INTRODUCTION

- Thermally driven open cooling cycles are based on a combination of adsorption processes and evaporative cooling
- In common DEC air handling units, the core components are desiccant wheel, rotating sensible heat exchanger and humidifiers

System based on simultaneous adsorption and desorption processes

- Enthalpy difference of the DEC AHU strongly dependent on the efficiency of sensible heat exchanger and recovery of heat to the processed air and has to be removed by means of the indirect evaporative process
- The rotating sensible heat exchanger has to carry over two tasks:
  - Heat recovery
  - Cold production
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, no cold production

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

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Furthermore:

- An increase of the desiccant material temperature is responsible also for higher regeneration temperatures required.
- Regeneration has to be continuously operated if cold production is requested.
- 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 heat capacity of the regeneration liquid loop.
- The use of hot air as regeneration fluid is suitable only with systems without storage.

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;

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### 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
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.

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

Adsorption bed with cooling

Cross section area: 0.24 m²
Flow rate: 210 m³/h
Weight of silica gel: 18 kg
Height: 13 cm
DP: 105 Pa

Desorption

T in
T out
T w in
T w out
x in
x out

[Graph showing adsorption and desorption processes with various parameters]

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INDIRECT EVAPORATIVE COOLING BASED ON WET PLATE HEAT EXCHANGERS

- Cross flow plate heat exchanger operated under wet conditions
- The surface of secondary flow air channels is wetted by water spraying, such that the water evaporates into the cooling air and decreases the temperature of the heat exchange surface

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INDIRECT EVAPORATIVE COOLING: COMPARISON BETWEEN 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
Temperature of 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

- Efficiency T2 in = 25°C
- Efficiency T2 in = 30°C
- Cooling Power T2 in = 25°C
- Cooling Power T2 in = 30°C

Performances vs mass flow rate ratio

- T in HX 1 = 40°C wet operation
- T in HX 1 = 40°C dry operation

Flow rate: 1200 m³/h
Flow rate ratio: 1/1

Flow rate of primary: 1200 m³/h
Mass flow rate ratio [%]
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**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

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**DESCRIPTION OF THE NEW DEC CYCLE**

- System 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 dumpers provides the commutation between the two adsorption beds in order to guarantee a continuous dehumidification process
- No auxiliary device included
TRNSYS SIMULATIONS

- 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 one minute in order to efficiently describe the dynamic effect of the desiccant beds.
- Commutation time between adsorption and desorption phases is fixed and equal to 0.25 h.
- The system has the configuration described above and is connected to a **conditioned space** of about **1200 m³** used as a classroom.
- Occupation profile is **150 persons** from 8:00 to 13:00, **20 from 13:00 to 15:00** and **100 from 15:00 to 18:00**.
- The weather data file used is related to the location of Palermo (**South Italy**) 38°6' N 13°20' E.

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TRNSYS SIMULATIONS

- **AHU flow rate delivered to the conditioned space is 8300 m3/h**.
- Maximum **sensible and latent** loads including internal gains, ventilation and infiltration, are respectively 25 and 51 kW.
- Each adsorption bed has a total volume of 0.3 m³ and contains about 115 kg of silica gel in grains.
- A surface of **46 m² of solar air collectors** provides the heat necessary for the regeneration of the desiccant material.
- Solar collector flow rate is 4200 m³/h.
- The maximum electricity consumption for the fans and the pumps is approximately **4.5 kW** when operated at full speed.
- The cooling power of the AHU can be varied controlling the speed of the process air fan.
- Five days of operation (19th - 23th July) to focus on instantaneous system performances during typical hot and humid summer days.
MODEL OF THE ADSORPTION BED: PRESSURE DROPS VERSUS LENGTH, AIR VELOCITY AND POROSITY

Desiccant rotor typical operation data

- T_in_pro 23 °C
- x_in_pro 16 °C
- T_out_pro 55 g/kg
- x_out_pro 5.9 g/kg
- T_rig 80 °C
- dx_pro 10.1 g/kg
- Air_velocity 2.55 m/s
- Dp 188.0 Pa

