Performance analysis and optimisation through system simulations of renewable driven adsorption chillers

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1. Introduction

The performance of adsorption chillers depends mainly on the temperature levels of the heating, cooling and chilled water circuits, but also on the adsorption/desorption cycle time and the mass flow rates [1-4]. Experience shows that the performance of solar driven adsorption chillers can be lower than expected if the design and the implemented control strategies are not optimal [2-3]. The office building of the headquarters of the company FESTO AG in Esslingen (Southern Germany) is equipped with a big adsorption cooling installation with a nominal chilled capacity of 1.05 MW. The 3 adsorption chillers (Silica-gel/Water) of the Japanese company MYCOM are currently driven by waste heat and heat from gas boilers. In order to increase the renewable fraction of the heat provided to the adsorption chillers significantly, a large solar thermal plant will be installed on the roof of one of the production halls.

2. Office building of the FESTO AG

The innovative and highly energy efficient office building of the FESTO AG & Co. KG in Esslingen, with a useful floor area of 25.000 m² is cooled in summer by three 350 kW adsorption chillers and additionally through thermally activated bore piles of the buildings foundation. The cooling energy of the bore piles is provided to the thermally activated concrete ceilings of the building and the cooling energy of the adsorption chillers is mainly used to cool the air in the ventilations systems of the building. In winter the thermally activated ceilings are used for heating with a very low supply and return temperature of the heating circuit, which offers optimal conditions for a very efficient utilisation of heating energy provided by a solar system.

3. Integration of the solar thermal system

The principle of the planned integration of the solar system into the heating distribution system of the building is shown in Figure 1. During the winter period the produced heat of the solar system is provided to the thermally activated ceilings with a maximum capacity of 200 kW on a low temperature level of 50/30°C. If the solar system delivers more than 200 kW (e.g. in autumn and spring), the heating energy is switched to a higher temperature level and connected to the main heating distribution system of the building for the rest of the day. In summer the heat is directly provided to the main heating distribution system, which supplies the adsorption cooling machines with the required heating energy.

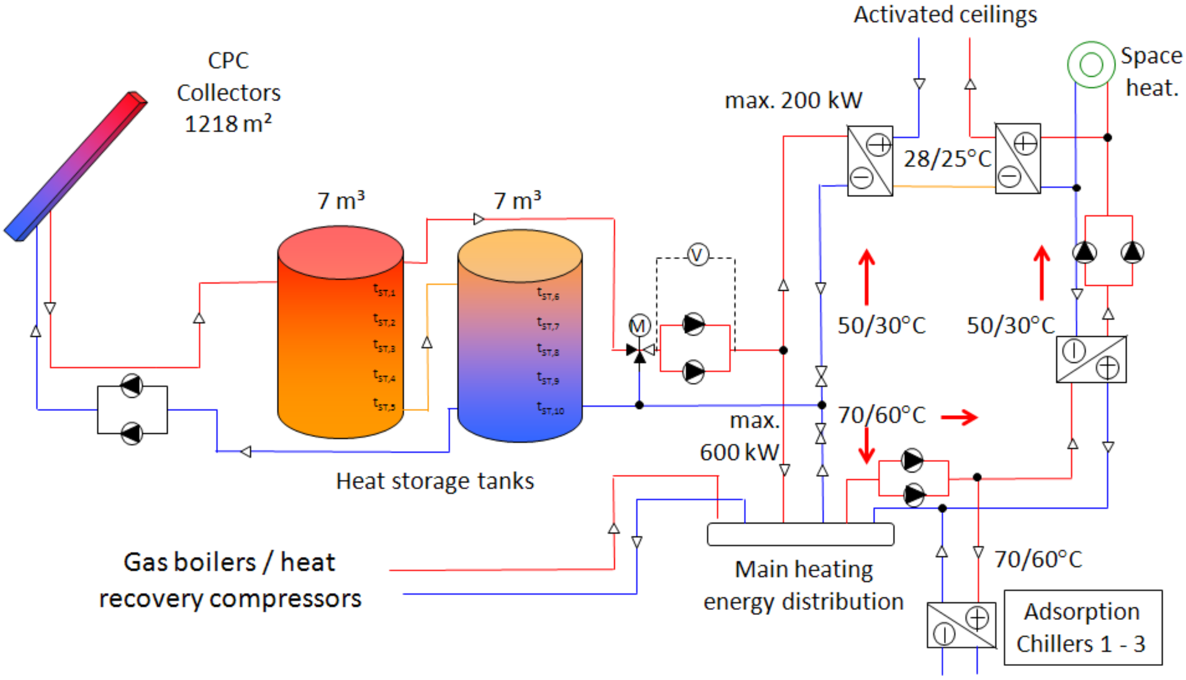

Figure 1: Integration of the solar system in the heating distribution system of the building

This system includes two 7 m³ hot water storage tanks, 1218 m² of CPC collectors (Paradigma) all facing south with an inclination of 30° and the heat carrier is pure water.

