Solid Desiccant Cycles and Machines

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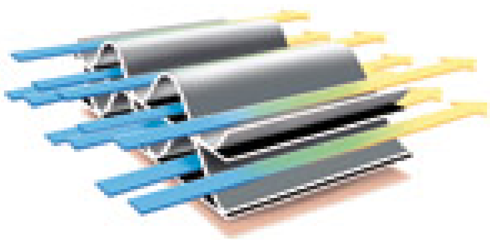
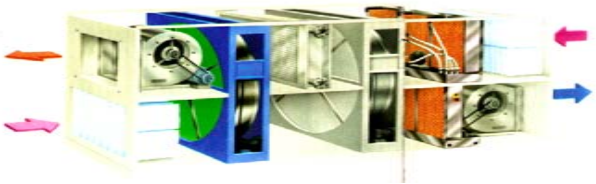




"desiccant open cycles"

What? thermally driven air conditioning processes usually based on a combination of sorptive dehumidification and evaporative cooling.

Why open? this term is used to indicate that the refrigerant (water) is discarded from the system after providing the cooling effect, and new refrigerant is supplied in its place in an open-ended loop.

"**Regeneration**" heat must be supplied in order to remove the adsorbed water from the desiccant material.

"desiccant open cycles"

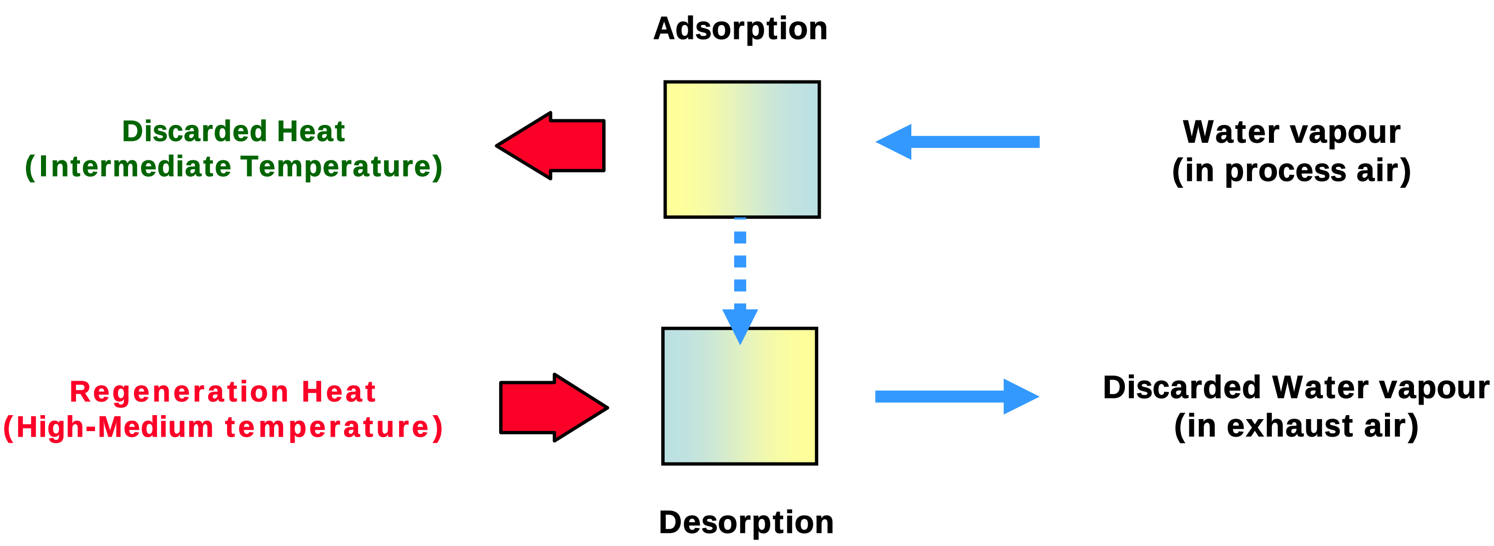
These systems are referred to as "Desiccant Cooling" or "Desiccant and Evaporative Cooling" (DEC).

The required heat is at a relatively low temperature, in the range of 50 to 100° C (120 – 210 ° F), depending on the desiccant material and the degree of dehumidification.

For this reason, coupling with thermal solar energy is particularly suitable.

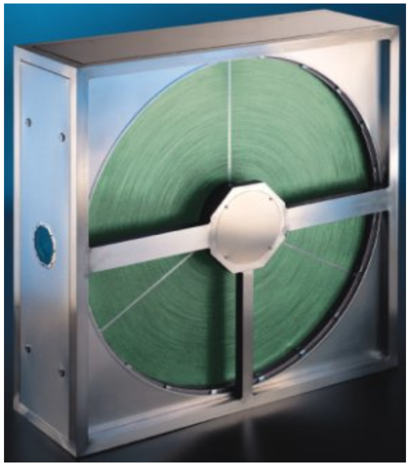
"desiccant open cycles"

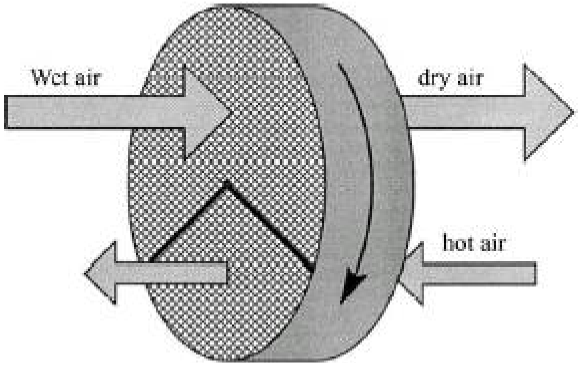
SORPTION-DESORPTION PRINCIPLE

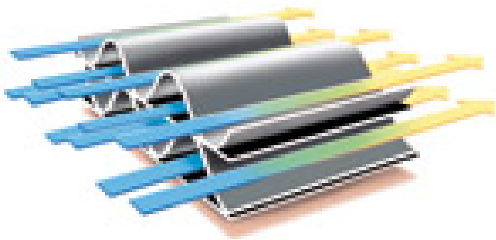


"desiccant open cycles"

Systems working with solid desiccant materials use either rotating wheels or periodically operated, fixed-bed systems.







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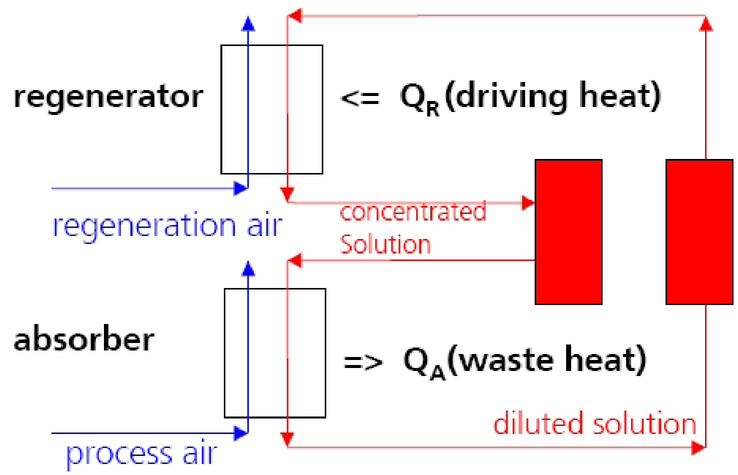
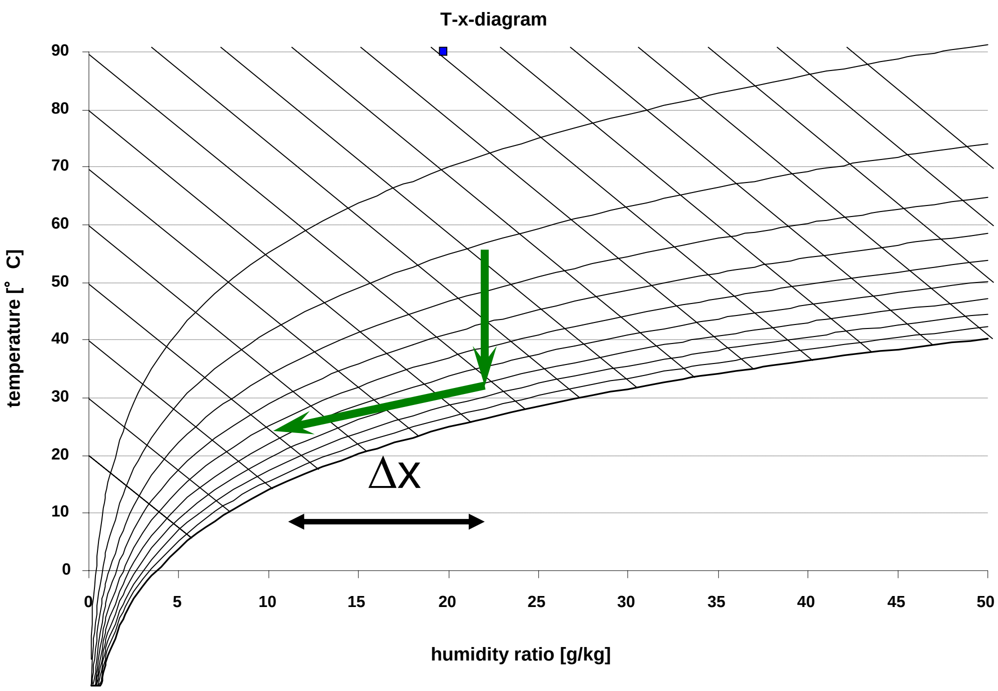
"desiccant open cycles"

Systems using liquid desiccant present a loop where "absorber" and "regenerator" devices allow for the dehumidification of air and for the regeneration of the desiccant.



DEHUMIDIFICATION

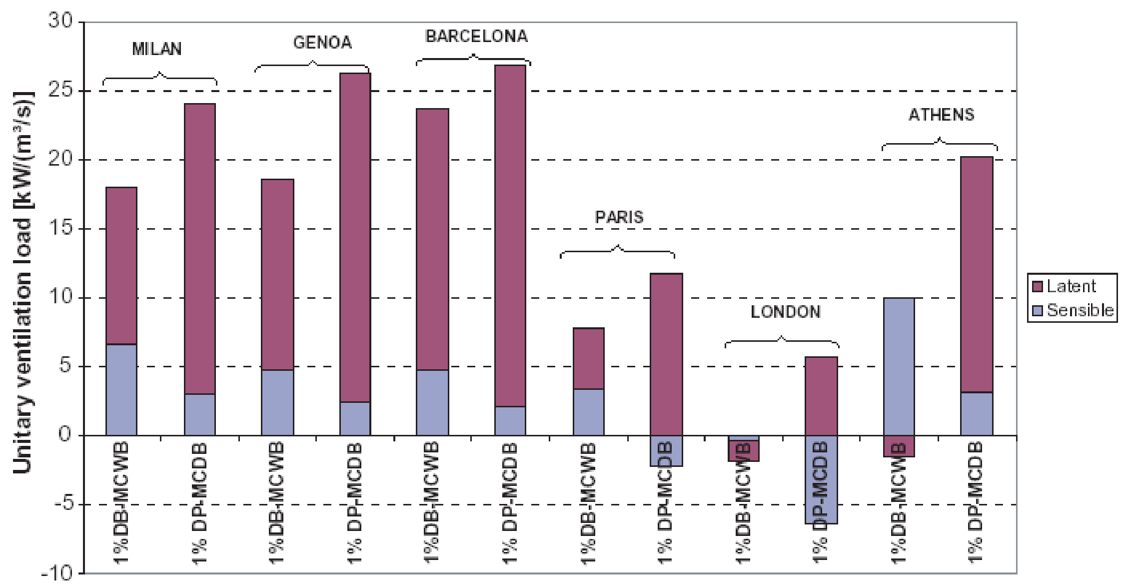
Dehumidification is considered to be a key feature of HVAC systems for thermal comfort. The usual dehumidification process is known as *mechanical*. It is based on cooling of the air below its dew point temperature.



MECHANICAL DEHUMIDIFICATION

Indoor conditions: T_{db} = 25° C - Φ = 50%
Six european sites
Two different outdoor design conditions

T_{db}	dry bulb temperature, ° C
Φ	relative humidity of the humid air
MCDB	mean coincident dry bulb, ° C
MCWB	mean coincident wet bulb, ° C



The latent component is very often the greater, particularly when peak dew point temperature data (ASHRAE 1% DPMCDB) are employed for design, with values up to 90% of the total load. What this means is that a dehumidification coil capable of dealing with such loads would need a particularly low values of parameter SHR_{cc}, which seldom occurs.

MECHANICAL DEHUMIDIFICATION

Re-heat control system is not energetically efficient. With reference to the building-plant whole, steady state energy balance may be given as:

$$\dot{Q}_{cc} = \dot{Q}_{z,SEN} + \dot{Q}_{z,LAT} + \dot{Q}_{hc} + \dot{Q}_{vent}$$

cc	referred to cooling coil
z	referred to zone
LAT	referred to latent load
SEN	referred to sensible load
hc	referred to heating coil
vent	referred to ventil. air or ventil. load

Thus energy use related to the re-heating coil weighs heavily not only for the generation of hot thermal carrier fluid, but also for the generation of cold thermal carrier fluid.

The increase in costs does not regard operating costs alone but also investment costs (an increase in power of the refrigerating machine, for example). It is worth pursuing energy recovery (thermal energy from condensation, for example) to avoid heating coil energy use.

SORPTIVE DEHUMIDIFICATION

Sorptive dehumidification removes the water vapour from the air by transferring it towards a desiccant material.

Desiccants are materials with a high affinity for water vapour and may be solid or liquid.

Basically, two chemical dehumidification processes are possible:

- **ADsorption (the desiccant is in solid phase)**
- **ABsorption (the desiccant is in liquid phase)**

CHEMICAL DEHUMIDIFICATION: ADSORPTION

Adsorption desiccants are typically chemical compounds, such as:

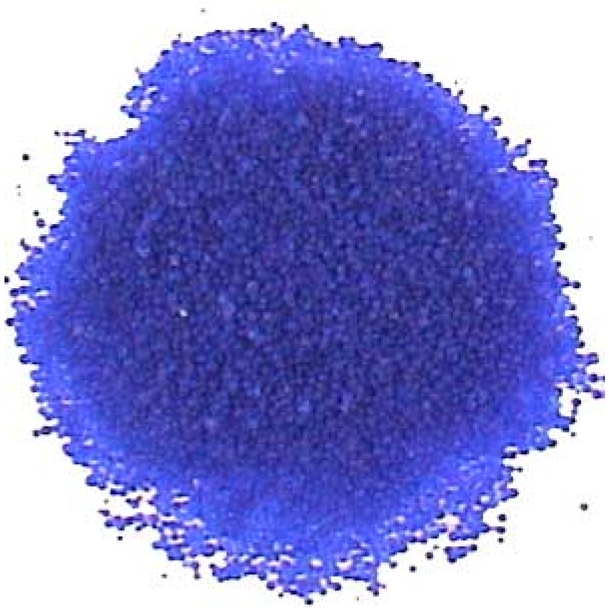
- synthetic polymers
- silica gels
- titanium silicates
- natural or synthetic zeolites
- activated aluminas
- ‘‘silica +’’

I.e. silica gel is like a “SUPERSPONGE”
Internal surface per volume unit is immense:

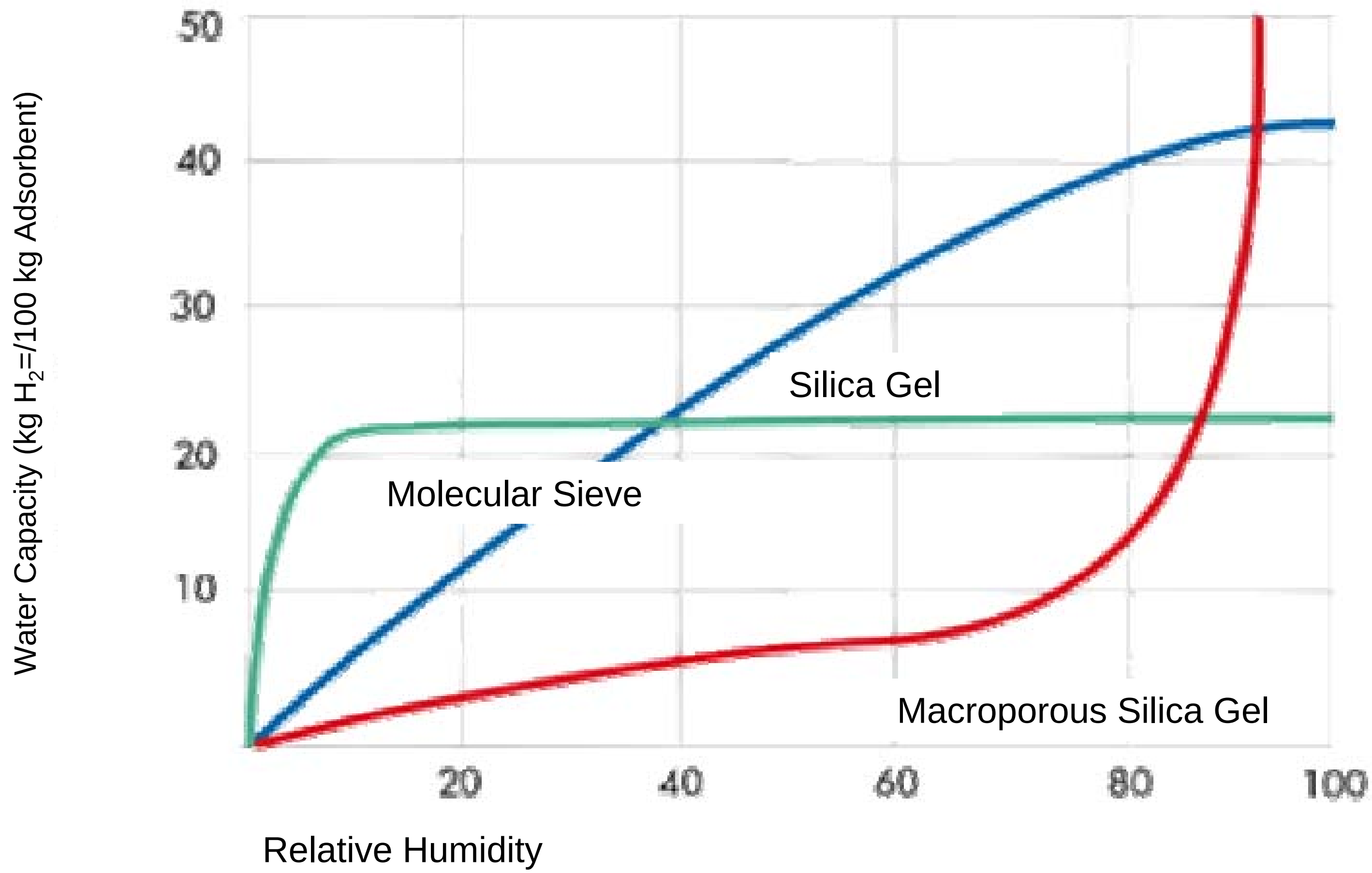
$250\ m^2/cm^3$ (850 sqyrd/cf) !!!!!!!

