

# IEA SHC TASK 48 5<sup>TH</sup> MEETING

FRAUNHOFER-INSTITUT FÜR SOLARE ENERGIESYSTEME ISE

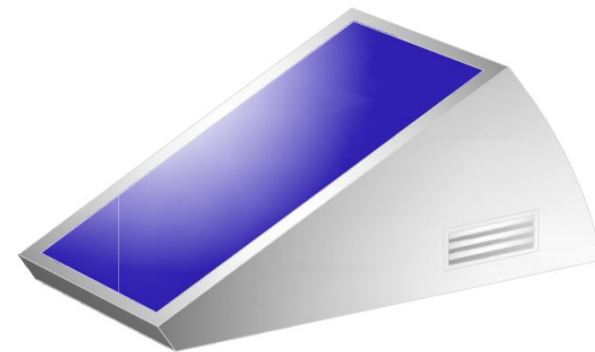
## FIRST MONITORING RESULTS OF A NEW COMPACT SOLAR AIR CONDITIONER BASED ON FIXED AND COOLED ADSORPTION BEDS

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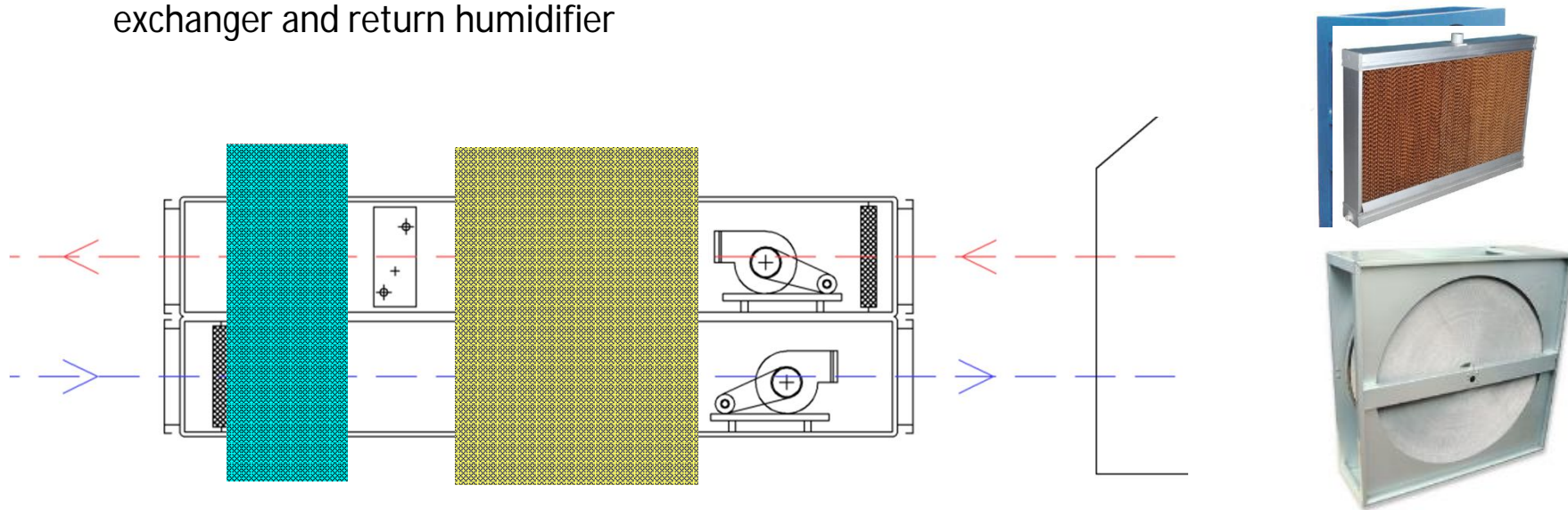
UNIVERSITÀ  
DEGLI STUDI  
DI PALERMO

DEIM - Dipartimento di Energia,  
ingegneria dell'Informazione, e modelli  
Matematici



# INTRODUCTION

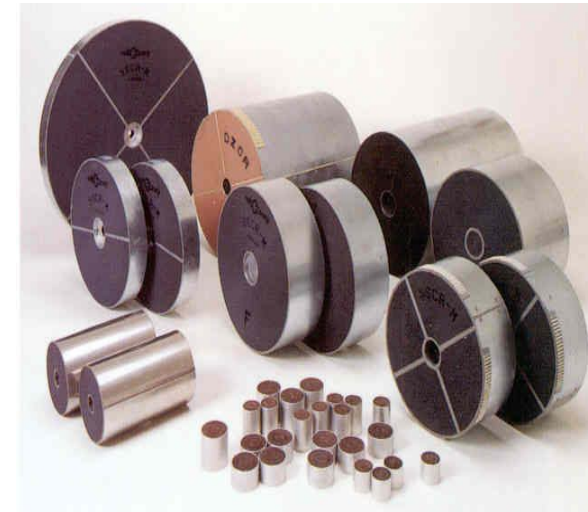
- In DEC systems desiccant rotors are commonly used
- The use of desiccant rotors implies that condensation heat is rejected into the processed air and has to be removed by means of the indirect evaporative cooling process
- System based on simultaneous adsorption and desorption processes
- The rotating sensible heat exchanger has to carry over two tasks:
  - Heat recovery
  - Cold production
- Enthalpy difference of the DEC AHU strongly dependent on the efficiency of sensible heat exchanger and return humidifier



# ADSORPTION PROCESS BASED ON DESICCANT ROTORS

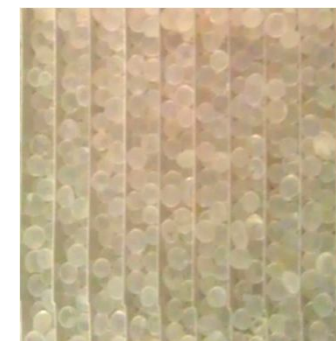
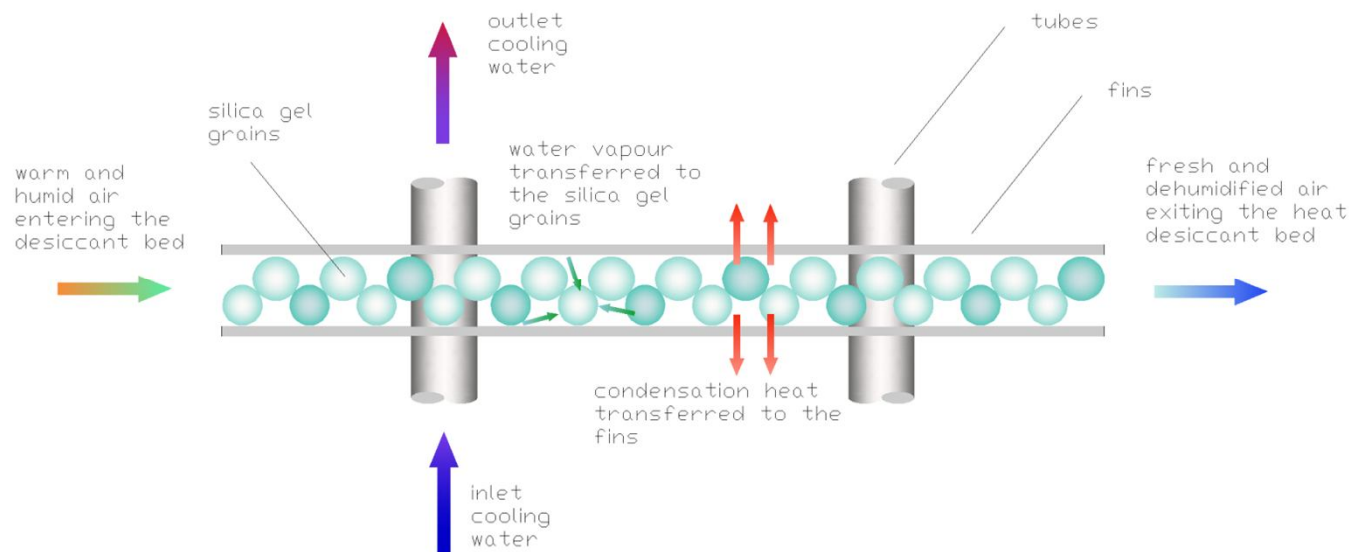
Furthermore:

- An increase of the desiccant material temperature is responsible also for higher regeneration temperatures required
- Desiccant rotors are built to host a relatively low mass of adsorbent.
- Energy storing is commonly based on the mass and the heat capacity of the fluid used for the regeneration of the desiccant
- The use of hot air as regeneration fluid is suitable only with systems without storage



