IEA SHC Task 48 4th meeting

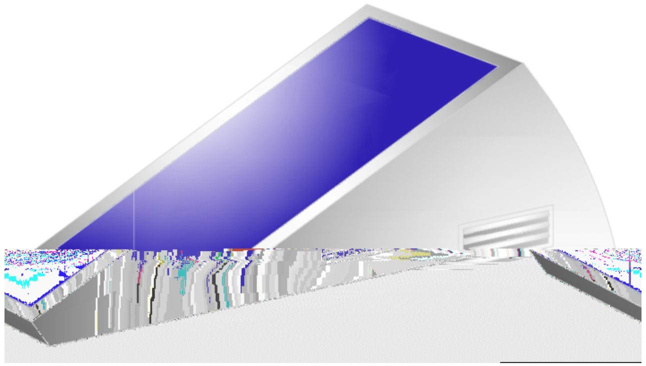
April 9th - 10th, 2013 CSIRO Energy Technology

A NEW COMPACT SOLAR AIR CONDITIONER BASED ON FIXED ADSORPTION BEDS AND HIGH EFFICIENT EVAPORATIVE COOLING CONCEPTS AND PROTOTYPE

Pietro Finocchiaro, Marco Beccali

finocchiaro@dream.unipa.it

marco.beccali@dream.unipa.it

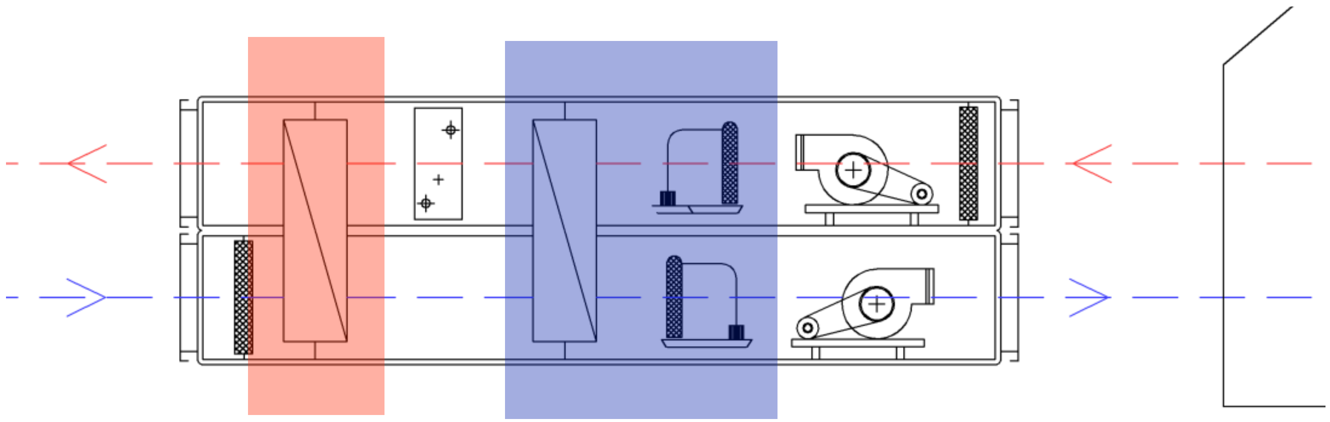


UNIVERSITÀ DEGLI STUDI DI PALERMO

DEIM - **D**ipartimento di **E**nergia, ingegneria dell'**I**nformazione, e modelli **M**atematici

INTRODUCTION

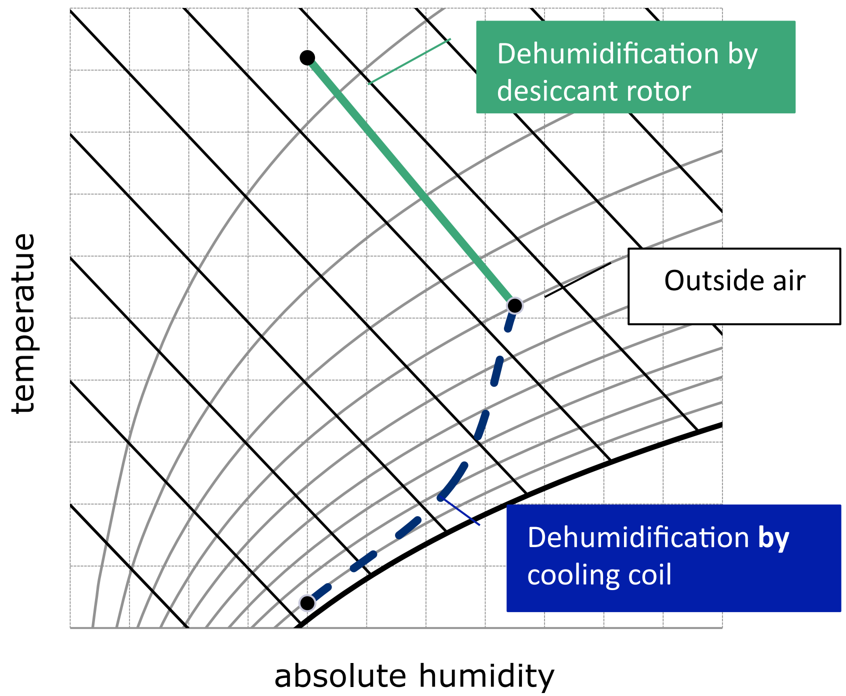
- The use of desiccant rotors implies that condensation heat is rejected into the processed air and has to be removed by means of the indirect evaporative cooling process
- System based on simultaneous adsorption and desorption processes
- The rotating sensible heat exchanger has to carry over two tasks: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



ADSORPTION PROCESS BASED ON DESICCANT ROTORS

- Adsorption process realized by means of desiccant rotors is a quasi – isoenthalpic transformation
- It presents the disadvantage of causing a temperature increase of the desiccant material

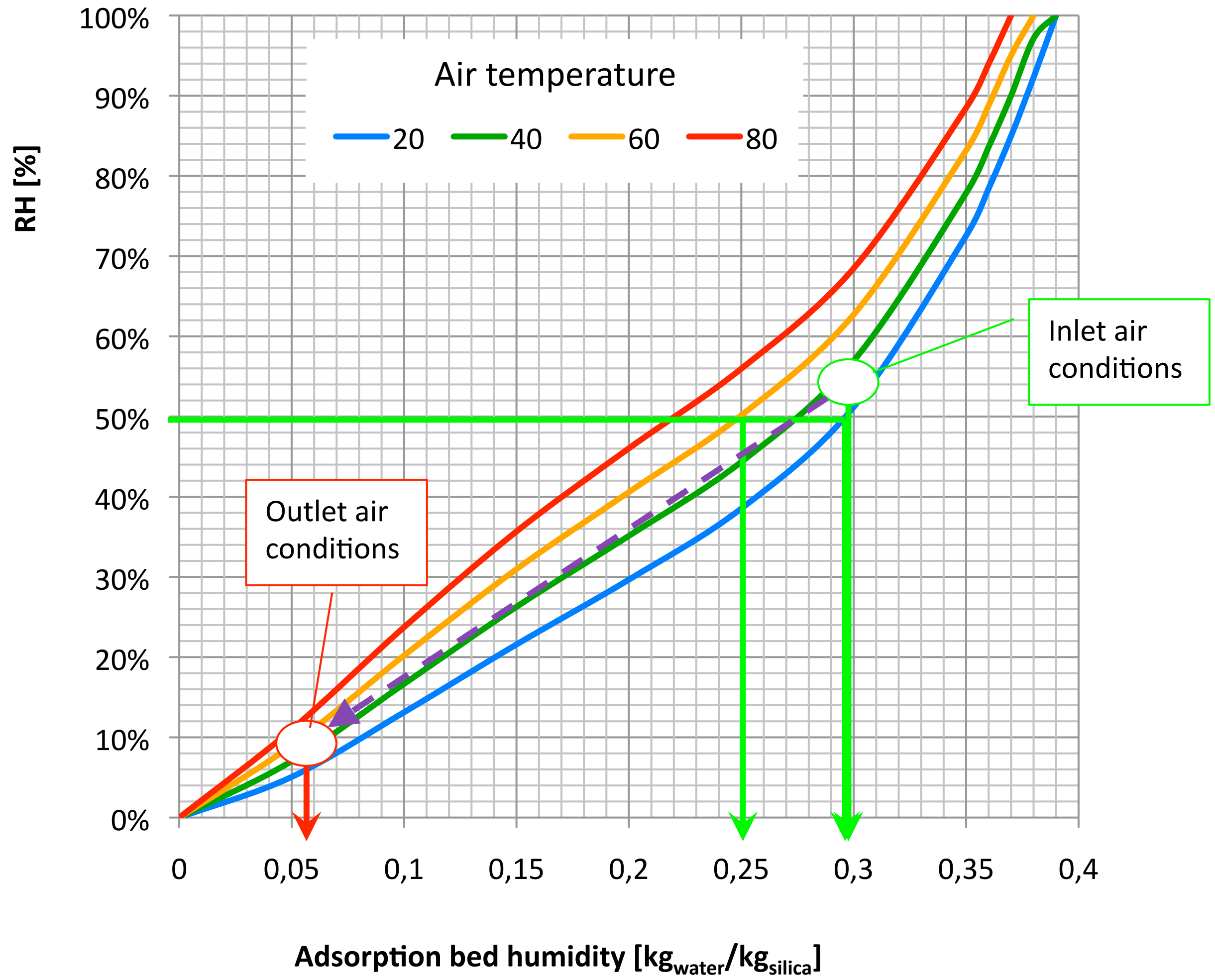
- This phenomena is mostly caused by the **release of adsorption heat** due to water condensation in the desiccant material and in a lower degree by **the carry-over of heat** stored in the desiccant material from the regeneration section to the process section. (The purge section can limit this last aspect)
- No enthalpy difference between in and out