4. Performance analysis of the adsorption chillers

The performance of the 3 waste heat driven adsorption chillers are analysed using detailed measured data from the building management system. 400 to 500 kW of heat are recovered from a large number of compressors producing compressed air for pneumatic test facilities, which covers around 30 % of the heating energy demand of the adsorption cooling machines. The figure 2 shows the performance (cooling power and COP) of the chillers measured under different operating conditions of regenerating and cooling temperatures.

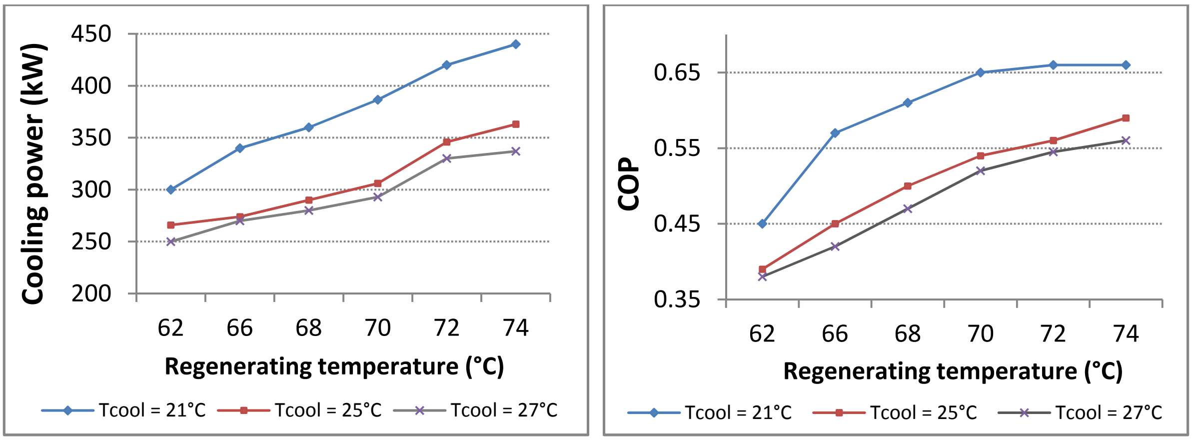

Figure 2: Performance of the chillers (Inlet chilled temperature - 12/13°C)

These results confirm the importance of controlling the temperatures of the heating and cooling water circuits in order to obtain the best performance of the chiller.

5. Dynamic model of the adsorption chiller

The discontinuous dynamics of the adsorption/desorption cycle caused the transient cooling output of the chiller. Therefore, a model that described this fluctuant behavior is needed when one wants to model the dynamic of an energetic system. The dynamic model proposed by Saha [4] has been implemented in the simulation environment INSEL [5] and validated against measurements data (Figure 3). This model was used to analyse the effects of different cycle times on the COP of the chiller (Figure 4). Although the use of longer cycle times leads to a drop of the cooling power output of the chiller, it allows the rise of the COP. The control of this parameter could be used to increase the performance of the chiller when the cooling demand is lower.

