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Operational experiences with solar air collector driven desiccant cooling systems

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ABSTRACT

Component performance and seasonal operational experiences have been analysed for desiccant cooling systems powered by solar air collectors. Measurements during the commissioning phase in Spain (public library) and in Germany (production hall) showed that the dehumidification efficiency of the sorption rotors was 80% and the humidification efficiency of the contact evaporators was 85–86%. Only in a two-stage desiccant system monitored in China (laboratory building), a dehumidification efficiency of 88% was reached. The rotary heat exchangers only had 62–68% measured heat recovery efficiency, which is lower than specified.

Seasonal performance monitoring carried out in the German installation showed that average seasonal COP's were close to 1.0, when related to all operation hours. COP's increase if low regeneration temperatures are used with low dehumidification rates, which is often sufficient for moderate German climatic conditions, but much less so in the humid Chinese climate. Electrical COP's for the German system including air distribution were between 1.7 and 4.6 and reach values of 7.4, when only additional pressure drops of the desiccant unit are considered.

It could be shown that conventional control strategies lead to high auxiliary energy consumption, for example if fixed heating setpoint temperatures are used. Furthermore the solar air collector energy yield was very low in the German system, as regeneration was only used when all other options such as humidification at high air volume flows did not reduce the room air temperature enough. The studies showed that the measured auxiliary energy consumption could be reduced to near zero, if regeneration temperature setpoints were not fixed to constant values. The solar air collector efficiency was good at about 50% both for the flat plate collectors used in Spain and Germany and the Chinese vacuum tube solution. A cost analysis demonstrated the viability of the concept, if some funding of the high investment costs is provided.

1. Introduction

Desiccant cooling systems are an interesting technology for sustainable building climatisation, as the main required energy is low temperature heat, which can be supplied by solar thermal energy or waste heat. Desiccant processes in ventilation mode use fresh air only, which is dried, pre-cooled and humidified to provide inlet air at temperature levels between 16 and 19 °C.

The concept of desiccant cooling was developed in the 1930s and early attempts to commercialize the system were carried out unsuccessfully. Pennington patented the first desiccant cooling cycle [1], which was then improved by Carl Munters in the 1960s [2]. Good technology overviews are given by [3], Davanagere et al. [4] or [5]. The most widely used desiccants are silica gel, lithium chloride or molecular sieves, for example zeolites. Solid desiccants such as silica gel adsorb water in its highly porous structure. Lithium chloride solution is used to impregnate for example a cellulose matrix or simpler cloth based constructions and can then be used to absorb water vapour from the air stream [6]. One main advantage of solid desiccant cooling system is that it can be driven by low grade thermal energy such as solar energy. There are already some successful demonstrations of solar driven adsorption chillers [7,8] and solar absorption chillers [9].

In a single stage desiccant cooling process, outside air (1) is dried in the sorption wheel (2), pre-cooled in the heat recovery device with the additionally humidified cool space exhaust air (3) and afterwards brought to the desired supply air status by evaporative cooling (4) (see Fig. 1). The space exhaust air (5) is maximally humidified by evaporative cooling (6) and warmed in the heat recovery device by the dry supply air (7). In the regeneration air heater the exhaust air is brought to the necessary regeneration temperature (8), takes up the water adsorbed on the supply-air side in the sorption wheel, and is expelled as warm, humid exhaust air (9).

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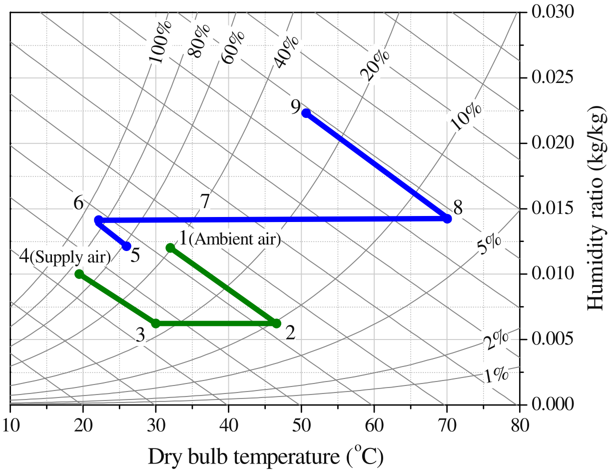

Fig. 1. Single stage desiccant cooling process using efficiencies of heat recovery, humidification and dehumidification measured in the Althengstett demonstration projects.

A single stage system is used in a factory in Althengstett/Germany and a library building in Mataró/Spain, which will be analysed in this paper.