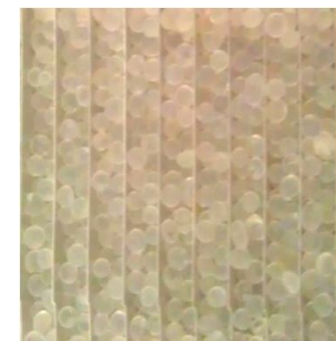
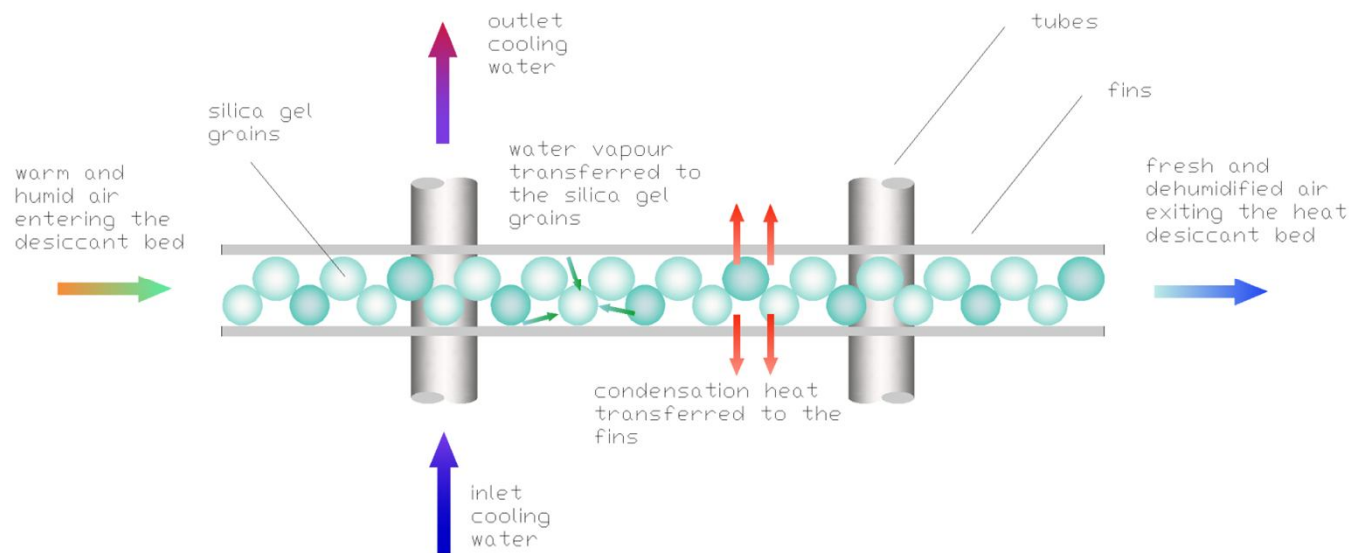
# INNOVATIVE FIXED AND COOLED ADSORPTION BED

- The component is a fin and tube heat exchanger commonly used in the air conditioning sector, wherein the spaces between the fins are filled with silica gel grains
- The developed component allows a simultaneous **mass transfer** between the moist air and the adsorbent media and **heat exchange** between the air and the water flowing into the heat exchanger tubes;
- The cooling of the desiccant material during the adsorption process allows high dehumidification performances of the desiccant bed and in general better overall energy performances of the system;



# INNOVATIVE FIXED AND COOLED ADSORPTION BED

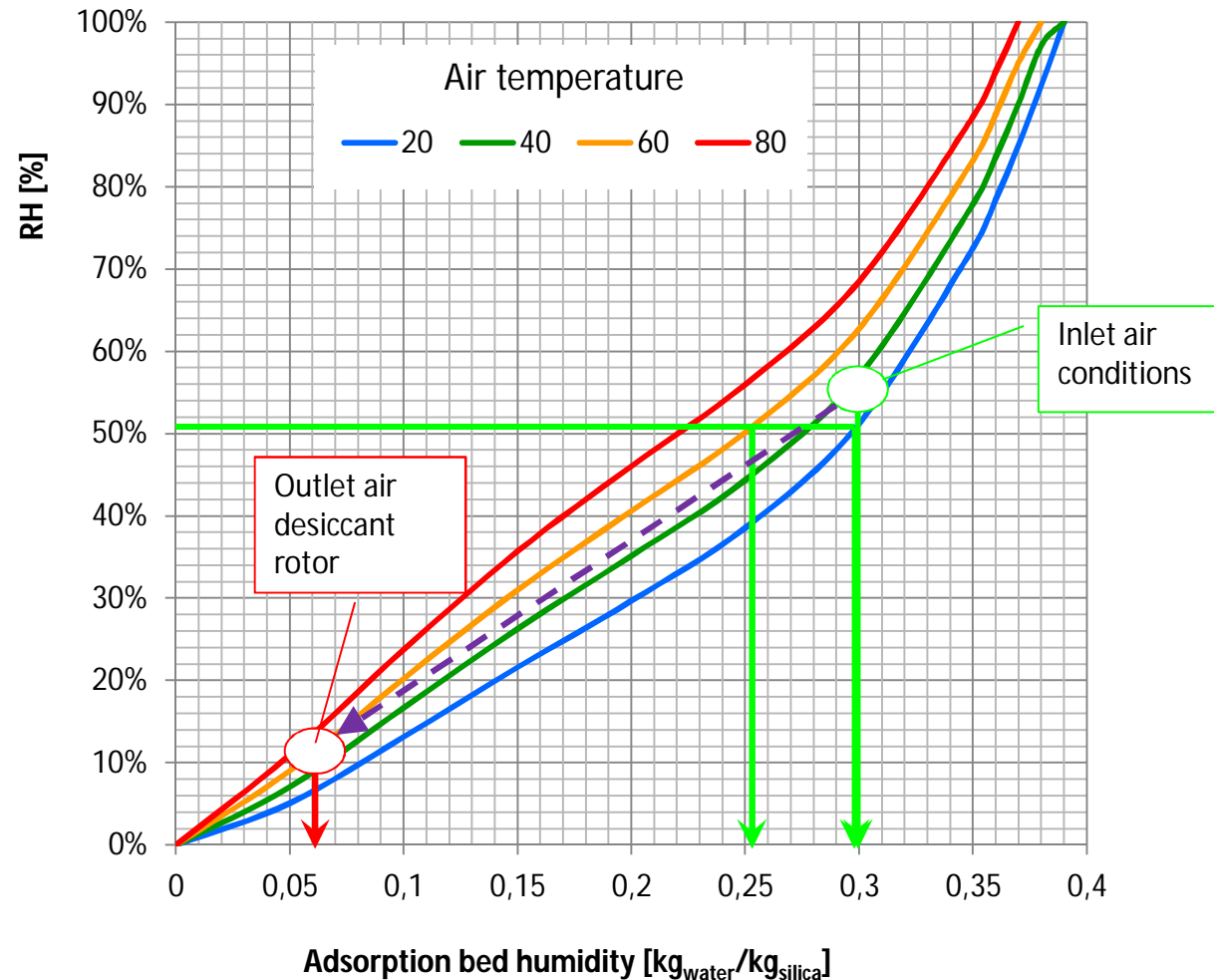
- Water temperatures required can be easily achieved with a cooling tower;
- High amount of silica gel can be used;
- Adsorption and desorption processes happen in different times;
- Solar energy can be efficiently stored in the desiccant in terms of adsorption capacity which can be used later when regeneration heat is not available, strongly reducing the necessity for thermal storage;



