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PRIMARY ENERGY OPTIMISED OPERATION OF SOLAR DRIVEN DESICCANT EVAPORATIVE COOLING SYSTEMS THROUGH INNOVATIVE CONTROL STRATEGIES

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1- Introduction

Conventional control strategies of open desiccant evaporative cooling systems (DEC) try to cover the required cooling load through a control cascade which switches on or off single components of the DEC system in dependence of the deviation between the setpoint and the actual measured room temperature. In the simplest case with cool and dry ambient air first the air volume flow is increased, afterwards the return air humidifier and the heat exchanger between supply and return air are activated before the supply air humidifier is switched on for combined humidification. The sorption mode with startup of the sorption wheel and return air heater is often considered as last control option in the control sequence if the maximum room air humidity is exceeded or if the supply air humidifier operates at full load and still more cooling energy is required to keep the room air below the upper threshold. Therefore, common problems of installed DEC systems are very low solar system efficiencies of the installed collector fields [1] and moderate primary energy efficiencies with values between 1.2 and 1.7 [2,3]. Comparable systems with compression chillers reach primary energy efficiencies in the region of 1.0 or slightly below 1.0 [2]. Some control strategies operate with constant regeneration temperatures although often much lower regeneration temperatures would be sufficient to cover the required cooling load. This further decreases the solar system efficiency of the installed collectors and significantly increases the additional heating or cooling energy. Control optimised systems therefore operate at variable regeneration temperatures between 45°C and 90°C. Actual published analyses show that an early increase of the air volume flow rates from the energetic point of few is only favourable, if the required regeneration heat can't be provided by the solar system [2-5]. Therefore, the regeneration mode should be activated with priority to the increase of the air flow rate if sufficient solar energy is available and the cooling load can't be covered with combined humidification at the lowest possible air flow rate. In the present work a primary energy optimised control strategy has been developed for a DEC demonstration pant installed at the University of Applied Science in Stuttgart, which supplies two lecture rooms with fresh and cold air.

2- Decription of the DEC System

The analysed DEC system is installed under the roof on the fourth floor of one of the buildings of the University of Applied Sciences in Stuttgart. For regeneration of the sorption wheel a 20 m² solar air collector field and a 20 m² vacuum tube collector field can be used. The vacuum tube collector field is connected to two 2.000 l hot water storage tanks. A water to air heat exchanger is used to further heat up the regeneration air by the solar hot water system after the solar air collectors. The maximum air flow rate on the supply and return air side is 3.000 m³ per hour. A new hybrid spray humidifier including a water treatment system has been integrated for supply air humidification. The humidification efficiency of this humidifier is controllable in seven stages. For return air humidification a single stage contact matrix humidifier with 95 % humidification efficiency is used. The system setup is shown in Figure 1.