Pores have a diameter of nanometers and their volume accounts for approximately half of the total volume

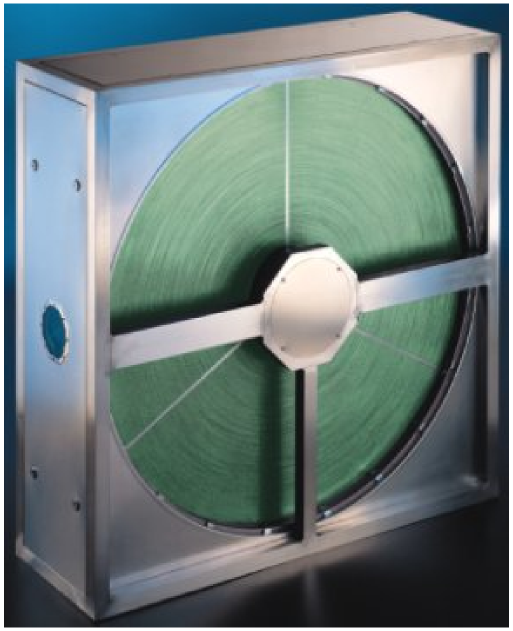
CHEMICAL DEHUMIDIFICATION: ADSORPTION

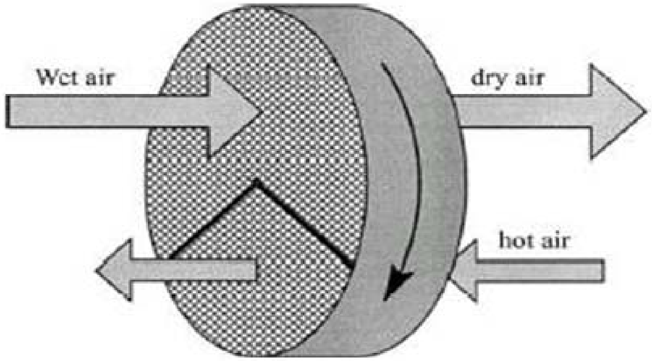


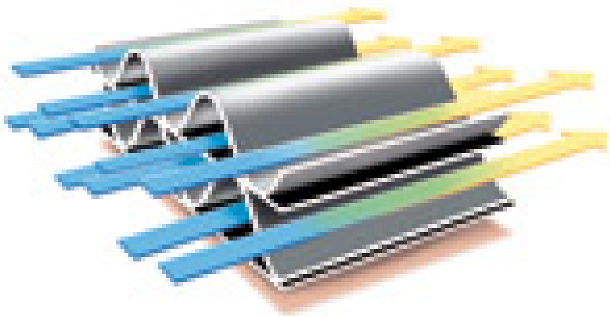
Materials


Water Capacity (kg H2=/100 kg Adsorbent)
50
40
30
20
10
20
40
60
80
100
Relative Humidity
Silica Gel
Molecular Sieve
Macroporous Silica Gel

Desiccant Wheels/Rotors





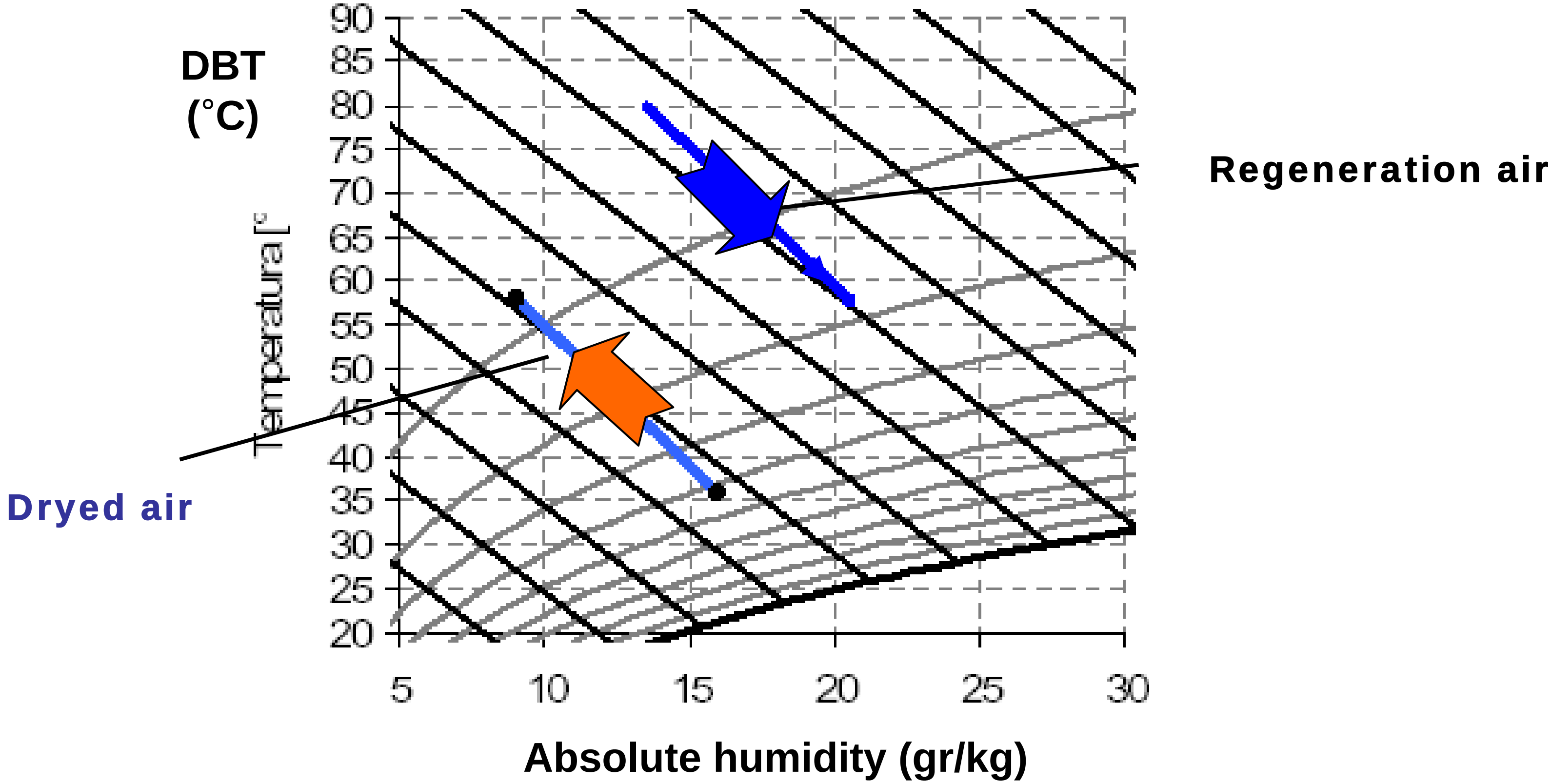


Manufacturers

Company	Country of origin	Desiccant	Wheel Size
Munters USA	USA	SiGel, AlTi, Silicates, New Proprietary	0.25 – 4.5 m
Munters AB	Sweden	SiGel, AlTi, Silicates, New Proprietary	0.25 – 4.5 m
Seibu Giken	Japan	SiGel, Am, Silicates, New Proprietary	0.10 – 6.0 m
Nichias	Japan	SiGel, Mol, Sieves	0.10 – 4.0 m
DRI	India	SiGel, Mol, Sieves	0.30 – 4.0 m
Klingenburg	Germany	Al oxide, LiCl	0.60 – 5.0 m
PorFlute	Sweden	SiGel, Mol, Sieves	0.50 – 3.0 m
Rotor Source	US	SiGel, Mol, Sieves	0.50 – 3.0 m
NovelAire	US	SiGel, Mol, Sieves	0.50 – 3.0 m

ADSORPTION USING ROTORS

This ideal dehumidification process is the opposite of the adiabatic saturation; the outlet dry air is warmed up because of the latent heat of condensation



FURTHER STEPS

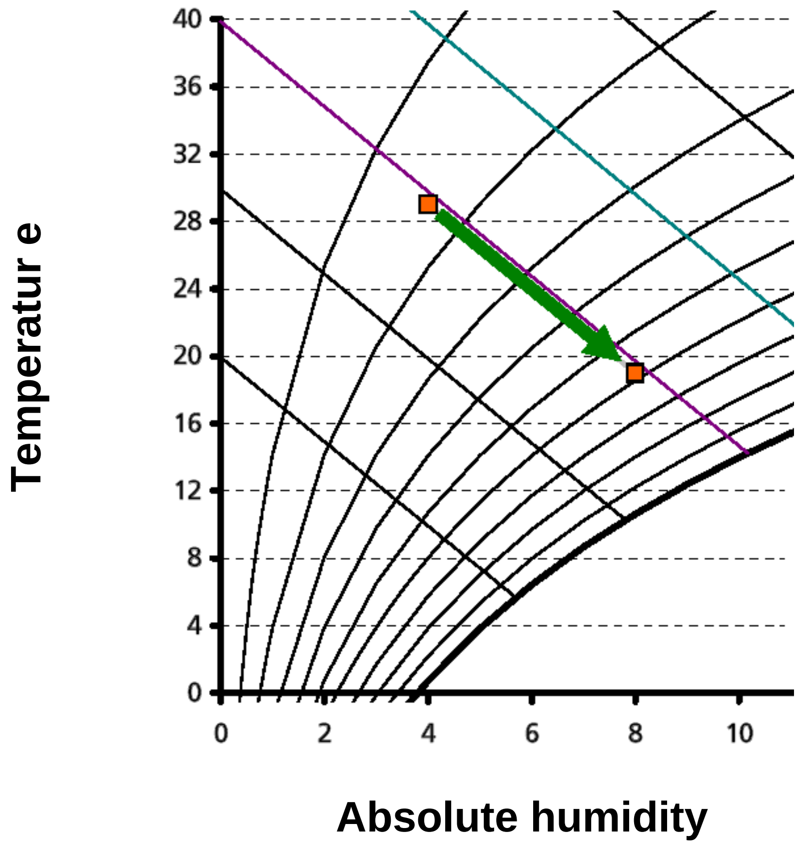
For this reason, subsequent cooling processes are necessary.

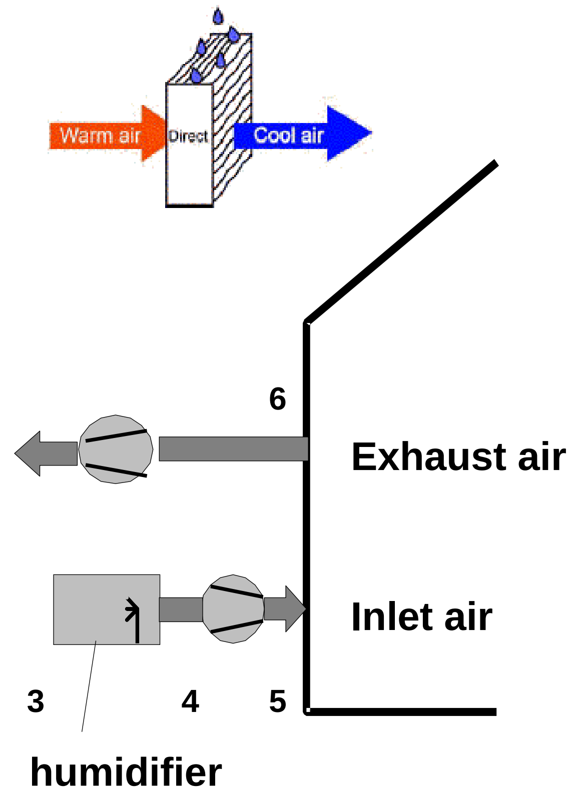
A good "free cooling" effect is achievable by using a combination of processes and equipment able to transfer heat from processed air to exhaust air that is then handled accordingly.

The evaporative cooling process uses the evaporation of liquid water to cool an air stream.

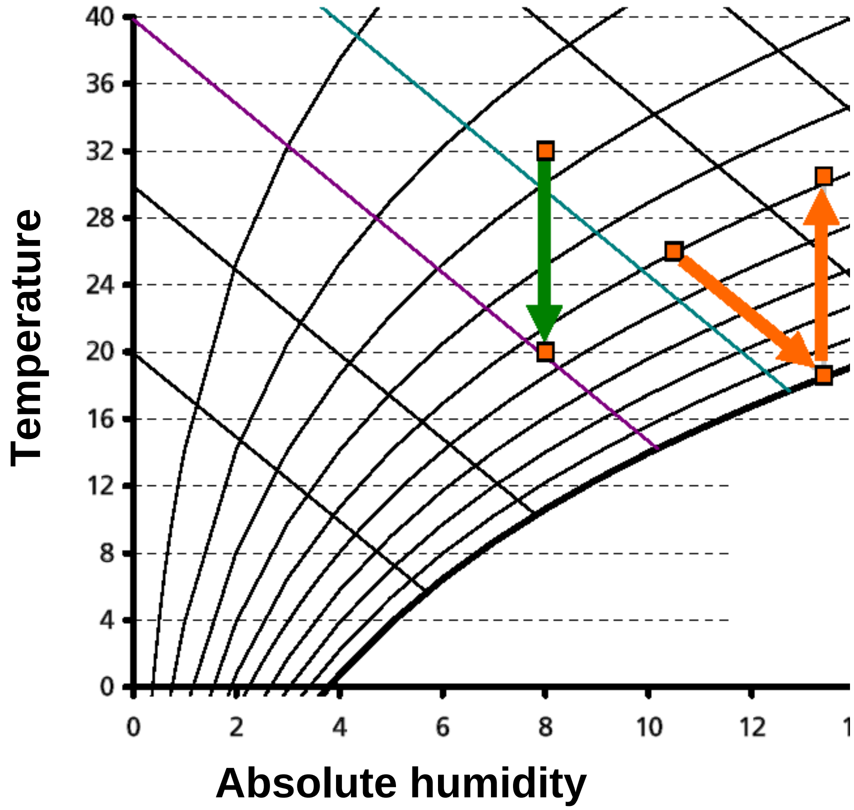
- direct evaporative cooling
- indirect evaporative cooling