# COMPARISON OF THE ADSORPTION PROCESSES

## Equilibrium isotherm of adsorption for silica gel RD

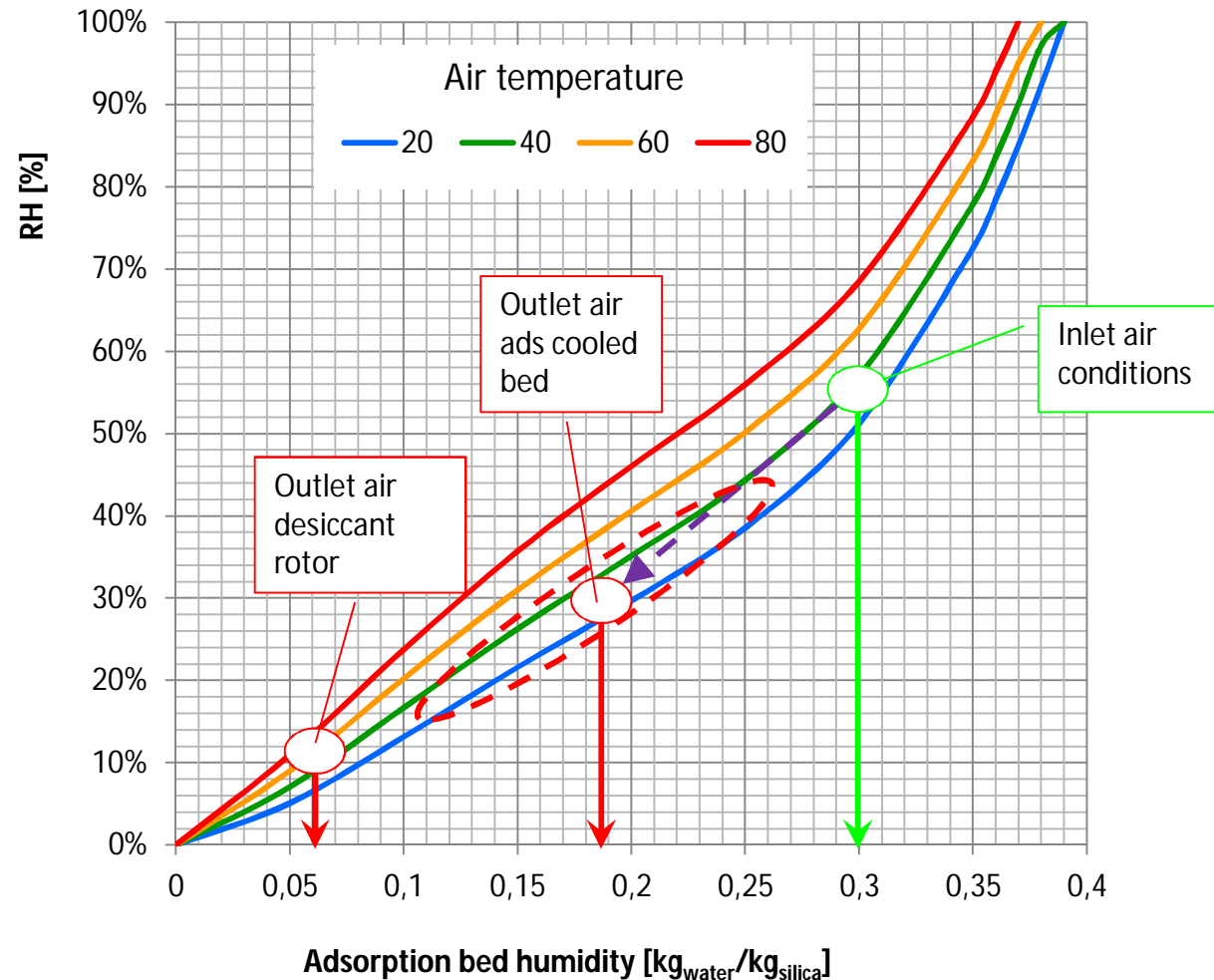
- The higher the temperature of the desiccant the lower the adsorption capacity
- During adsorption in **desiccant rotors**, air temperature increases and relative humidity strongly decreases



# COMPARISON OF THE ADSORPTION PROCESSES

## Equilibrium isotherm of adsorption for silica gel RD

- During adsorption in **adsorption cooled bed**, air temperature can slightly decrease and relative humidity ranges from 15% at the beginning of the process to 40% at the end
- Average adsorption bed humidity at equilibrium is much higher than for desiccant rotors



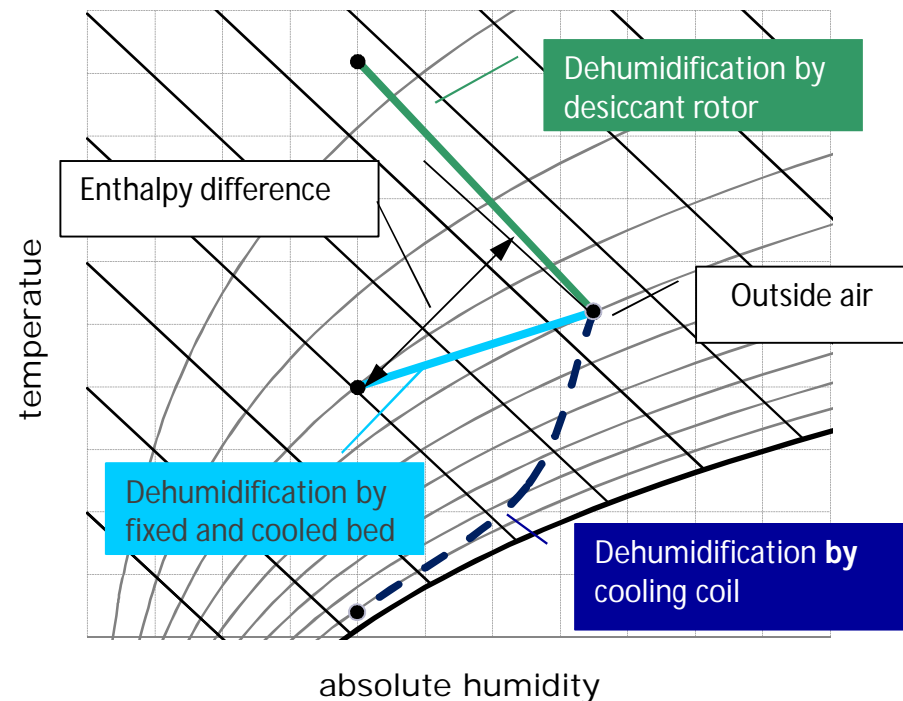
# COMPARISON OF THE ADSORPTION PROCESSES

## Dehumidification by desiccant rotor

- Adsorption process realized by means of desiccant rotors is a quasi – isenthalpic transformation
- It presents the disadvantage of causing a temperature increase of the desiccant material
- No enthalpy difference between in and out

## Dehumidification by fixed and cooled desiccant bed

- Condensation heat can be rejected
- The thermodynamic process causes an enthalpy difference between inlet and outlet air conditions
- In general, the temperature of air exiting the adsorption bed can be lower than the one of incoming air
- Downstream indirect evaporative cooling process can be operated at lower temperature

