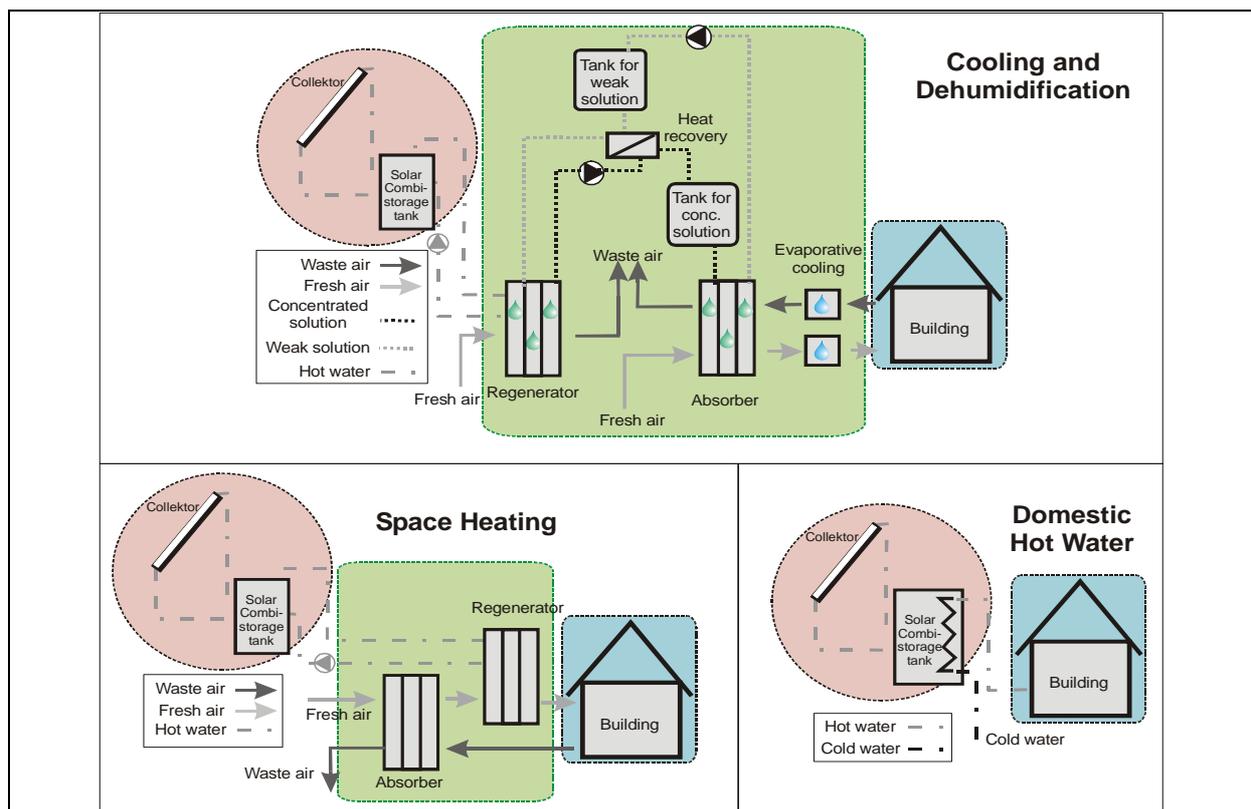
Figure 1: Possible system design for a combination of solar hot water generation, space heating and air conditioning. The regenerator serves for drying the desiccant solution in the cooling mode or as a water-to-air heat exchanger for space heating. For the latter, the desiccant circuit and the evaporative cooling stages are not in operation, whereas the absorber can provide heat recovery.

A possible system concept for an integrated system, which reduces overall costs for heating, cooling and domestic hot water, is shown in Figure 1. In particular for humid climates, the application of open cycle liquid desiccant systems is a promising option for solar assisted air-conditioning. The main components of these systems are the absorber, regenerator, indirect and/or direct evaporative cooling units for the dehumidified fresh air and heat recovery stages for both, the desiccant solution and the regeneration air. In the absorber, ambient air is directly dehumidified using salt solutions, such as LiCl or $CaCl_2$. After absorbing the moisture, the desiccant solution needs to be regenerated and solar thermal energy can be used to drive the process. With additional solution storage tanks, dehumidification of the fresh air is possible even at times, when no solar energy is available.