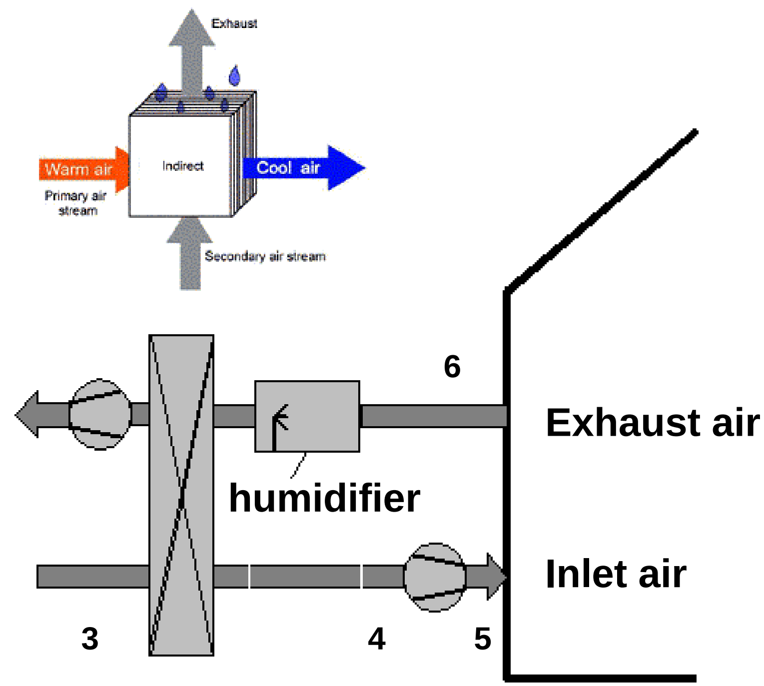
DIRECT EVAPORATIVE COOLING



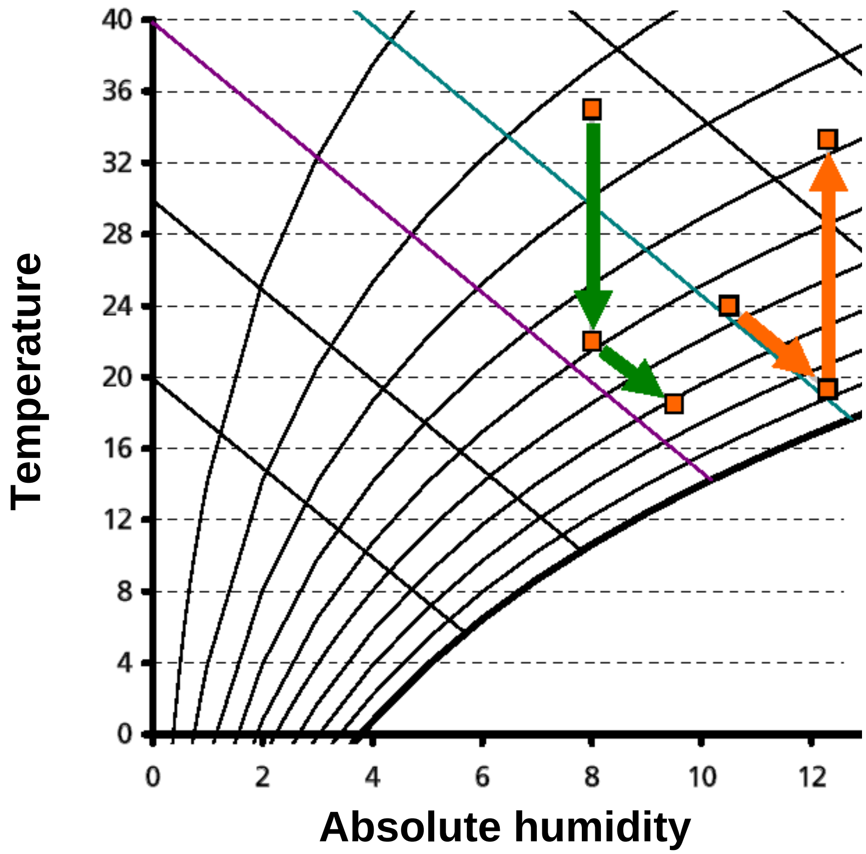


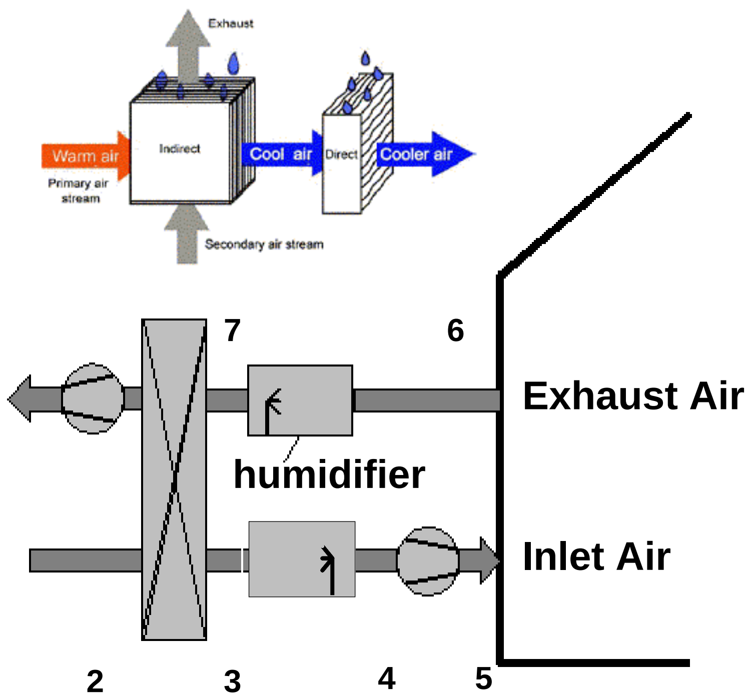
INDIRECT EVAPORATIVE COOLING



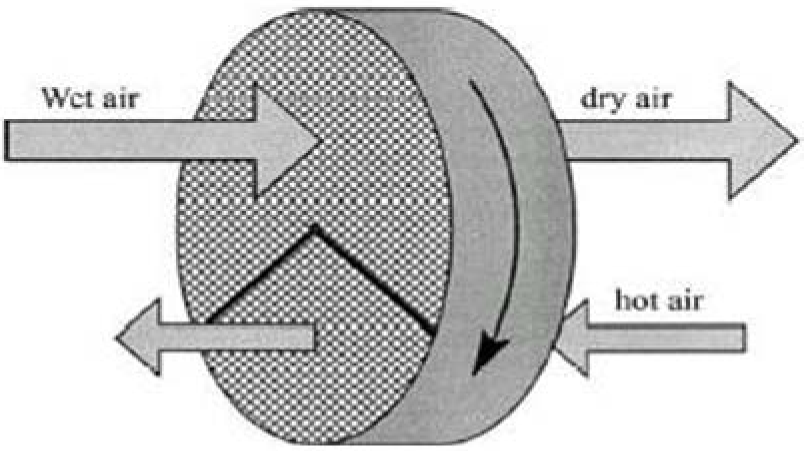


COMBINED EVAPORATIVE COOLING





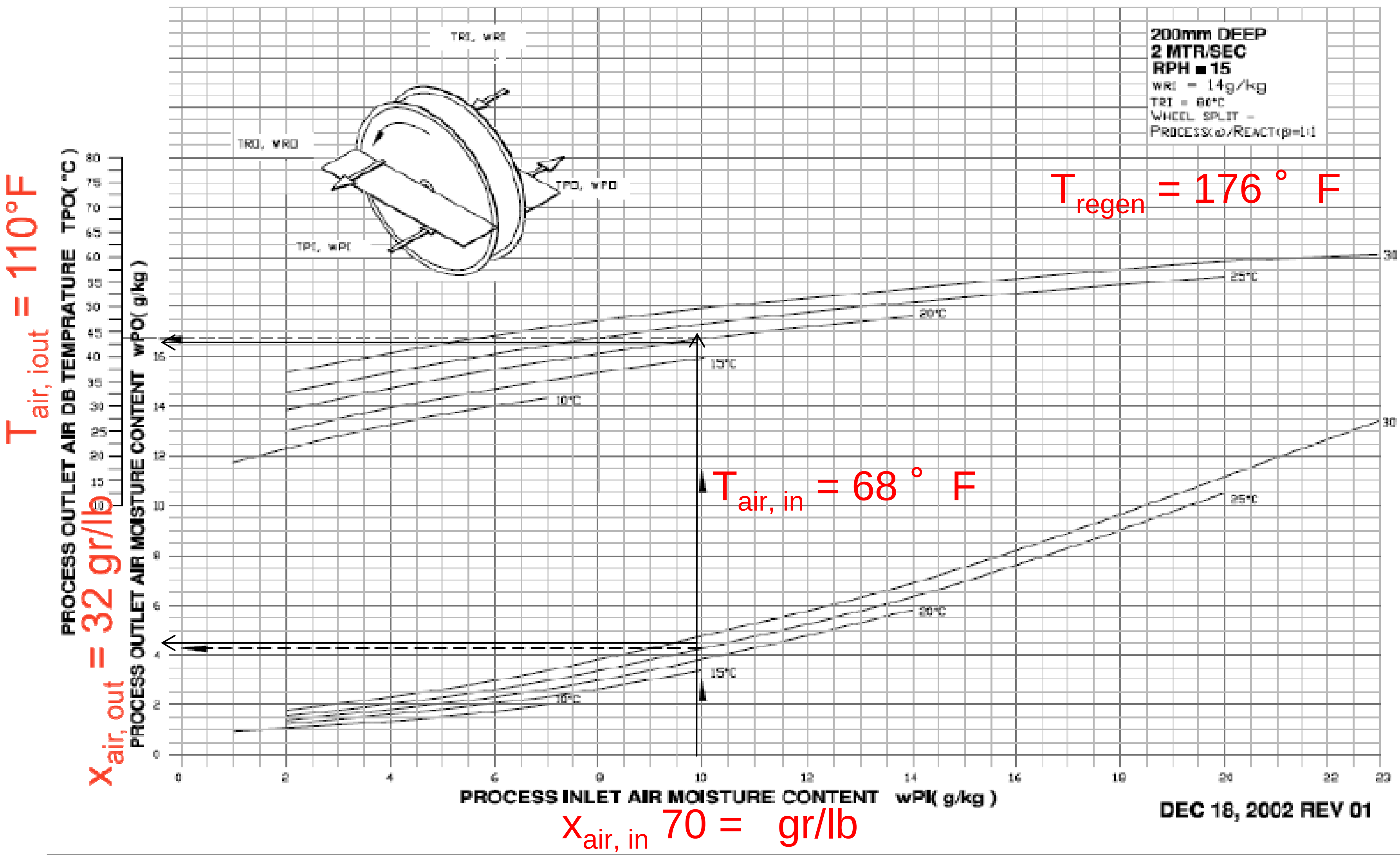
SORPTION USING ROTORS



The effectiveness of the dehumidification rotor is influenced by many parameters such as:

- Material and geometry
- Temperature and humidity ratio of the processed air
- Temperature and humidity ratio of the regeneration air
- The velocity of the air
- The mass of desiccant compared to the air mass flow

Inlet / Outlet Temperatures and humiditiy



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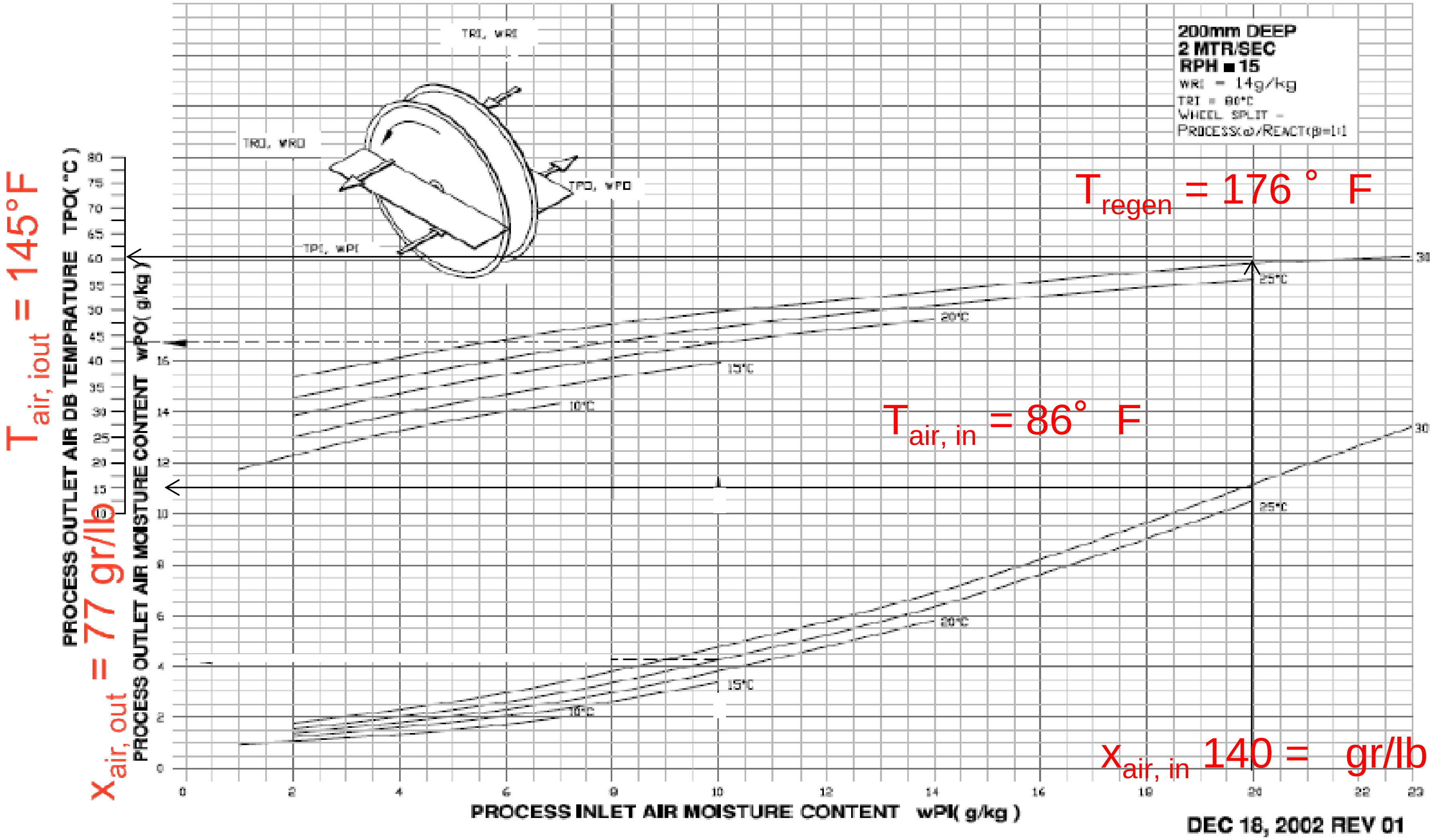
Inlet / Outlet Temperatures and humiditiy



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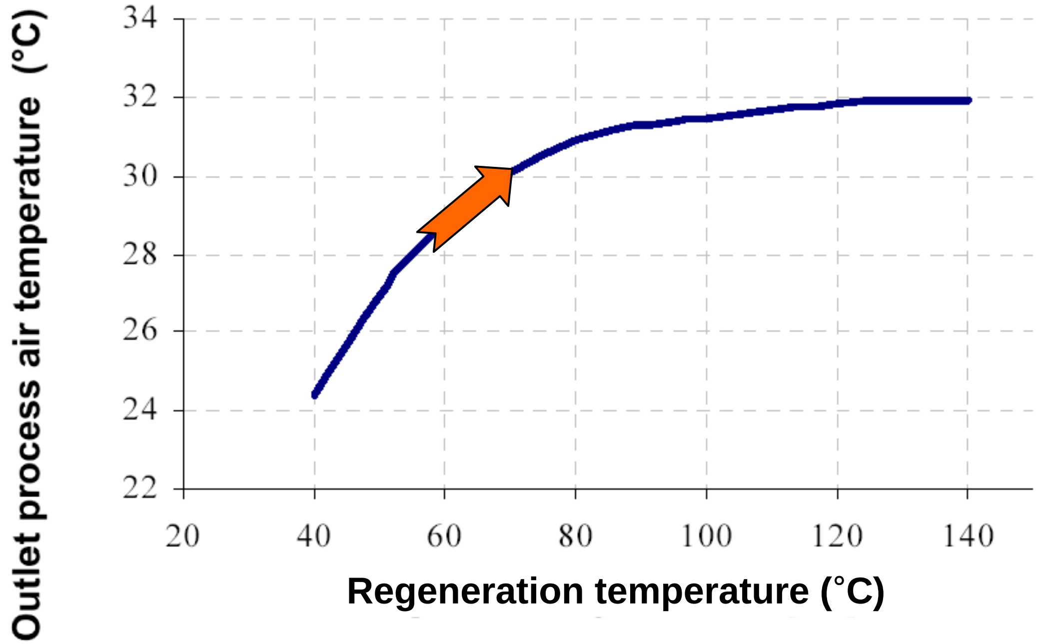
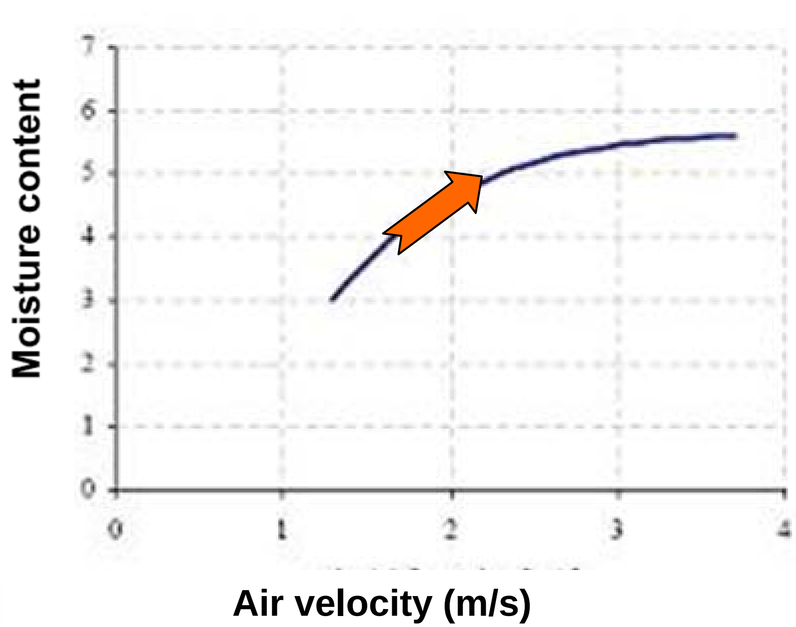
Regeneration temperature / Outlet process air temperature

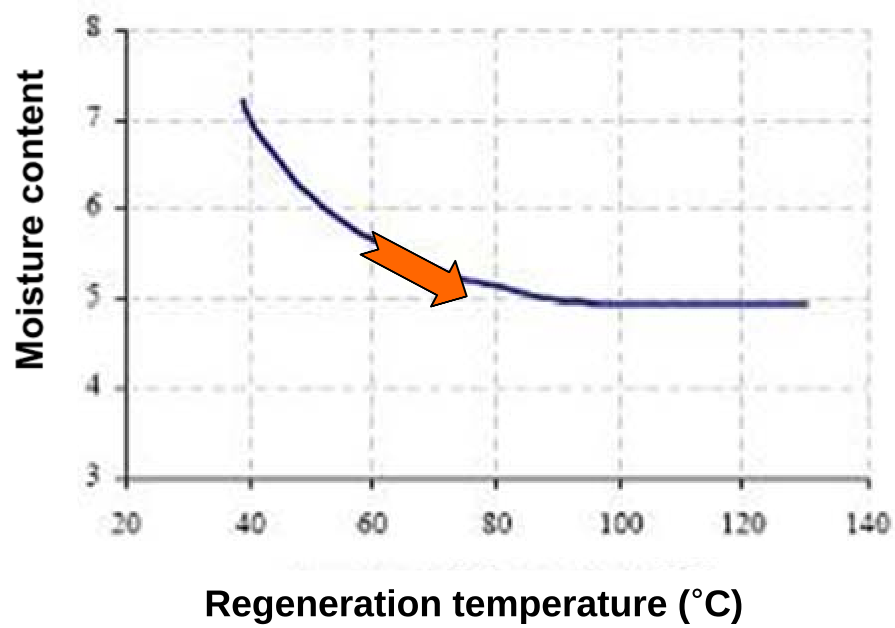


Outlet temperature for different temperatures of regeneration

Source: Finocchiaro 2008

Outlet moisture content / Air velocity and regeneration temperature





Outlet absolute humidity for different air velocities and temperatures of regeneration

Source: Finocchiaro 2008

inlet process air temperature and humidity

Best performances occurs with lower inlet process air temperature and humidity

- The colder is the desiccant materials the higher is its capacity to adsorb the vapor

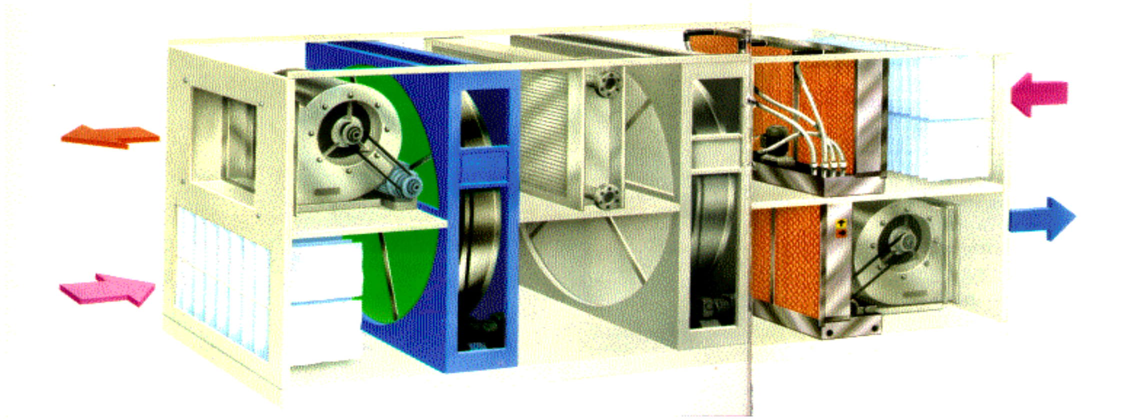
This results:

