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Small Power Liquid Sorption Cooling for Building Ventilation Systems

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1- Introduction

Air conditioning in residential buildings is a large and growing market, almost exclusively covered by electrical compression systems. In order to supply this market with sustainable technologies the development of cost-effective solar or waste heat driven cooling systems is necessary. The widely used closed absorption technology does not cover the low power range under 10 kW cooling capacity, so that there is currently no alternative to electrical split units available. As buildings with low energy demand are often equipped with mechanical ventilation systems, it is obvious to consider air based thermal cooling technologies, such as open desiccant cooling systems (DCS), for low power applications. Small desiccant rotors, heat exchangers and humidifiers are market available for volume flows in the range of typical mechanical ventilation systems (around 300 $m^3 h^{-1}$ fresh air supply for single family houses). Liquid sorption systems have also been patented for such applications [1], but there is no system yet on the market and only limited experimental results are available [2]-[4]. Both conventional desiccant cooling units and liquid sorption systems dehumidify the outside air, which is then pre-cooled, humidified and injected into the rooms. The direct humidification of inlet air still causes concerns about hygiene. To avoid any hygienic problems, a new system configuration (Fig. 1) is proposed in this work, which shifts the whole air treatment to the exhaust air side and only uses sensible cooling for the outside air stream. As the cooling power is generated on the exhaust air side, the dehumidification process needs to be highly efficient to provide low supply air temperatures. As shown in Fig. 1, four different technological options for return air cooling were experimentally and theoretically investigated, with increasing integration of components and improvement of performance:

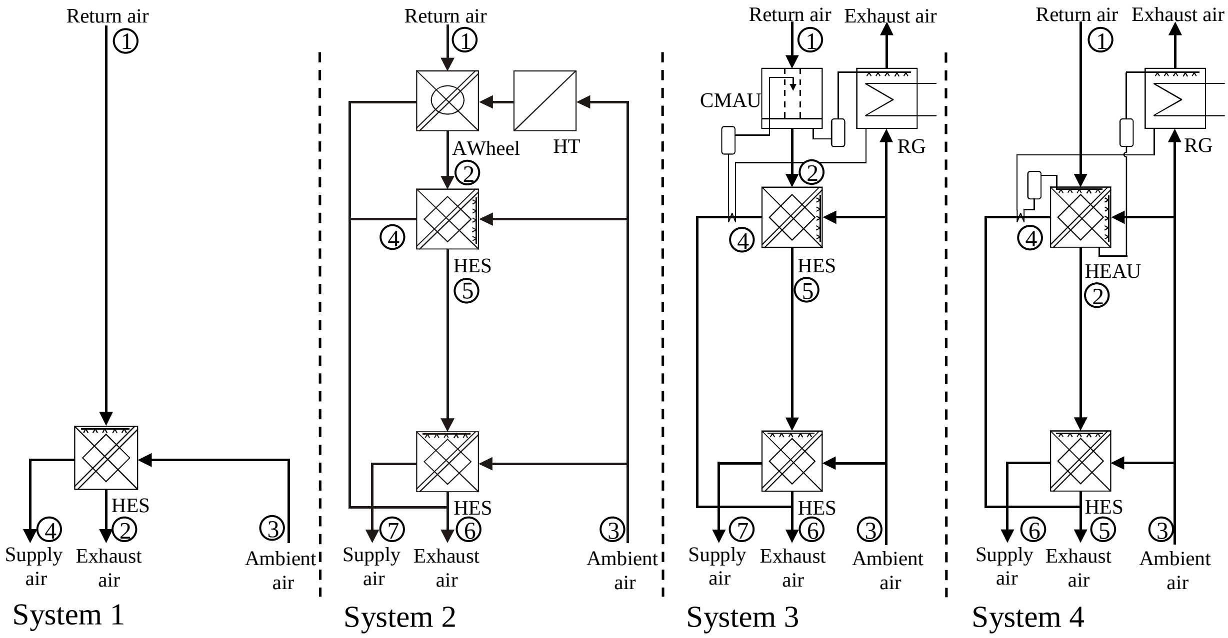

Fig. 1: Investigated systems, *System 1:* HES only. *System 2:* AWheel with two HES. *System 3:* CMAU and two HES. *System 4:* HEAU and one HES.

System 1: Simplest system; the supply air is just cooled by the return air in a cross flow heat exchanger (300 x 300 x 250 mm with 54 channels in each flow direction and a heat transfer efficiency of 70%), which is sprayed with water on the return air side for evaporative cooling (HES: Heat exchanger sprayed with water).

System 2: Basic desiccant cooling system; DCS with market available solid desiccant rotor (AWheel: ϕ =350 mm, 20 rotations h^{-1}) and two water sprayed cross flow heat exchangers (HES), one for pre-cooling of the dehumidified return air and one for supply air cooling.

