Development of a Sorption Assisted Air Conditioning System Driven by a Solar Air Collector

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Introduction

Depending on climate and humidity up to 80% of primary energy consumption of HVAC system must be spent for dehumidification of ambient air to achieve conditions of comfort in the room [1]. This large amount is caused by the condensation process, including the cooling down of the air flow below dew point. At the same time, following state of the art, the air has to be warmed up after this step again. The dehumidification can be performed more energy efficient by using sorption technologies. Due to this background, an open system based on a sorptive coated cross-flow heat exchanger of ECOS-type [2] in combination with an evacuated tube solar air collector as heat source is developed within the collaborative project “SorLuko” of Fraunhofer ISE and companies airwasol and Contherm. The development is including a complete re-design of all components, starting with the aluminum heat exchanger, layout of the collector for providing high temperature, and a new developed coating technique. For attesting the improvement of the new components as well as functional proof of the concept, a demonstration system has been built up at airwasol facility. The dehumidification and cooling application makes use of an adsorptive coating in one channel of the cross-flow heat exchanger (HX) of ECOS type [2], while the cooling of the supply air can be achieved by indirect evaporative cooling generated by saturation of the waste air with water sprayers in the second channel.

Experimental

The demonstration system consists of the components solar air collector, which is a vacuum tube type, HVAC unit containing a sorptive coated cross-flow heat exchanger, several piping, flap valves, sensors for temperature, humidity and air flow, as well as hardware for data acquisition and control. The accuracy of the sensors and data acquisition equipment is +/-0.1K for temperature, +/-3%RH for humidity, and +/-5% for the mass-/volume flow measurement.

The supply air is transferred to the technical center of airwasol facility, acting as a test room (see Figure 1).

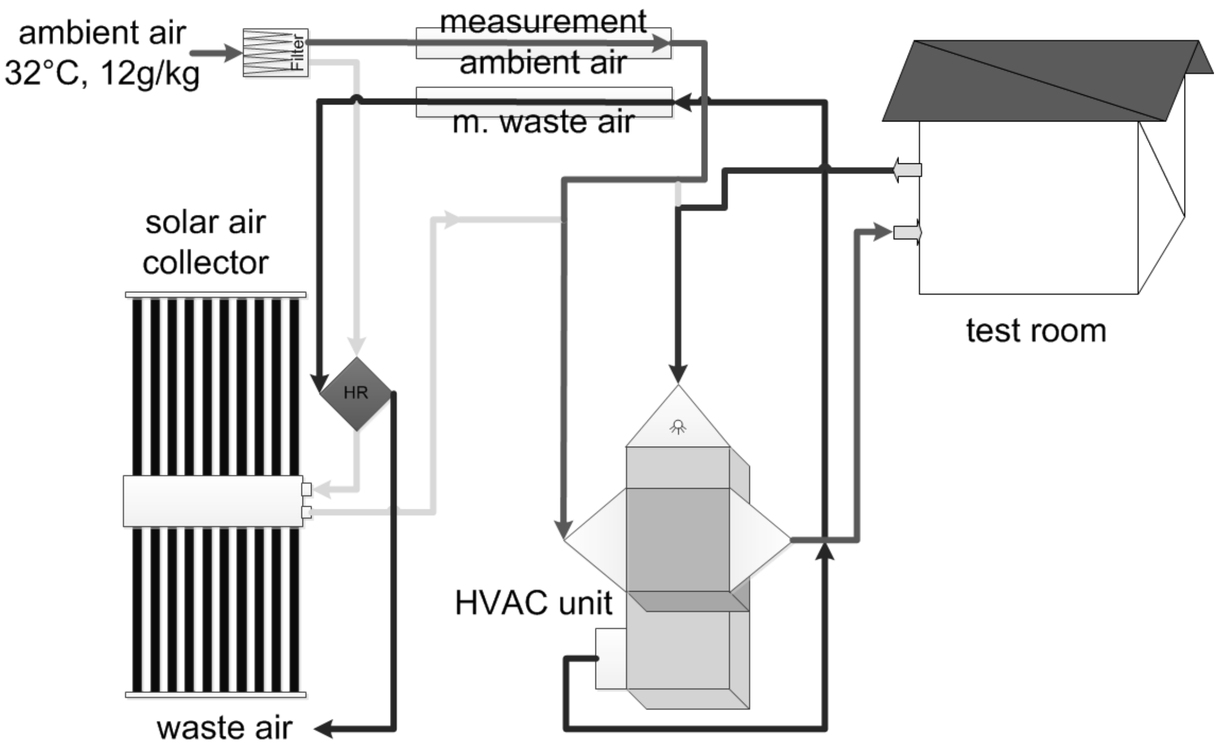

Figure 1: Scheme of the demonstration system at airwasol facility

At the given state of start of operation of the demonstration system, two vacuum tube solar air collectors of type SunStorm from Kollektorfabrik are used as heat source. Due to the large pressure drop of this type compared to the airwasol TST under development, the process air flow is limited to 180kg/h. The heat exchanger mounted in the HVAC unit is a plate HX made of aluminum, with metal mass of 6.99kg and surface of 8.7m^2 in each channel and pitch of 8mm. The coating is a resin glued one with silica gel Grace 123 and adsorbent mass of 5.3kg. A SAPO-34 coated HX shall be applied in the future, but is still under development.

