In-Situ Analysis and Operational Optimisation of a Solar-Driven DEC-System

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Abstract

Most of the worldwide energy supply for air-conditioning processes is based on non-renewable energy sources, as today the commonly used technology for air-conditioning is electrically driven compression-type refrigeration. This consumption of fossil primary energy affects the depletion of resources and contributes to the global warming through CO_2-emissions. Solar air-conditioning is an approach, which uses solar-thermal heat, in contrary to electricity, to drive air-conditioning systems. The *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* at *Ingolstadt University of Applied Sciences* (Germany) investigates a solar-driven desiccant cooling system in a multipurpose building, operated with two arrays of solar-thermal flat-plate collectors. This paper initially gives an overview on previous monitoring experiences on the solar desiccant and evaporative cooling system (DEC) in Ingolstadt. Furthermore, it shows the extensive measurement equipment added to the DEC-plant prior to cooling period 2009 in detail as well as measurement results of this operational period. This includes a detailed analysis of component behaviour and system efficiency. Finally, an outlook referring on system simulation and future research is provided.

1. Introduction

The *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* at *Ingolstadt University* investigates and optimises an innovative, solar-driven air-conditioning system with desiccant and evaporative cooling technology (DEC) in a multipurpose building. The 10,000 m² gross floor area building is part of the biggest logistic centre in the region. Next to a ground source heat pump plant for base-load heating and cooling, the building is equipped with two arrays of solar-thermal flat-plate collectors (108m² + 178m²) and a DEC-system (fig. 1). This consists of two plants with a nominal air flow of 8,000 m³/h each.


Fig. 1: Solar DEC-System in Ingolstadt

The heating and cooling system is not only innovative because of its regenerative system components in an industrial environment, but also because of the multivalent use of solar collectors for cooling, hot water supply, space heating and regeneration of the heat pump energy source. This fully-integrated system approach in principle leads to a maximum utilisation of the solar collectors and therefore to a minimum pay-back time. The building with its heating and cooling system is described in detail by Haller et al. [1].

2. In-situ Investigation

2.1. Previous Monitoring Results

The solar DEC-system in Ingolstadt showed massive problems during the first year of operation (2006). While the degree of comfort in the building was found to be satisfying during the cooling period, the solar-driven DEC-plant showed major deficiencies in cooling performance, hydraulics and control. Especially, a too high rotational speed of the desiccant wheel and an inadequate adjustment of solar collector arrays, DEC-plants and building structure were identified. Therefore, in an overhaul of the system several problems in the hardware were identified and corrected such as blocked spray nozzles due to calcifications, leakages in the sealing of the desiccant wheel and an incorrect installation of a non-return valve in the hydraulic system of the regeneration air heater. Moreover, the control strategy regarding the cooling power of the plant and the speed of the desiccant wheel were checked. Detailed results of cooling period 2006 are described by Haller [2].

In the second year of operation (2007), some deficiencies of the first year were found to be removed, but still the plant did not work according to its capacity. Insufficient dehumidification by the desiccant wheel was identified as a major problem. Based on a detailed analysis of the desiccant wheel, one-sided displacement of the sorbent was assumed to be the reason for insufficient cooling capacity. Obviously, control or mechanical malfunctions during operation led to a one-sided oversaturation and thus to a one-sided damage of the desiccant wheel as described by Haller et al. [3]. Consequently, the damaged wheel was removed prior to the 2008 cooling period.

During the third year of operation (2008), the DEC-plant was not permanently in operation throughout the cooling period due to organisational complicacies. However, analyses on exemplary days proved that the one-sided damage of the desiccant wheel in 2007 could be solved by replacing the desiccant wheel during maintenance in spring 2008. Considering the plant settings of a reduced volume flow, a maximum refrigeration capacity of around 24 kW was expected, when the plant was operating in DEC-mode. However, with an analysed refrigeration capacity (ambient air to supply air) of around 15 kW (including the surface radiator) this value was by far not reached. The reason for this malfunction was supposed to be a limited dehumidification capacity of the desiccant wheel as described by Bader et al. [4]. Since the DEC-plant was until then regarded as a black box, these kinds of in-process problems could hardly be analysed with the existing measurement equipment (fig. 2; only temperature and humidity of ambient air, supply air, return air and exhaust air were measured).