2. Experimental investigation

In previous investigations at the University of South Australia, a plate heat exchanger design was used for the absorber and an open cycle solar air collector to regenerate the desiccant solution [1]. As most solar collectors in use are water or water/glycol based, a new regenerator prototype, which uses hot water for the regeneration process, has been developed. Like the absorber, the regenerator has been designed as a plate heat exchanger and the following requirements have been considered:

Requirement	Measure
Low air pressure losses	Plate heat and mass exchanger design, 23.7 m² surface area
No corrosion	Plastic construction
Cheap plates with good heat transfer through plates and high stability and thermal resistance	43 Polypropylene twin walls, 5 mm thickness, 6 mm distance
Good surface wetting of the plates to maximise the transfer area	Using cotton as a coating material and an irrigation system to apply the solution
No carry over	Irrigation system with perforated tubes on top of each plate: 100 outlets, diameter 0.32 mm each, low desiccant flow rates
High heat and mass transfer	High air velocities, mass flow rates of about 1800 kg/h
Good performance	Internal heating (regenerator) and counter/cross flow arrangement
High collector efficiencies	Low driving temperature of about 70°C
High concentration lifts	Low desiccant flow rates of about 1.5-4 L/h m²

Table 1: Specifications of the regenerator prototype

A photograph of the regenerator prototype is shown in Figure 2. Similar designs have been investigated before for water cooled absorber constructions [2].

Figure 2: Photograph of the regenerator prototype. Air flows from the bottom to the top in between the plates of the regenerator, desiccant solution wets the cotton layers, introduced by an irrigation system on top of each plate and hot water flows through the channels of the twin walls from the bottom of the front manifold to the top of the rear manifold in a counter/cross flow arrangement.

3.   Model development

As shown in Figure 3, the numerical models for the absorber and the regenerator are developed as two-dimensional models. In the case of the regenerator, the enthalpy balances for the hot water flow, the desiccant film and one air stream are determined for each of the elements along the channels. In the absorber, two air streams, a desiccant film, and a water film are considered. For each element, heat and mass transfer from the desiccant and the water film, respectively, to the air streams as well as heat transfer through the heat exchanger plates are determined simultaneously. The single enthalpy equations follow approaches from [3]. The heat transfer coefficients are determined using Reynolds and Nusselt number relationships. With these coefficients, the mass transfer coefficients follow from the Lewis analogy.
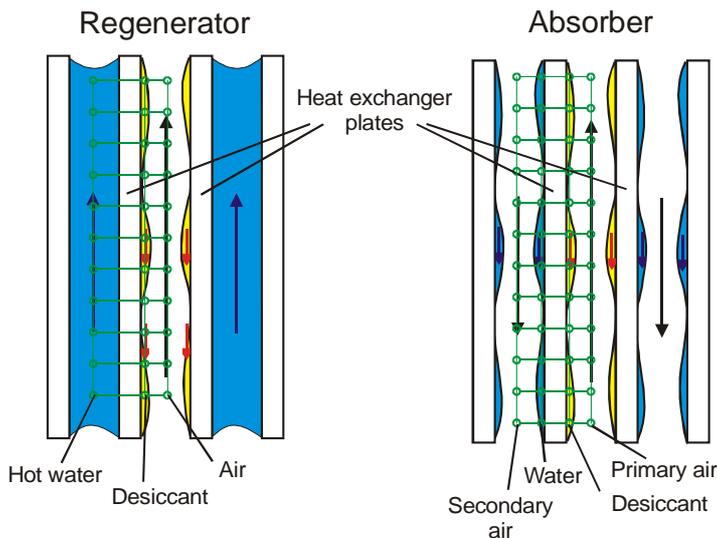

Figure 3: Schematic of the numerical models for the regenerator and the absorber. As indicated by the grid, both models are implemented as two-dimensional models. For each grid point, the enthalpy of the respective fluid is calculated for every time step during the simulation.