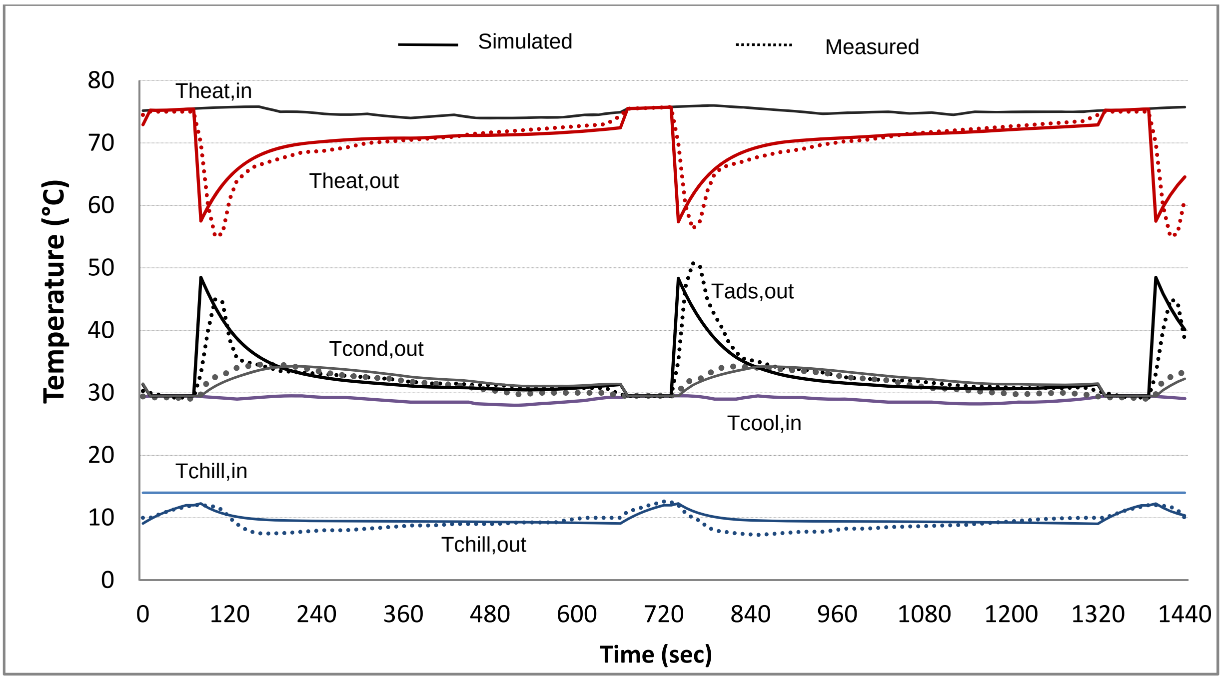

Figure 3: Measured and simulated temperatures of the adsorption chiller (cycle 10 min)

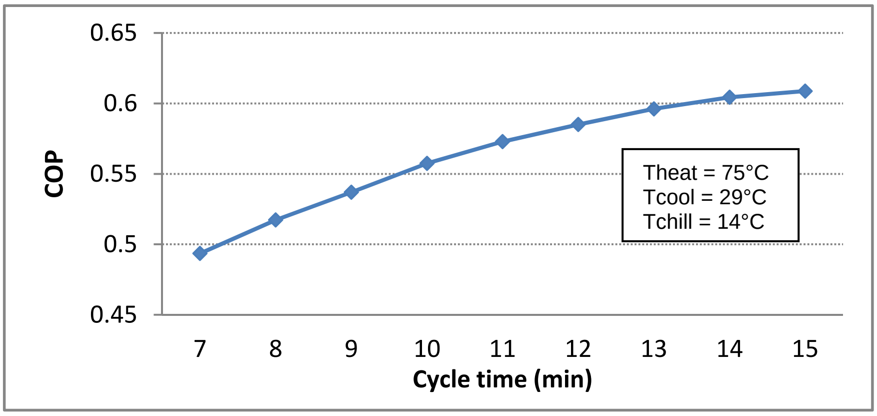

Figure 4: Influence of the cycle time on the COP

6. Simulation of the solar thermal plant

A detailed dynamic simulation model of the solar system has been developed in INSEL [5] in order to analyse the effect of different control strategies (Table 1) and configuration options on the overall system performance and the reachable solar fraction on the heating energy demand during summer and winter. We have assumed that the heating demand is always higher than the energy obtained from the solar collectors. Heat losses in tubing as well as shading effects of the rows of collectors have been taken into account. The thermal energy used for frost protection of the pure water system and the additional electrical energy required to run the pump are analysed. The results are summarized in figure 6 and table 2.

	Control 1	Control 2	Control 3
Control of the collector pump	ON/OFF	Mass flow control	Mass flow control
Winter temperature level	50 / 30°C	50 / 30°C	40 / 30°C
Summer temperature level	70 / 60°C	70 / 60°C	70 / 60°C