2.2. Additional Measurement Equipment for DEC-Process Analysis

Hence, prior to the 2009 cooling period, additional measurement equipment was installed within the DEC-plant (fig. 2) to closely monitor the solar DEC-process and to evaluate the performance of its single components. This additional measurement equipment integrated in the DEC-system consists of six combined temperature and humidity sensors and four temperature sensors.

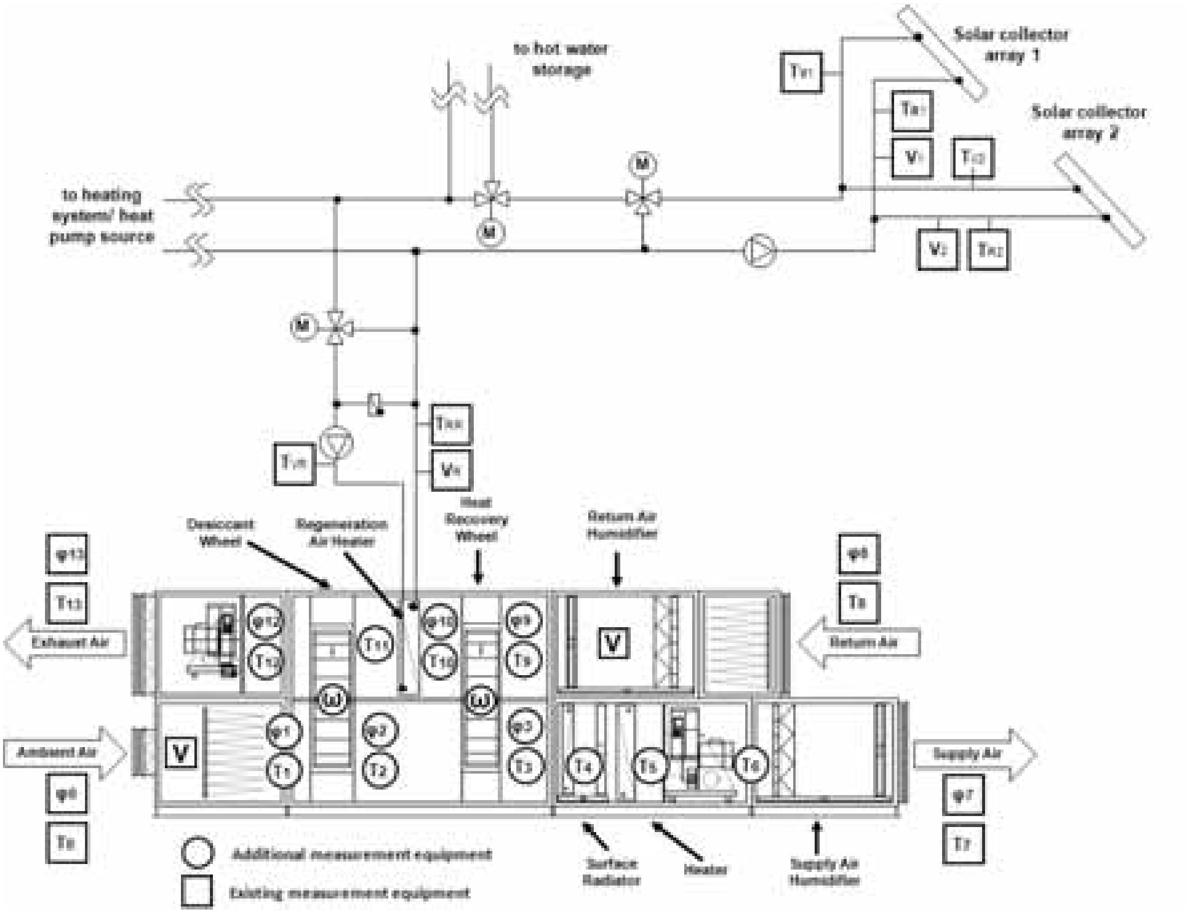

Fig. 2: Solar DEC-system layout with existing and additional measurement equipment

An inhomogeneous air-distribution within the ducts was approached with the integration of special measurement devices developed by Franzke [5] as illustrated in fig. 3.

Fig. 3: Measurement device downstream the desiccant wheel in the return air duct

Through seven pipes, the air is sucked in with a fan and then mixed with a rotator, after which temperature and where appropriate the humidity are finally measured with the sensor. Altogether seven measurement pipes were installed within in the DEC-plant: In the supply air duct they were placed downstream the desiccant wheel, the heat recovery wheel, the surface radiator and the surface heater. In the return air duct, measurement devices were placed downstream the heat recovery wheel, the regeneration air heater and the desiccant wheel.