ADSORPTION PROCESS BASED ON DESICCANT ROTORS

Equilibrium isotherm of adsorption for silica gel RD

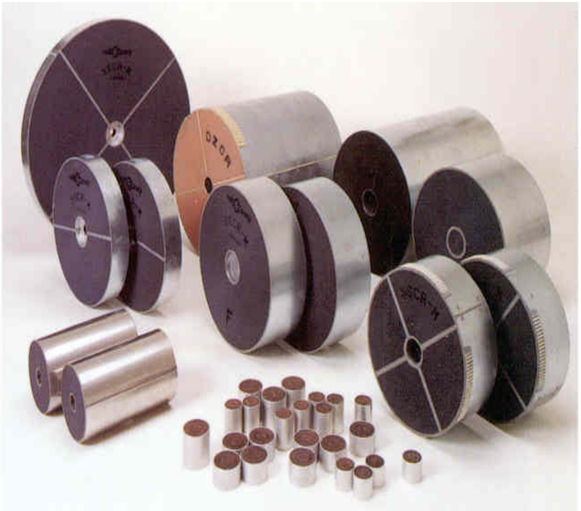
- The higher the temperature of the desiccant the lower the adsorption capacity
- During adsorption in desiccant rotors, air temperature increases and relative humidity strongly decreases



ADSORPTION PROCESS BASED ON DESICCANT ROTORS

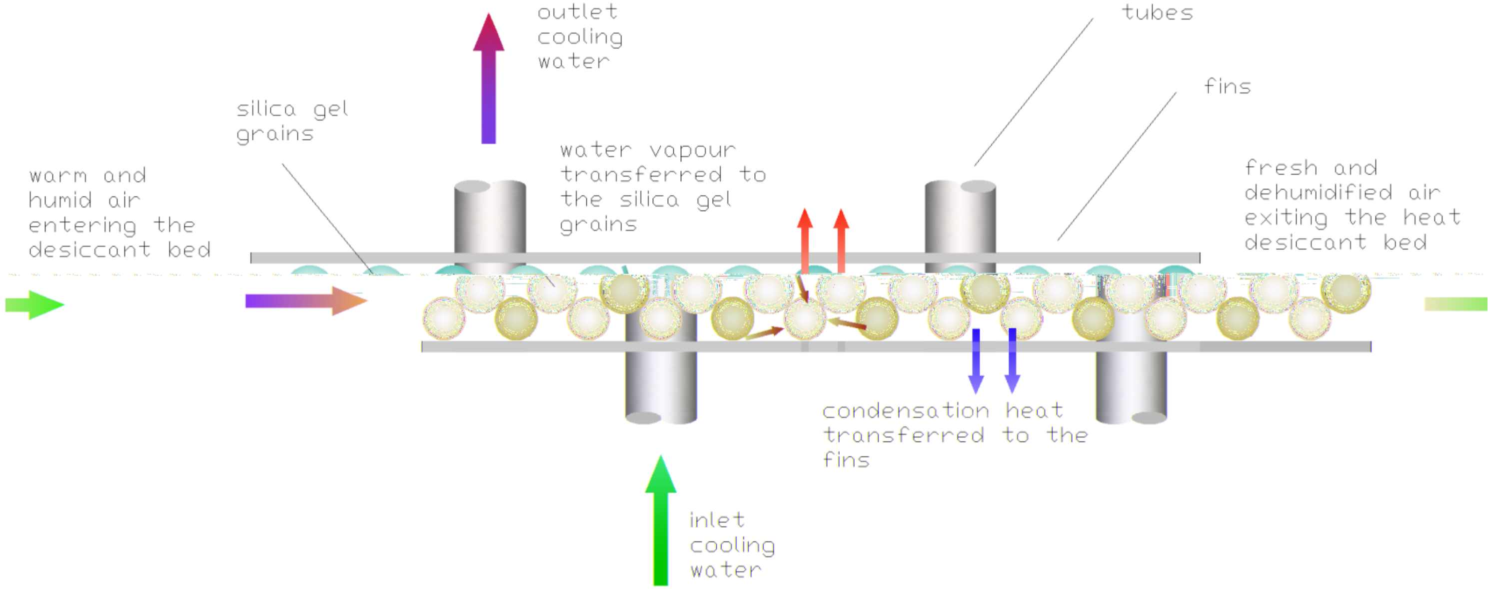
Furthermore:

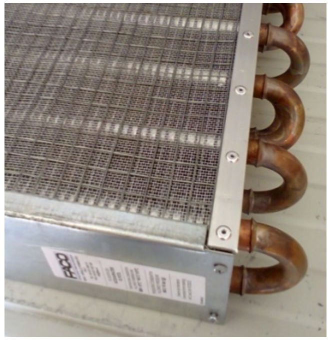
- An increase of the desiccant material temperature is responsible also for higher regeneration temperatures required
- No opportunity to store adsorption capacity into the desiccant material since they are built to host a relatively low mass of adsorbent.
- Only option for energy storage is related to the storage mass of the regeneration fluid
- The use of hot air as regeneration fluid is suitable only with systems without storage



ADSORPTION BED: HEAT AND MASS TRANSFER MECHANISM

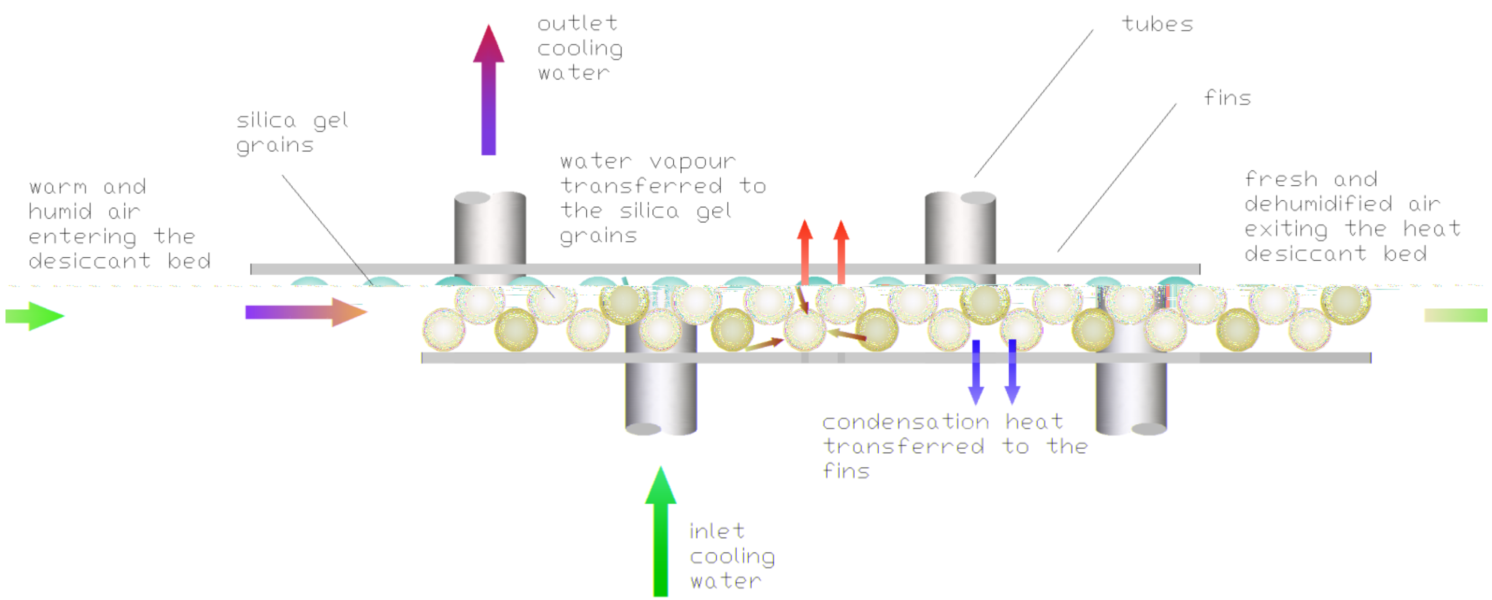
- The developed component allows a simultaneous **mass transfer** between the moist air and the adsorbent media and **heat exchange** between the air and the water flowing into the heat exchanger tubes
- Cooling of the desiccant material during the adsorption process is possible, allowing high dehumidification performances of the desiccant bed and in general better overall energy performances of the system
- Water temperatures required can be easily achieved with a cooling tower