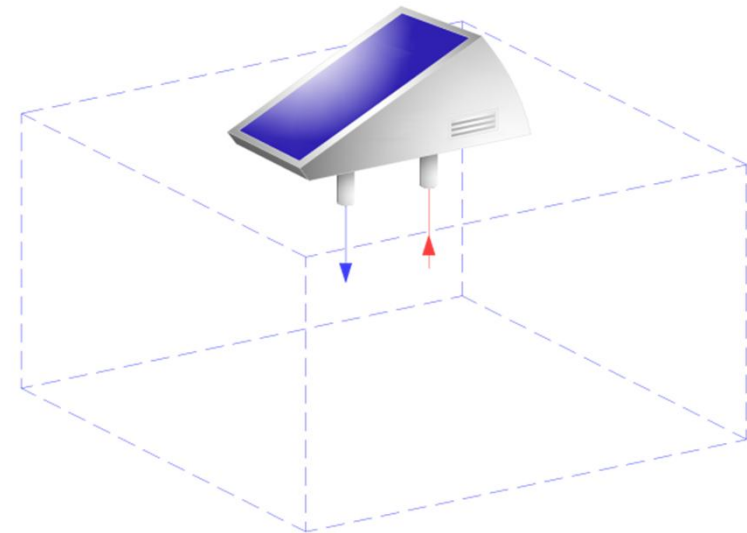




# DESIGN CONCEPT OF THE NEW DEC CYCLE

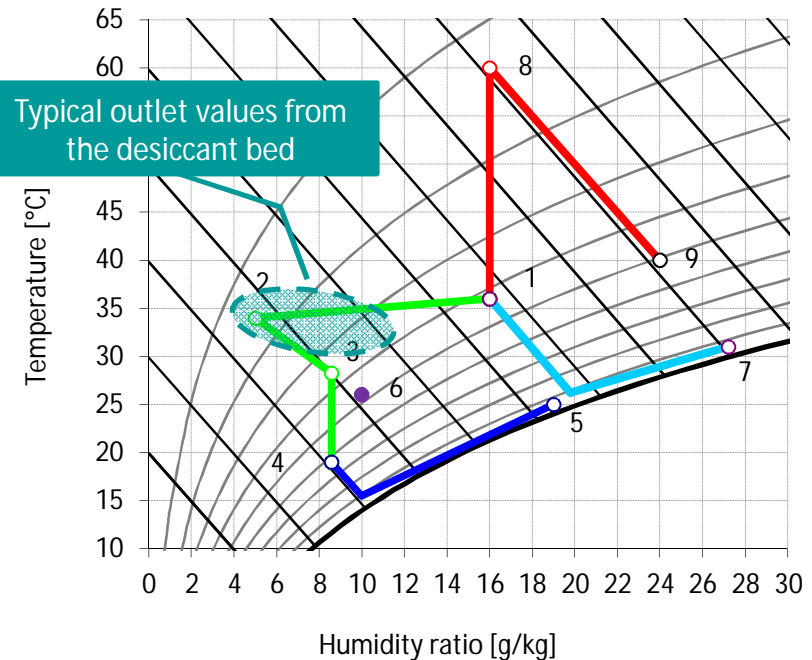
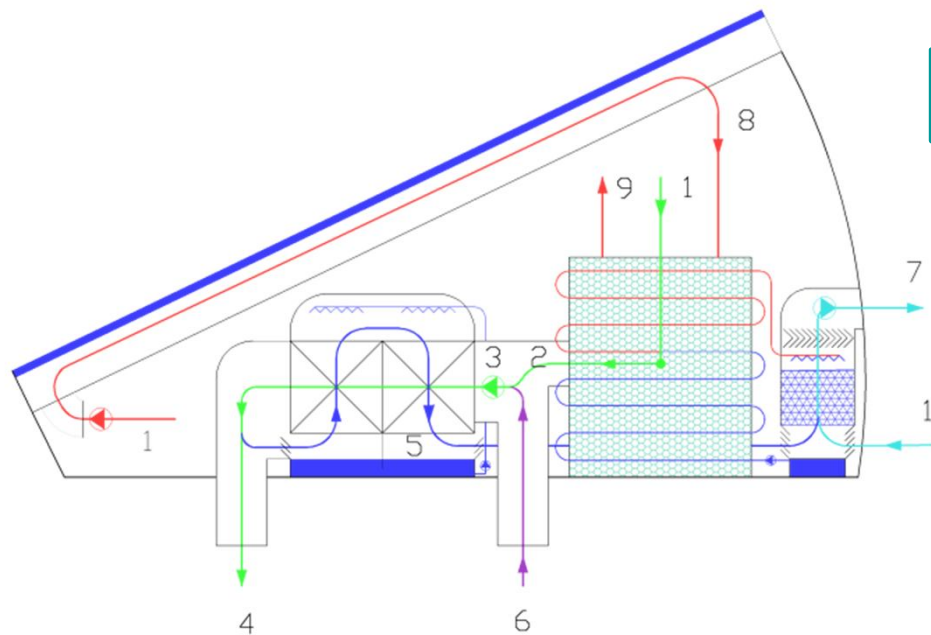
## SYSTEM DESIGN SPECIFICATIONS

- Designed for small scale applications of air ventilation, dehumidification and cooling
- Based on fixed and cooled adsorption beds and high efficient evaporative cooling concepts
- Use of solar air collectors
- Minimization of parasitic energy consumption
- Solar autonomous, no use of auxiliary energy source
- System should be compact, all in one, reliable, and easy to install



# DESCRIPTION OF THE NEW DEC SYSTEM

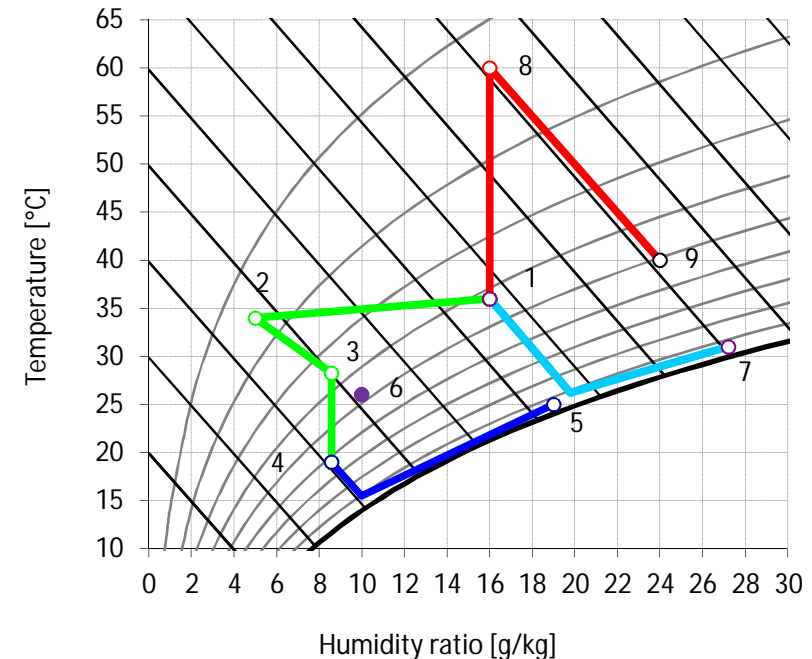
- The new compact system developed is based on the use of two fixed packed desiccant beds of silica gel operating in a batch process and cooled by cooling tower, and two wet heat exchangers connected in series
- Adsorption bed designed to be operated in “low flow” mode (air velocity =0.16 m/s)
- A portion of the primary air flow rate exiting the wet heat exchanger is drawn into the secondary side



# DESCRIPTION OF THE NEW DEC SYSTEM

- Main electricity consumptions of the system are related to the use of three fans (solar, main, cooling tower) and two pumps (wet HX, cooling tower)
- A system of air valves provides the switch from one bed to the other in order to guarantee a continuous dehumidification process
- No auxiliary device included

	Description	x	T	H
	-	g/kg	°C	kJ/kg
Process air	1 Outside air	16.0	36.0	77.2
	2 Adsorption bed	6.0	34.0	49.5
	3 Mixing	9.6	28.3	52.8
	4 Wet HX1 + HX2	9.6	19.0	43.3
Building	6 Return air	11.0	26.0	54.1
Secondary air in wet heat exchangers	4 Wet HX1 + HX2	9.6	19.0	43.3
	5 Humidification	10.8	17.0	44.4
Cooling tower	1 Inlet cooling	19.8	28.0	78.7
	7 Cooling tower	25.5	30.0	95.3
Regeneration air	1 Outside air	16.0	36.0	77.2
	8 Solar collector	16.0	60.0	102.0
	9 Desorption	24	40	101.96



# REALIZED PROTOTYPE

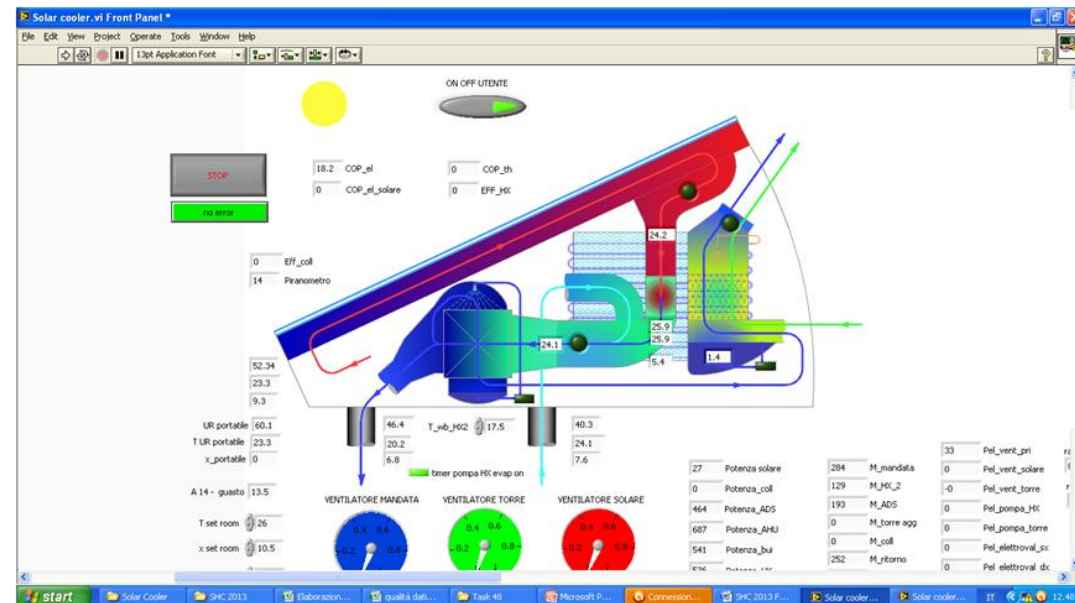
- Solar air collector area: (1x2) m<sup>2</sup>
- Two ADS beds, with 15 kg of silica gel each
- One wet HX
- Total flow rate: 500 m<sup>3</sup>/h
- Max electric power: 0,2 kW
- Max cooling power: 2,2 kW (at  $T_{\text{outside}} = 35^{\circ}\text{C}$ ,  $\text{RH}_{\text{outside}} = 50\%$ ,  $T_{\text{bui}} = 27^{\circ}\text{C}$ ,  $\text{RH}_{\text{bui}} = 50\%$ )
- Total weight  $\approx 150$  kg



International PCT pending

# MONITORING AND CONTROL SYSTEM

- **five** HIH – 4000 series Honeywell **humidity sensors** with accuracy  $\pm 3,5\%$
- **nine** integrated-circuit **temperature sensors**, type LM35CAZ by National Semiconductor, accuracy of  $\pm 0,5^{\circ}\text{C}$  positioned upstream and downstream of the main components
- flow rate were measured using a anemometer with a accuracy of  $\pm 3 \%$  over the full scale
- solar radiation was measured using a **pyranometer** (1st class, ISO 9060) installed on the collector plane
- electricity consumption was measured using a DC meter with  $\pm 0,5\%$  accuracy
- a Microprocessor **Arduino Mega 6025** in combination with **Labview** was used as control and acquisition unit.