- In hot climates it is necessary to check the rotor performances at the highest temperatures
- In same case is better to pre-cool the air
- The lower is the inlet humidity the lower is the positive effect of pre-cooling

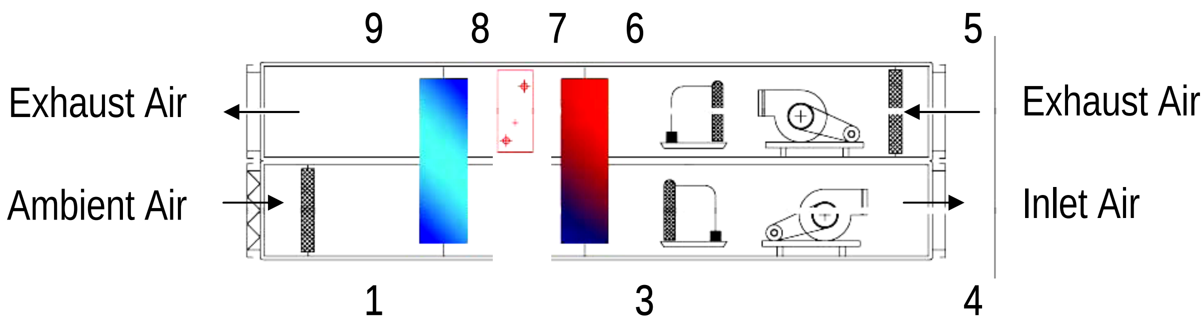
Open-cycle systems: DEC air handling units

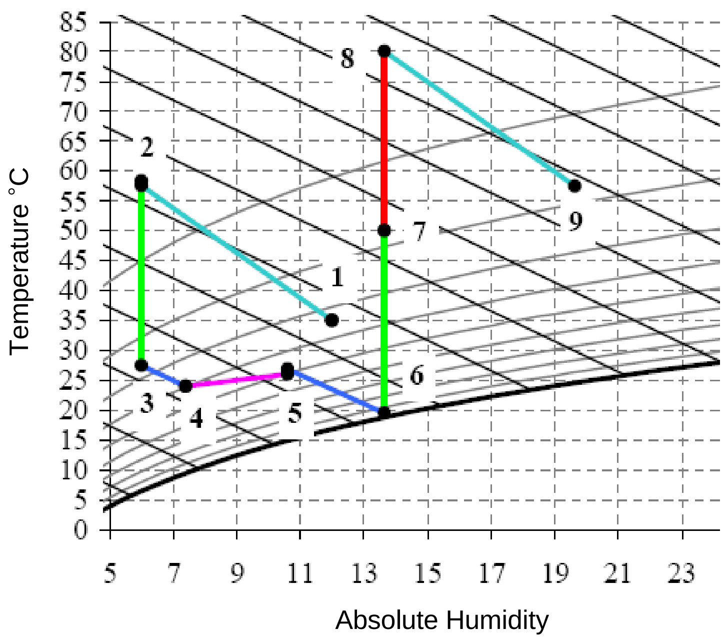
- In air conditioning applications, it is necessary to implement either a process air cycle either a regeneration cycle for the desiccant inside an air handling unit (AHU)

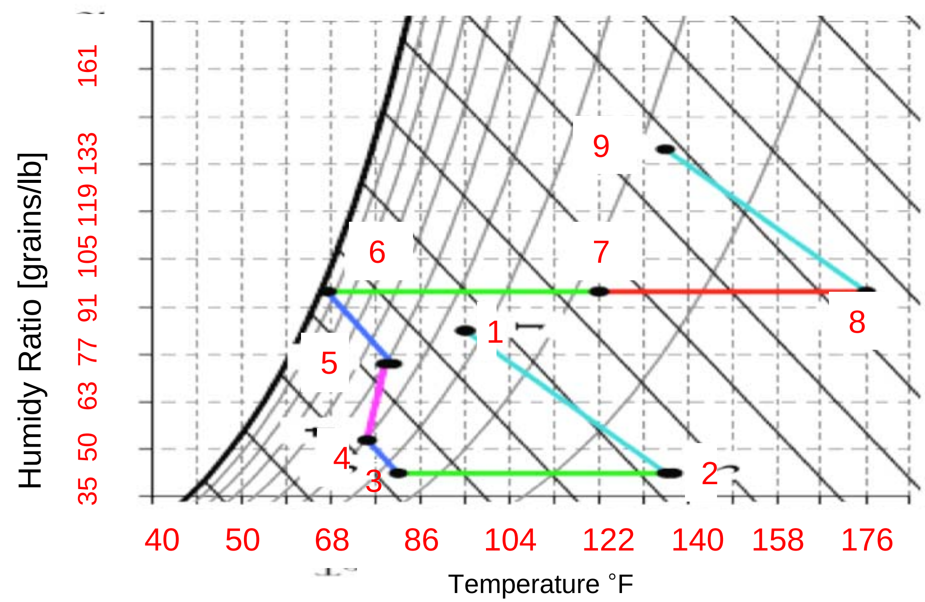
There are several possible configurations of the AHU, according to the design conditions. The most common one is known as a “standard DEC cycle”



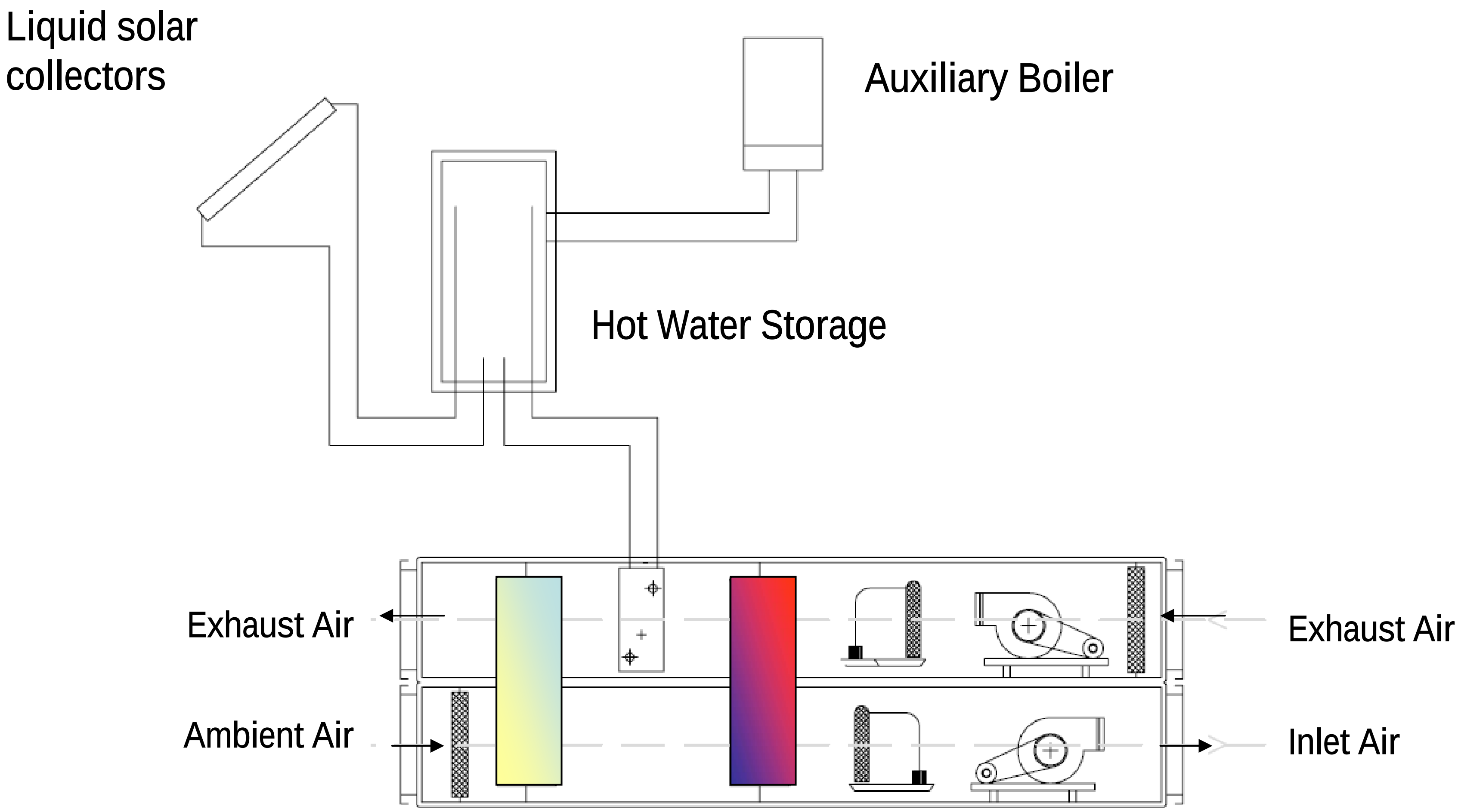
THE STANDARD DEC CYCLE



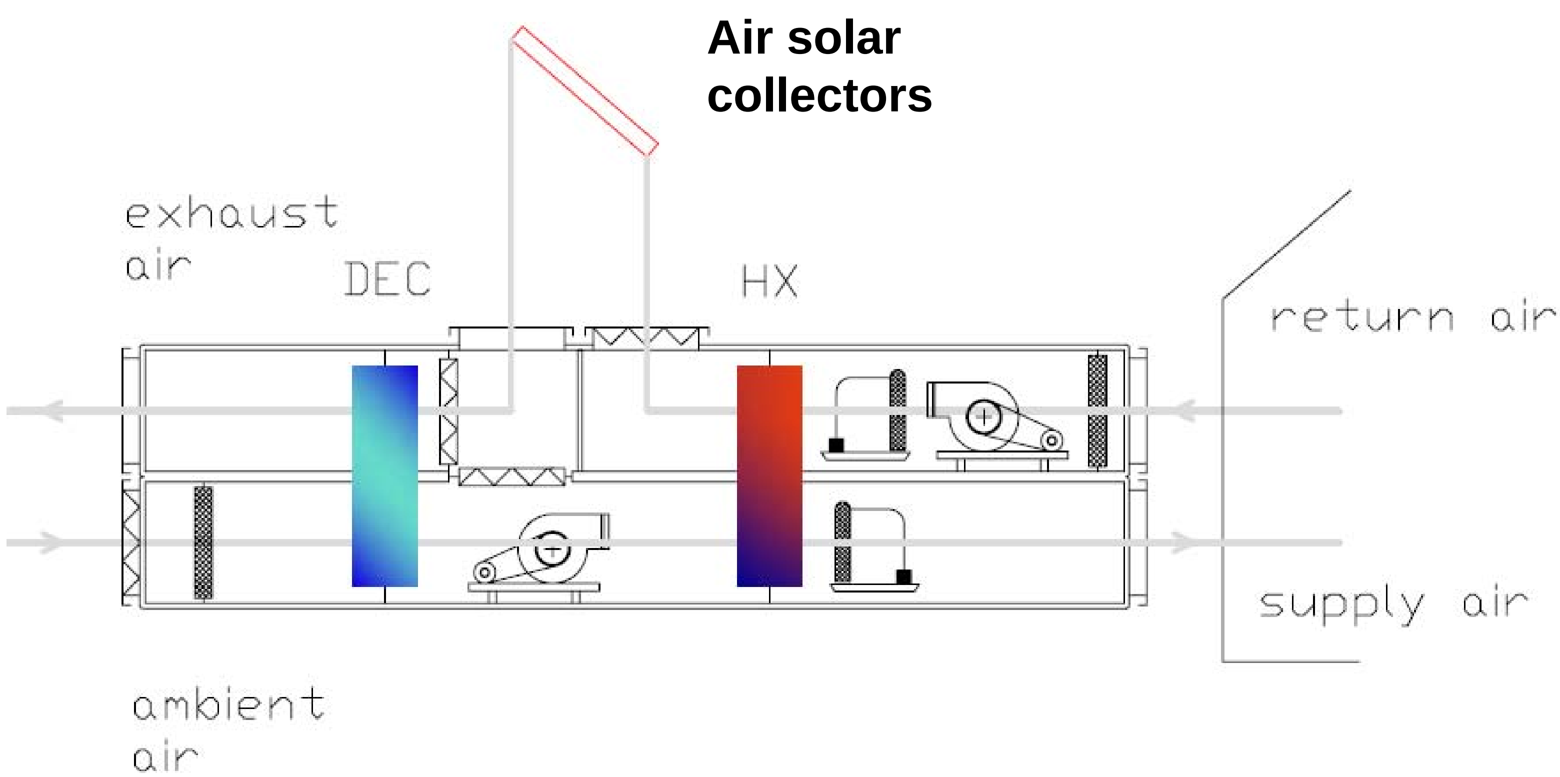




THE STANDARD DEC CYCLE WITH SOLAR THERMAL



THE STANDARD DEC CYCLE WITH SOLAR THERMAL



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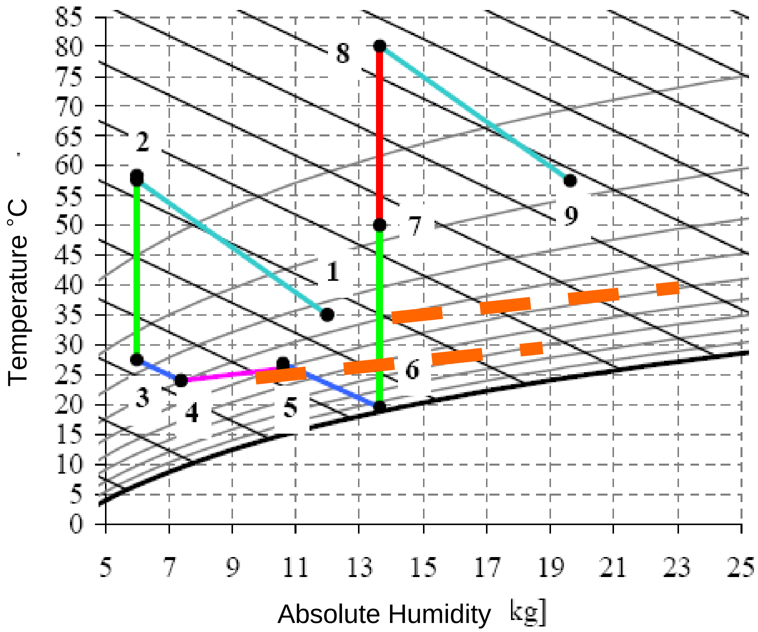
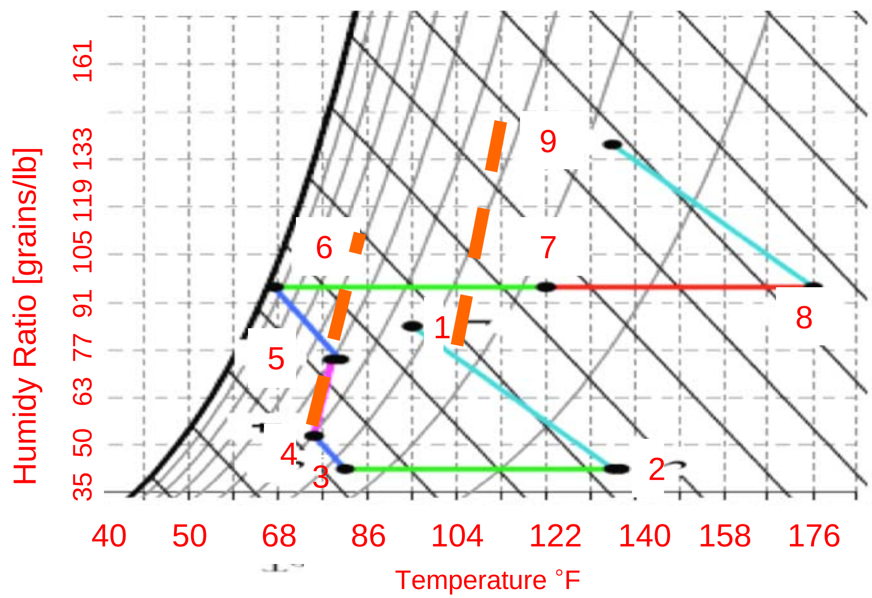
The use of standard solar desiccant systems presents some technical limitations in hot and humid climates, mainly due to the high latent loads to be handled by the wheel and to the reduced potential of evaporative cooling.

