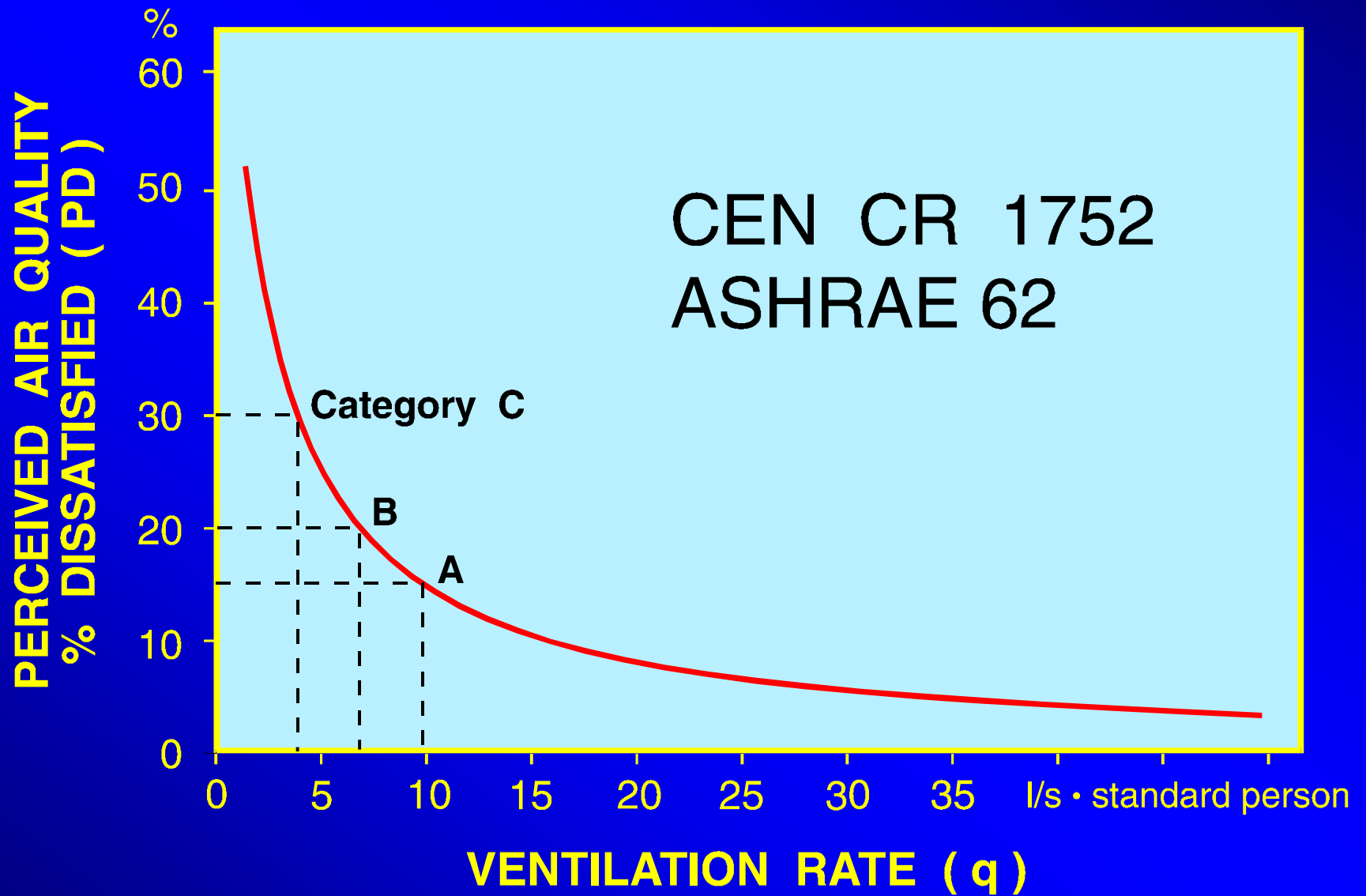


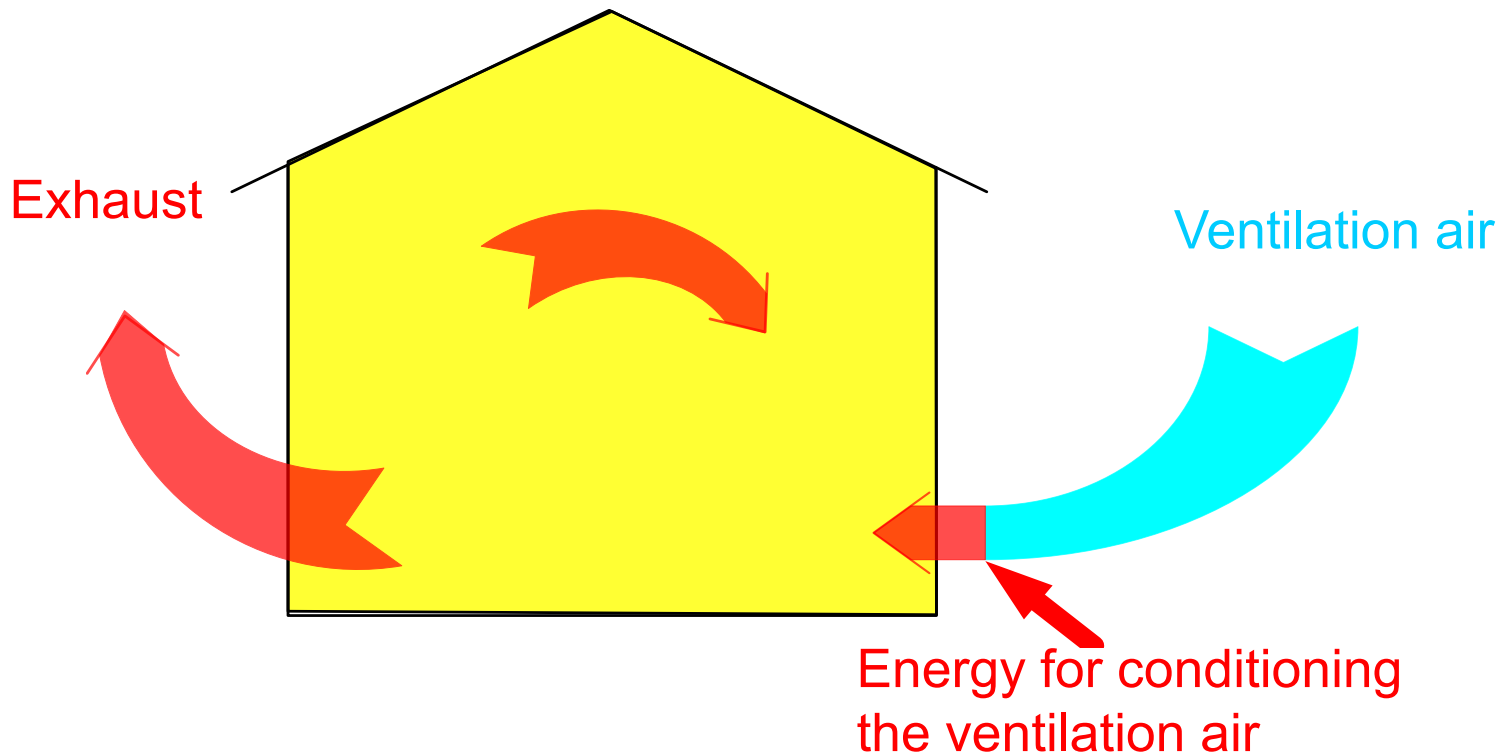
Air cleaning by desiccant wheel and the application in ventilation systems - Clean Air Heat Pump

Lei Fang

International Centre for Indoor Environment and Energy
Technical University of Denmark