2.3. Measurement Results and Operational Optimisation in Cooling Period 2009

The monitoring of the DEC-plant in cooling period 2009 showed that the expected refrigeration capacity of around 24 kW was not reached. The DEC-plant, which was supposed to supply peak-load cooling, only shortly reached a maximum refrigeration capacity of 15 kW while, as fig. 4 shows for an exemplary day, the average refrigeration capacity measured around 6 to 8 kW. However, the regeneration air temperature measures around 68°C throughout the entire DEC-process and therefore provides appropriate conditions for the DEC-process. To solely analyse the solar DEC-process, the surface radiator has been deactivated in cooling period 2009.

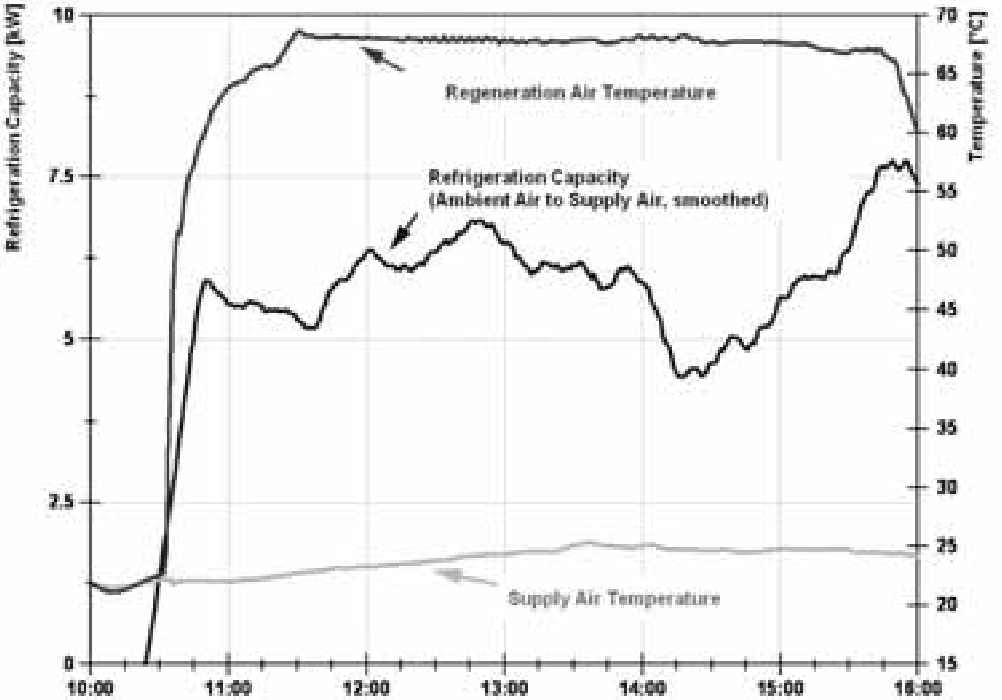

Fig. 4: Solar DEC-plant performance for an exemplary day (August 20th, 2009)

The analysis of the thermal comfort in an exemplary selected hotel room in the entire month of August showed a “comfortable” or “still comfortable” room condition. Only approximately two percent of the measured values could be ranked as “uncomfortable warm”. However, when regarding the thermal comfort in the same hotel room only during DEC-operation on an exemplary day (August 20th, 2009), 68 % of the measured values were “uncomfortable warm”. This was mainly because within the entire month of August also air conditions of cooler days and nights were influencing the thermal comfort, while the comfort during DEC-operation exclusively reflected the thermal comfort of the room on a hot summer day. Nevertheless, on the exemplary day August 20th 2009, the supply air temperature of up to 25°C during DEC-operation can be evaluated as too high, as illustrated in fig. 4. Especially the uncomfortably high room temperature showed that there was a higher cooling demand.

To analyse the cause for the considerably low refrigeration capacity in spite of a sufficient regeneration air temperature, the operation of the critical components desiccant wheel and heat recovery wheel was investigated. The numbers in brackets in the following diagrams thereby refer to the corresponding sensors in the system (cf. fig. 2).