The cycle would not be able to meet the loads

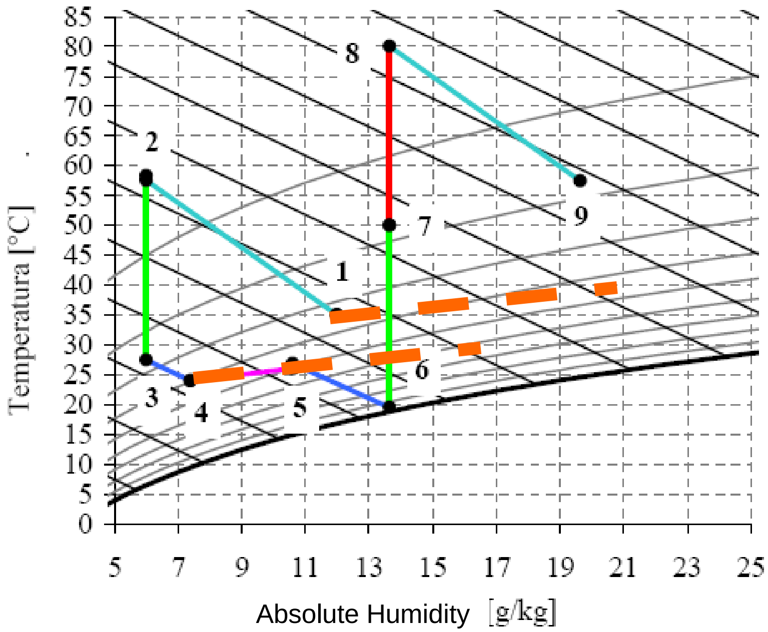




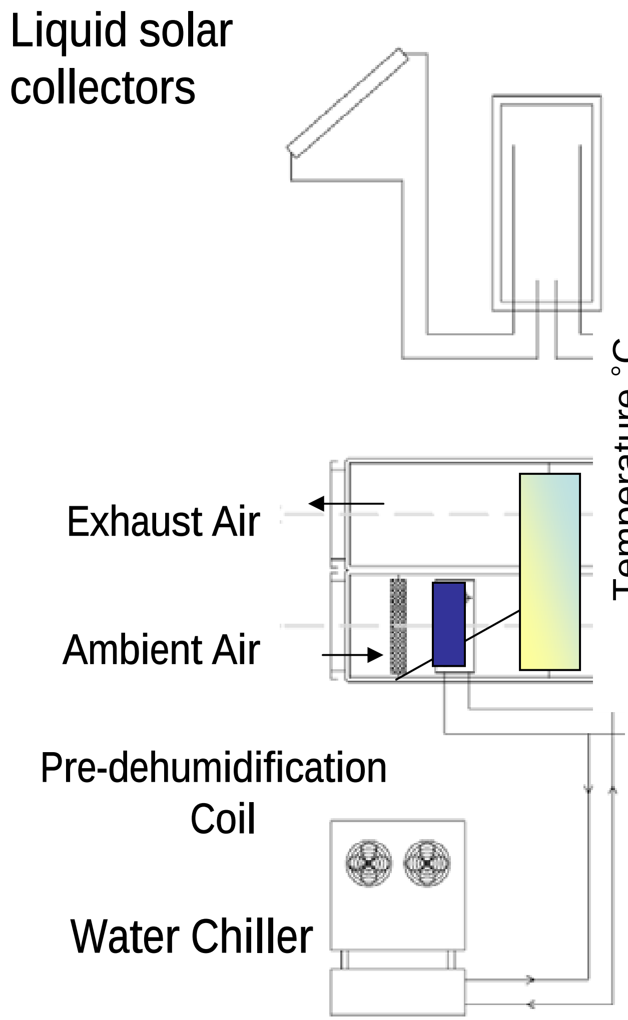
LIMITATIONS OF THE STANDARD DEC CYCLE

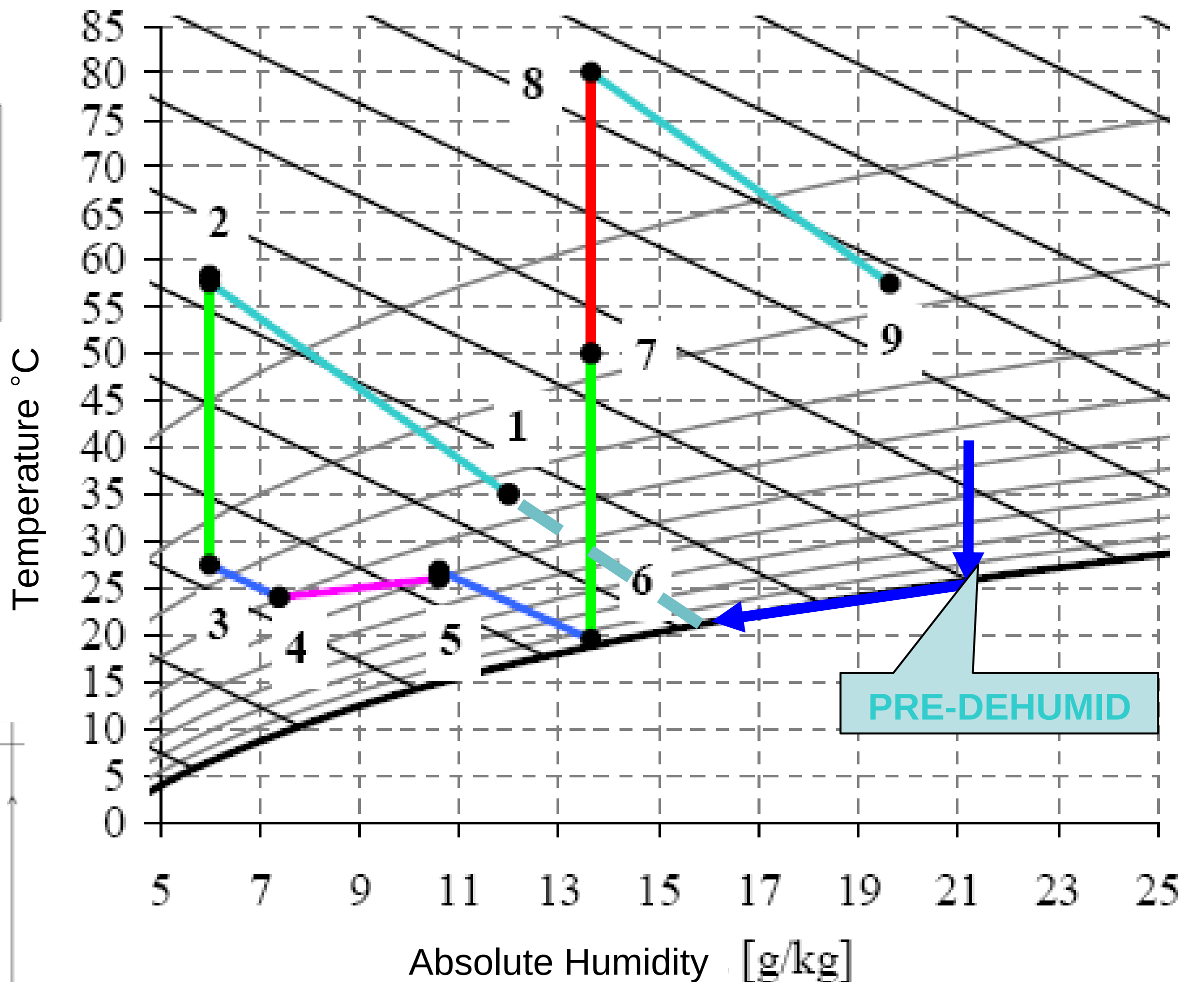
Furthermore, it must be noted that:

- **the higher dehumidification is required by the wheel, the higher the outlet temperature and the higher the sensible load to be met by auxiliary equipment (i.e. cooling coil installed downstream)**
- **the upgrade of the regeneration temperature if obtained through a conventional heat back-up, is not energy efficient**

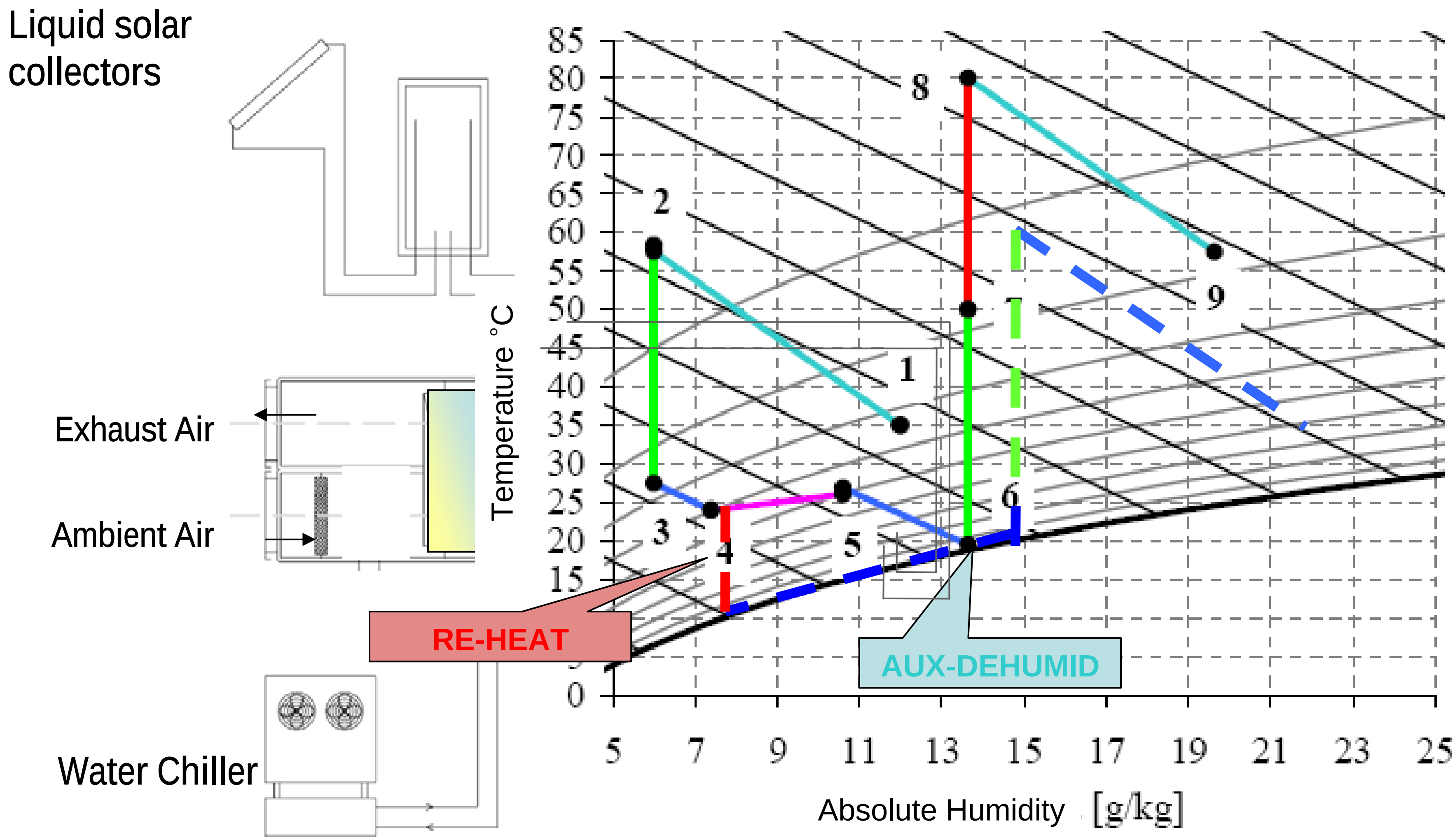


DEC CYCLE WITH PRE-DEHUMIDIFICATION

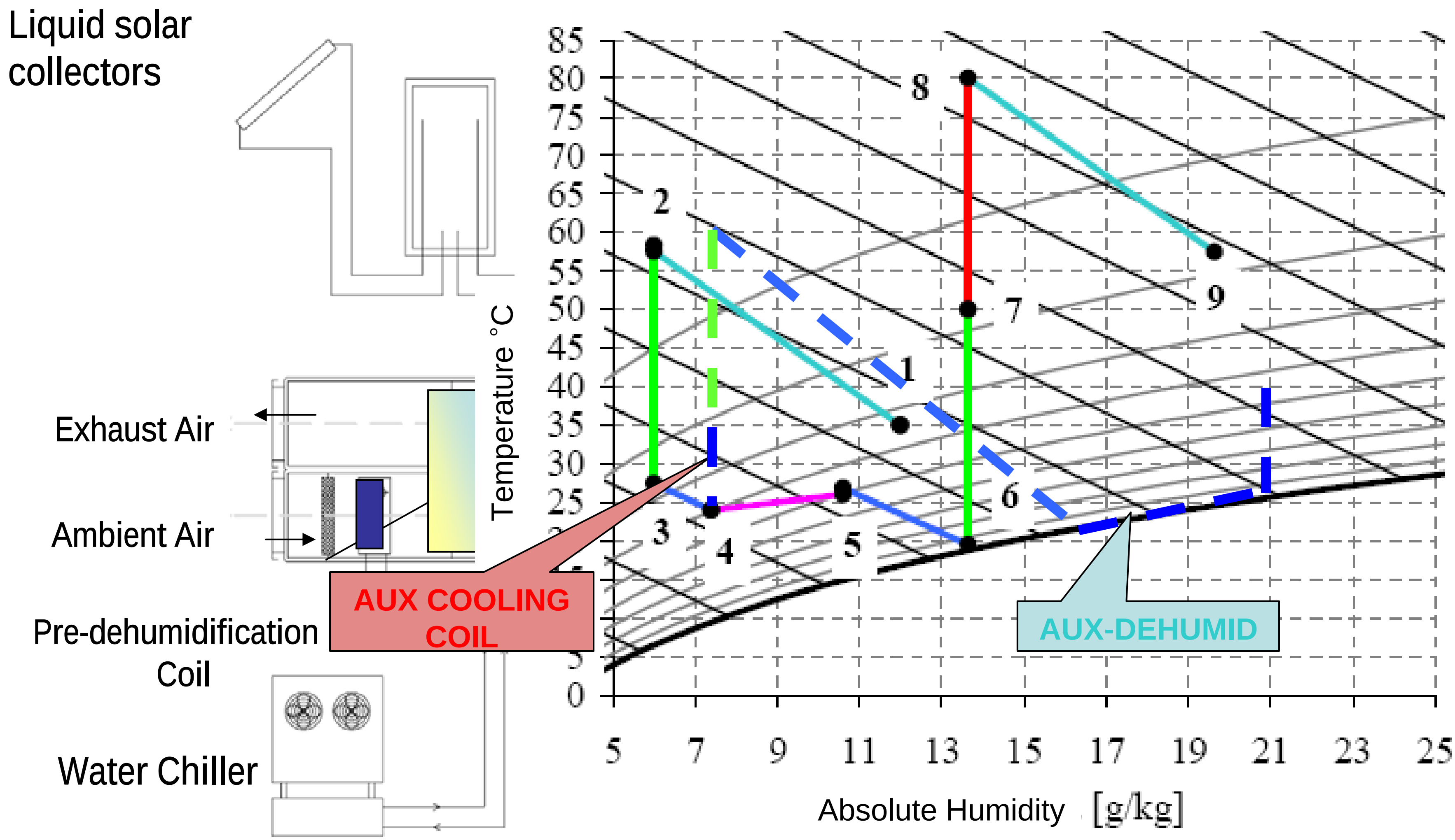




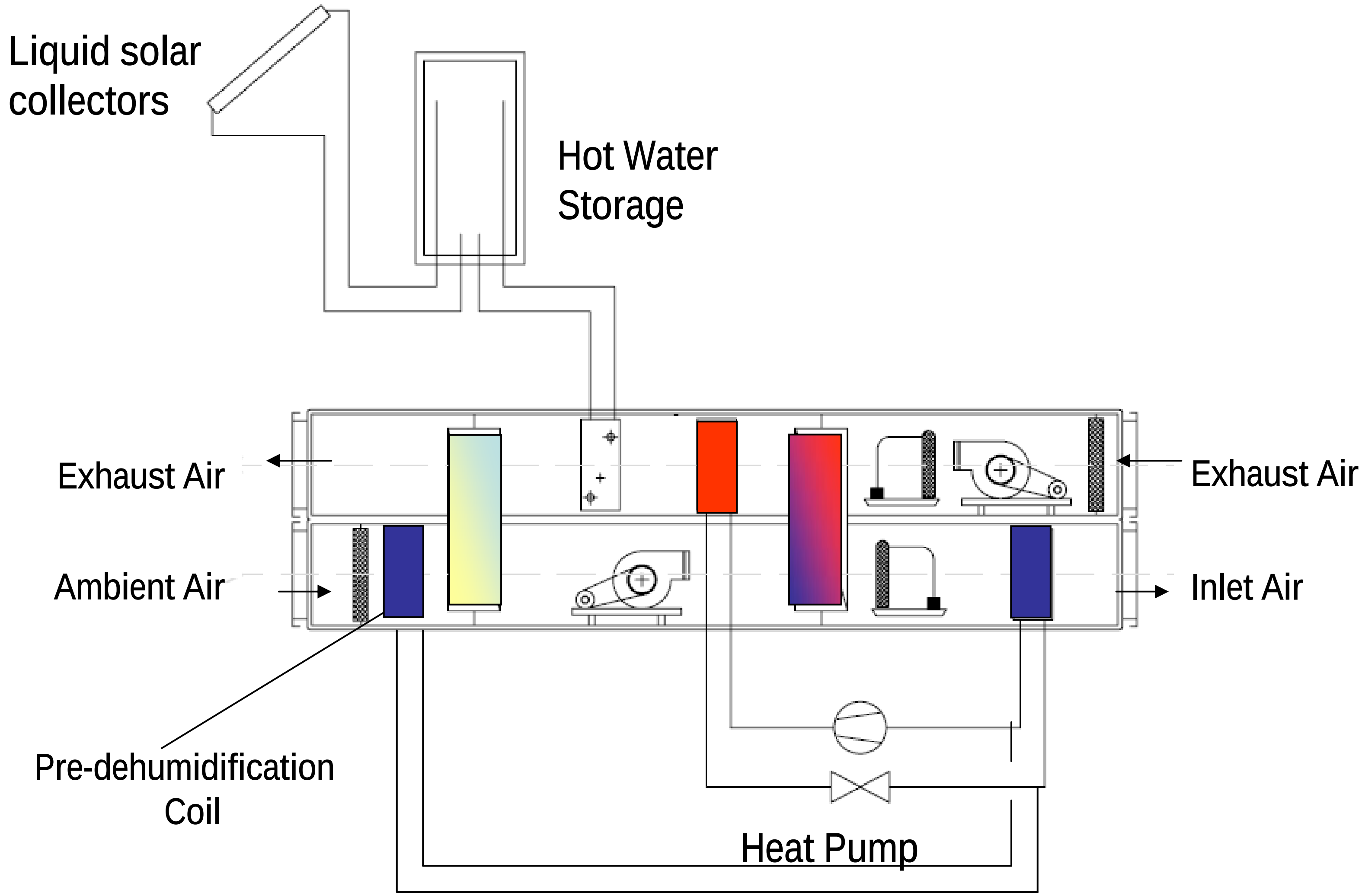
DEC CYCLE WITH AUXILIARY COOLING/DEHUMIDIFICATION COIL



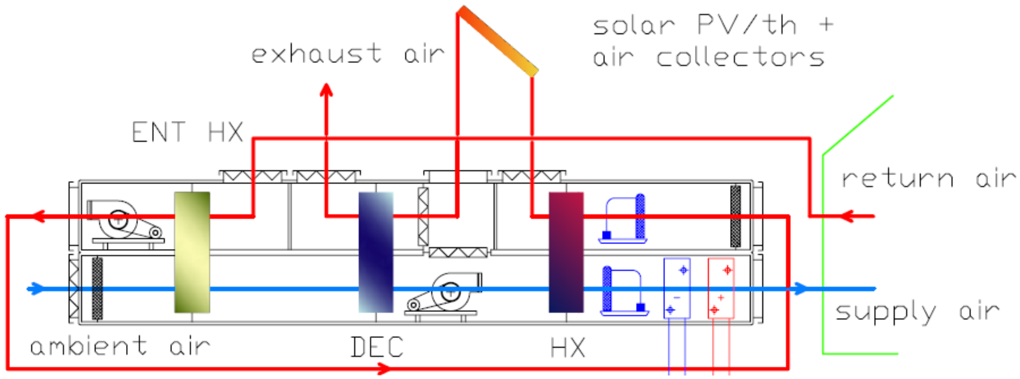
DEC CYCLE WITH TWO AUXILIARY COILS



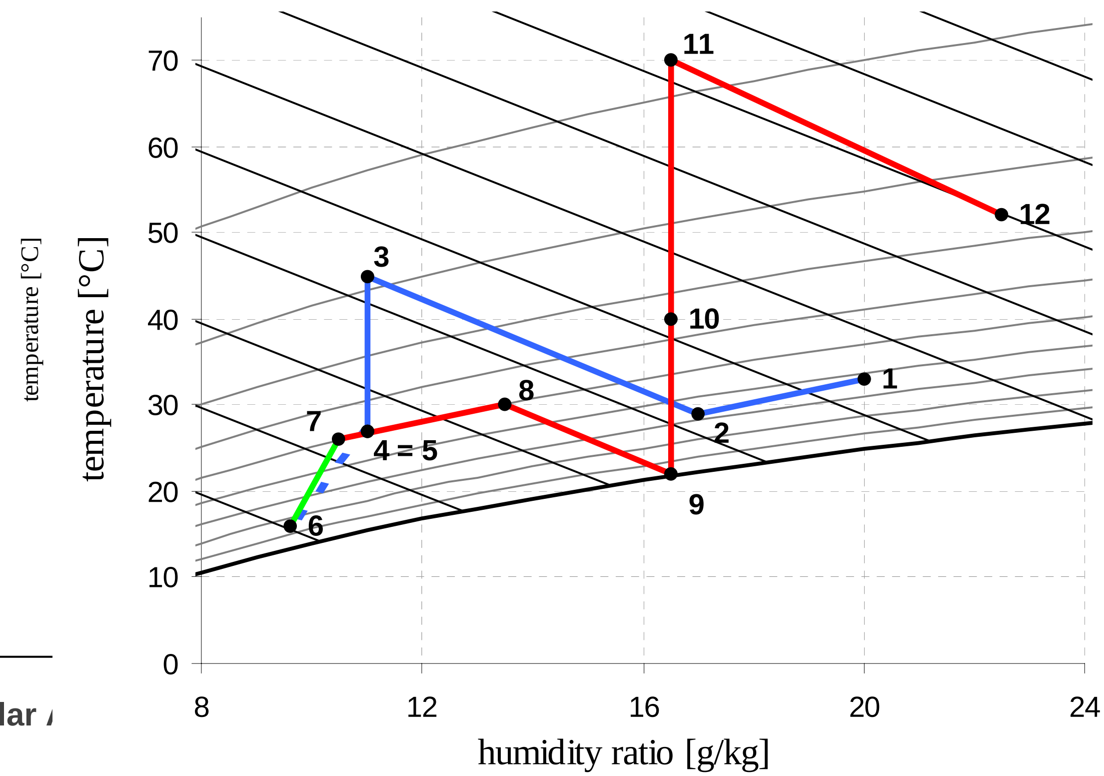
DEC CYCLE WITH 2 coils (and integrated heat pump)