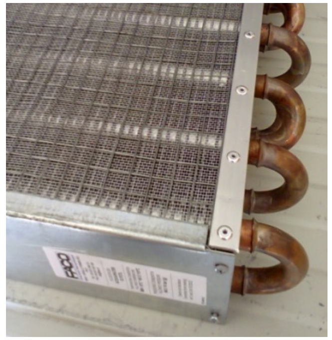




ADSORPTION BED: HEAT AND MASS TRANSFER MECHANISM

- Very low humidity ratio can be obtained ;
- 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;

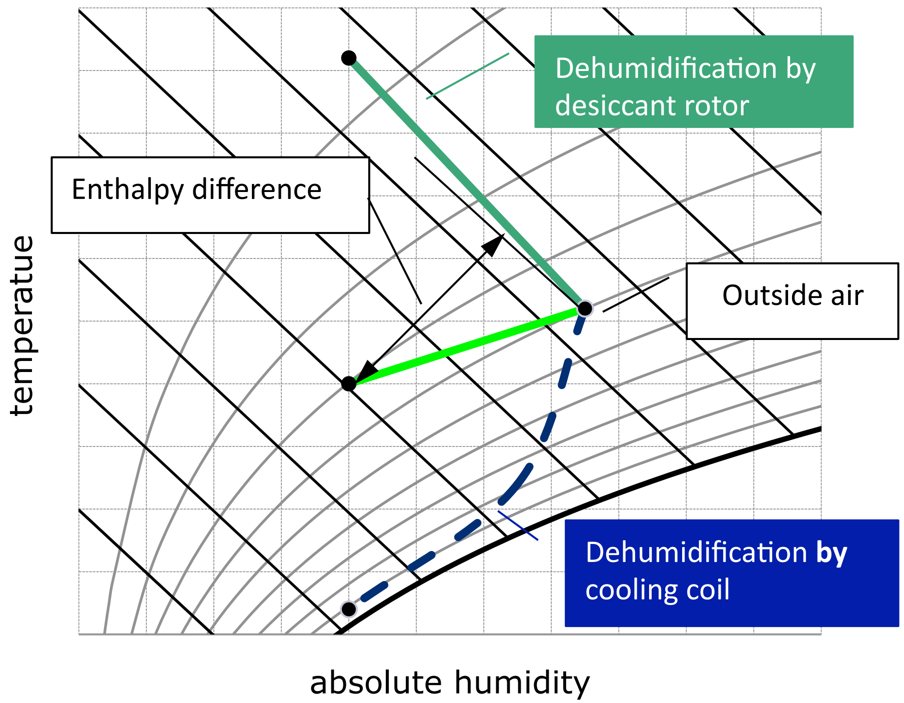




ADSORPTION PROCESS BASED ON ADSORPTION COOLED BED

- The thermodynamic process causes an enthalpy difference between inlet and outlet air conditions
- Condensation heat can be rejected

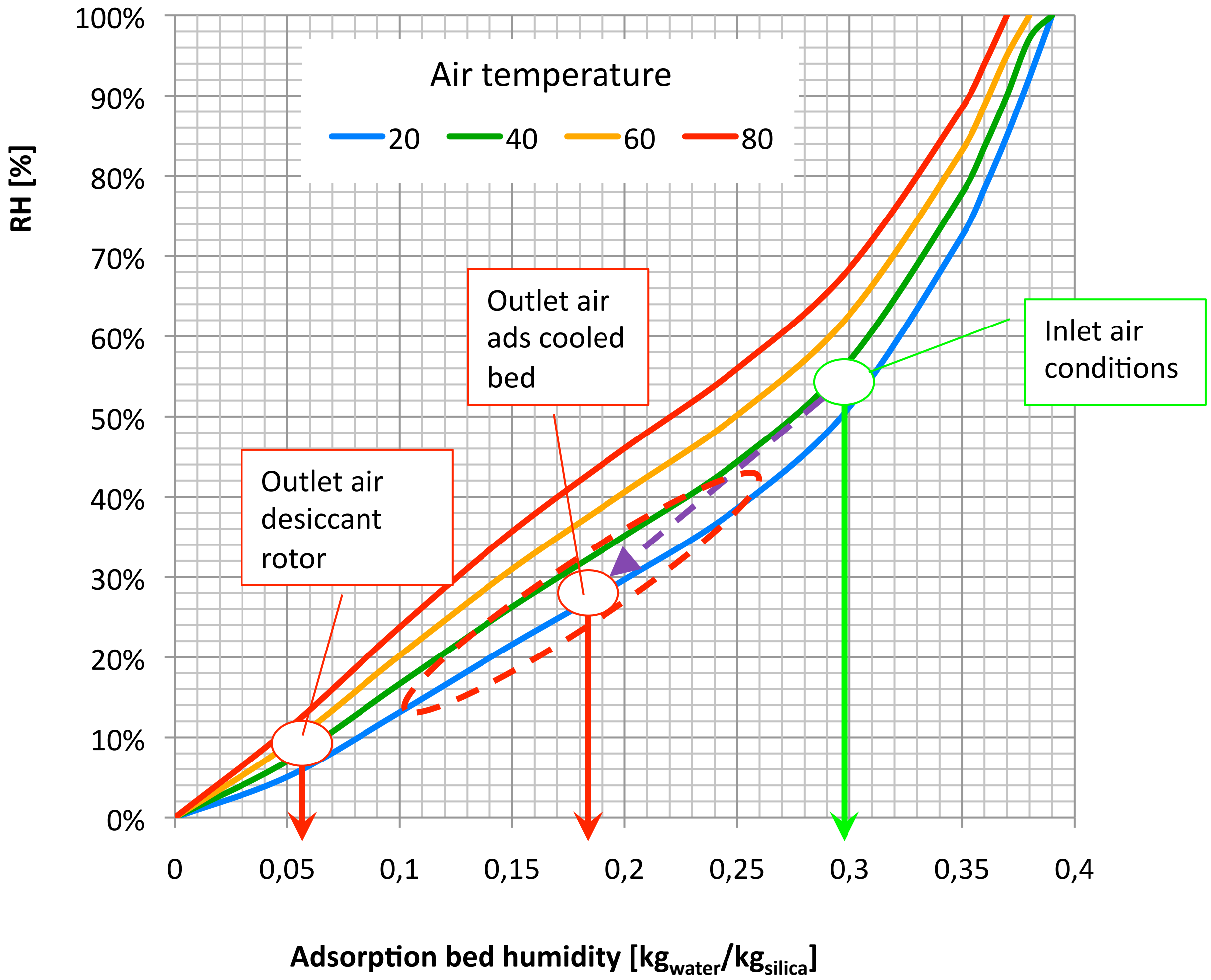
- In general, the temperature of air exiting the adsorption bed is lower than the one of incoming air
- Downstream indirect evaporative cooling process can be operated at lower temperature



ADSORPTION PROCESS BASED ON ADSORPTION COOLED BED

Equilibrium isotherm of adsorption for silica gel RD

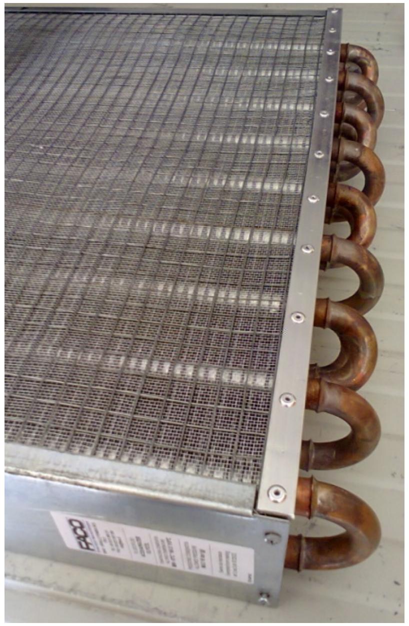
- During adsorption in adsorption cooled bed, air temperature can sliglty decrease and relative humidity ranges from 15% at the beginning of the process to 40% at the end
- Average adsorption bed humidity at equilibrium is much higher than for desiccant rotors