Table 1: Analysed control strategies of the solar system

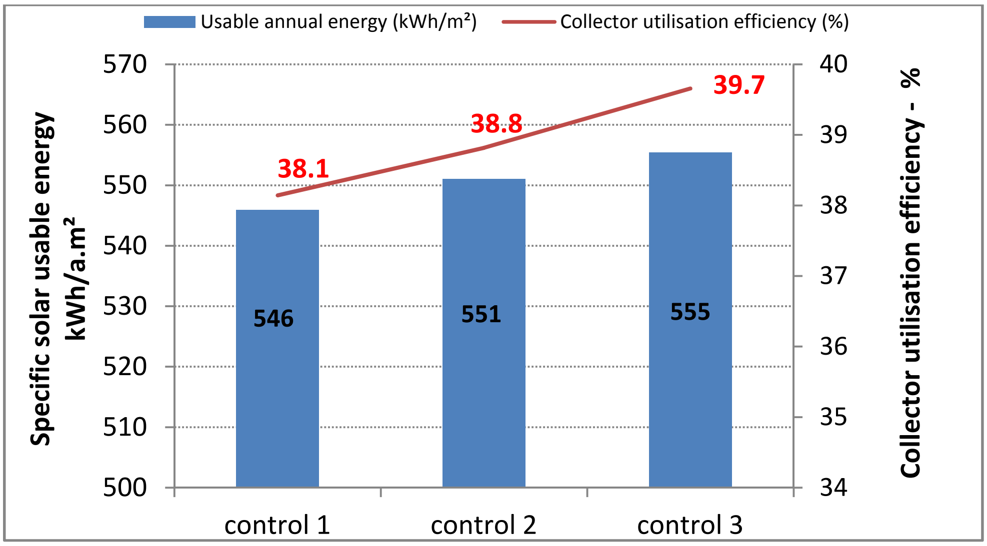

Figure 6: Overall system performance of the different control strategies

We can observe that the influence of the mass flow control of the collector pump is not significant (only 1% gain for the control 2). This is mainly due to the relatively low temperature levels required by the system and also to the use of very efficient collectors.

Pump ON	Pump OFF	Additional annual thermal energy	Usable solar energy lost	Additional annual electrical energy
Tcol<5°C	Tcol>10°C	11 MWh	1.65%	250 kWhel

Table 2: Frost protection of the pure water system (Control 1)

The additional energy required for the frost protection represents only a slight part of the usable solar energy which makes the use of pure water an attractive solution for the problem of glycol deterioration with high temperatures. In order to see how this solar plant can contribute to the energy needs of the chillers, the period of Mai - September 2006 was simulated with real weather data and compared with the cooling energy delivered by the chillers during this period (Figure 7).

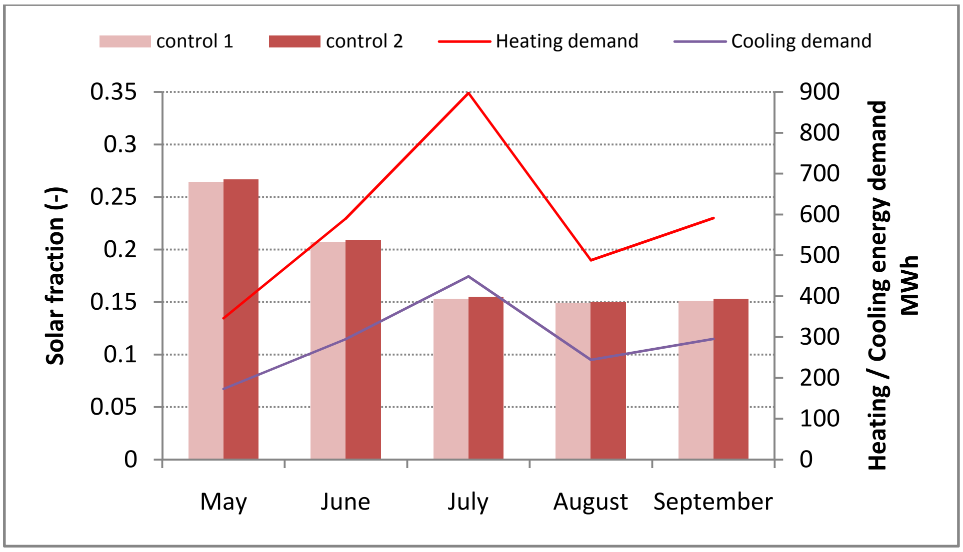

Figure 7: Simulation Mai - September 2006 – Real data

About 19% of heating energy needs of the chillers could have been supplied with solar energy during the period of Mai-September 2006. These results were obtained assuming a constant COP of 0.5 for the adsorption chillers.

7. Conclusions

The fraction of renewable heat provided to the adsorption cooling installation of the FESTO Company could be raised from 30 to around 45 - 50% with the installation of the solar thermal plant. An optimal control of the operating conditions of the chillers (heating and cooling temperatures, cycle time, and mass flow rates) will permit to raise the COP of the chillers and therefore increase the solar fraction.

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