The basic process consists of three stages, which are repeated continuously [3] : First, the heat exchanger is heated up and desorbed with hot air from the collector flowing directly in the sorptive channel, withdrawing the desorbed humidity to the waste air exit. This step is referred to as desorption step. After this, the heat exchanger is at high temperature and has to be cooled down, which is performed with ambient air led through the cooling channel and assisted by a water sprayer, so called pre-cooling. In the last step, the useful dehumidification and cooling effect of supply air is generated. For that purpose the ambient air is led in the sorptive channel and dehumidified by the adsorbent material, while the air stream is cooled by means of indirect evaporative cooling of the waste air saturated by sprayers passing through the cooling channel at the same time. This step is denoted as adsorption step.

Results and discussion

The temperature of the air stream flowing in and out the sorptive channel of the HX is depicted in Figure 2 for one test campaign from 10 am to 8 pm on 22 July, 2013. One can clearly relate the maxima in temperature of the process air, coming from the solar collector, to the solar altitude. The baseline of the HX_in slope represents the temperature of the ambient air streaming in the HX in the adsorption step, with values above 30°C from 10:30 until 19:30 reaching its maximum of 35°C between 13:30 and 15:30.

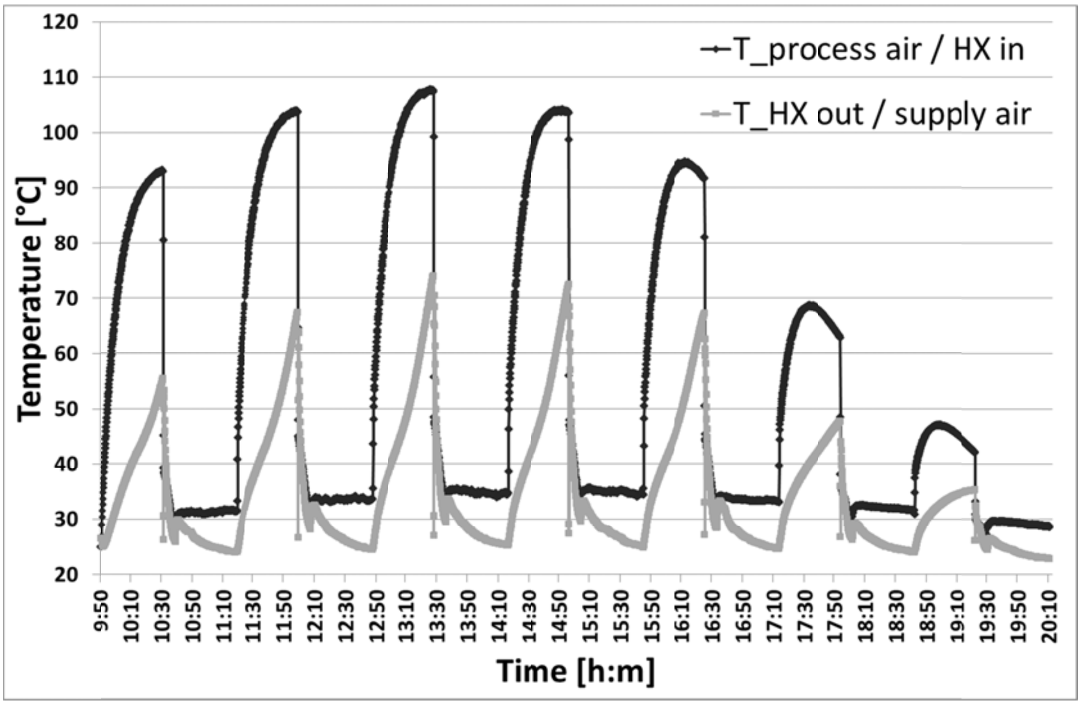

Figure 2: Developing of temperatures in the sorptive channel for one test day

Following, one of the cycles starting at 11:20 is discussed and balanced more in detail. The duration of each phase is 40 minutes desorption, 8 min. pre-cooling (last 5 min. assisted by water sprayer), and 40 min. of adsorption. The mass flows in the sorptive channel are 180kg/h for desorption and 396kg/h for adsorption phase.