# PERFORMANCE INDICATORS USED

$$MR = \frac{\dot{m}_{outside}}{(\dot{m}_{supply} + \dot{m}_{outside})}$$

Mass flow ratio  
between secondary  
and primary side of  
wet HX

$$\text{Cooling energy}_{ADS\ BED} = \dot{m}_{outside} (h_1 - h_2)$$

$$\text{Cooling energy}_{WET\ HX} = (\dot{m}_{outside} + \dot{m}_{supply})(h_3 - h_4)$$

$$\text{Total cooling energy delivered} = [\dot{m}_{outside} (h_1 - h_2) + (\dot{m}_{outside} + \dot{m}_{supply})(h_3 - h_4)] (1 - MR)$$

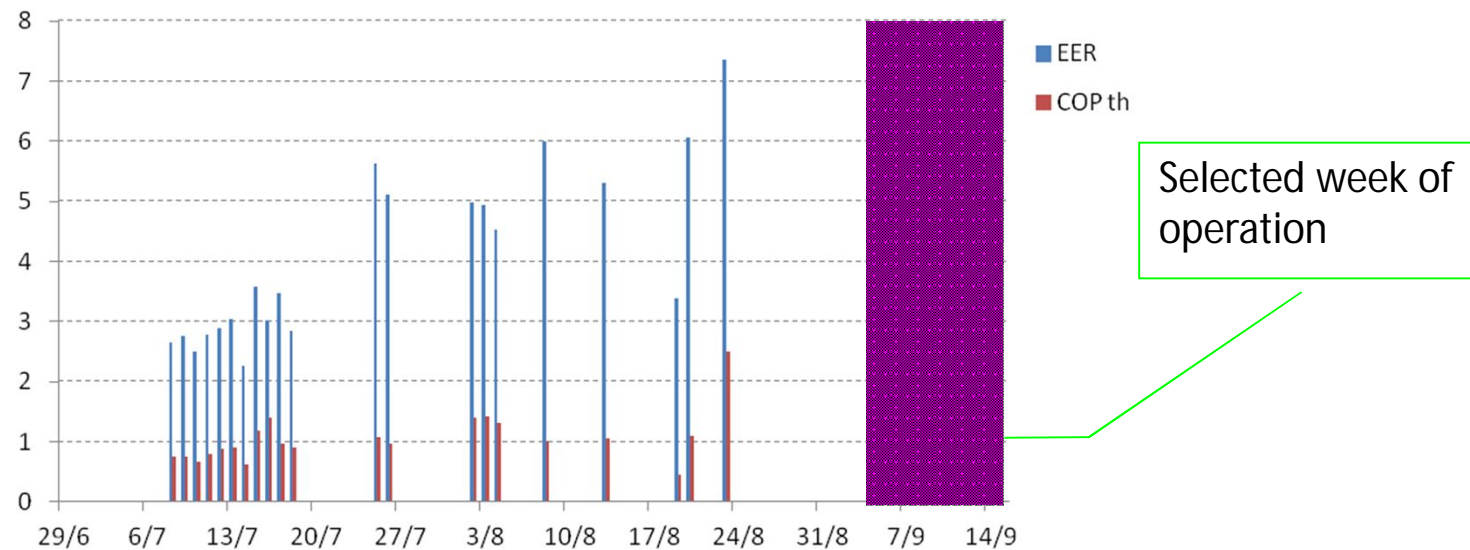
$$EER = \frac{\text{Total cooling energy delivered}}{\text{Total electricity consumed}}$$

Cooling power due to  
the handing of the  
outside air **included**

$$COP_{th} = \frac{\text{Total cooling energy delivered}}{\text{Solar Heat delivered}}$$

# MONITORING DATA SELECTION

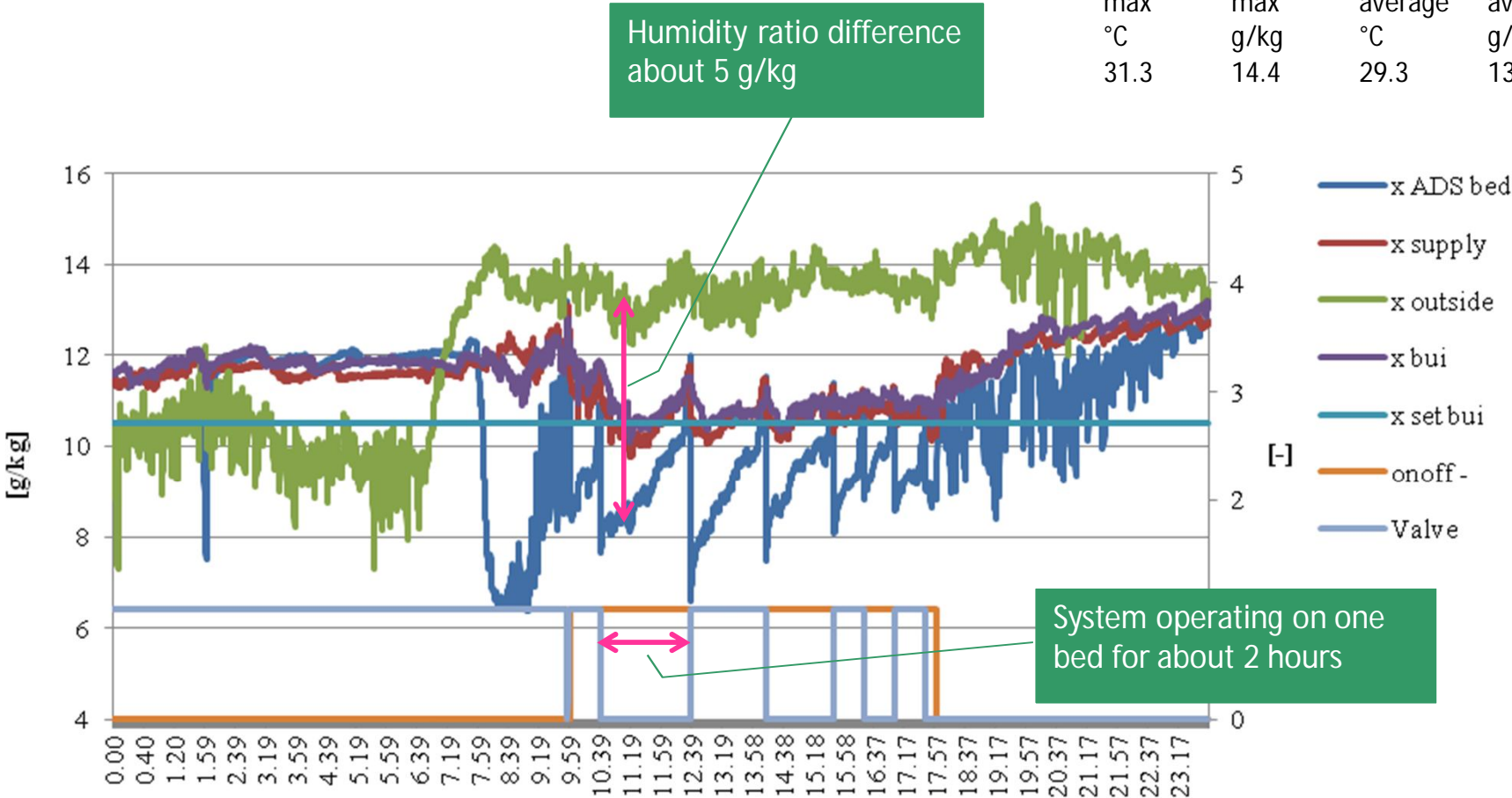
- First tests were aimed to the verification of the control and monitoring system and to the tuning of components started in June of this year
- After the this first phase, monitoring could start at the 2<sup>nd</sup> week of July
- Lack of monitoring data caused by interruptions on data transmission and stops
- Globally about 30 days of monitoring data are available with a total amount of 240 operation hours
- A selection of one week operation data with a total amount of **54 operation hours** was carried out



# HUMIDITY RATIO VALUES

5<sup>th</sup> day of the selected week

T outside max °C	x outside max g/kg	T outside average °C	x outside average g/kg
31.3	14.4	29.3	13.4