DESIGN OF THE COMPONENT

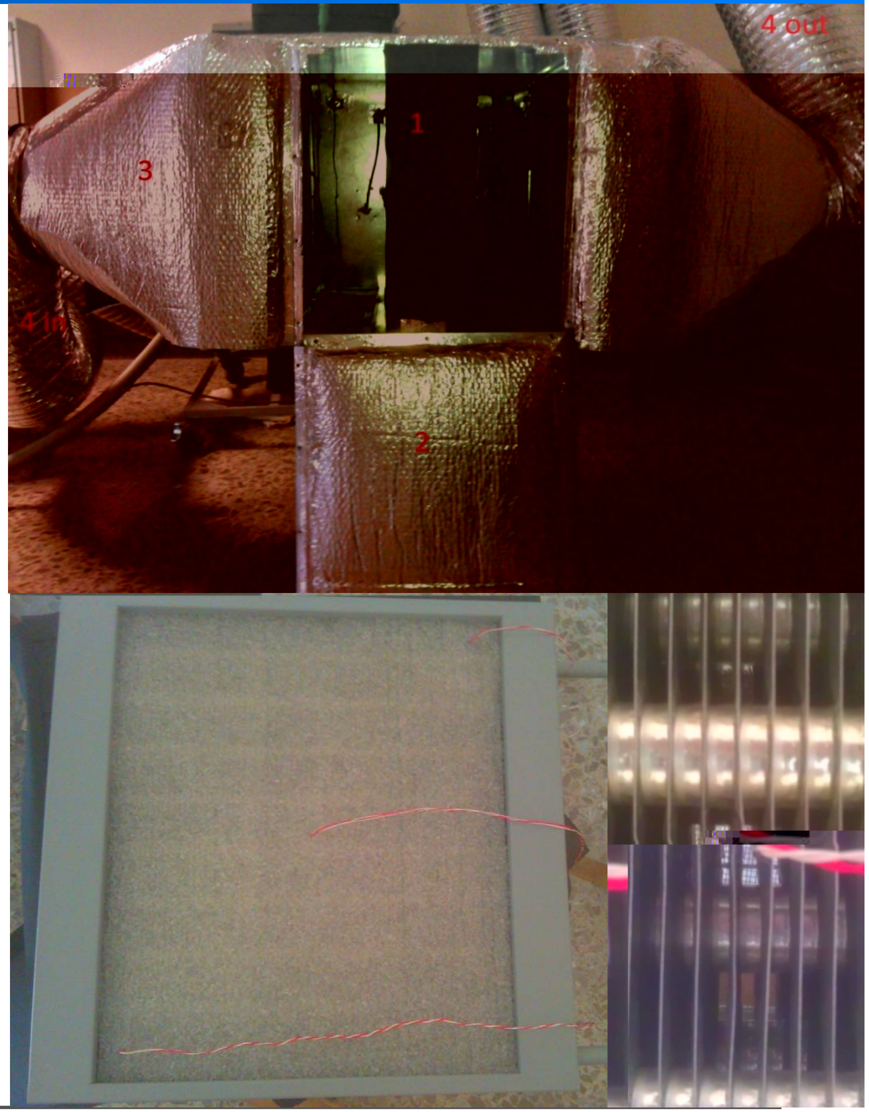
The adsorption bed should be designed taking into account the following issues:

- The total amount of silica gel has to be chosen according to the dehumidification rate requested, flow rate to be processed and desired storage of adsorption capacity
- In order to minimize pressure drops across the bed the most important issues are:
  - High rate of empty spaces between the desiccant grains (global porosity of the bed)
  - Low air velocity
  - Large crossing area, minimum length
- Pressure drop can be similar or lower to the ones typical for rotors



MEASUREMENT TESTS AT UNIPA ON ADSORPTION BEDS

- Tests carried out were aimed to assess the performance of adsorption beds for application in small scale desiccant air conditioning systems
- Focus on low air flow operation
- Tests of three different configurations of adsorption bed
- Adsorption bed with and without cooling
  - Measured quantities:
    - Temperature and humidity of inlet and outlet air
    - Inlet and outlet temperature and flow rate of cooling water loop
    - Fins temperatures
    - Pressure drops across the adsorption bed

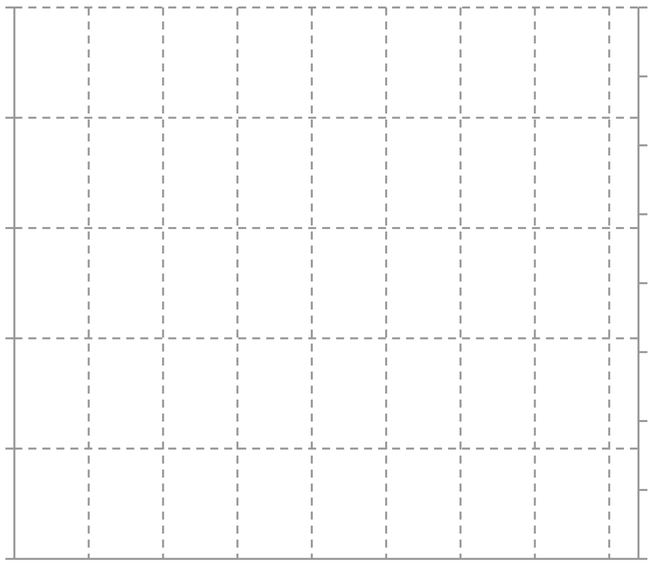


MEASUREMENT TESTS AT UNIPA ON ADSORPTION BEDS

Adsorption bed with cooling

Desorption

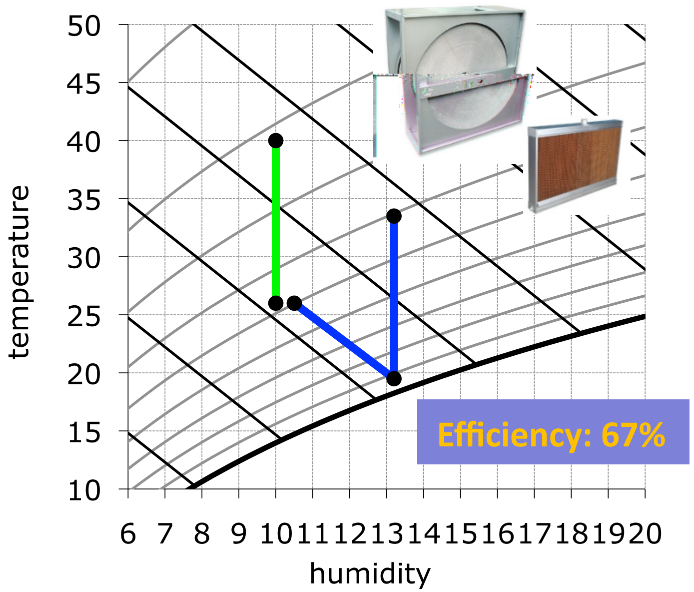
Adsorption

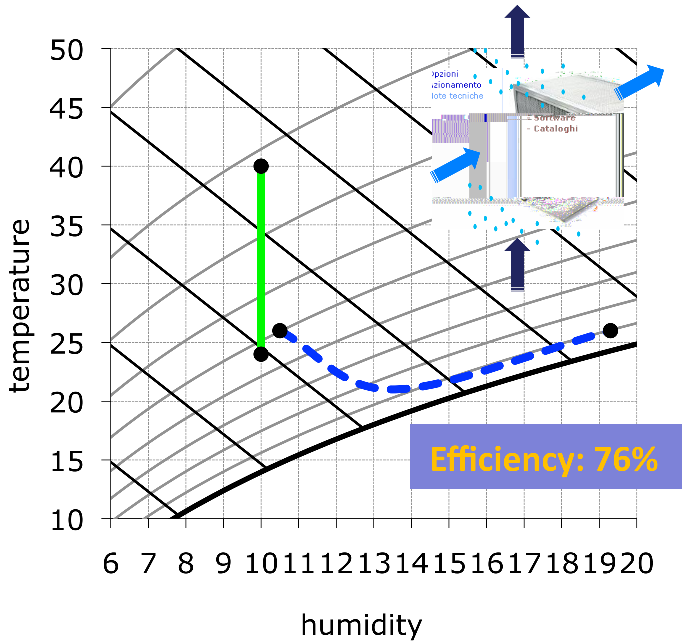


INDIRECT EVAPORATIVE COOLING: COMPARISON OF THE SOLUTIONS

- Saturation inside the heat exchanger not possible
- Secondary air flow passing through the channels rapidly increases its temperature