DEC CYCLE + Enthalpy wheel + 1 Coil



1 - 2	enthalpy heat exchanger
2 - 3	desiccant wheel
3 - 4	sensible heat exchanger
4 - 5	supply humidifier
5 - 6	cooling coil
6 - 7	building
7 - 8	enthalpy heat exchanger
8 - 9	return humidifier
9 - 10	sensible heat exchanger
10 - 11	solar heating coil
11 - 12	regeneration DEC wheel



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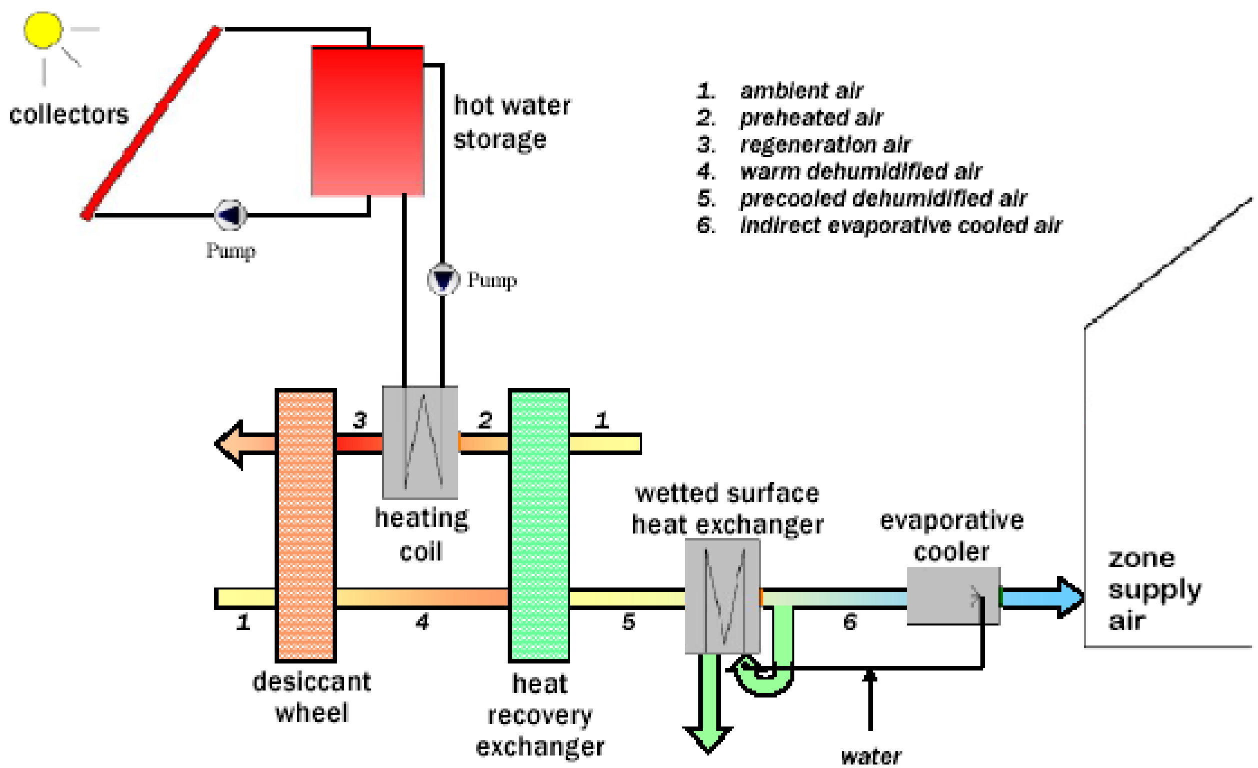
DEC CYCLE + Indirect Evap. Cooling with partial recirculation of process air



Source: **White, Kohlenbach, Bongs**
CSIRO Energy Technology, Australia

COEFFICIENT OF PERFORMANCE

Total cooling effect (not considering the aux cooilng coil)

Thermal COP

$$COP_{therm} = \frac{\dot{Q}_{DEC}}{\dot{Q}_{reg}} = \frac{\left(\dot{Q}_{cool\_AHU} - \dot{Q}_{CC\_aux}\right)}{\dot{Q}_{reg}}$$

Heat input (not considering the condenser coil)

Electrical COP

$$COP_{el} = \frac{\dot{Q}_{DEC}}{\dot{Q}_{el\_AHU}}$$

SOLAR FRACTION

It is usefull to consider two Solar Fractions

For regeneration

$$SF_{reg} = \frac{Q_{solar}}{Q_{reg}}$$

$$SF_{cool} = \frac{Q_{DEC}}{Q_{cool\_AHU}} = \frac{\left(Q_{cool\_AHU} - Q_{CC\_aux}\right)}{Q_{cool\_AHU}}$$

For Cooling

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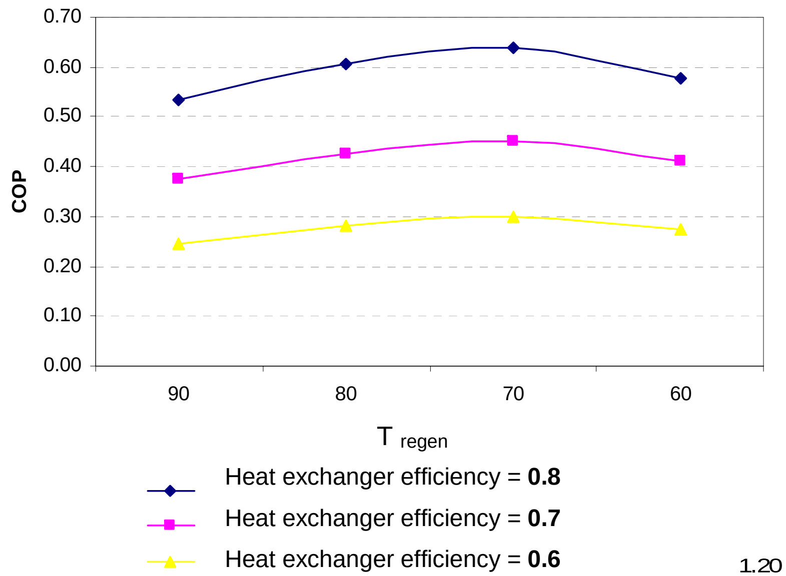
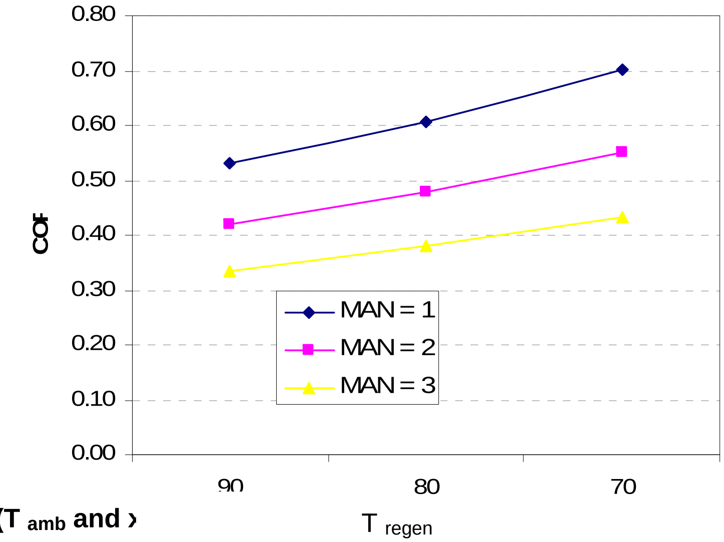
DEC CYCLE WITH INTEGRATED HP and 2 coils

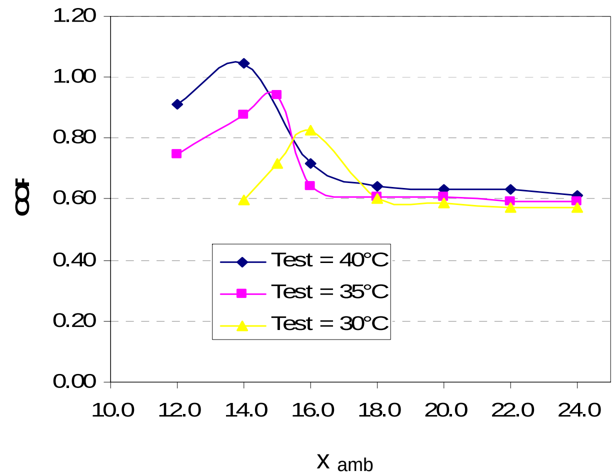
COP = *f* (T regen and HX efficiency)



COP = *f* (T regen and Rotor Type)



COP = *f* (T amb and x



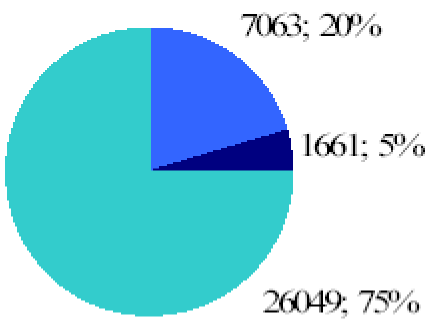
$$COP_{therm} = \frac{\dot{Q}_{DEC}}{\dot{Q}_{reg}} = \frac{\left(\dot{Q}_{cool\_AHU} - \dot{Q}_{CC\_aux}\right)}{\dot{Q}_{reg}}$$

Results for DEC + 2 Aux coils

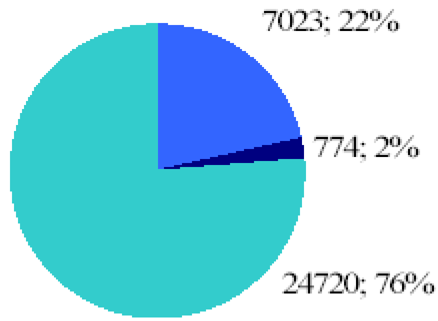
Allocation of cooling effect

■ Q_{cool} Cooling Coil 1 [MJ/a]
■ Q_{cool} Cooling Coil 2 [MJ/a]
■ Q_{cool} DEC [MJ/a]