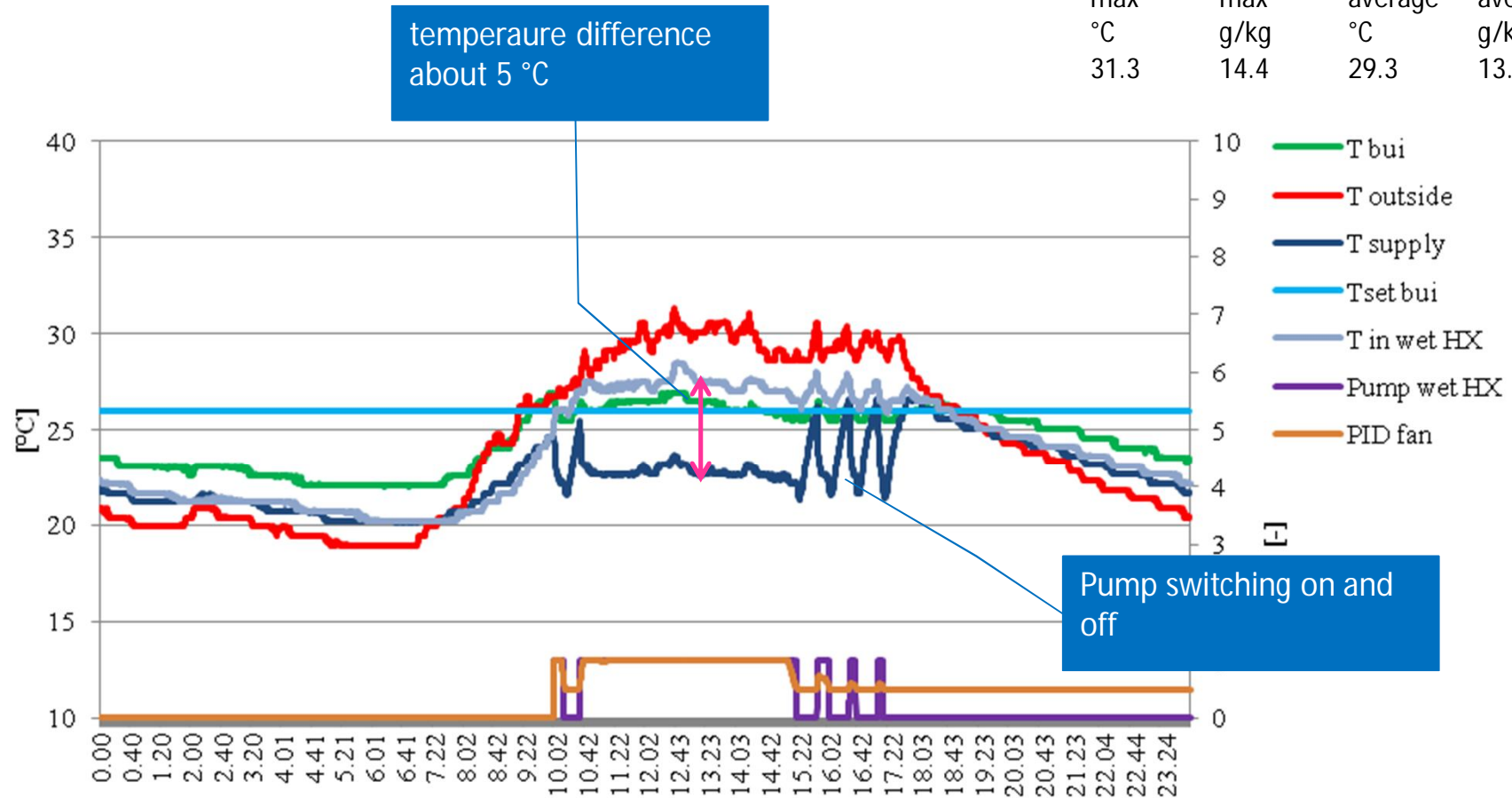




# TEMPERATURE VALUES

5<sup>th</sup> day of the selected week

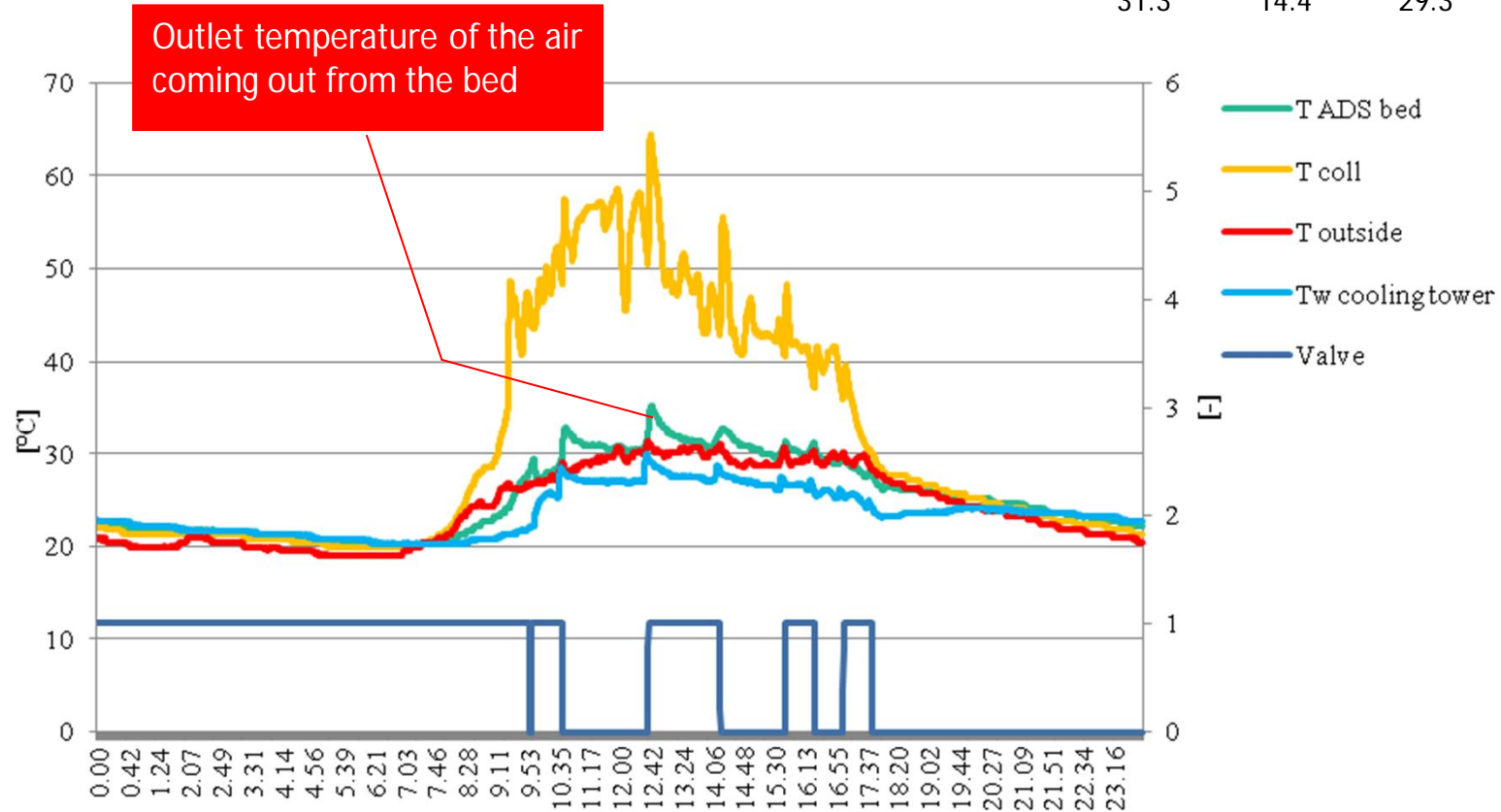
T outside max °C	x outside max g/kg	T outside average °C	x outside average g/kg
31.3	14.4	29.3	13.4