After the start of desorption, the process air temperature rises up to its maximum of 103°C at the end of the step (see Figure 3). The slow rise of temperature is related to the sensible heating of piping in combination with the low air velocity at 180kg/h, which as well has a negative effect on the heat losses in relation to the heat delivered. The air leaving the HX shows a deflection point, which is correlated with the amount of humidity driven out of the sorptive coating (see Figure 4). With rising temperature of the HX the humidity output steeply approaches its maximum during the first 10 min., however the slope of temperature leaving the HX is lowered, as more of the heat is consumed by desorption of water from the adsorbent. Vice versa, as the sorption material reaches an increasingly dryer state, the humidity output is lowered, and the slope of temperature leaving the HX rises again.

At the end of the pre-cooling phase a medium HX temperature of 30°C is reached by indirect (evaporative) cooling, which enables the initiation of the adsorption or cooling phase respectively.

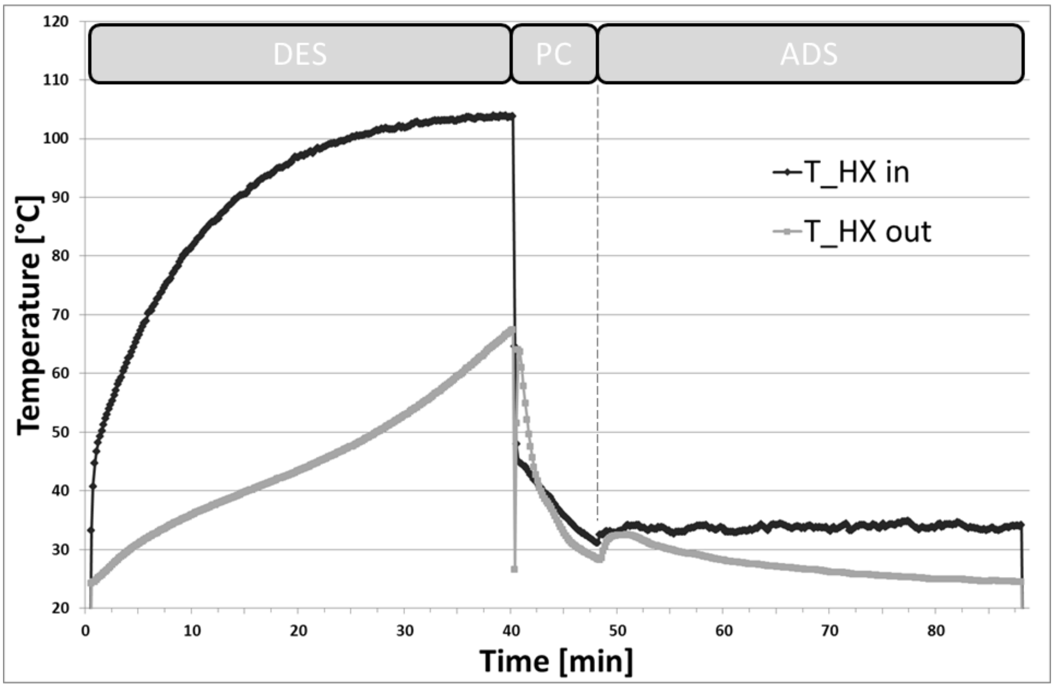

Figure 3: Temperature signal of air flow in the sorptive channel of the HX for one cycle

A small maximum in temperature leaving the HX is visible at the beginning of the adsorption phase, which is related to the high rate of adsorption and thus a bigger release of heat of adsorption during the first 5 minutes. As the adsorption rate is lowered more and more towards the end of the cooling phase, the indirect evaporative cooling results in an increased temperature reduction of the supply air.

As mentioned, the developing of humidity shows desorption and adsorption peaks related to the temperature rise or high rate of adsorption of the dry silica gel at the beginning of the cooling phase. During pre-cooling the air flow of the sorptive channel is not connected to any humidity sensor, so there is no signal for this time step. Please note that the phases of desorption and adsorption are driven with different air flows of 180kg/h and 396kg/h respectively, which results in non-congruent areas between in- and outgoing lines of the plot for the two phases.