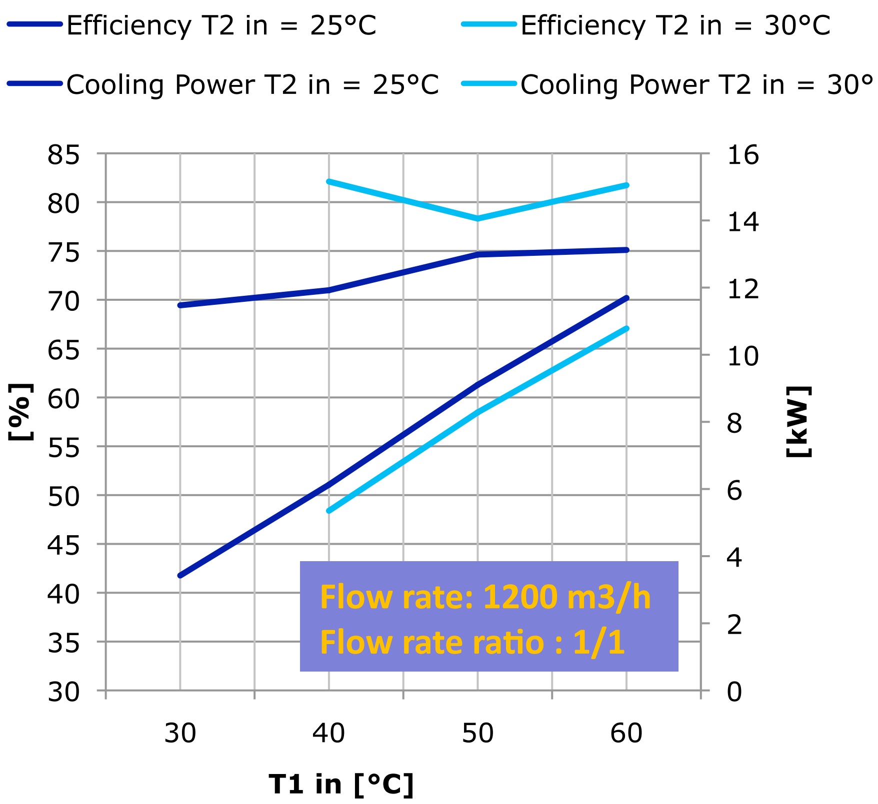
- Saturation inside the heat exchanger possible
- the temperature of the secondary air is close to the local wet-bulb temperature of the air stream which increases gradually during the humidifying process