4. Results and Conclusion

Figure 4 shows the modelled influence of the hot water temperature on the regenerator performance. It can be seen that the driving hot water temperature has a distinct influence on the moisture removal. With 85°C, a desiccant concentration of 0.38 can be achieved whereas with 60°C, only 0.33 is possible. However, the solid lines demonstrate that the same desiccant concentration of about 0.38 can be achieved if both, water and air flow rates, are increased by a factor of 2.5.
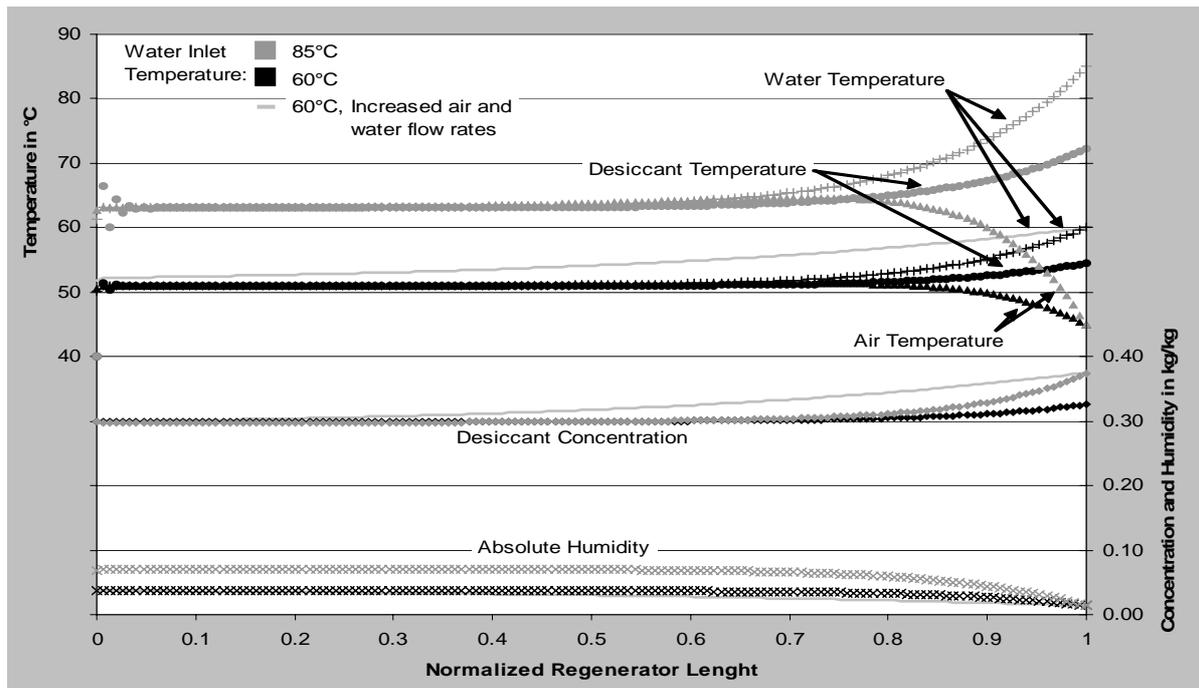
Figure 4: Influence of the hot water temperature on the performance of the regenerator. Here, water and air flows from the right hand side to the left hand side, whereas desiccant is streaming in the opposite direction. The simulation parameters are: transfer area of the regenerator: 23.7 m², mass flow rate of dry air: 1800 kg/h, water mass flow rate: 350 kg/h, desiccant mass flow rate: 50 kg/h.

In order to increase the overall efficiency of the system considering all three modes, optimal sizes and types of all components have to be determined. For this, a TRNSYS system model, consisting of a typical Australian single family house (ground floor area: 170 m²), designed as a solar combi-system (A_{coll}: 18 m², V_{tank}: 1.5 m³) with an open cycle liquid desiccant cooling system has been developed. Using the Brisbane climatic data, the cooling and dehumidification performance has been determined for different system configurations. A measure for this performance was the required additional cooling and dehumidification demand to ensure the desired building comfort conditions of 26°C and 50 % relative humidity as well as the required auxiliary heat demand for space heating, cooling and domestic hot water.