System 3: Simple liquid desiccant system; the desiccant rotor of system 2 is replaced by a liquid desiccant sprayed onto a contact matrix absorber unit (CMAU: 300 x 200 x 150 mm, specific contact area A = 650 m^2/m^3). A regeneration unit (RG) for the liquid desiccant replaces the air heater of system 2.

System 4: Most integrated system; the liquid desiccant is directly sprayed into a cross flow heat exchanger absorber unit (HEAU: 300 x 300 x 250 mm with 54 channels in each flow direction and a heat transfer efficiency of 70%), which also integrates a spray humidifier on the secondary side. The number of components is now reduced to three.

The dehumidification process of the desiccant rotor and the liquid desiccant systems including the regeneration unit were experimentally analysed. Theoretical models have been developed for the liquid desiccant absorption and regeneration units and validated against the measurement data. A Lithium Chloride (LiCl) solution with a salt concentration of 43 % was sprayed into the liquid desiccant absorber units with a flow rate of 100 l/h.

2- Results

The different dehumidification processes were compared for a constant return air condition of 26°C and 55% relative humidity and air flow rates of 200 m^2 h^{-1}.The results are depicted in Fig. 2.

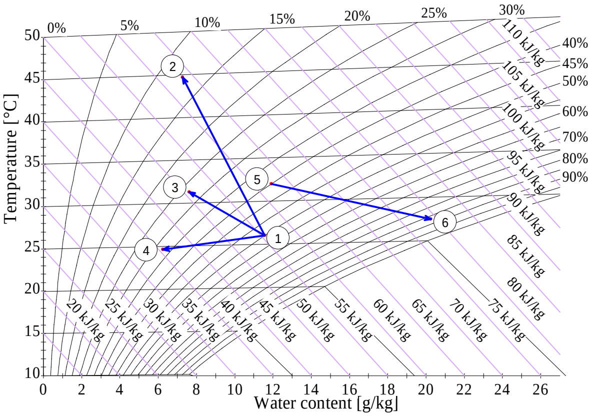

Fig. 2: Paths of return air dehumidification, *path 1-2*: AWheel; *path 1-3*: CMAU; *path 1-4*: HEAU; path 5-6: Humidification of the ambient air in the HEAU (return air inlet conditions: 26°C, 55%RH, 200 m^3 h^{-1}; ambient air inlet conditions (HEAU): 32°C, 40%RH, 200 m^3 h^{-1}).

As shown in Fig. 2, the return air humidity is reduced by about 4.3 g$_{Water}$ kg$_{Air}^{-1}$ in the investigated desiccant rotor (AWheel), while the temperature of the return air is increased by about 19 °C (Path 1-2). For regeneration of the desiccant rotor ambient air with 12 g$_{Water}$ kg$_{Air}^{-1}$ heated to a temperature of 70°C was used. In the contact matrix absorber unit the return air is dehumidified by 4.2 g$_{Water}$ kg$_{Air}^{-1}$ combined with an increase in the return air temperature of about 5 °C (Path 1-3). The highest return air dehumidification of 5.7 g$_{Water}$ kg$_{Air}^{-1}$ combined with a 1°C reduction in return air temperature is reached with the heat exchanger absorber unit. Path 5-6 shows the humidification and evaporative cooling process of the ambient air in the cooling channels of the heat exchanger absorber unit.

The main objective for all systems is to reach high cooling performances, which can be calculated from the reachable supply air temperatures. The supply air temperature was obtained using the experimental results from the different sorption units and a theoretical model for the water sprayed cross flow heat exchangers (HES). This model was developed similar to the HEAU model and used to calculate the cooling and humidification performance of the HES.

The paths describing the processes in the different systems are shown in the Mollier diagrams depicted in Fig. 3 - Fig. 6.

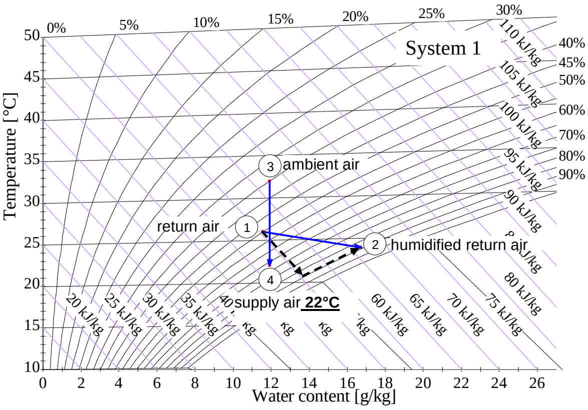

Fig. 3: System 1: *path 1-2*: humidification return air in HES(---> process can be described as isenthalpic humidification followed by further heating and humidification with constant relative humidity); *path 3-4*: cooling supply air in HES.