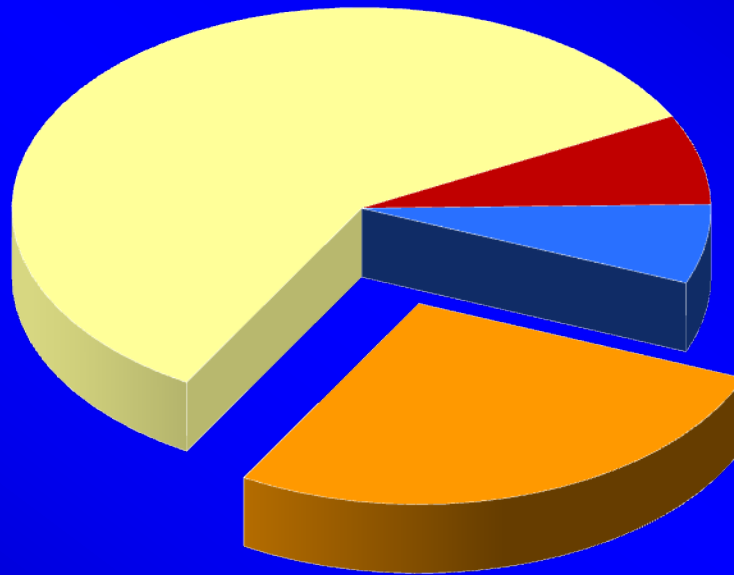


Energy consumption for ventilation



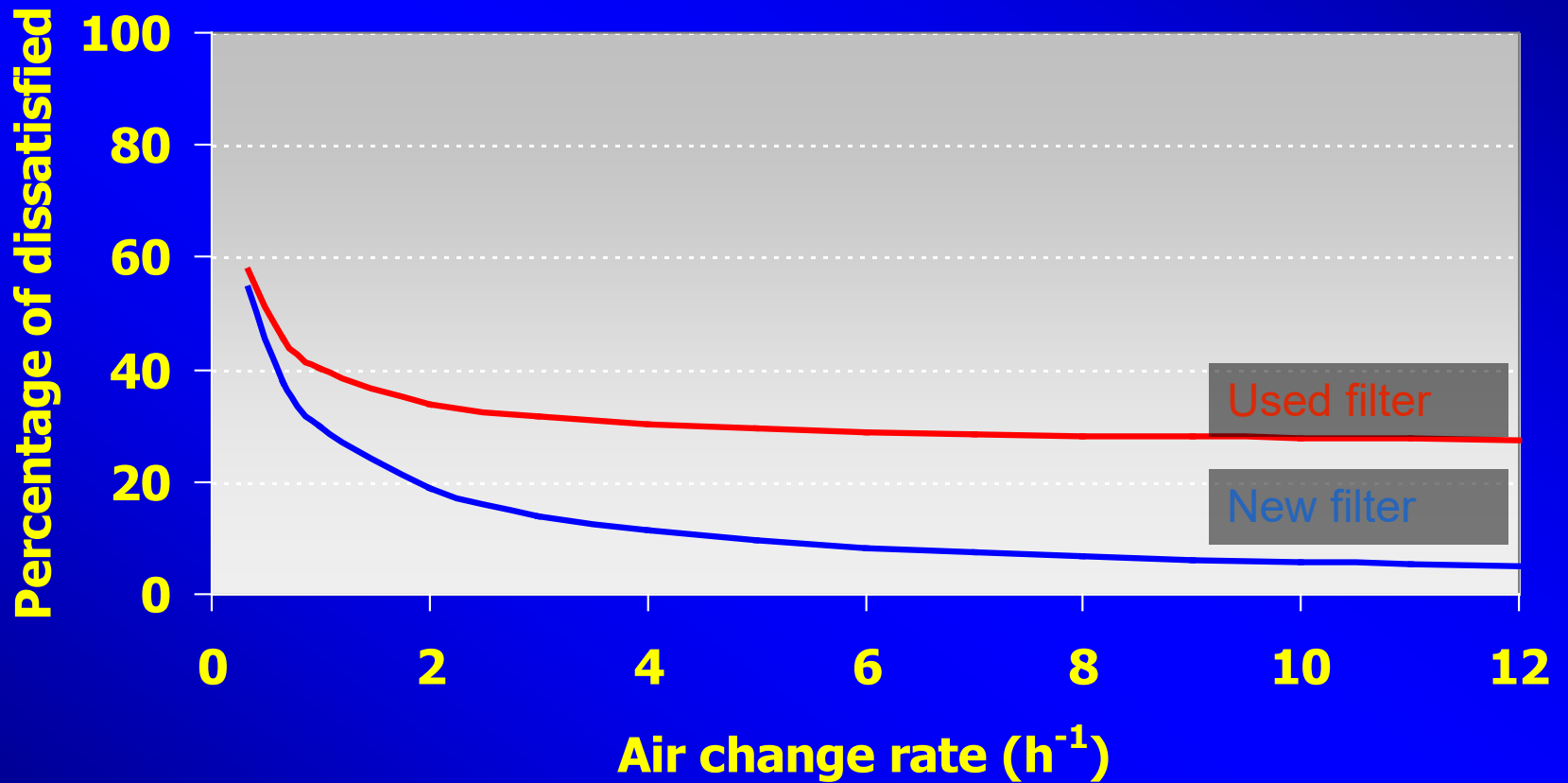
Up to 30% of the total energy consumption in buildings

*Average pollution loads in 56 European office buildings
in 9 EU countries*



- Building materials and activities
- Outdoor air
- Occupants
- Ventilation system