The analysis of the desiccant wheel (sorbent: LiCl) on the same exemplary day (August 20th, 2009) shows that the regeneration air heater heated the return air in front of the desiccant wheel to around 68 °C (fig. 5, upper diagram). Therefore, sufficient solar regeneration conditions for the dehumidification of the desiccant wheel were available throughout the entire duration of the DEC-operation. A closer investigation of the desiccant wheel's dehumidification capacity (fig. 5, lower diagram) at a volume flow ratio of 1.14 (supply air to return air), shows that the desiccant wheel initially dehumidified the process air by around 4.3 g/kg dry air. Thus, at the beginning of the process the dehumidification capacity reached a value as it would be expected according to manufacturer information. However, the dehumidification capacity steadily decreased with ongoing DEC-process to around 2.5 g/kg dry air, even though the boundary conditions like the regeneration air temperature were measured as stable. Furthermore, on other days the dehumidification capacity permanently measured around 2 g/kg and therefore was below the expected level.

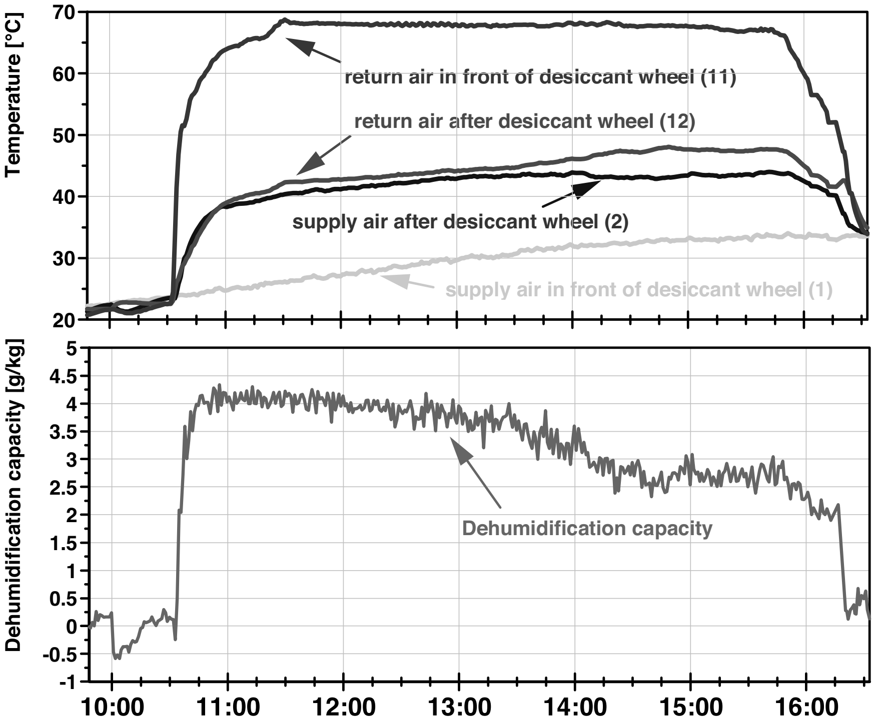

Fig. 5. Desiccant wheel analysis (August 20th, 2009)

A temporary adjustment of the volume flow ratio from 1.14 to 1.05, as suggested by the manufacturer of the desiccant wheel, did not result in an improved dehumidification capacity. Hence, the results gained by Schürger [6] in laboratory tests could be proven under in-situ conditions. The insufficient dehumidification of the supply air did not create optimal conditions for the subsequent heat recovery. The cause for the decreasing dehumidification capacity could for instance be an unexpectedly varying rotational speed of the desiccant wheel, which will be subject to further investigations.

The behaviour of the heat recovery wheel as a central element of the DEC-process was as well analysed in detail. Fig. 6 illustrates the process conditions for the heat recovery on the exemplary day August 20th, 2009. It was found that the heat recovery ratio only reached 58 % at a rotational speed of 600^{-1} and a volume ratio (supply air to return air) of 1.14. According to information of the component manufacturer, a heat recovery ratio of 75 % would be expected under the given conditions. Therefore, also this component did not reach the planned efficiency. Comparable in-situ measurements carried out by Eicker et al. [7] at the DEC-plant in Althengstett (Germany) showed a similar difference between the measured heat recovery ratio and the expected value.