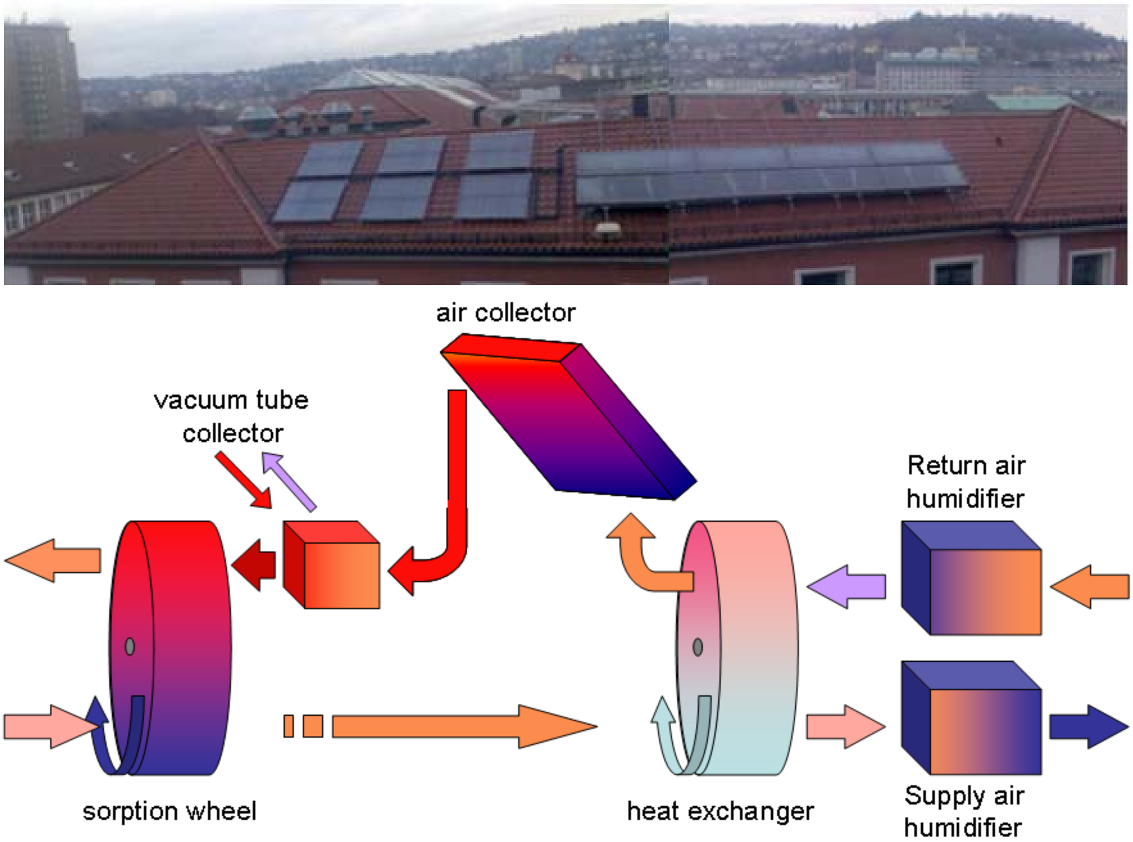

Figure 1: Schematic diagram of the installed DEC system

At present the DEC-system is connected to a large presentation room on the fourth floor directly below the roof. Due to the large cooling load in this room, the maximum sensible cooling power provided by the installed DEC system of 10 kW is far too low and has nearly no influence on the room temperature. To overcome this unsatisfactory situation, in the near future the DEC system will be connected to two smaller seminar rooms in the third floor below the presentation room. The seminar rooms offer a floor area of 71 m² and 79 m², each for around 25 students. The maximum sensible cooling load of the two rooms together is 10 kW which gives 67 W per square meter conditioned floor area. For the development of the control system a detailed dynamic simulation model of the whole DEC system including the seminar rooms has been developed in INSEL (www.insel.eu) and validated against measured performance data. This model was used for the development and test of the new primary energy optimised system controller.

2- Description of the Primary Energy Optimised Controller

As visible from figure 2 the architecture of the developed controller is quite similar to standard control systems. It consists mainly of a sequence controller part which turns on or off the components of the DEC system in dependence of the room temperature and humidity. It starts with ventilation in free cooling mode at minimum air flow rate and switches to indirect humidification as soon as the room temperature increases above 23.5°C. If the room temperature further increases and reaches 24.5°C, the direct evaporative cooling mode is activated. The seven stages of the hybrid humidifier are controlled in order to reach 16°C supply air temperature. The supply air humidity is limited to 10 g/kg. If the room temperature reaches 25.5°C or the humidity of the ambient air increases above 10 g/kg the desiccant cooling mode is activated. In this case first the solar air collector is used before the solar heat exchanger is activated and heating energy from the vacuum tube collector is used to further heat up the supply air. A proportional controller is used to control the regeneration air temperature according to the measured room air temperature. As a last option the air volume flow control is activated if the room air temperature increases above 26.5°C. A PID controller tries to control the air volume flow rate in order to keep the room temperature at 26°C. Especially at lower ambient air temperatures such a simple control cascade can lead to conditions, at which the indirect humidification mode is activated without providing real cooling power or even heats up the ambient air. Additionally, in some cases the components are activated too fast after one another, even if dead times are implemented in the control. In consequence the DEC mode is activated although not required at the given load and ambient conditions. To overcome these problems an optimisation tool has been developed and implemented in the control system, which consist of an online tool based on simplified simulation models of all relevant components.