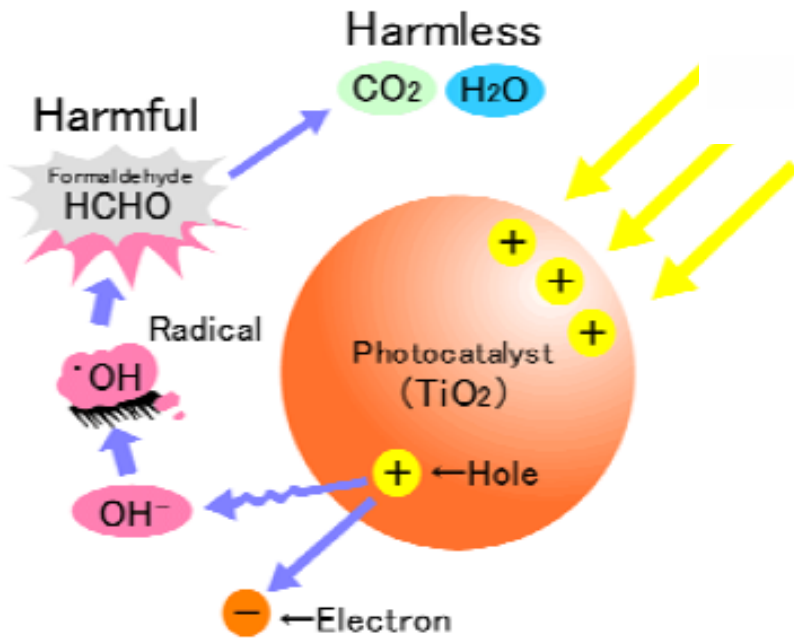
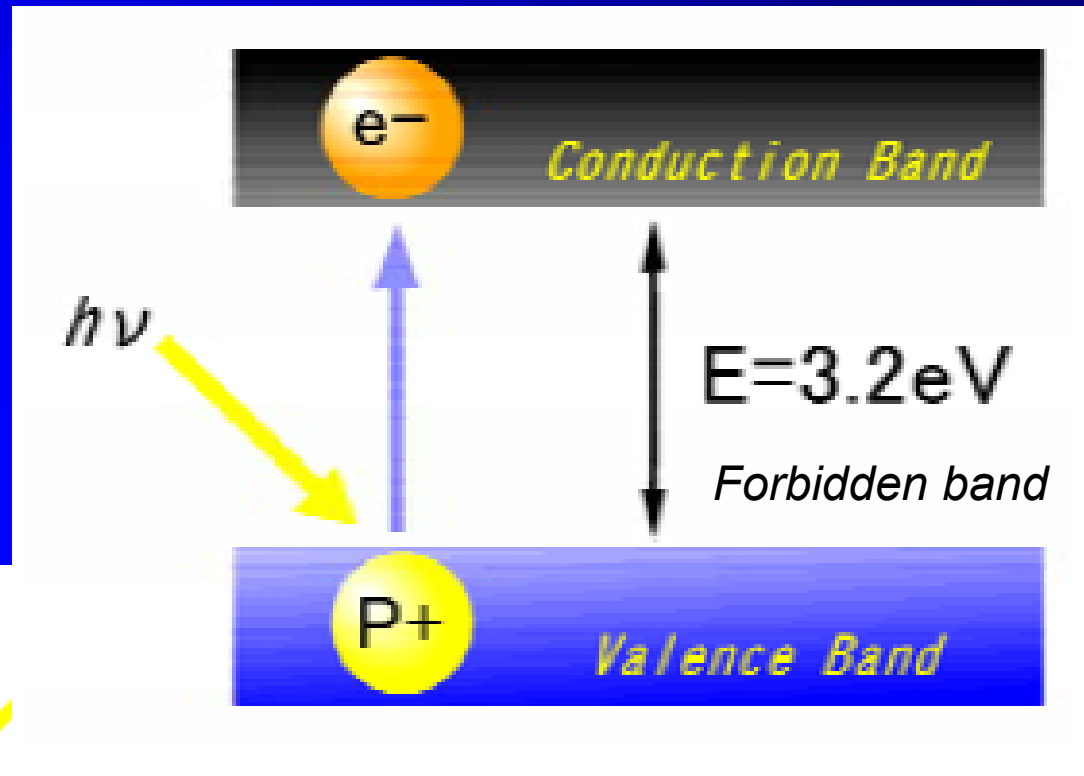
Air quality in the office