Figure 5 demonstrates that a liquid desiccant system can reduce the additional dehumidification and cooling demand of the investigated building considerably. The variation of desiccant and the regeneration hot water flow rates show that small flow rates lead to high efficiencies of the whole system.
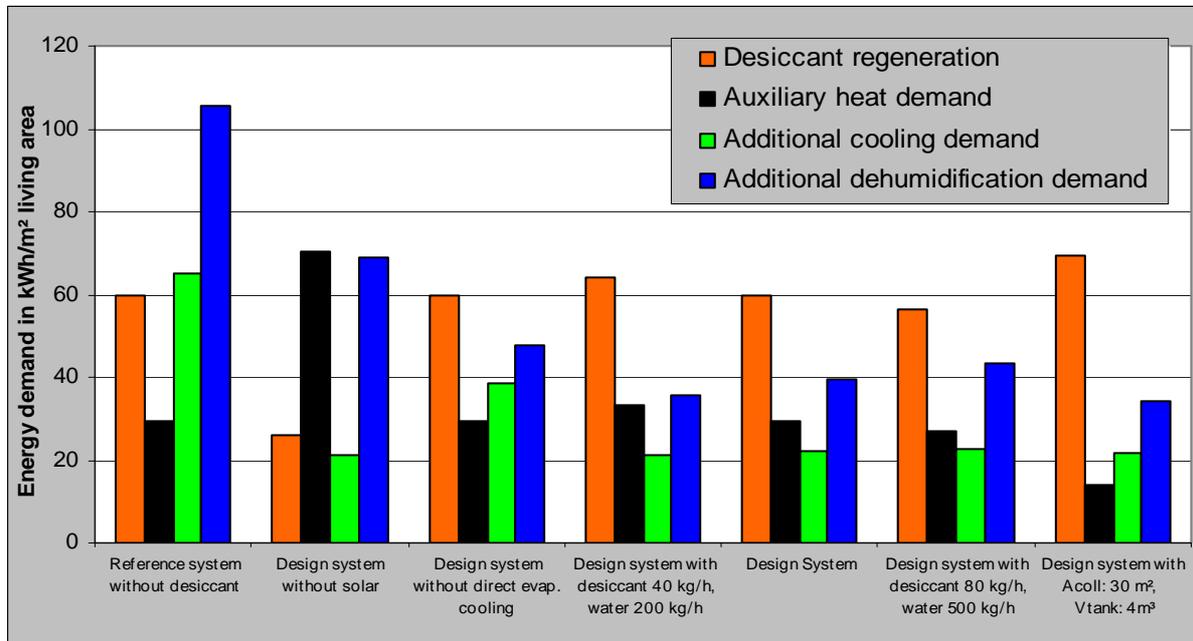
Figure 5: System performance for different system configurations. The specifications of the design system are: Ground floor area: 170m², A_{coll}: 18 m², V_{tank}: 1.5 m³, desiccant mass flow rate: regenerator: 60kg/h, absorber 50kg/h, regenerator water mass flow rate: 350kg/h. The values on the left hand side represent the energy demand of the building investigated, the second columns represent a system without a collector field and the third columns the system without an additional direct evaporative cooling stage. The last columns on the right hand side show the influence of the solar thermal system on the additional energy demand.

Work is currently in progress to evaluate the experimental performance of the regenerator prototype. With the results, further parametric studies of the regenerator and absorber components as well as the whole system will be carried out.

5.   Acknowledgments

6.   References

[1]   Alizadeh, S., Saman, W.: *An experimental study of a forced-flow solar collector/regenerator using liquid desiccants*, Solar Energy, Vol. 73, No. 5, pp 345-362, 2003.
[2]   Röben, J.: *Sorptionsgestützte Entfeuchtung mit verschiedenen wässrigen Salzlösungen*, Dissertation, Shaker Verlag, 1998.
[3]   Khan, A., Sulsona, F.: *Modelling and parametric analysis of heat and mass transfer performance of refrigerant cooled liquid desiccant absorbers*, International Journal of Energy Research, **22**, pp 813-832, 1998.