Specific dehumidification capacity: 0.081 kg/h/Pa

Adsorption bed

- Inlet air condition are the same
- Adsorption bed cross area: 1 m²
- Air velocity: 0.41 m/s
- Mass of silica gel: 78 kg for porosity 0.6 and length 0.1 m
- 350 kg for porosity 0.4 and length 0.3 m
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**TEMPERATURE AND HUMIDITY OF THE AIR IN THE CONDITIONED ROOM**

Five days of operation (19th - 23rd July)

<table>
<thead>
<tr>
<th>Building temperature</th>
<th>Building relative humidity</th>
<th>Outside humidity ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>22°C</td>
<td>45%</td>
<td>0.85</td>
</tr>
</tbody>
</table>

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**TEMPERATURES IN THE AHU COMPONENTS**

Five days of operation (19th - 23rd July)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>T supply</td>
<td>17-23°C</td>
</tr>
<tr>
<td>T outlet</td>
<td>17-23°C</td>
</tr>
</tbody>
</table>

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COOLING POWER OF THE AHU, SOLAR HEAT PRODUCTION, EFFICIENCY OF WET HEAT EXCHANGERS

Five days of operation (19th - 23rd July)

Cooling power

Range 60 - 65 %

Wet heat exchanger efficiency

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Daily average data

T building [°C] 26.4
RH building [%] 55.2
T supply [°C] 20.7
x supply [g/kg] 10.3

Monthly data - July

Operation hours [h] 341
Cooling energy delivered by the DEC system [kWh] 10360
Electricity consumed by the DEC system [kWh] 1210
Heat delivered by the solar collectors [kWh] 7450
Electrical COP [-] 8.6
Thermal COP [-] 1.7
Water consumption [m³] 12.1

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CONCLUSIONS

- An innovative solar DEC concept using a combination of fixed cooled adsorption beds packed with silica gel and two wet heat exchangers was developed and analyzed.
- The proposed adsorption bed realizes the simultaneous mass and heat transfer, permitting to dehumidify and to cool the processed air.
- Simulation results have shown high dehumidification potential even in presence of high humidity values and the opportunity to store the adsorption capacity.
- A lower air velocity is needed in comparison to the standard values commonly used for AHU components.
- An accurate design of the desiccant bed can limit pressure drops under 100 Pa.
- Performance tests have been carried out also on wet plate heat exchangers in several controlled air conditions, with the aim to assess the efficiency for unbalanced flow rate ratio.
- A complete TRNSYS model of the proposed DEC system was created.
- Simulation results show that high electrical and thermal COPs can be expected in comparison to traditional DEC systems.

PROTOTYPE OF A COMPACT SYSTEM FOR RESIDENTIAL APPLICATION

- Collector area: 2 m²
- Flow rate: 500 m³/h
- Max cooling power: 3 kW
- Max cooling power to the cond. room: 1.8 kW

Patent pending
Thank you for your attention!
PERFORMANCE OF THE ADSORPTION BED IN HUMID CLIMATES

Cross section area: 1m²
Bed porosity: 0.5
Length: 0.2 m
Mass of silica: 194 kg
Tin: 30°C
v: 22 g/kg
Initial water content of bed: 0.05 kg/kg
M water in: 2000 kg/h
T water in: 25°C
DP: 85 Pa

ABSOLUTE HUMIDITY DIFFERENCE FOR UNITARY PRESSURE DROP
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Cross section area: 0.25 m²
Empty space rate: 0.38
Length: 0.13 m
Initial water content of bed: 0.05 kg/kg

Simulation Time = 6.00 [hr]
COMPARISON BETWEEN TRNSYS MODEL AND MEASUREMENT DATA

Cross section area: 0.25 m²
Empty space rate: 0.38
Length: 0.13 m
Initial water content of bed: 0.05 kg/kg.

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