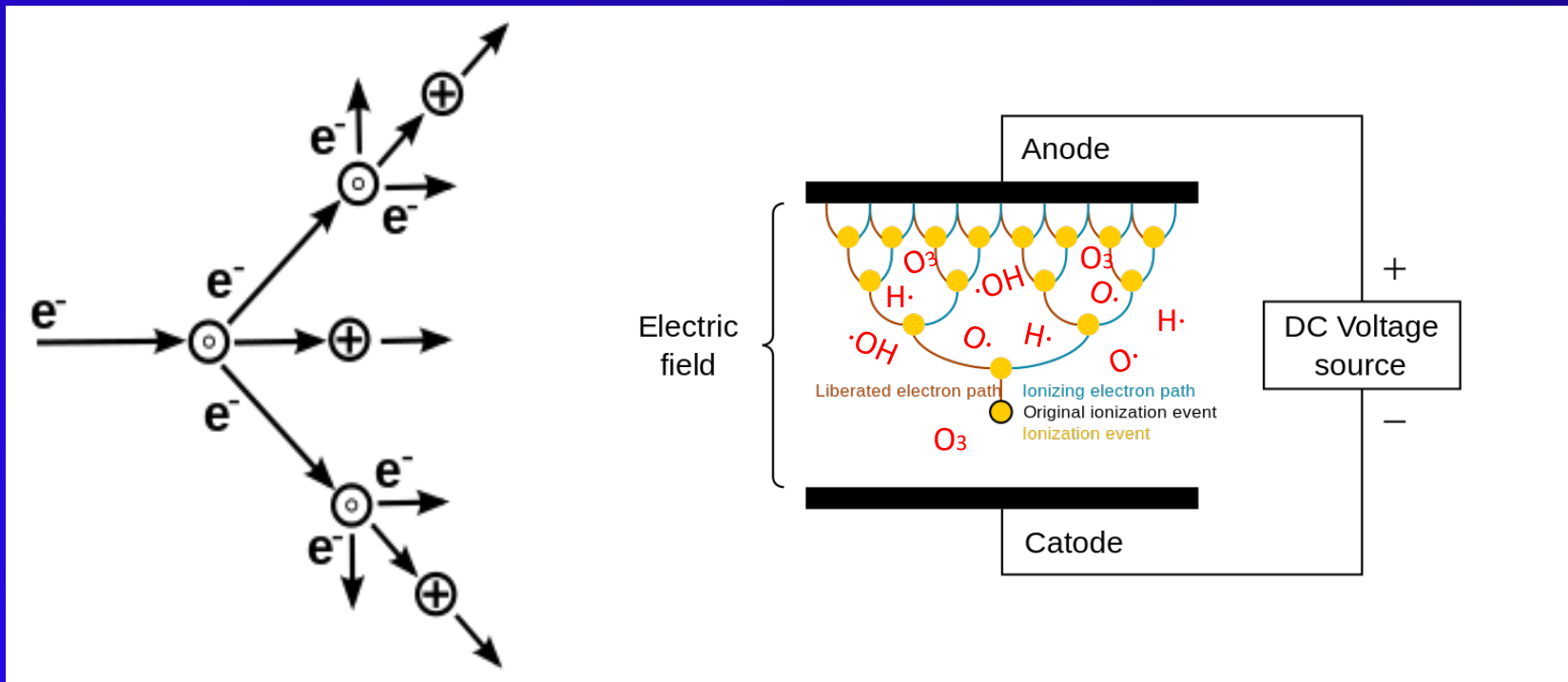
Clean and dirty filters



Photo-catalytic Oxidation

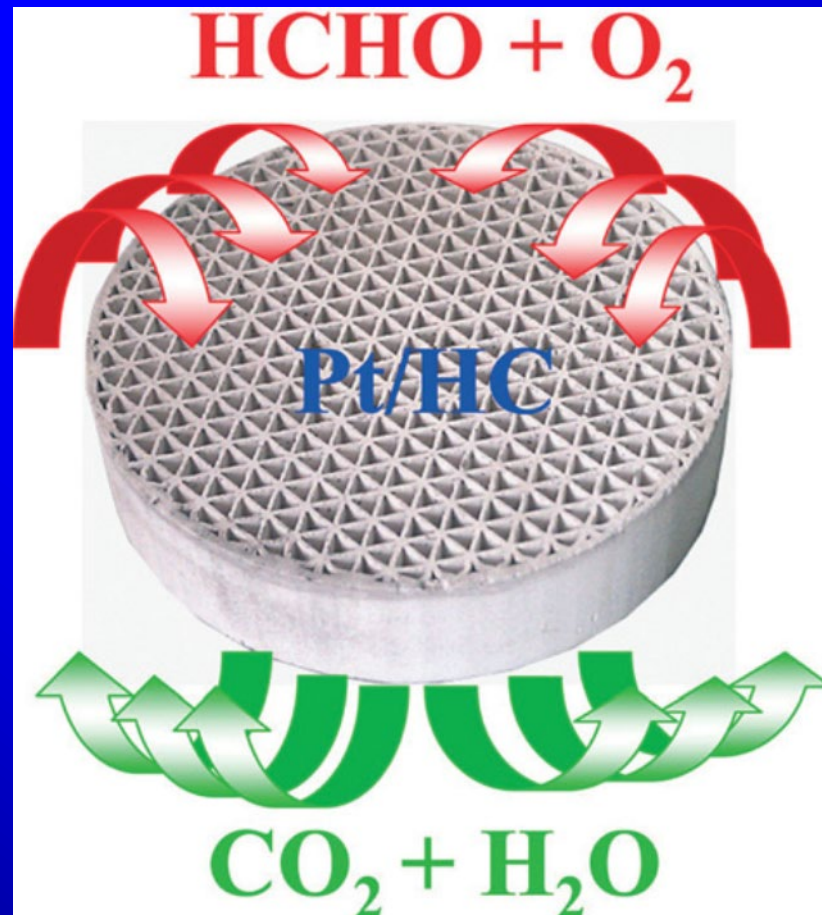


Non-thermal plasma oxidation