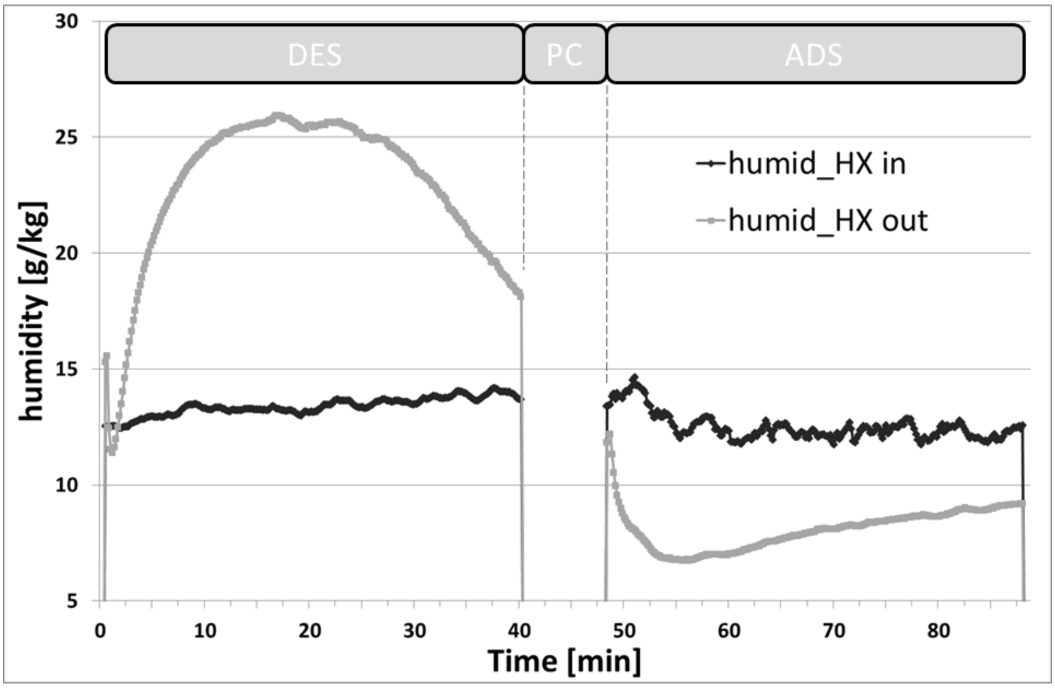

Figure 4: Humidity signal of air flow in the sorptive channel of the HX for one cycle

Calculation of the water exchange according to the following equation gives 1.12kg for desorption and 1.15kg for adsorption, which is in good agreement within given measurement uncertainty.

$$m_{H2O} = \int_{phase\_start}^{phase\_end} (x_{in} - x_{out}) * \dot{m}\ dt$$

Multiplying the amount of water with the condensation enthalpy gives the latent cooling load of the cycle provided by the sorptive dehumidification, which is 2945kJ.

$$Q_{lat} = m_{H2O} * h_{cond}(T)$$

The sensible heat loads are calculated as follows:

$$Q_{sens} = \int_{phase\_start}^{phase\_end} (T_{in} - T_{out}) * cp_{air}(x) *\ \dot{m}\, dt$$

For the adsorption step, this amounts to 1822kJ. Balanced with the adsorption duration of 40 minutes, the loads correspond to an averaged cooling power of 1.24kW latent and 0.76kW sensible, giving 2kW overall. However this power is calculated for the adsorption phase only, meaning for covering a constant cooling load of this value a second HVAC unit must be in operation, alternating in phases of de-/adsorption with the first, which is not the case in the demonstration system.

The spent heat for desorption can be calculated in a similar way as depicted for Q_{sens} above:

$$Q_{Des} = \int_{phase\_start}^{phase\_end} (T_{HX_{in}} - T_{ambient}) * cp_{air}(x) * \dot{m}\, dt$$

This is the heat the solar air collector has to provide the process, and accounts for 7355kJ. Finally the thermal coefficient of performance (COP_{therm}) can be calculated by:

$$COP_{therm} = \frac{Q_{used}}{Q_{spent}} = \frac{Q_{sens} + Q_{lat}}{Q_{Des}}$$

The COP value calculated as 0.65 is unexpectedly high for the process driven with more than 100°C. It shall be mentioned that some effects like e.g. heat losses along the piping from collector to the HVAC unit are not considered in the calculation presented above. However there are some approaches for optimization like e.g. heat recovery of the process air flow (see Figure 1), adjustment of cycle times and finally applying the airwasol TST collector as well as the SAPO coated HX, that can even top the good performance of the system so far.

Conclusion

An energy efficient HVAC system has been developed in a cooperative project with the partners Fraunhofer ISE, airwasol and Contherm. The demonstration system, which incorporates a vacuum tube solar air collector with an ECOS system for sorption assisted evaporative cooling, shows even at the start of operation very good performance values with cooling power of 2kW and a COP of 0.65. By small adjustments as well as application of new developed components, the performance is estimated to be improved even beyond that.

Acknowledgements

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References

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