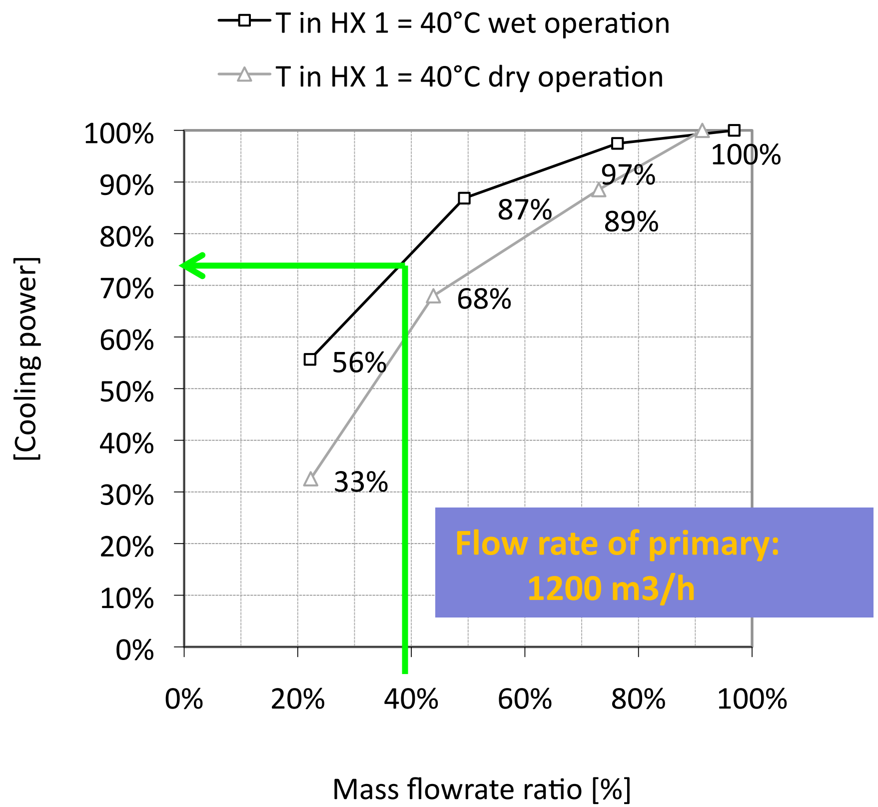


MEASUREMENT TESTS ON WET HEAT EXCHANGERS

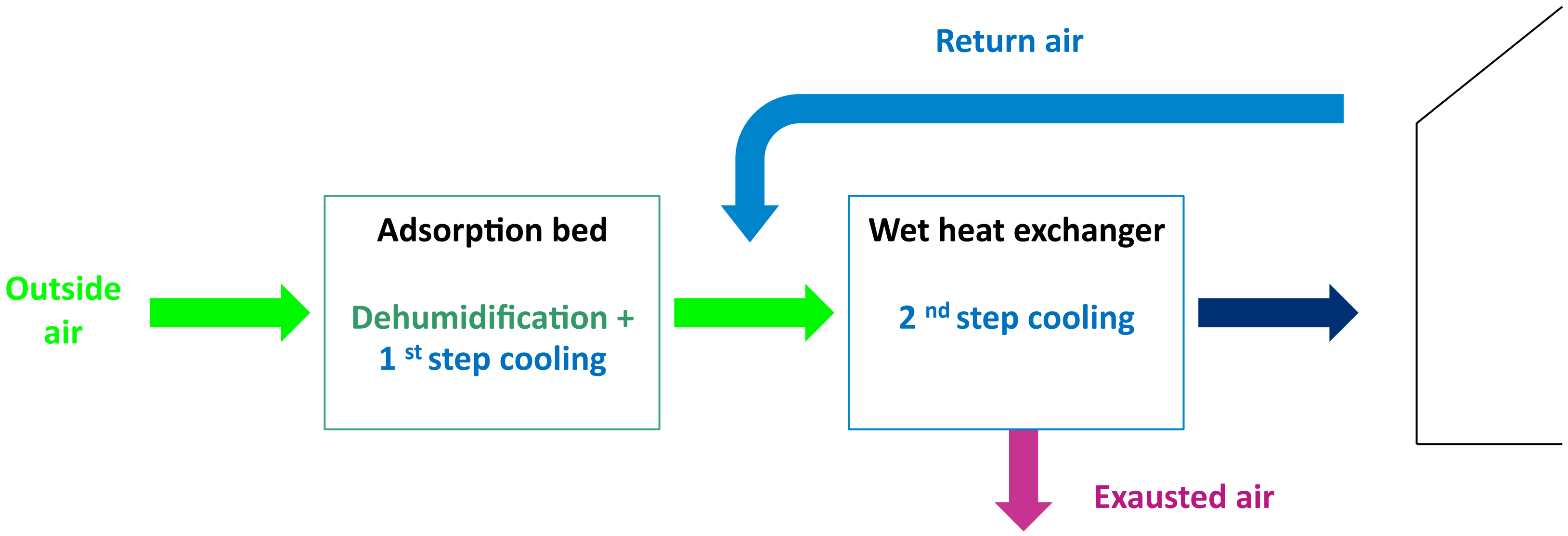
Efficiency and cooling power



Performances vs mass flow rate ratio



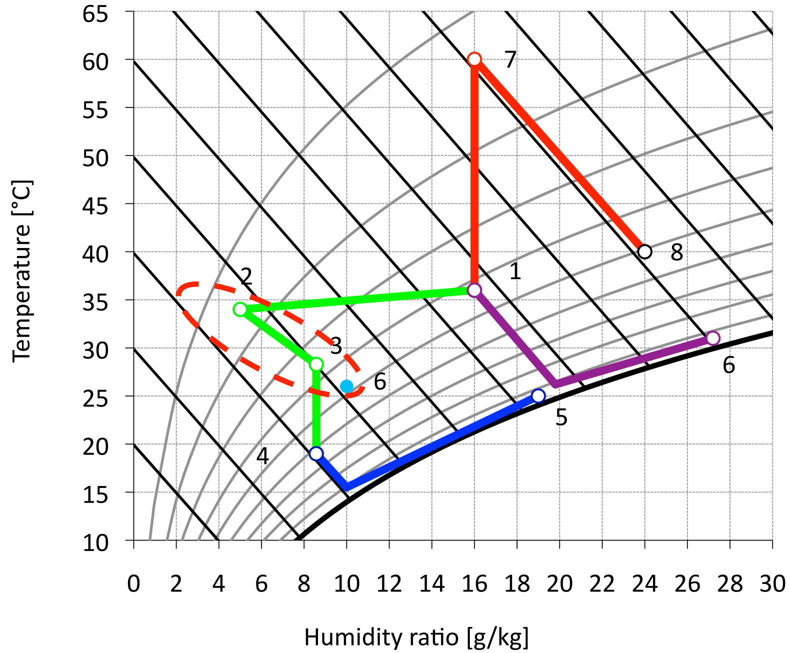
DESIGN CONCEPT OF THE NEW DEC CYCLE



- System based on a combination of the proposed solutions for air dehumidification and cooling
- Avoiding or minimizing the use of auxiliary energy source
- System designed for air ventilation, dehumidification and cooling (heating in winter is also possible)
- Dehumidification and regeneration operated using outside air
- Regeneration carried out using solar air collectors

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 evaporative heat exchangers connected in series
- 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
- Adsorption bed designed to be operated in "low flow" mode
- A portion of the primary air flow rate exiting the wet heat exchanger is drawn into the secondary side
- Electricity consumptions of the system are related to the use of two fans, two pumps and a cooling tower