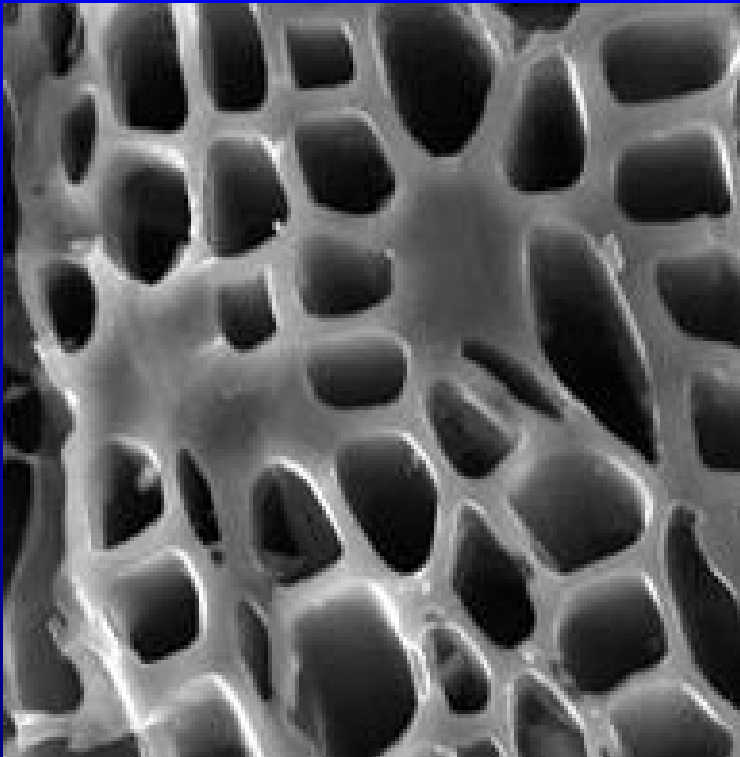


[https://en.wikipedia.org/wiki/Plasma_\(physics\)](https://en.wikipedia.org/wiki/Plasma_(physics))