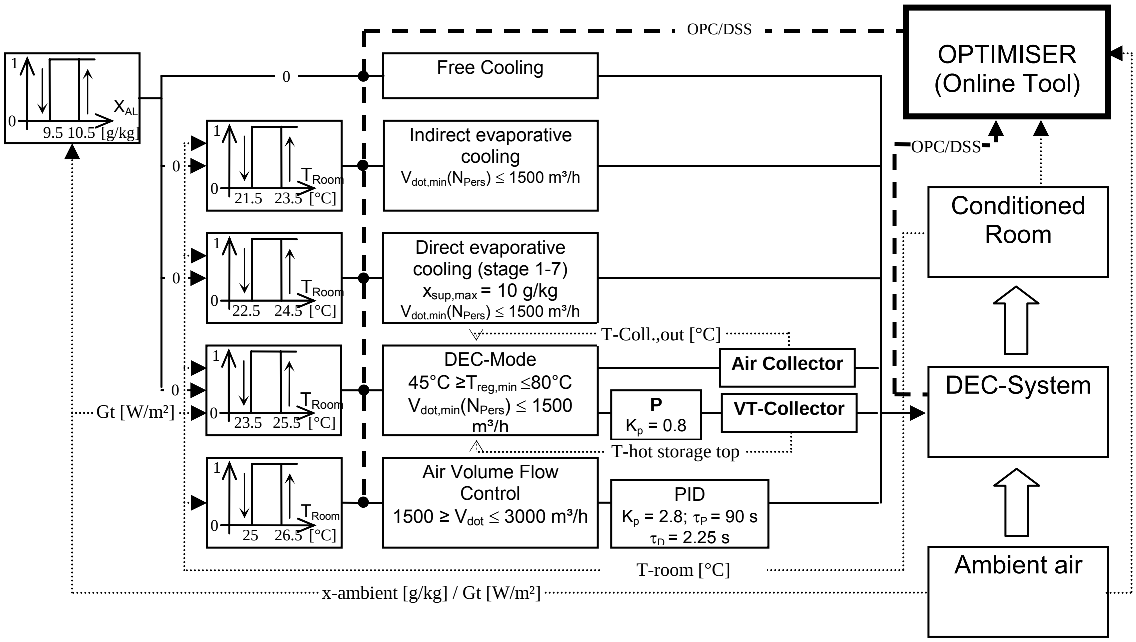

Figure 2: Architecture of the developed innovative DEC controller

This tool permanently evaluates online the optimum system operation mode with the highest primary energy efficiency and transfers the recommended operation mode to the main system controller. Within the optimisation tool only the decision is taken, whether different operation modes are required to reach the maximum cooling capacity of the DEC system at highest possible primary energy efficiency. The activation command for the components comes from the controller in dependence of the room air temperature and humidity. If the optimisation tool decides that some operation modes are not useful, the activation command of the cascade controller is ignored for these components. Additionally the optimisation tool evaluates the optimum supply air humidifier stage in order to reach the lowest possible supply air temperature and to avoid supply air humidity above 10 g/kg. To demonstrate the efficiency of the developed controller, simulations have been performed for a typical cooling period (May to September) for the following four cases:

Case 1: Standard control cascade (1.free cooling/2.volume flow control/3.indirect humidification/4.combined humidification/5.DEC mode)
Case 2: Electricity optimised standard control cascade (1.free cooling/2.indirect humidification/3.combined humidification/4.DEC mode/5.volume flow control)
Case 3: Advanced model based control (without and with bypass of sorption wheel)
Case 4: Electricity optimised reference system (Ventilation system with air volume flow control / compression chiller with average COP of 2.8)

3- Simulation Results and Discussion

The main results are shown in figure 3, where the primary energy ratio (PER) is compared for all analysed cases. The required heating energy for regeneration of the sorption wheel is completely covered by the two solar systems described above. Therefore the primary energy consumption of the analysed cases with DEC system only depends on the electricity consumption of the ventilators (main part) and the other components (pumps, wheels etc.).