PROTOTYPE

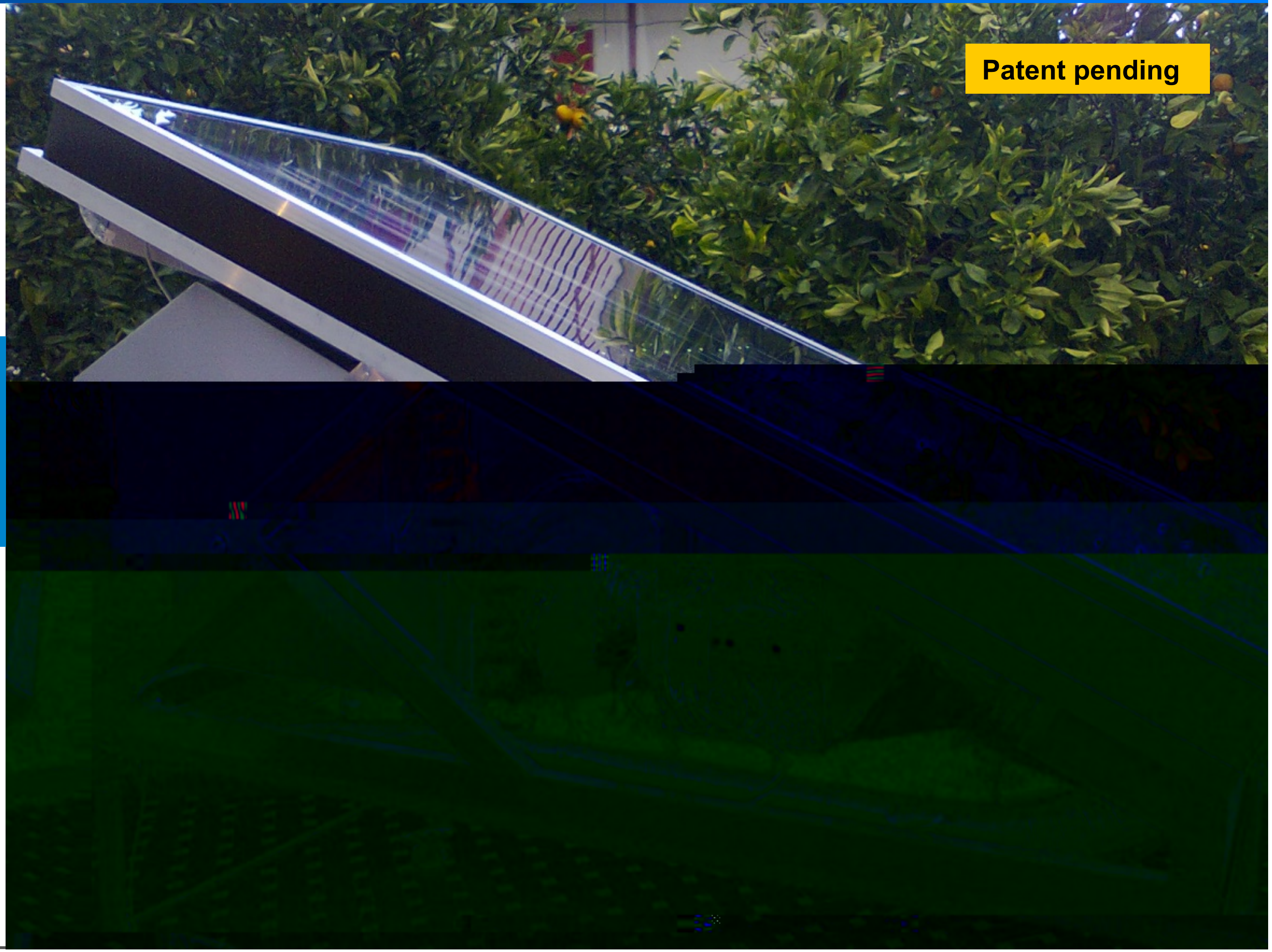
Collector area: 2 m^2

Flow rate: 500 m^3/h

Max cooling power: 3 kW

Max cooling power to the cond. room: 1.8kW

PROTOTYPE

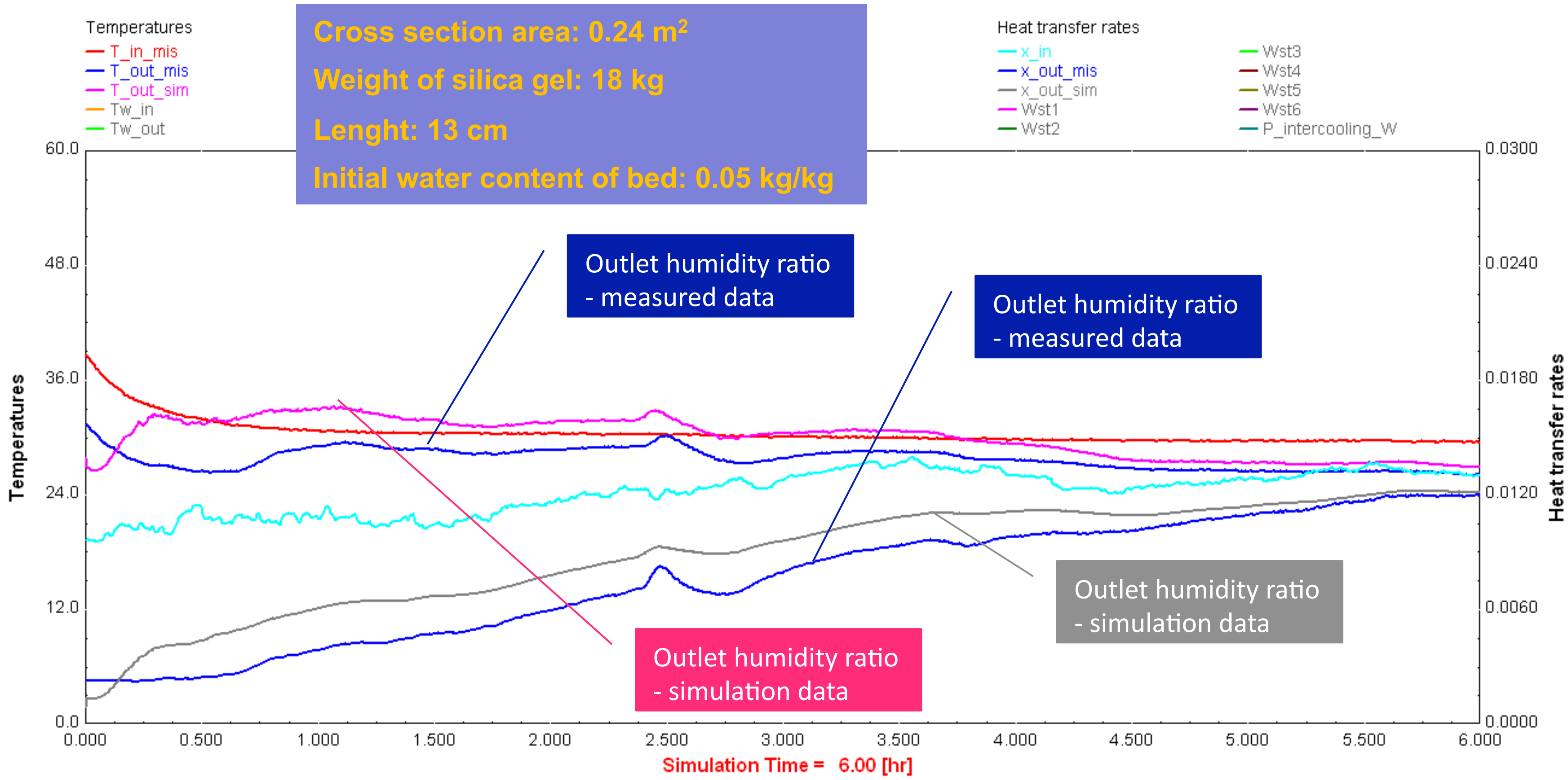


- Collector area: 2 m^2
- Flow rate: 500 m^3/h
- Max cooling power: 3 kW
- Max cooling power to the cond. room: 1.8kW

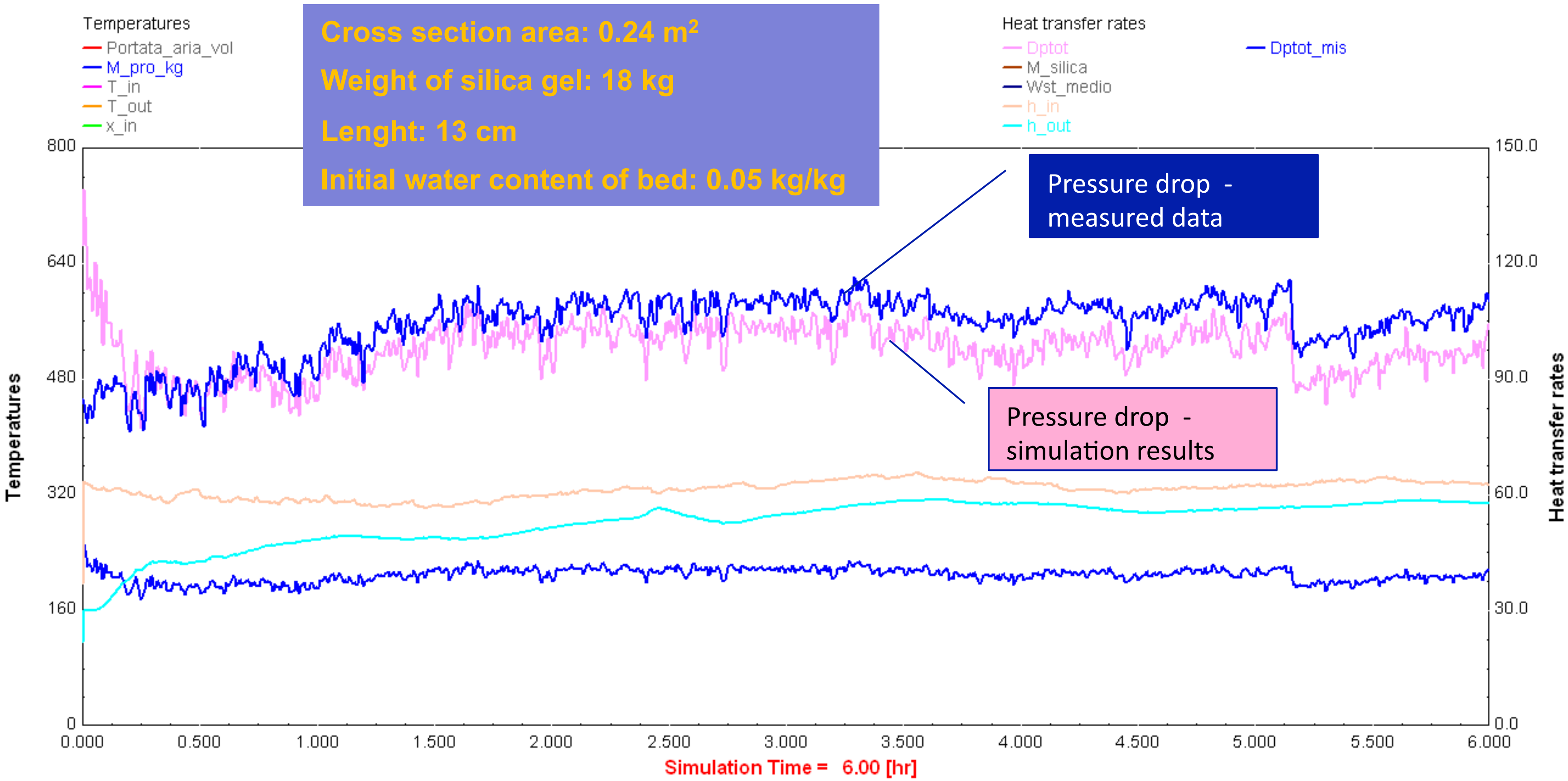
TRNSYS SIMULATIONS

- Measurement data on the desiccant bed and the wet heat exchanger were used to create some new TRNSYS types were created
- For the adsorption bed a semi-empirical model (Type 165) partially based on the approach suggested by Pesaran and Mils was created
- For the simulation of the wet heat exchanger, a modification of the Type 757 was necessary in order to correctly assess the influence of the variation of the mass flow rate ratio between the primary and secondary side of the heat exchanger.
- Simulation time step is two minutes in order to efficiently describe the dynamic effect of the desiccant beds wherein the commutation time between adsorption and desorption phases is fixed and equal to 1 h.
- System flow rate delivered to the conditioned space is **500 m3/h**
- A maximum flow rate of 200 m3/h flows into the adsorption bed
- Each adsorption bed has a total volume of 0.55 x 0.6 x 0.13 m^3 and contains about **18 kg of silica gel in grains**.
- A surface of 2 m^2 of solar air collectors provides the heat necessary for the regeneration
- Maximum electricity consumption for the fans and the pumps is approximately **250 W**
- Cooling power can be controlled through **variable speed fans**.
- A **room of 80 m^3** located in South Italy was used for the simulations