Non-thermal catalytic oxidation

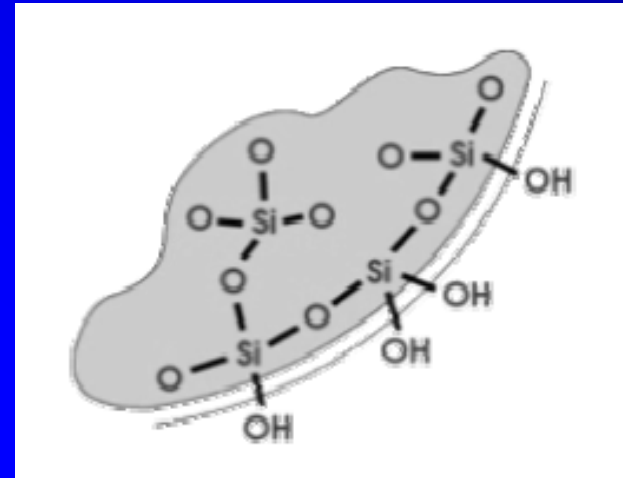
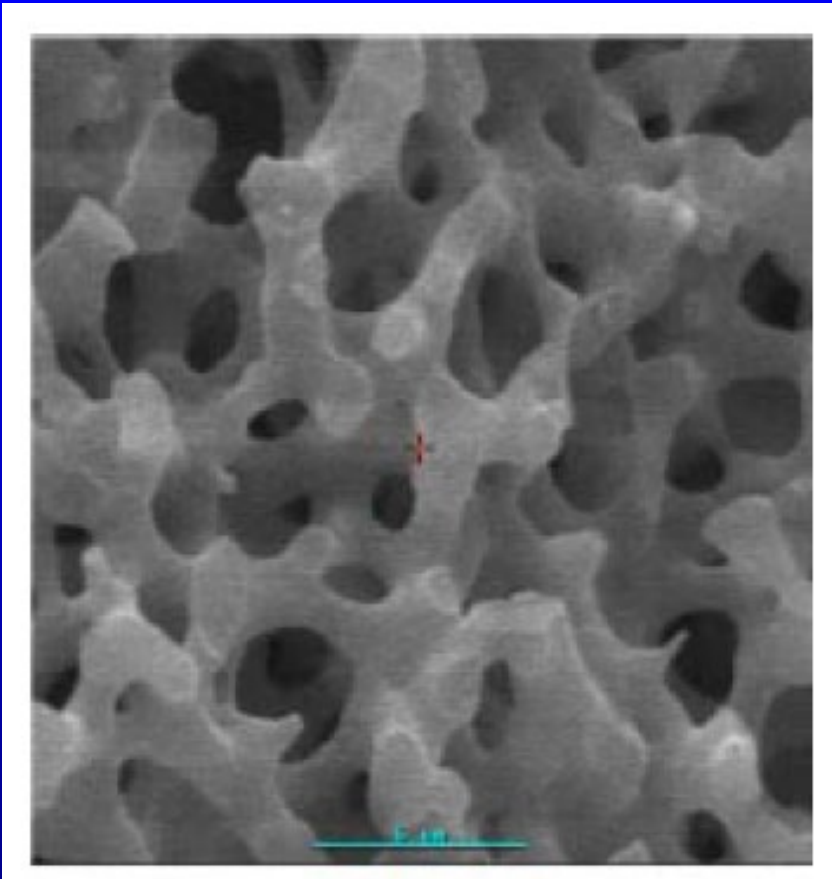


Activated carbon



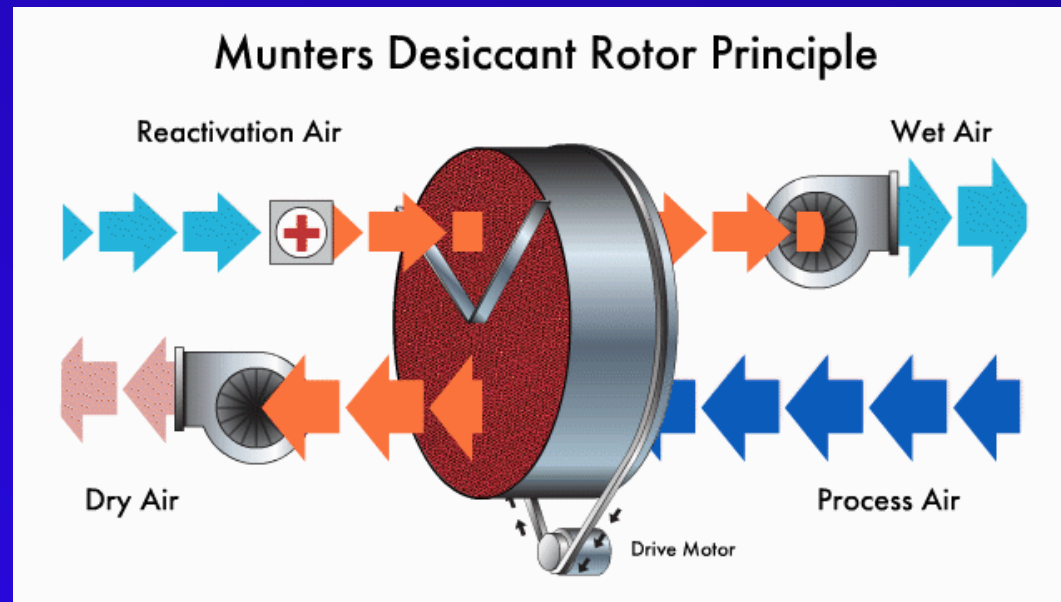
Pore Size (nm)	Surface area (m ² /g)
<2	100-1000
2-50	10-100
>50	0.5-2