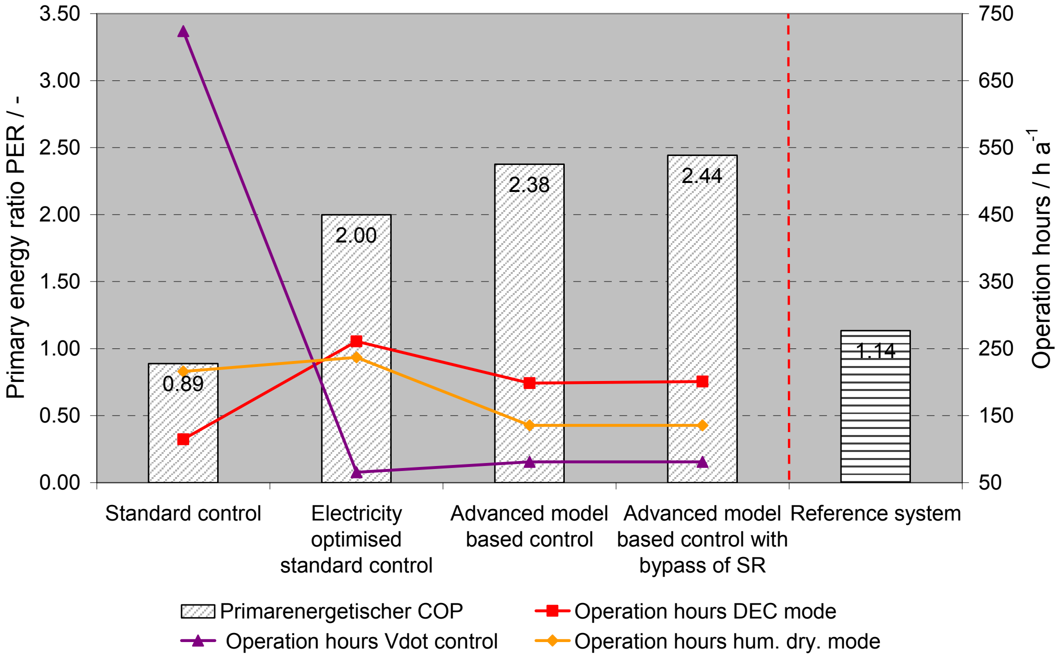

Figure 3: Simulation results for the overall primary energy ratio of a cooling period

As clearly visible from figure 3, the standard control, which uses the fan speed control as first option, reaches the lowest PER of 0.89 which is even below the PER of the reference system of 1.14. This results from the fact, that the system in this case is operated very often at high air flow rate. The electricity optimised standard control has the lowest operation hours in fan speed control mode but the highest operation hours in desiccant mode and in humidifier drying mode (end of day). All together this already significantly increases the primary energy ratio to an average value of 2.0 which is already significantly above the value of the reference system. If the developed advanced model based control is applied, the DEC system reaches a PER of 2.38, which is 19 % higher than for the electricity optimised standard control and more than a factor two better as the reference system. The better overall performance compared to the electricity optimised standard control results mainly from lower operation hours in humidifier drying mode and lower operation hours in full desiccant mode, which significantly reduces the electricity consumption at same comfort level in the connected rooms. The advanced model based control operates the system more often in free cooling and direct humidification mode and very seldom in indirect humidification mode. Since the supply air humidifier operates in this case only with one or two stages, the required operation time of the ventilators for humidifier drying is much lower than in case of indirect humidification, where always the complete contact matrix is wetted. Additionally, at direct humidification mode lower supply air temperatures are supplied to the rooms, which reduces the peak cooling load in the early afternoon and therefore reduces the operation time in full desiccant mode.

3- Conclusion

A primary energy optimised system controller for DEC systems based on an online optimisation tool has been developed and tested in the simulation environment. The results show that a primary energy ratio of 2.38 can be reached, which is 19 % better compared to a system with electricity optimised standard control and a factor two better than a good reference ventilation system with compression chiller. It is also shown, that an intelligent fan speed control is crucial for DEC systems in order to compete with standard air conditioning systems.

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