# SOLAR, ADS BED AND COOLING TOWER

5<sup>th</sup> day of the selected week

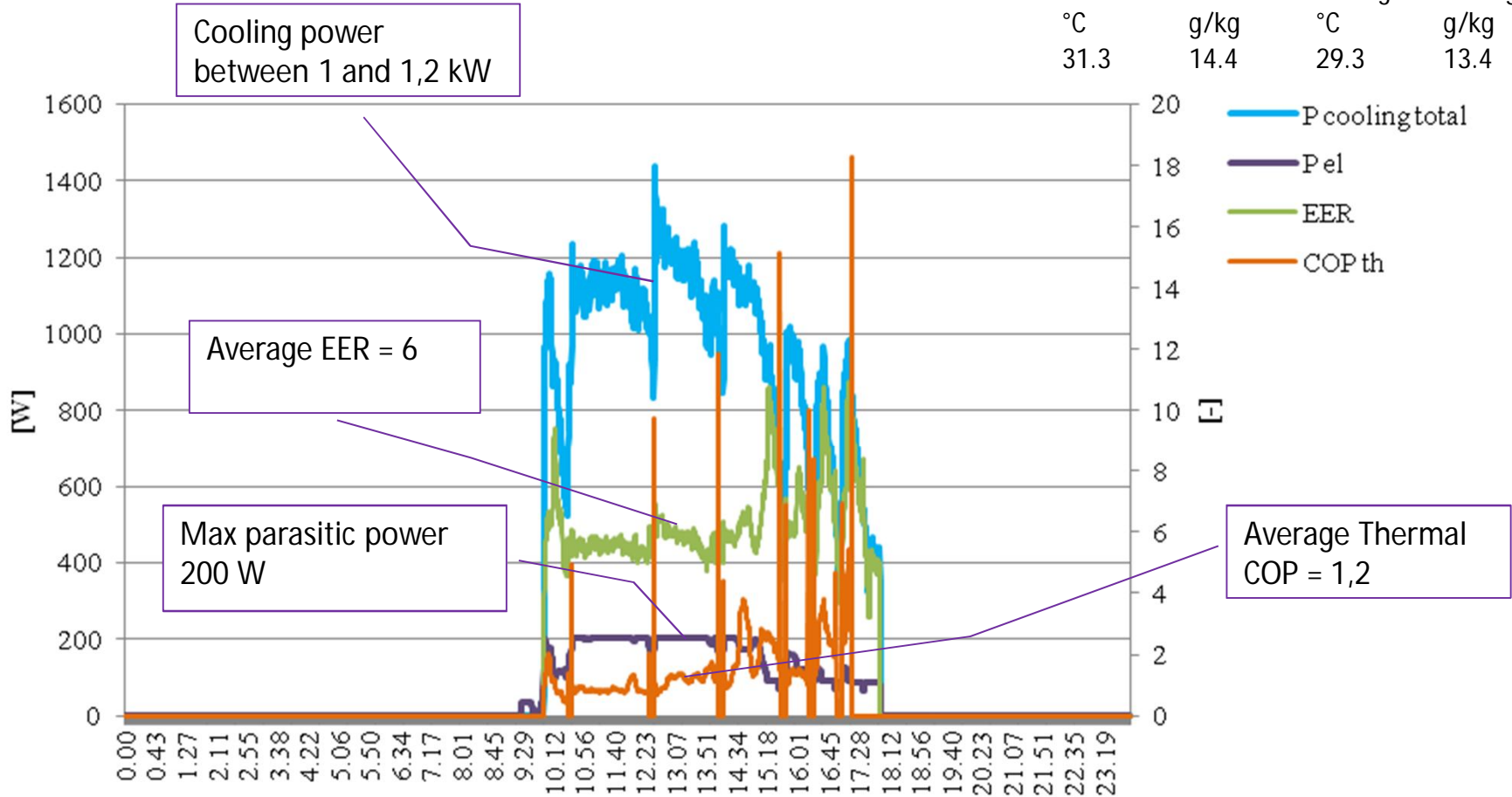
T outside max °C	x outside max g/kg	T outside average °C	x outside average g/kg
31.3	14.4	29.3	13.4



# MAIN ENERGY PERFORMANCES

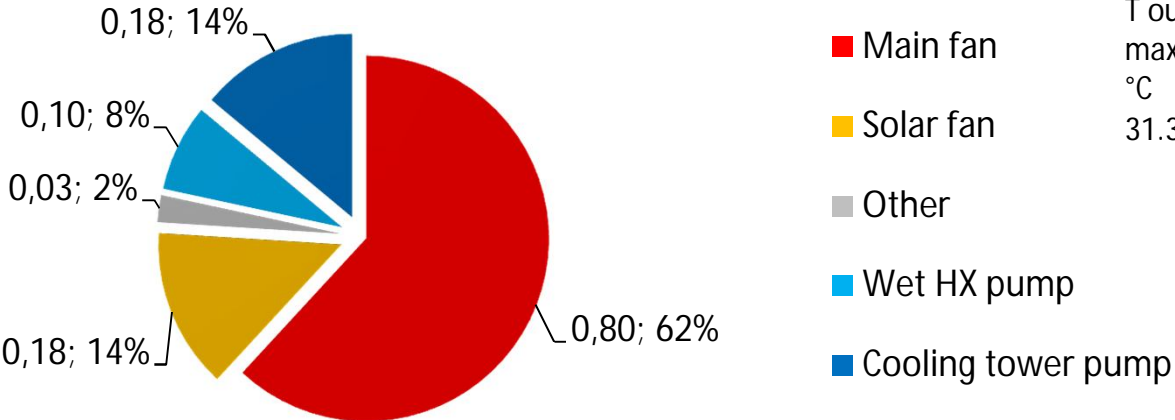
5<sup>th</sup> day of the selected week

T outside max	x outside max	T outside average	x outside average
°C	g/kg	°C	g/kg
31.3	14.4	29.3	13.4

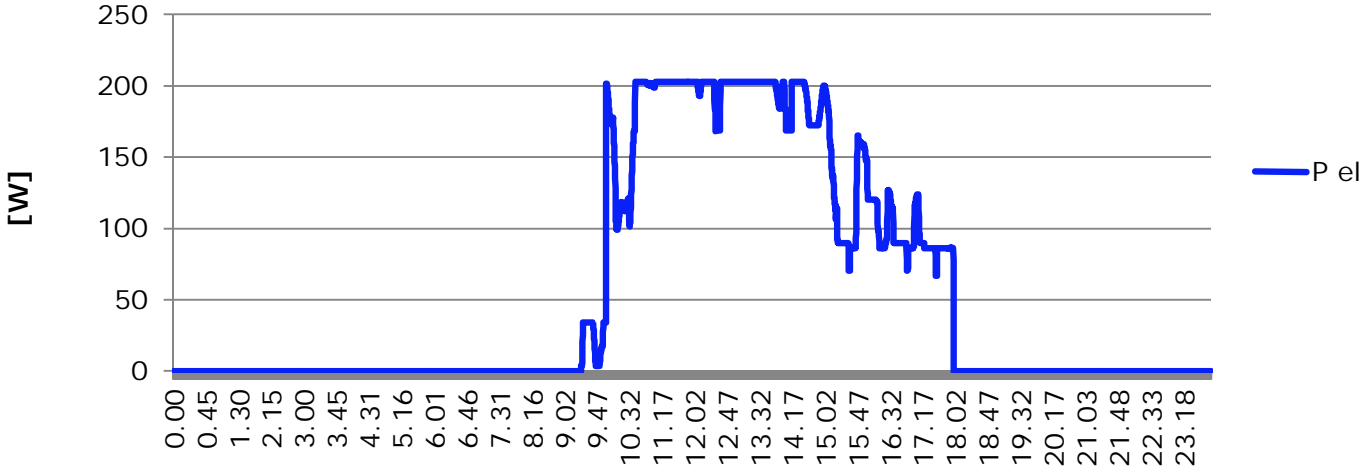


# ELECTRICITY CONSUMPTIONS DISTRIBUTION

5<sup>th</sup> day of the selected week



T outside max	x outside max	T outside average	x outside average
°C	g/kg	°C	g/kg
31.3	14.4	29.3	13.4