Liquid collectors



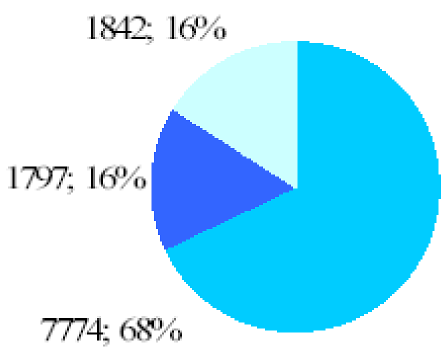
Air collectors



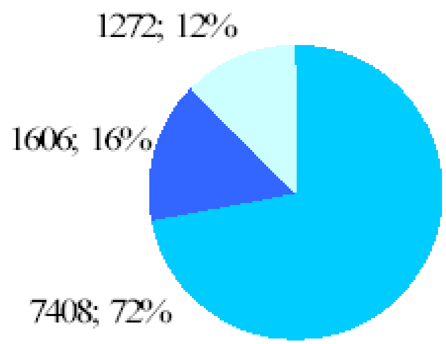
Allocation of electricity consumption

■ Air Handling Unit
■ Heat pump
■ Auxiliaries

Liquid collectors

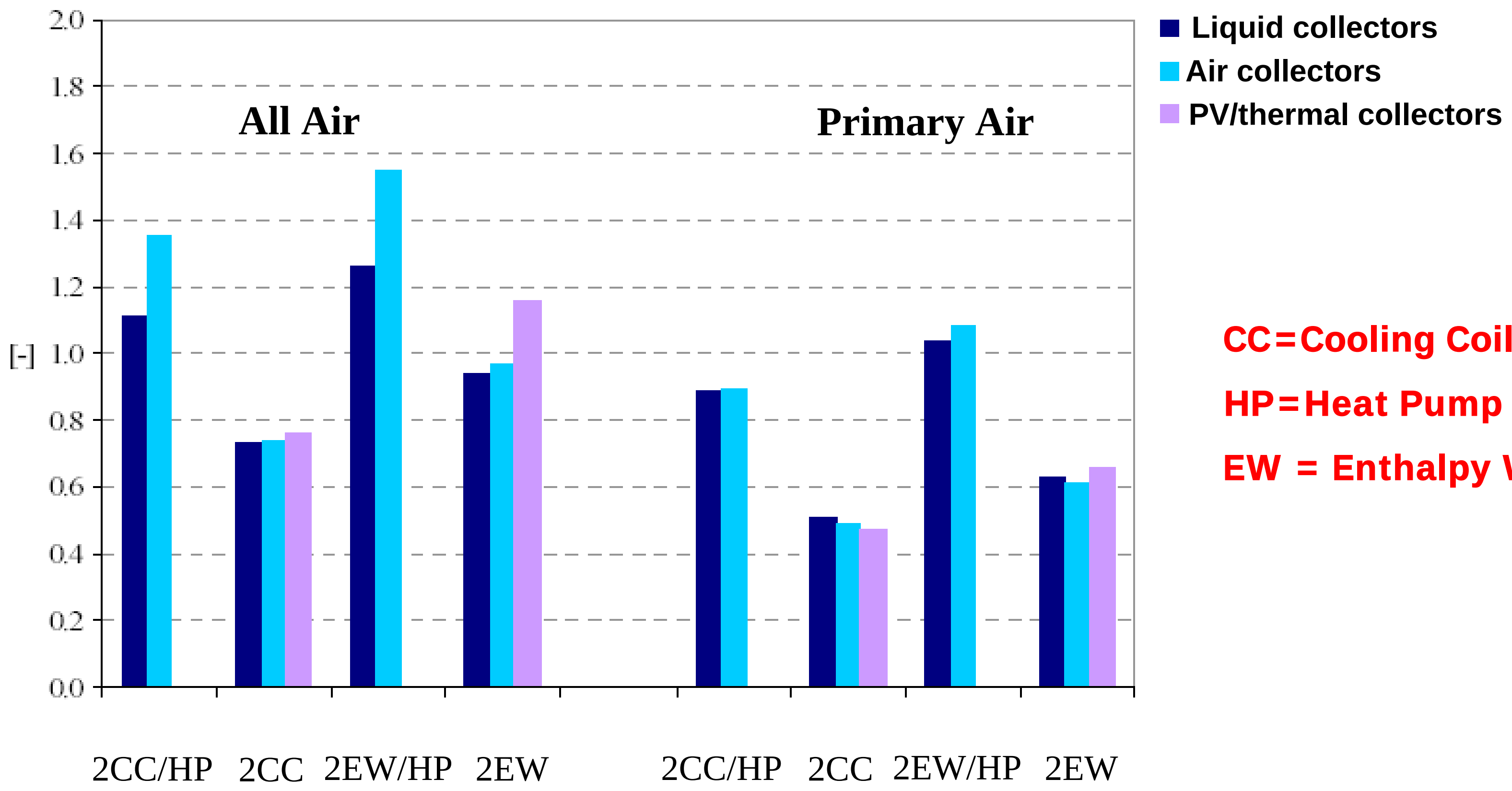


Air collectors



GENERAL RESULTS

COP $_{th}$



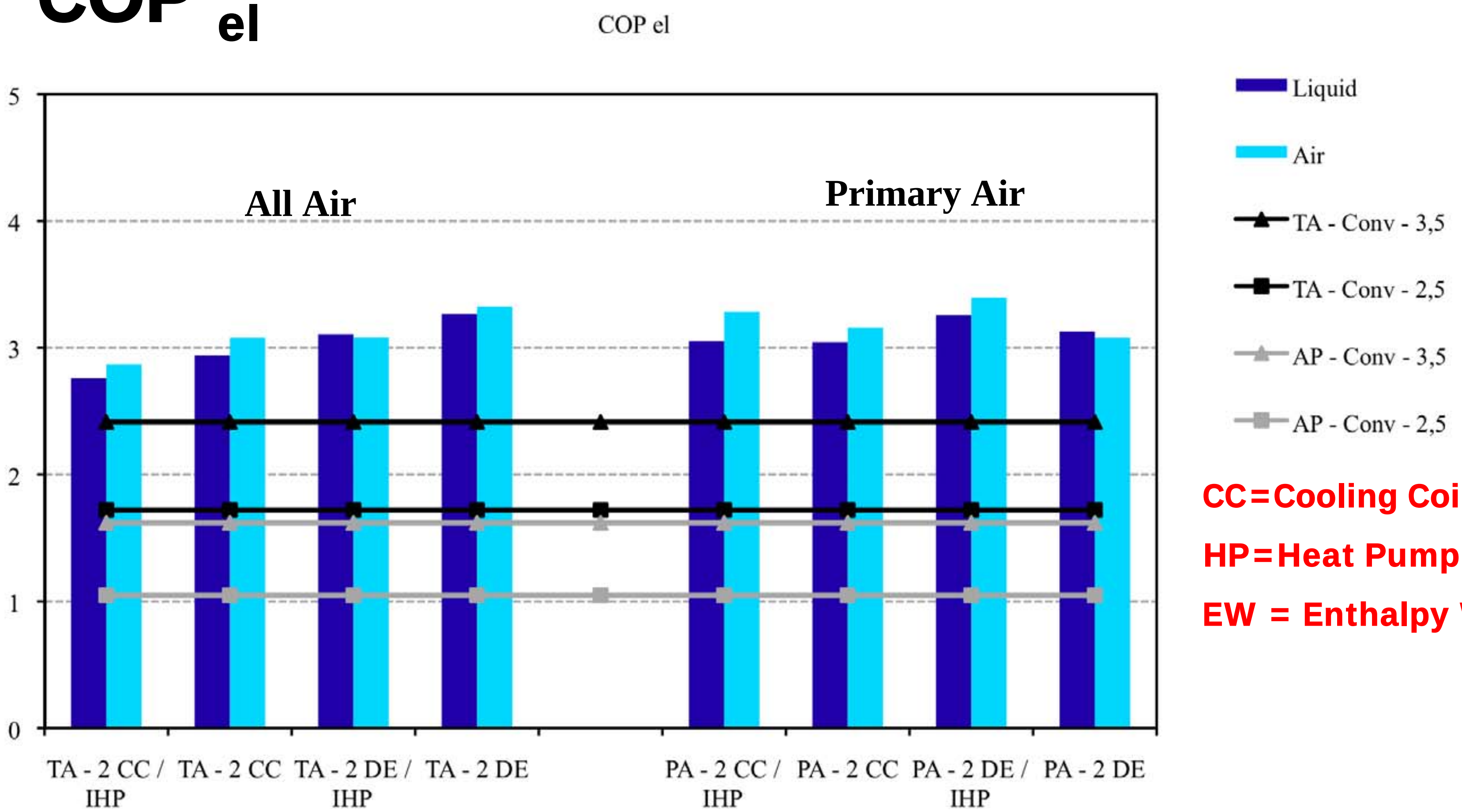
CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

GENERAL RESULTS

COP $_{el}$

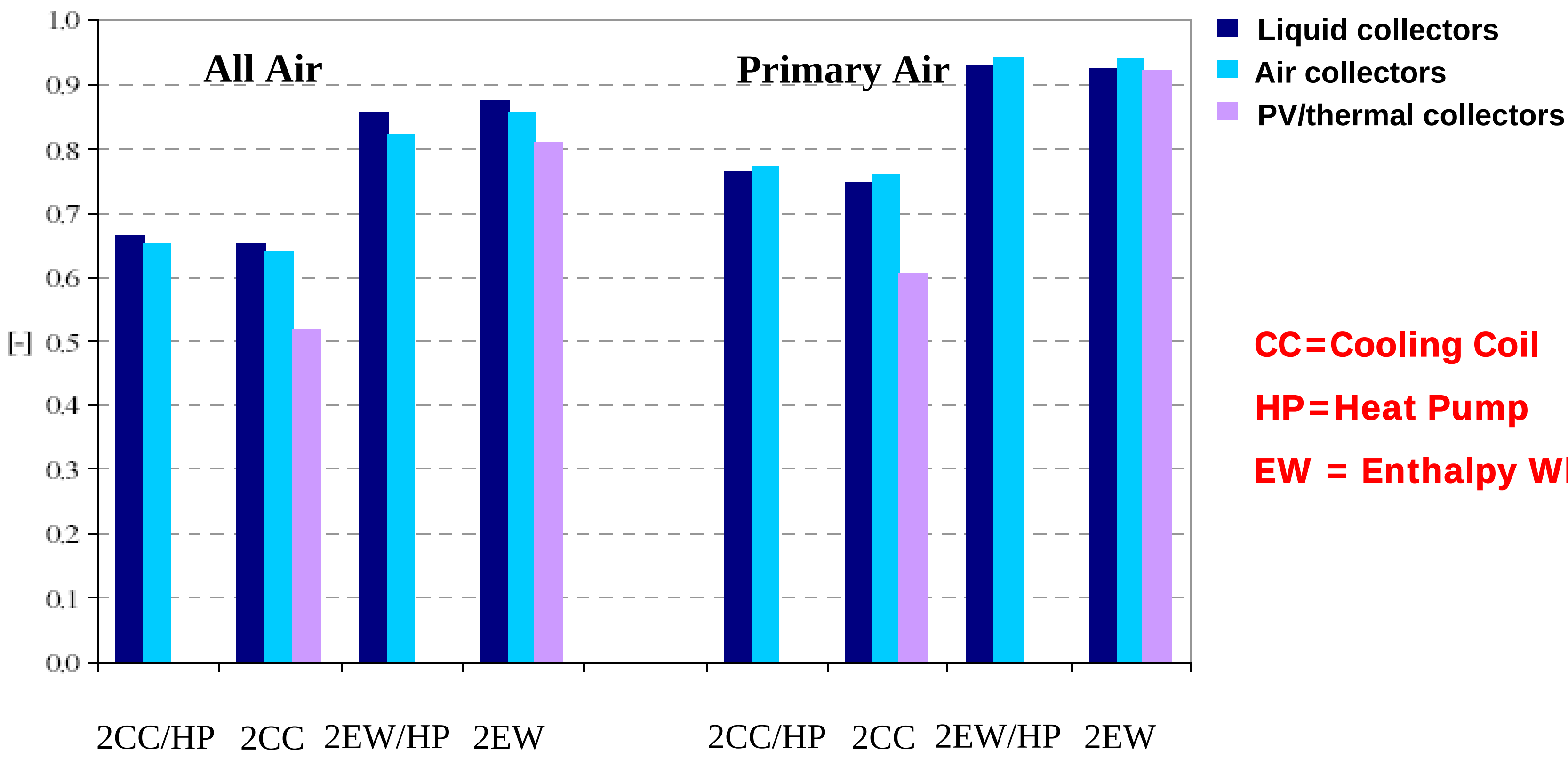


CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

Solar Fraction for Cooling



CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

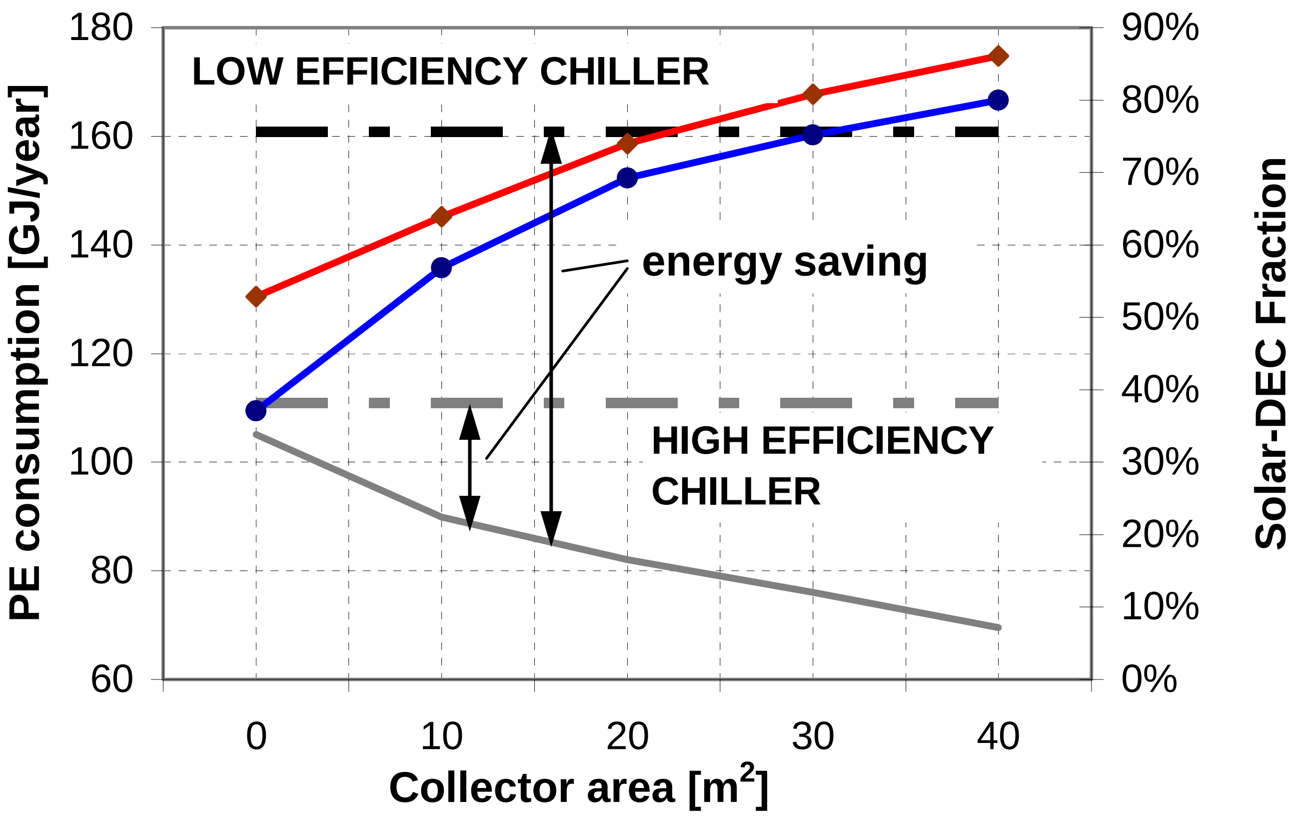
PRIMARY ENERGY SAVING

Any energy consumption balance for solar assisted air conditioning systems must take all energy flows into account in order to provide a realistic picture.
This includes the energy for:

- **Pumps (e.g., in the solar circuit and in the return flow circuit)**
- **Fans (in AHU or in the in the cooling towers)**
- **Refrigeration when insufficient solar heat is available**
- **Auxiliary heating**

The energy demand of a DEC system is caused by either electricity or heat, thus a good index for assessing the energy performance is the amount of primary energy consumed by the system.

PRIMARY ENERGY SAVING



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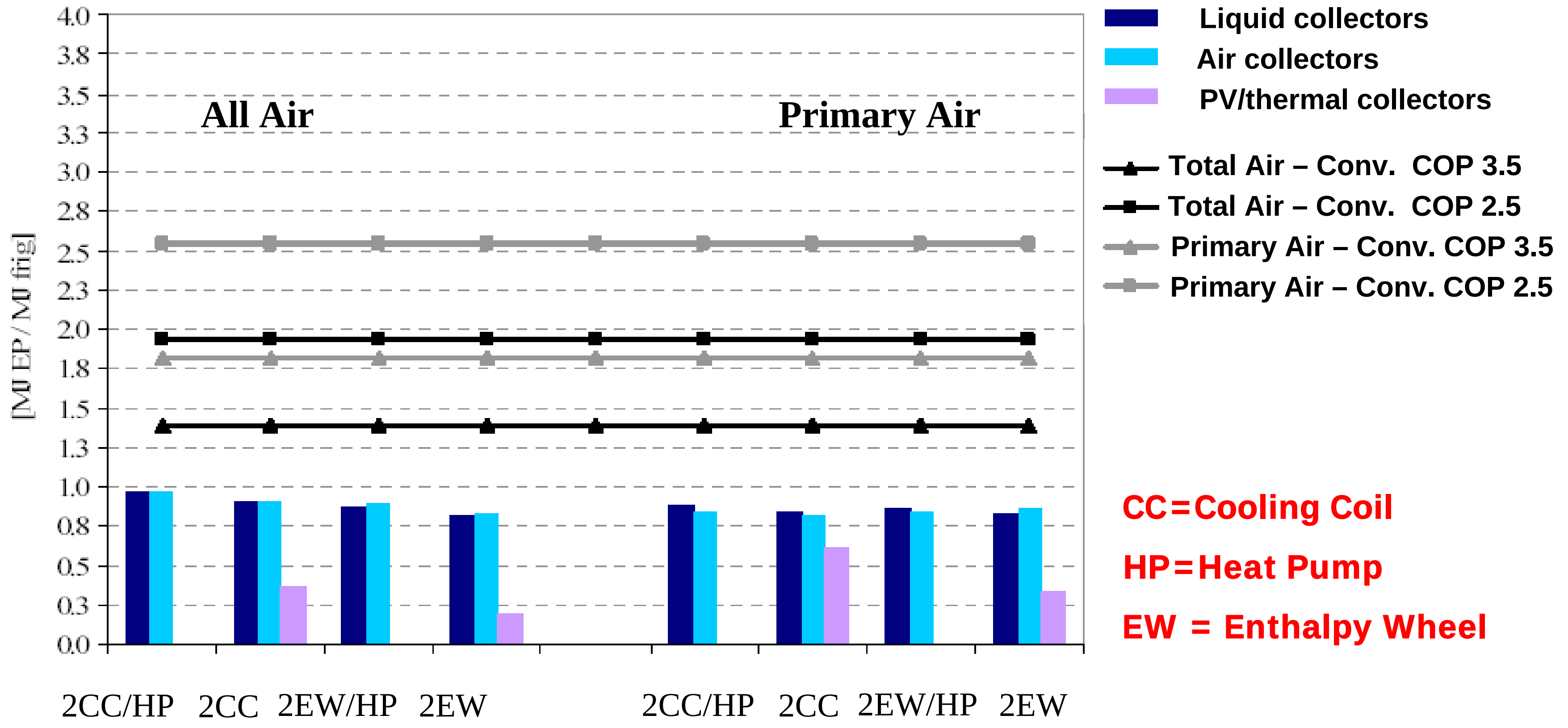
Primary Energy Consumption



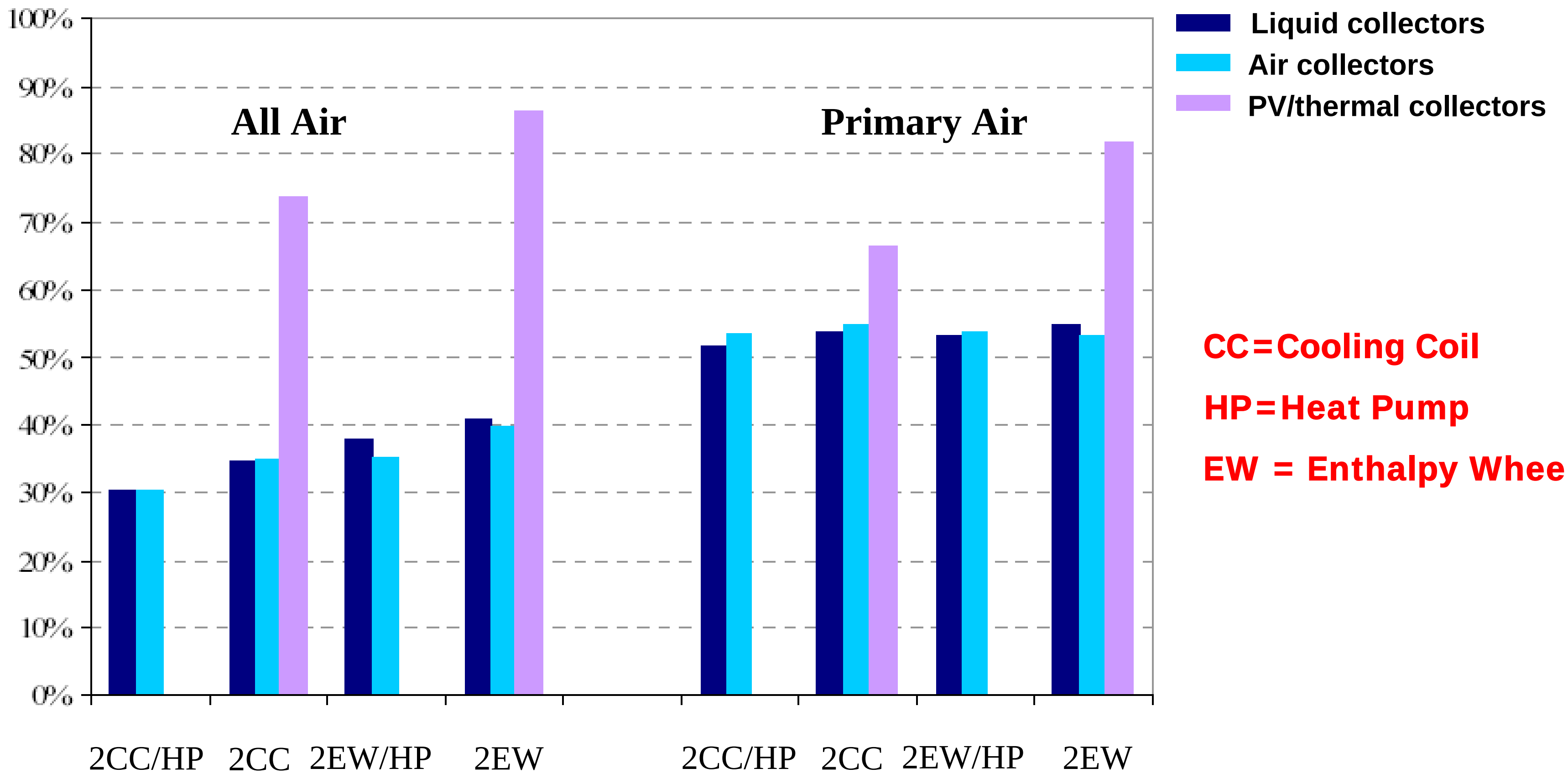
CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