ADSORPTION BED: TRNSYS MODEL AND MEASUREAMENTS

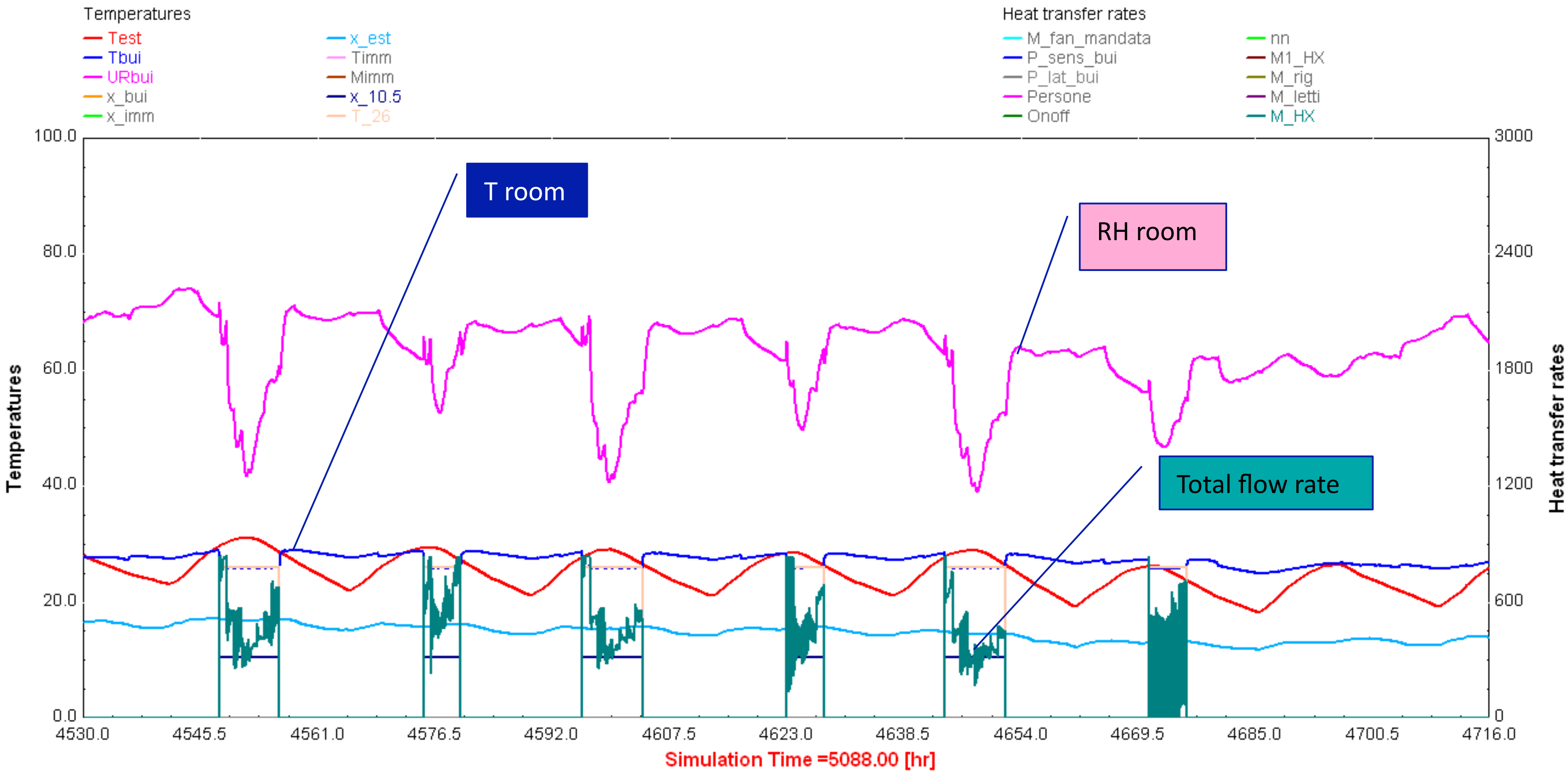


ADSORPTION BED: TRNSYS MODEL AND MEASUREAMENTS



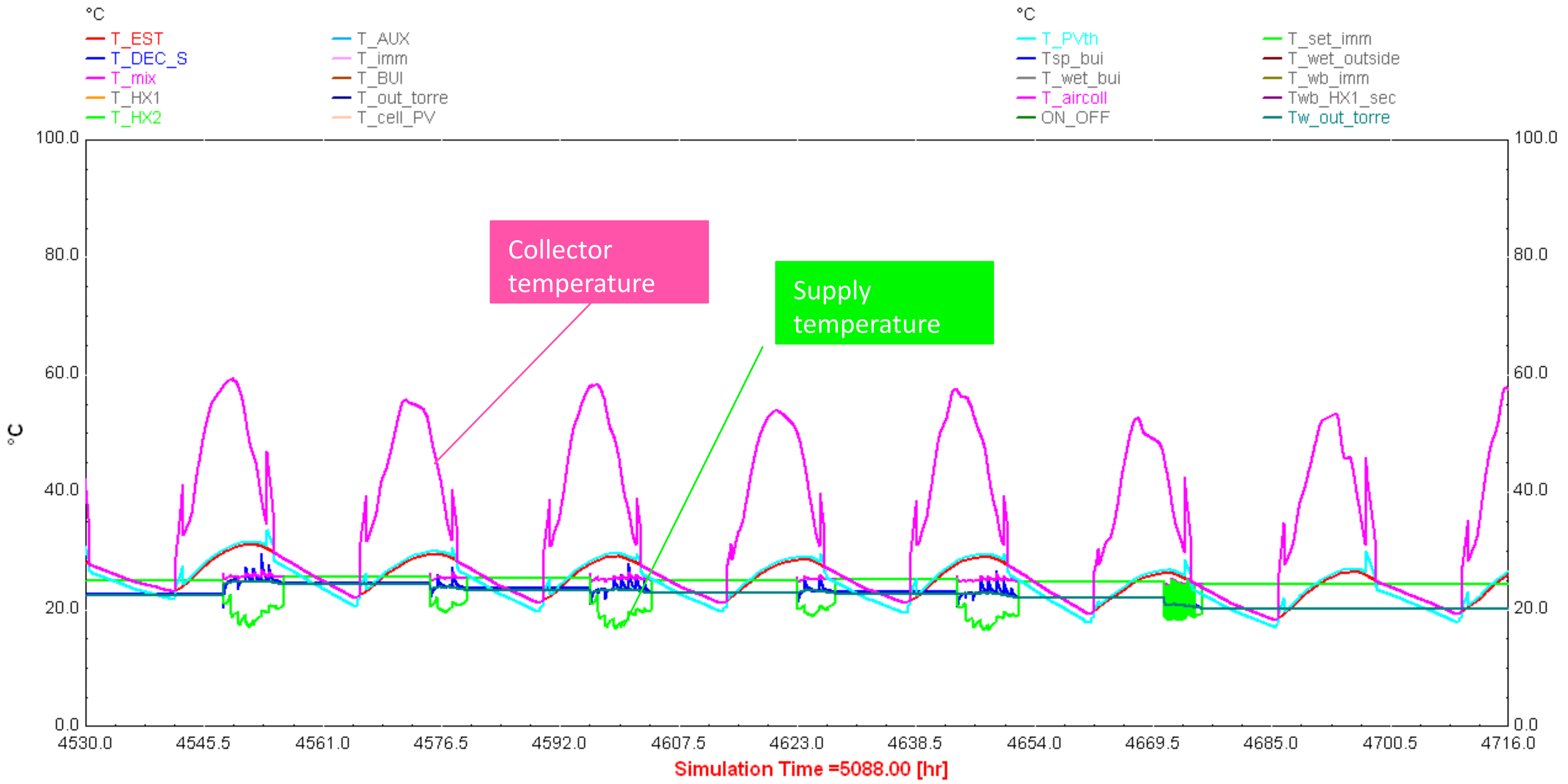
TEMPERATURE AND HUMIDITY OF THE AIR IN THE CONDITIONED ROOM

Weather data of 2nd week of July



TEMPERATURES IN THE AHU COMPONENTS

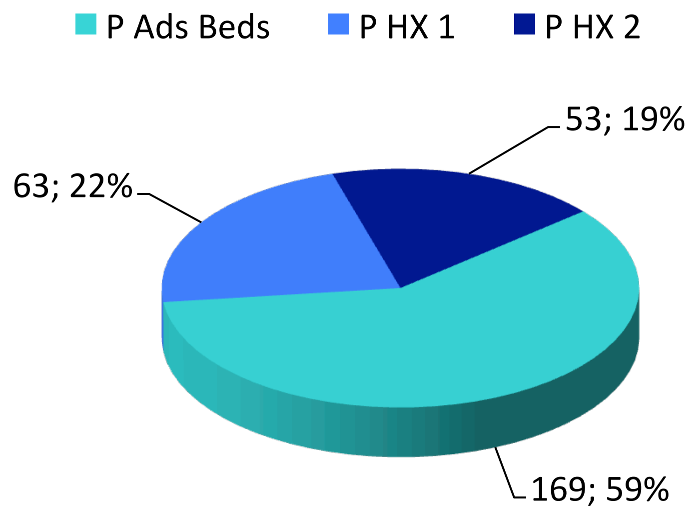
Weather data of 2nd week of July



SIMULATION RESULTS: MONTHLY PERFORMANCES

Total operation hours	168	[h]
T outside	28.2	[°C]
x outside	15.8	[g/kg]
T room	26.1	[°C]
RH room	54.6	[%]
T supply	20.1	[°C]
x supply	10.4	[g/kg]
Pel	28.5	[kWh]
P AHU	254.6	[kWh]
P rad	429.7	[kWh]
P coll	317.4	[kWh]
P coll useful	95.0	[kWh]
Water consumption	350	[lt]
COP el	8.9	[]
COP th	2.5	[]

Distribution of cold production



Simulation results for the mounth of July

Daily operation time: 12:00 – 20:00

CONCLUSIONS

- The proposed adsorption beds realize the simultaneous mass and heat transfer, permitting to dehumidify and cool the processed air
- Tests carried out with “low flow” incoming air have shown high dehumidification potential even in presence of high humidity values and the opportunity to store the adsorption capacity
- Lower air velocities are needed in comparison to the values commonly used for AHU components
- An accurate design of the desiccant bed can limit pressure drops
- Performance tests have been carried out also on wet plate heat exchangers, with the aim to assess the efficiency for unbalanced flow rate ratio
- A new compact DEC system based on a combination of the innovative components providing dehumidification, cooling, partial air change was developed
- A complete TRNSYS model of the proposed DEC system was created
- Simulation results show that high electrical and thermal COPs can be expected
- A prototype for residential application was realized and will be tested in the next months

Thank you for your attention!