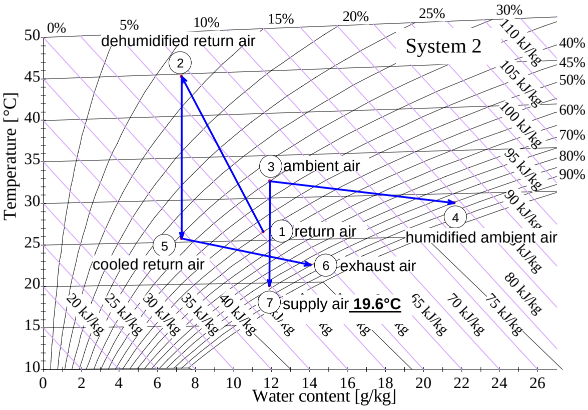

Fig. 4: System 2, *path 1-2*: dehumidification return air in AWheel; *path 3-4*: humidification ambient air in HES; *path 2-5*: cooling return air in HES; *path 5-6*: humidification return air in HES; *path 3-7*: cooling supply air in HES.

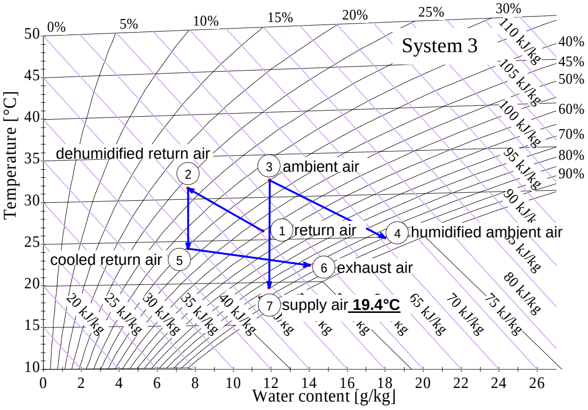

Fig. 5: System 3: *path 1-2*: dehumidification return air in CMAU; *path 3-4*: humidification ambient air in HES; *path 2-5*: cooling return air in HES; *path 5-6*: humidification return air in HES; *path 3-7*: cooling supply air in HES.

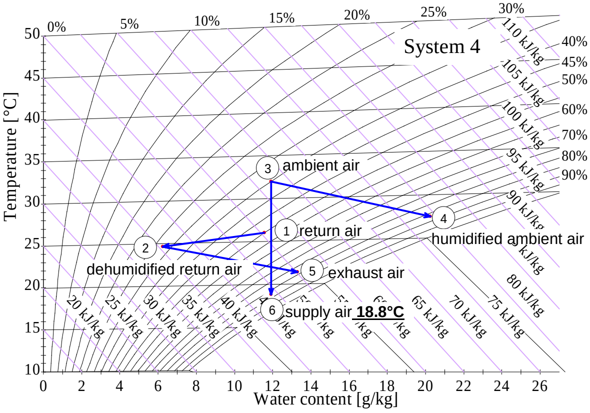

Fig. 6: System 4, path 1-2: dehumidification return air in HEAU; path 3-4: humidification ambient air in HEAU; path 2-5: humidification return air in HES; path 3-6: cooling supply air in HES.

The lowest supply air temperature can be reached with the heat exchanger absorption unit in system 4 (18.8°C), followed by the contact matrix absorption unit in system 3 (19.4°C) and the adsorption wheel in system 2 (19.6°C). The simplest supply air cooling in system 1, with just one water sprayed heat exchanger, reaches a supply air temperature of 22°C. However, the essential advantage of the heat exchanger absorber unit is the combination of the absorber, the heat exchanger and the humidifier in one single unit. This allows a very compact construction of an air conditioning system for residential buildings. Furthermore the liquid desiccant systems offer the possibility of a loss free storage of the concentrated solution, which enables the systems to produce the cooling performance independently from the actual solar irradiation and therefore avoids the necessity of an extra heating device for regeneration. The results for the summer design conditions of 32°C, 40%RH outside air and 26°C, 55%RH room air, are summarised in Table 1.

Table 1: Summary of performance results for different system technology options with 200 m^3h^{-1} supply air flow rate.

System description	t_{Supply} [°C]	Q_{Cool} [W]
System 1: Water sprayed heat exchanger (HES)	22.0	671
System 2: Desiccant rotor (AWheel) and two HES	19.6	832
System 3: Contact matrix absorber unit (CMAU) and two HES	19.4	846
System 4: Heat exchanger absorber unit (HEAU) and one HES	18.8	886

For the given design conditions of 200 $m^3\ h^{-1}$ volume flow, a maximum of 886 W cooling power can be achieved using the most integrated liquid desiccant system 4.

Additional analyses with the developed theoretical model of the HEAU and HES show, that if the surface wetting in the HEAU can be improved from currently only 35% to 60%, about 15% higher dehumidification rates can be achieved at significantly lower solution flow rates. A further improvement of system 4 can be reached, if the efficiency of the water sprayed cross flow heat exchanger is increased from 70% to about 76%, by the implementation of heat transfer ribs between the heat exchanger walls. With these improvements the supply air temperatures could be reduced to 18°C.

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