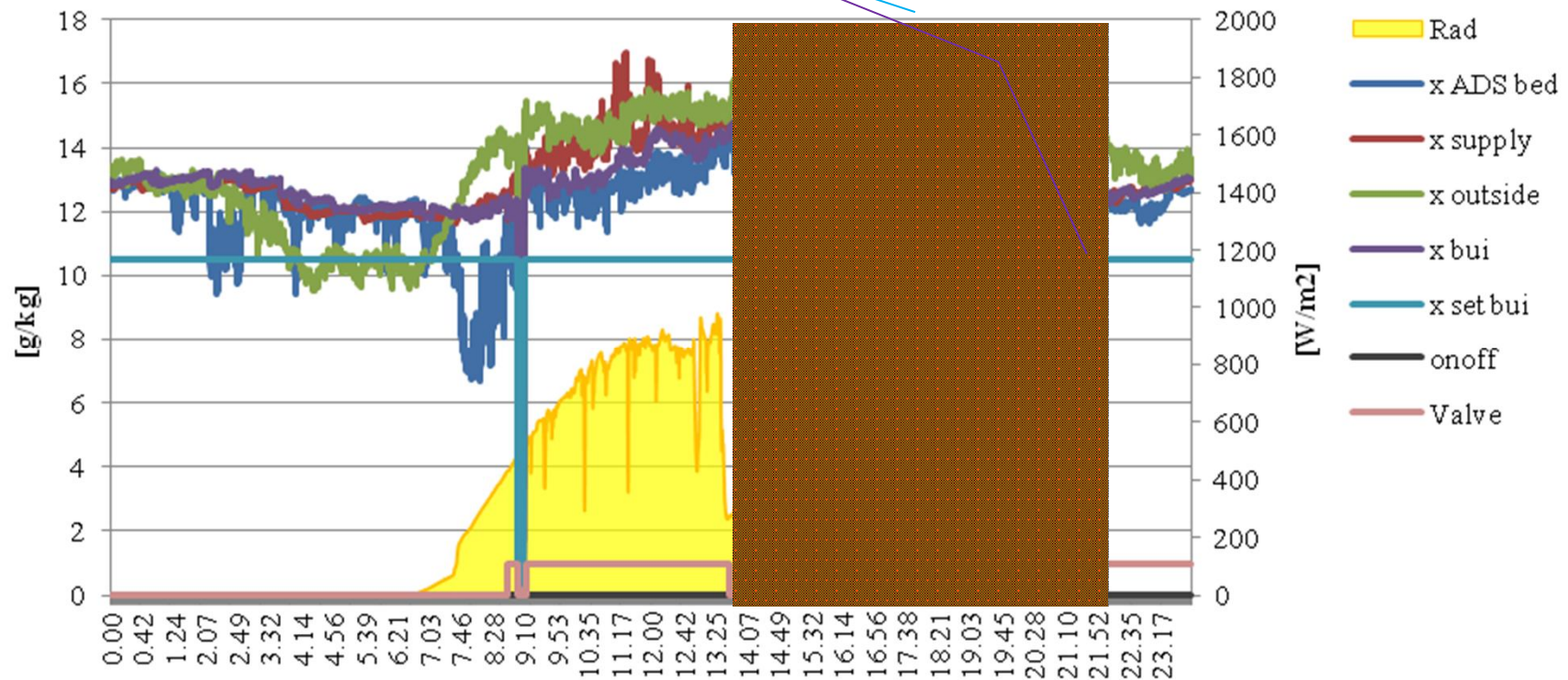
# HUMIDITY RATIO VALUES

6<sup>th</sup> day of the selected week

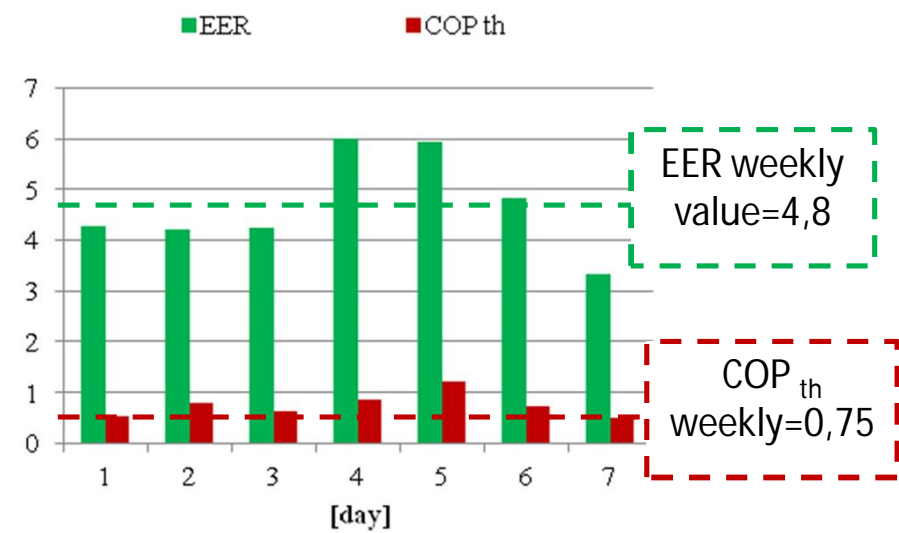
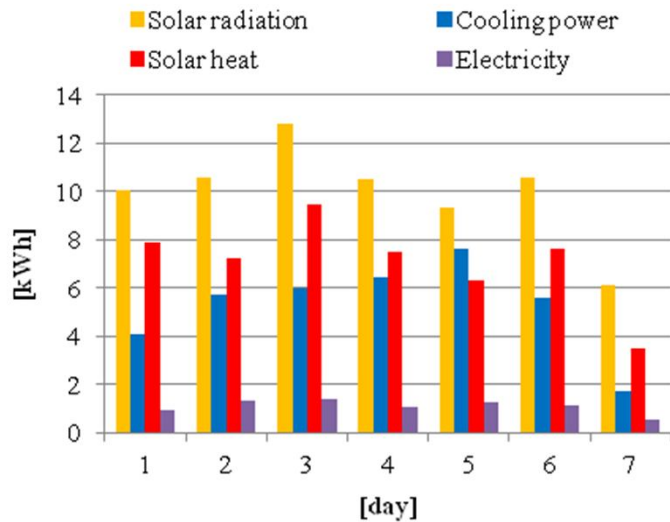
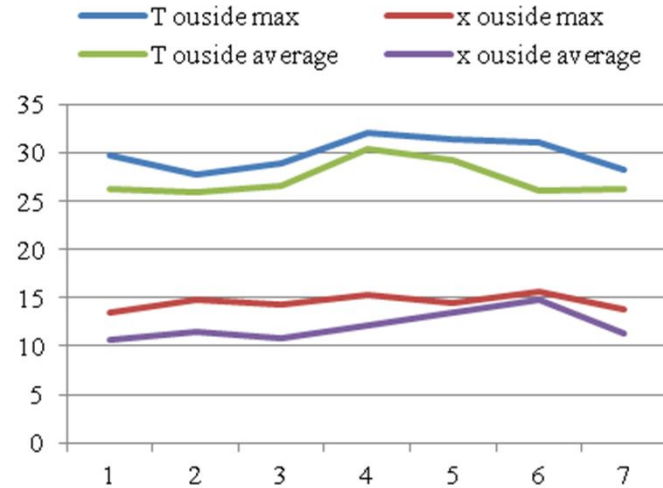
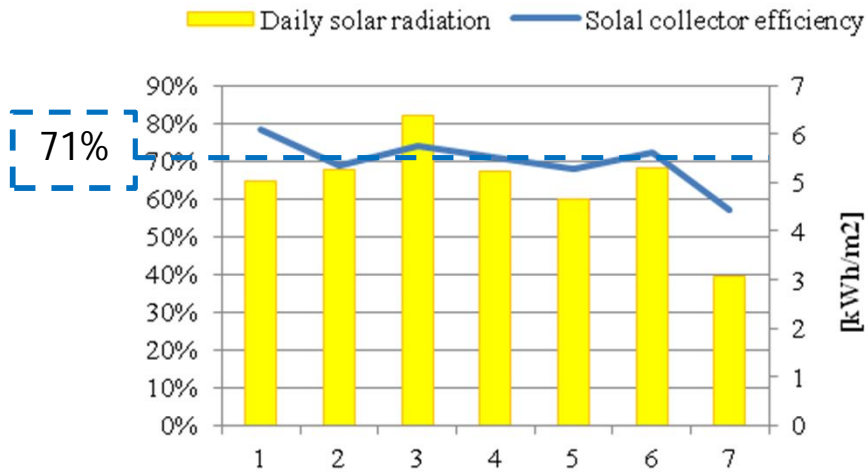
System could provide dehumidification for several hours after the sunset

operation time from 2:00 am to 10:00 pm

T outside max	x outside max	T outside average	x outside average
°C	g/kg	°C	g/kg
31.1	15,7	26,0	14,8



# DAILY WEATHER CONDITIONS AND PERFORMANCE INDICATORS – ONE WEEK OF OPERATION



# CONCLUSIONS

- An innovative concept of a compact desiccant cooling system for small scale applications was developed
- The core component is a fixed and cooled adsorption bed which permits to dehumidify and cool the air
- Low temperature required for the regeneration of the desiccant material (max 60°C), standard solar flat plate air collector can be used
- A prototype for residential application was realized and tested
- Monitoring results show the validity of the proposed solution and good performances both in terms of building temperature and humidity control
- EER and thermal COP values are also encouraging, but optimizations are still possible
- The cooling power delivered to the building could be increased by the use of two wet heat exchangers connected in series instead of only one
- Electricity consumptions could be reduced by a redesign of the air channels

# CONCLUSIONS

- The opportunity to use the desiccant bed as latent storage permits to supply cooling energy to the building also several hours after the sunset
- Control of the dehumidification process acting on the temperature of the bed is possible
- The fact that adsorption and desorption processes happen in different times can be considered an advantage for the control of the dehumidification process



Thank you for your attention!