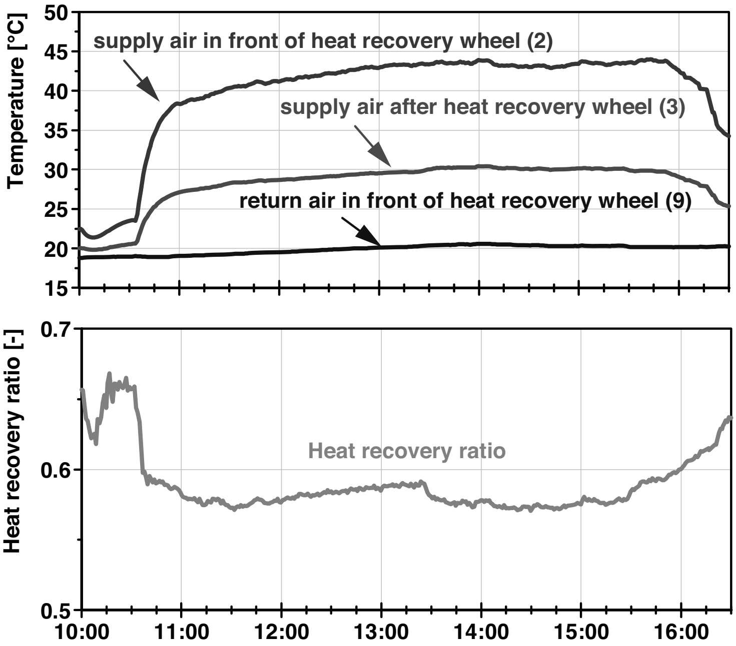

Fig. 6: Heat recovery wheel analysis (August 20th, 2009)

Both solar-thermal flat-plate collector arrays with a size of 286 m² have originally been designed for the operation of a solar air-conditioning system including two DEC-plants with a nominal refrigeration capacity of 35 kW each. Due to modified demands, currently only one DEC-plant is in operation, at a reduced air flow and therefore with a reduced nominal refrigeration capacity of around 24 kW. Hence, this should be considered when evaluating the solar integration.

The hydraulics and the control strategy currently realised allow the use of the solar heat either for the preparation of hot water for the hotel or alternatively for the supply of regeneration heat for the DEC-plant. As a third option, the solar heat can be used for the regeneration of the heat pump source in the building’s base plate or for the heating support if required. At present, a simultaneous utilisation of the solar heat for diverse consumers is not possible with the implemented hydraulics and control strategy. Due to the dimensioning of the collector array for originally two DEC-plants, however, this would in principle be interesting from an energetic and operational point of view. As fig. 7 illustrates, the flow temperature of the regeneration air heater constantly reached a temperature of 72 °C to 73 °C on the exemplary day August 20th, 2009. Therefore, the DEC-process was provided with an adequate regeneration temperature of around 68 °C (cf. fig. 5).

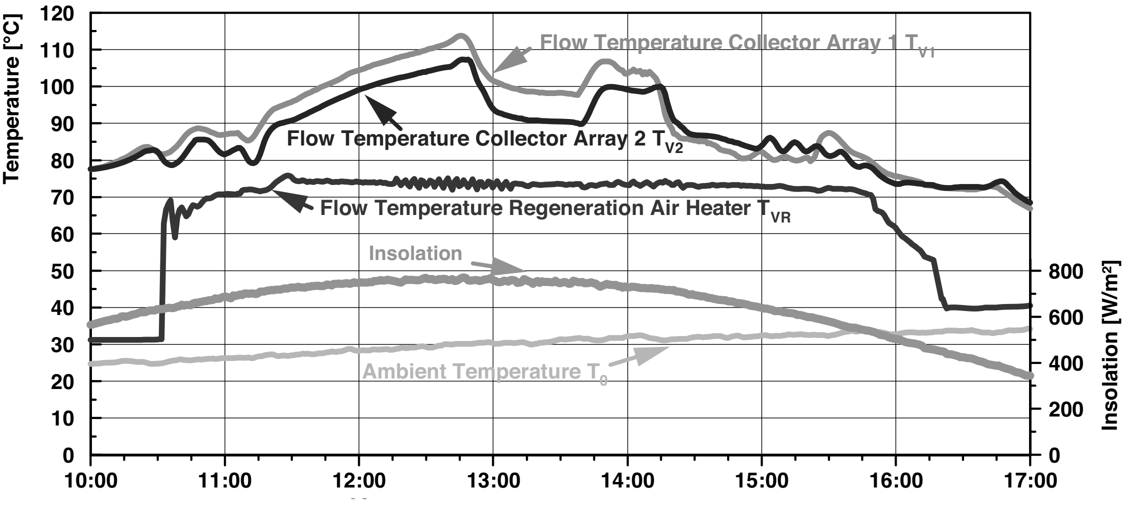

Fig. 7: Solar integration analysis (August 20th, 2009)