In a two-stage desiccant process, the dehumidified air is pre-cooled and passes again through a sorption wheel for further dehumidification. This process is used for very humid climates (see Fig. 2). Often two sorption rotors are used, which increases costs and space requirements. As an alternative, the sorption wheel can be subdivided into two drying and two regeneration sections, so that the same air stream passes one rotor twice [10]. If room air is recirculated, the desiccant wheel is used to dry the room exhaust air, which is then pre-cooled using the rotating heat exchanger and humidified to provide the cooling effect. Regeneration of the desiccant wheel and precooling of the dried recirculation air is done by ambient air, which is first humidified, then passes the rotating heat exchanger, is heated to the necessary regeneration temperature and finally used to regenerate the desiccant wheel. A two-stage desiccant process is used in the Chinese system described in the paper.

Crucial for the process is an effective heat exchange between the dried fresh air (state 2) and the humidified exhaust air (state 6), as the outside air is dried at best in an isenthalpic process and is warmed up by the heat of adsorption. For a rather high heat exchanger efficiency of 85%, high humidifiation efficiencies of 95% and a dehumdification efficiency of 80%, the inlet air can be cooled from design condition of 32 °C and 40% relative humidity to below 16 °C. These design conditions are typically used in Germany, but are currently under discussion. Even in the moderate German climate, for several locations higher ambient air enthalpies are suggested for the design (for example in the Rhine area 35 °C, 37% relative humidity [11]). This is very close to the summer conditions defined by the American Air conditioning and Refrigeration Institute (so called ARI conditions) with 35 °C and 40% relative humidity.

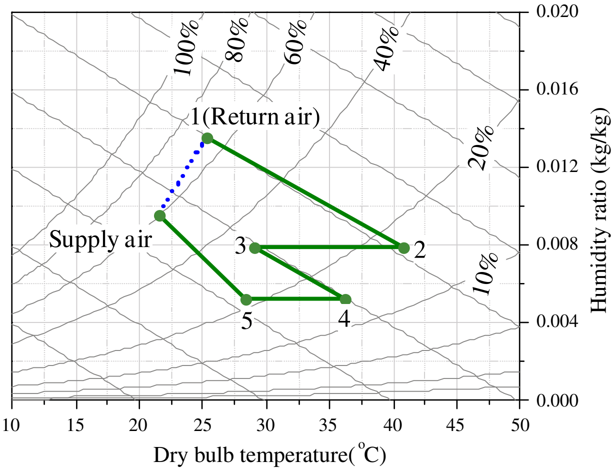

Fig. 2. Typical thermodynamic process for the Shanghai two-stage desiccant cooling system with room air dehumidification.

Apart from cooling applications with adiabatic humidification, desiccant systems have been proposed for air drying only. Recent studies consider for example museum buildings with high requirements on air properties [12].

Simple models have been used to estimate the working range of desiccant cooling systems, for example to provide room conditions not just for one set point, but for a range of acceptable comfort conditions [13]. Different control strategies have been compared by Ginestet et al. [14] to study the influence of air volume flow and regeneration temperature. As the increase of regeneration temperature does not linearly lower the supply air temperature, the study concluded that increased air flow rates are preferable to increased regeneration temperatures, if the cooling demand is high. Mean calculated COP's for the climatic conditions of Nice were between 0.3 and 0.4. Henning and others also remarked that increasing the air flow is useful in desiccant cooling mode, but that the minimum acceptable flow rate should be used in adiabatic cooling or free ventilation mode to reduce electricity consumption [15]. When thermal collectors with liquid heat carriers are used in combination with a buffer storage, Bourdoukan and others suggested to operate the cooling system only in adiabatic cooling mode during the morning and then allow desiccant operation in the afternoon, using heat from the buffer storage [16]. However, in many applications, dehumidification is already required during the morning hours. Also if cheaper air collectors are used, heat storage is not possible.

Although the technology is known for decades, there are only a few demonstration plants which are powered by solar energy [17–19]. This causes a lack of operational experience and know how on the control strategy, which strongly influences the overall system performance. To introduce the technology into the market, information about the energy performance, water consumption and maintenance issues need to be provided.

2. Characterisation of desiccant cooling cycles

2.1. Thermal COP

Compared to closed cycle cooling systems, where the energy efficiency is simply defined by the ratio of produced cold to the input heat, open cycle system efficiency can either be related to the removed cooling load of the building (enthalpy difference between room supply and exhaust air) or to the enthalpy decrease of ambient air.

For the hygienically needed fresh air supply the enthalpy difference between ambient air and room supply air can be considered as useful cooling energy. If the building has higher cooling loads than can be covered by the required fresh air supply, then the useful cooling energy has to be calculated from the enthalpy difference between room exhaust and supply air, which is mostly lower. The thermal coefficient of performance (COP_{th}) is obtained from the ratio of enthalpy differences for the cooling process and the energy required to heat the air after exiting the heat exchanger