Primary Energy Saving

COP conv = 3.5



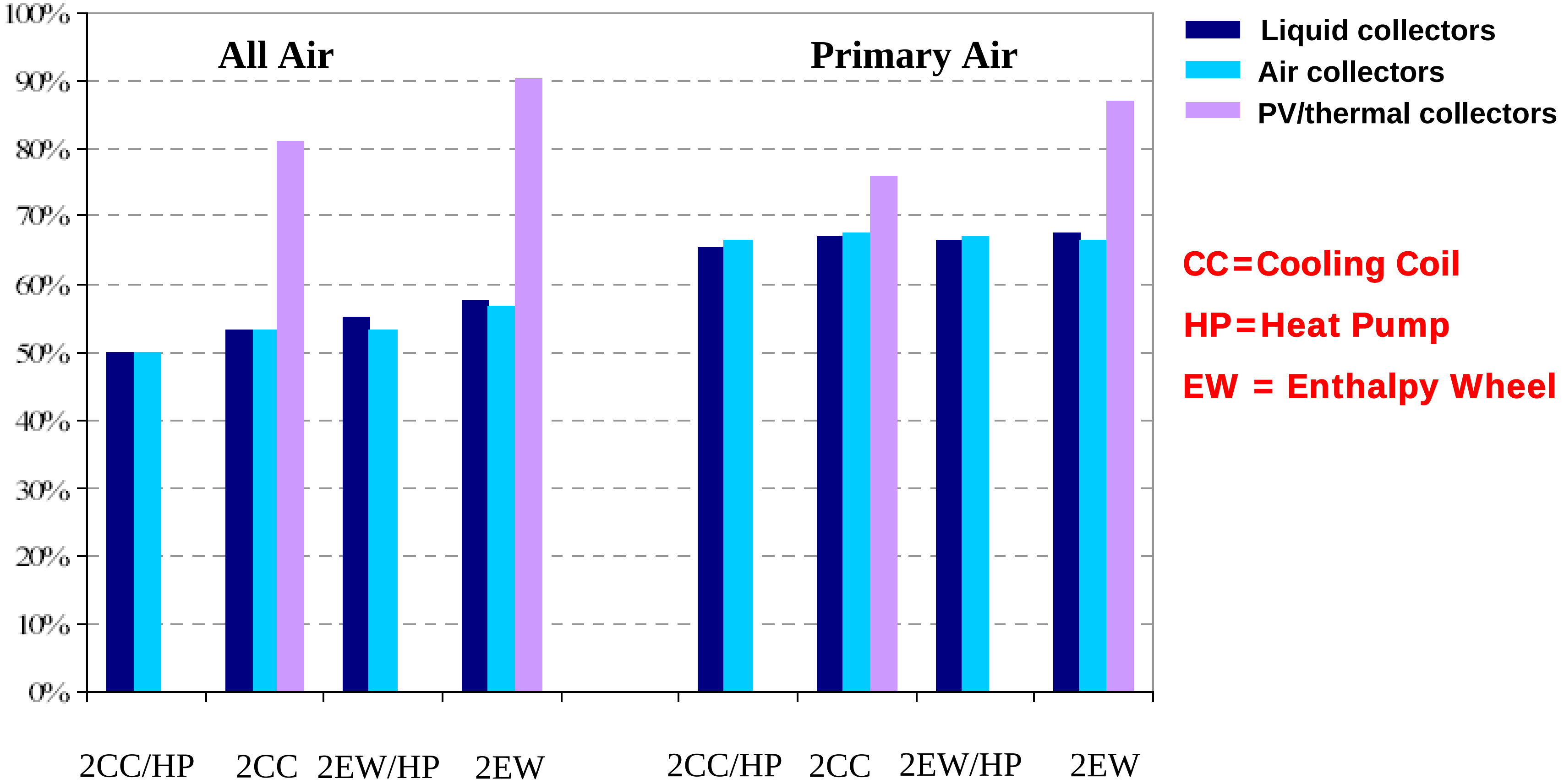
CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

Primary Energy Saving

COP conv = 2.5



CC=Cooling Coil

HP=Heat Pump

EW = Enthalpy Wheel

Good performances are achievable only through a good design

- the hydraulic system and the air paths should be as simple as possible and as complex as necessary;

- the design should be supported by detailed simulations of loads and system performances;

- a smart and reliable control system is required;

- a rigorous commissioning phase with subsequent recording and analysis of operating data is crucial in order to achieve the targeted energy savings

Thank you for your attention

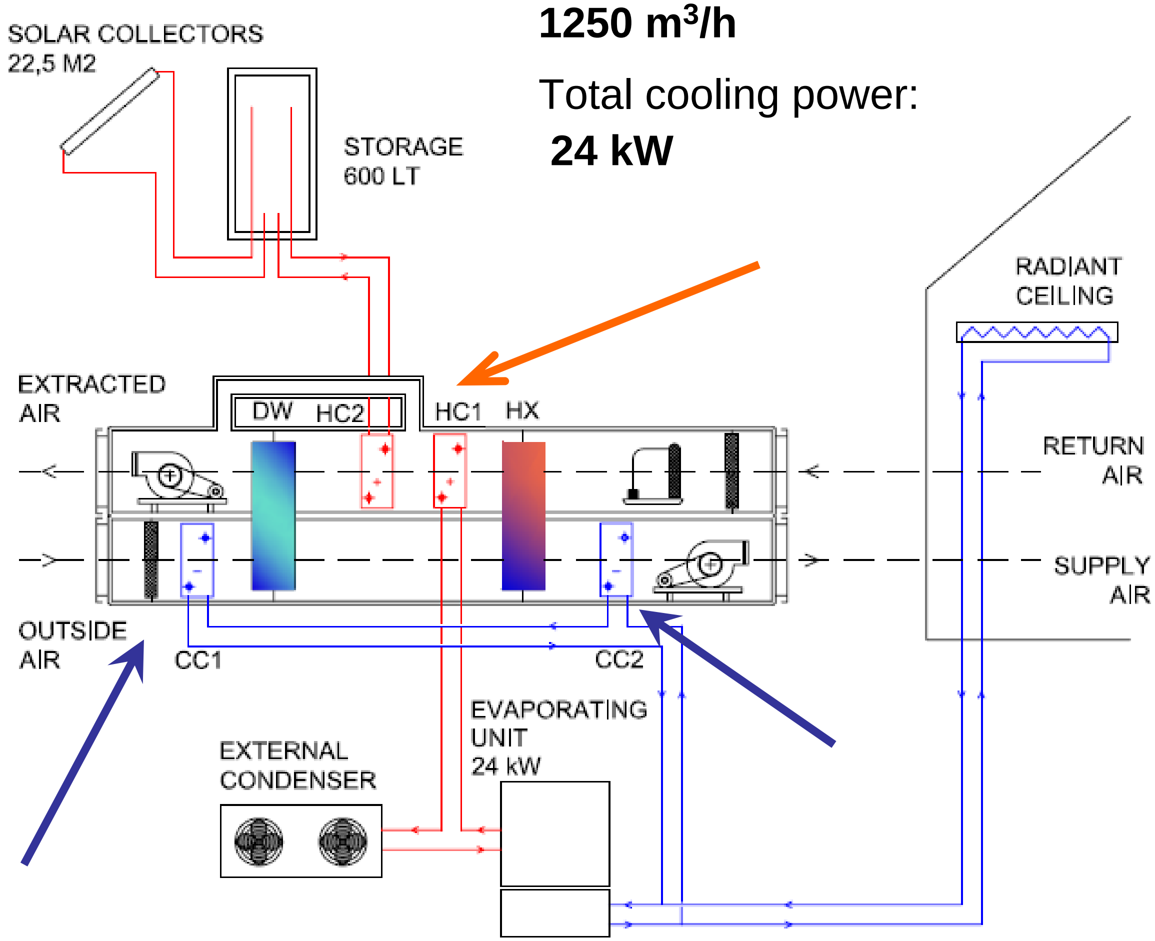
Annex

DEC plant (Test Set-Up) at Palermo – Cooling Operation

AHU for primary air, with **desiccant wheel** and **sensible heat recovery**

Supply nominal air flow rate:
1250 m³/h

Total cooling power:
24 kW

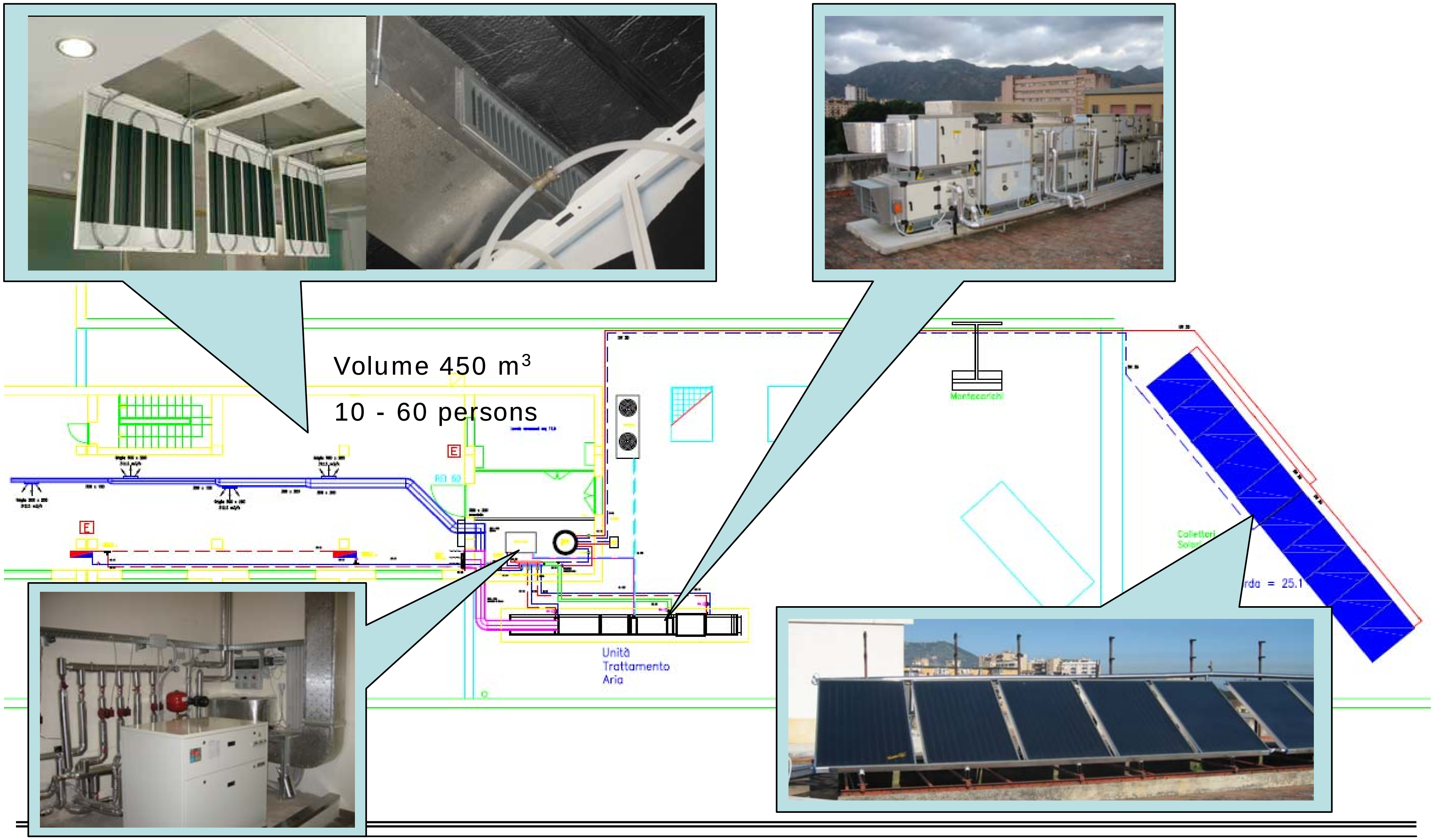


partially heat rejection from the auxiliary water chiller to the regeneration air stream

radiant ceiling provides part of the required sensible cooling power (76 m²)

2 auxiliary cooling coils for possible pre-dehumidification and re-cooling of the air

DEC plant (Test Set-Up) at Palermo



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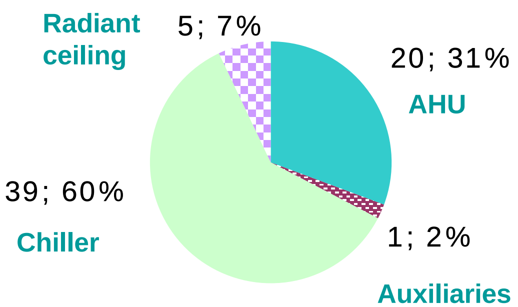
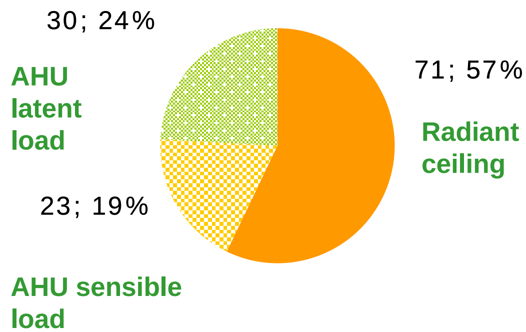
DEC plant at Palermo – Summer operation
Daily Results and Primary Energy Saved

Daily results (day of July 2008):

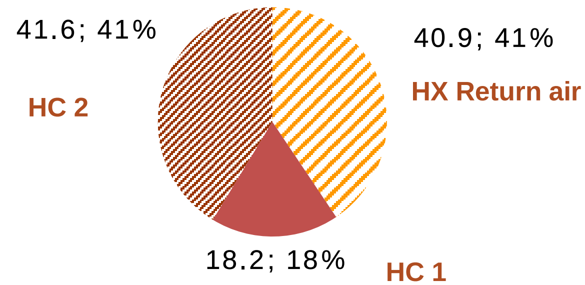
Electricity consumption



Building



Regeneration Heat



SPECIFIC CONSUMPTION SUMMER 2008: 1.12 kWh PE/kWh cool

Primary Energy Saved in relation to a conventional AHU, cooling operation 2008:	48%	July 54% August 46% September 45%
Solar-DEC-Fraction (ventilation)	46%	July 42% August 56% September 34%

(low exploitation of the plant in the month of september due to the comfortable climatic conditions)

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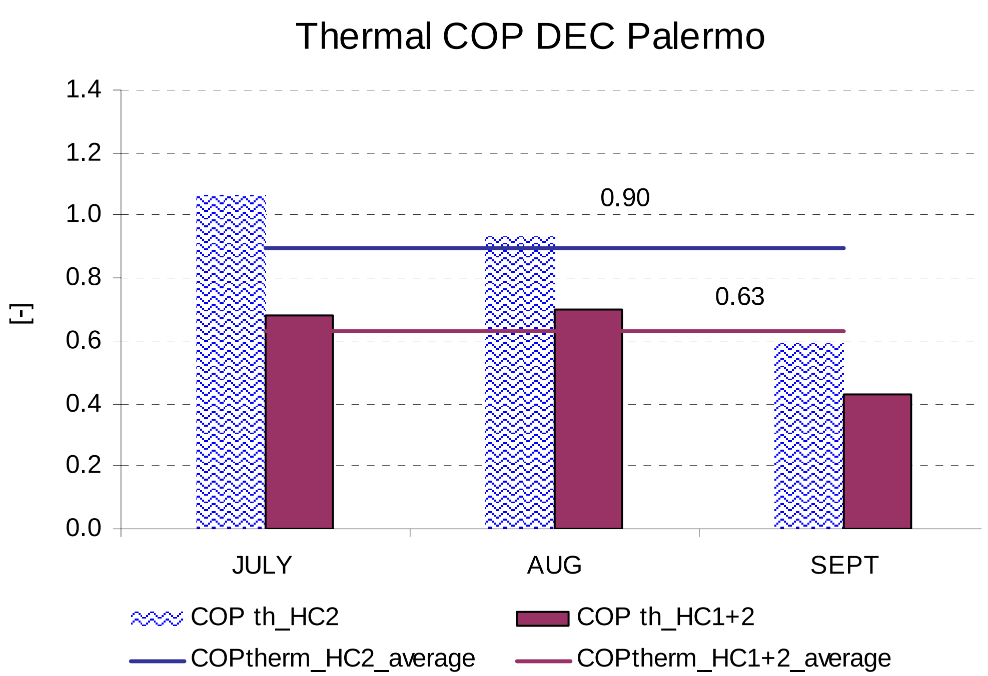
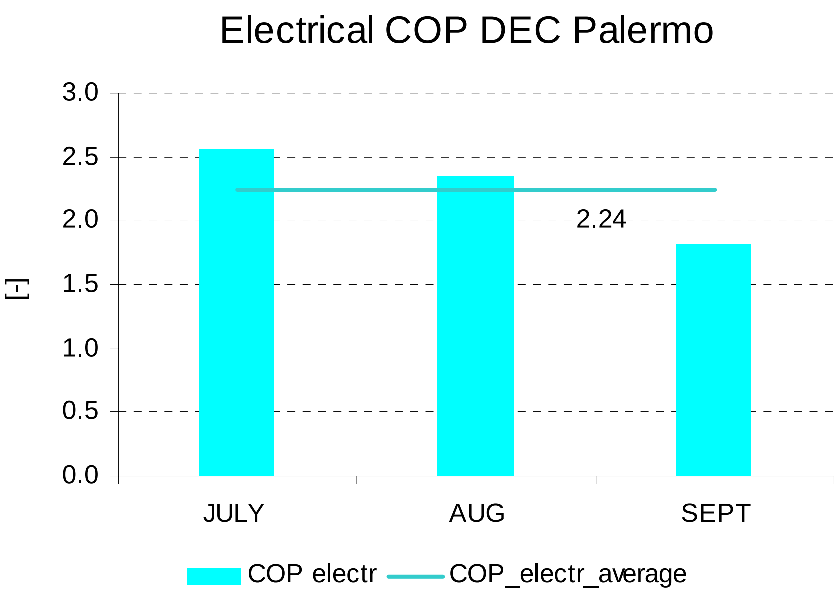
DEC plant at Palermo – Winter operation
Primary Energy Saved

SPECIFIC CONSUMPTION WINTER 2008/2009:		0.97 kWh EP/kWh (heat)
Primary Energy Saved in relation to a conventional AHU in heating operation 2008/2009:	29%	December 30% January 30% February 28%
Solar-Fraction	61%	December 59% January 74% February 53%

DEC plant at Palermo – Thermal and Electrical COP





Thermal COP

	related to solar coil		related to solar and condensation coil	
July	1.07		0.68	
August	0.93	**0.90**	0.7	**0.63**
September	0.59		0.43	

Electrical COP

	related to solar coil	
July	2.56	
August	2.35	**2.24**
September	1.81	