The collector arrays, however, provided flow temperatures of up to 110 °C. As these temperatures are far too high for the DEC-process, they were consequently adjusted using the flow temperature mixer of the regeneration air heater, in order to reach reasonable temperatures for the DEC-process and to avoid a damage of the desiccant wheel. On the one hand, the detailed analysis proved the existing potential of an integration of further heat sinks in the hydraulics and control of the solar system. On the other hand, the importance of a flow temperature control of the collectors was approved. However, in cooling period 2009 there was obviously no interdependence between the insufficient refrigeration capacity of the DEC-plant and the integration of the solar collectors in the DEC-process. Solar regeneration heat was sufficiently available at a reasonable temperature level for the DEC-plant.

3. Conclusion

Previous research at the solar DEC-plant in Ingolstadt (Germany) reveals room for improvement both on component and on system level. The monitoring in cooling period 2009 therefore proved the identified future fields of research for solar DEC-systems, which are illustrated in fig. 8.

Obviously, the planning reliability for such plants is currently not sufficient. However, this is the requirement for a further spread of the technology. Hence, an appreciable distribution of the technology urgently requires the development of scientifically and operationally proven, optimised and fail-safe plant concepts and control strategies.

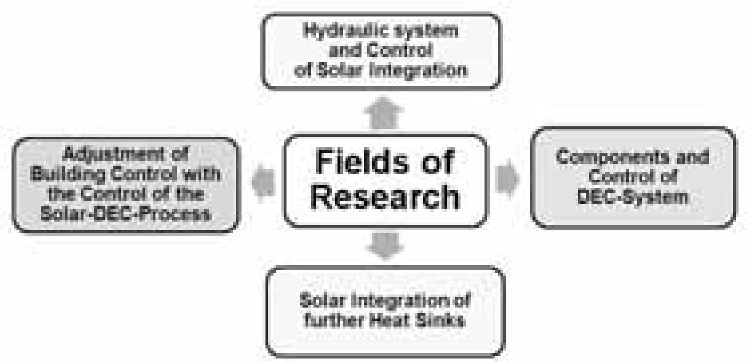

Fig. 8: Future fields of research for solar DEC-systems

Within a proceeding 3-year research project, a close monitoring and a continuous failure and operating analysis of the solar-driven DEC-system is currently carried out by the *Centre of Excellence for Renewable Energy Research*. This will be the basis for an operation accompanying simulation to optimise the system. Finally, the optimisation and gained technical expertise on the system will essentially influence planning criteria and optimised strategies for construction, operation and control of solar-driven DEC-systems.

This project is carried out in cooperation with the building owner *IFG Ingolstadt GmbH*, the architecture and planning office *pbb Planung + Projektsteuerung GmbH*, the DEC-plant manufacturer *WOLF-Anlagentechnik GmbH* and the solar system supplier *SolarNext AG*.
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References

[1] A. Haller, W. Zörner, V. Hanby, *Solar-Assisted DEC-System in a Multipurpose Building*. In: Proc. 1st International Conference on Solar Air-Conditioning, Bad Staffelstein, Germany, October 2005

[2] A. Haller, *The performance of a regenerative heating and cooling system in a multipurpose building*, Thesis (MPhil), De Montfort University Leicester, United Kingdom, 2007

[3] A. Haller, C. Trinkl, R. Wittmann, W. Zörner, V. Hanby, *Solar Desiccant Air-Conditioning: Practical Experience Regarding Operation and Performance*, In: Proc. 2nd International Conference on Solar Air-Conditioning, Tarragona, Spain, 2007

[4] T. Bader, M. Finkenzeller, C. Trinkl, W. Zörner*, In-situ measurements, simulation and system optimisation of a solar-driven DEC-system in an industrial environment*, Proc. 3rd International Conference on Solar Air-Conditioning, Palermo, Italy, 2009

[5] U. Franzke, Offene Verfahren mit festen Sorbentien. In: Proc. DBU Workshop Kälte aus Wärme, Osnabrück, Germany, 2008

[6] U. Schürger, *Investigation into solar powered adsorption cooling systems – Adsorption technology and system analysis*, Thesis (PhD), De Montfort University Leicester, United Kingdom, 2007

[7] U. Eicker, M. Huber, U. Schürger, J. Schumacher, A. Trinkle, *Komponenten- und Anlagenverhalten solar betriebener sorptionsgestützter Klimaanlagen*. KI – Luft und Kältetechnik, 27 (11), 2002, pp. 541-547