Silica gel



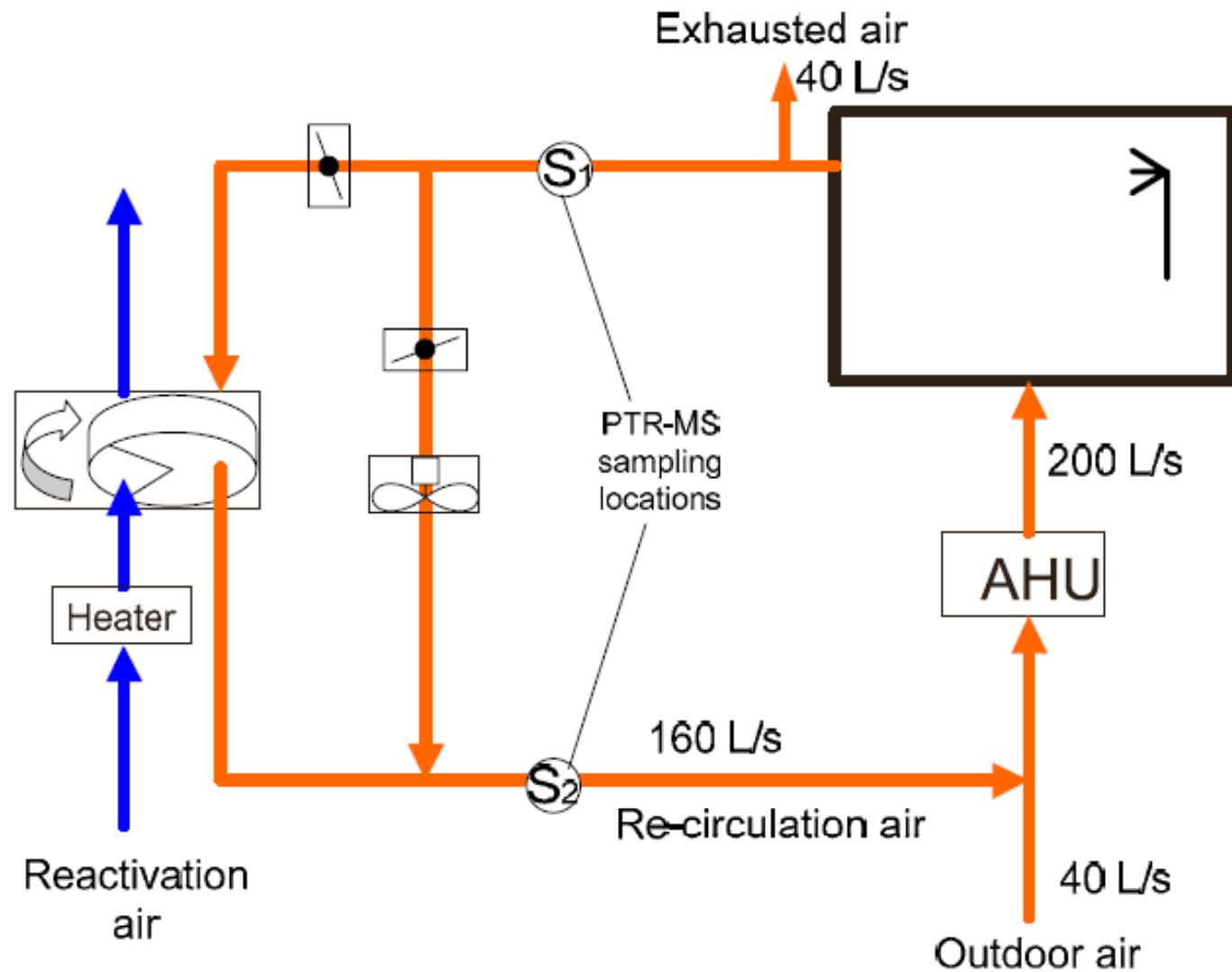
Pore size (nm)	1-40
Surface area (m ² /g)	800

Regenerative desiccant wheel as air cleaner

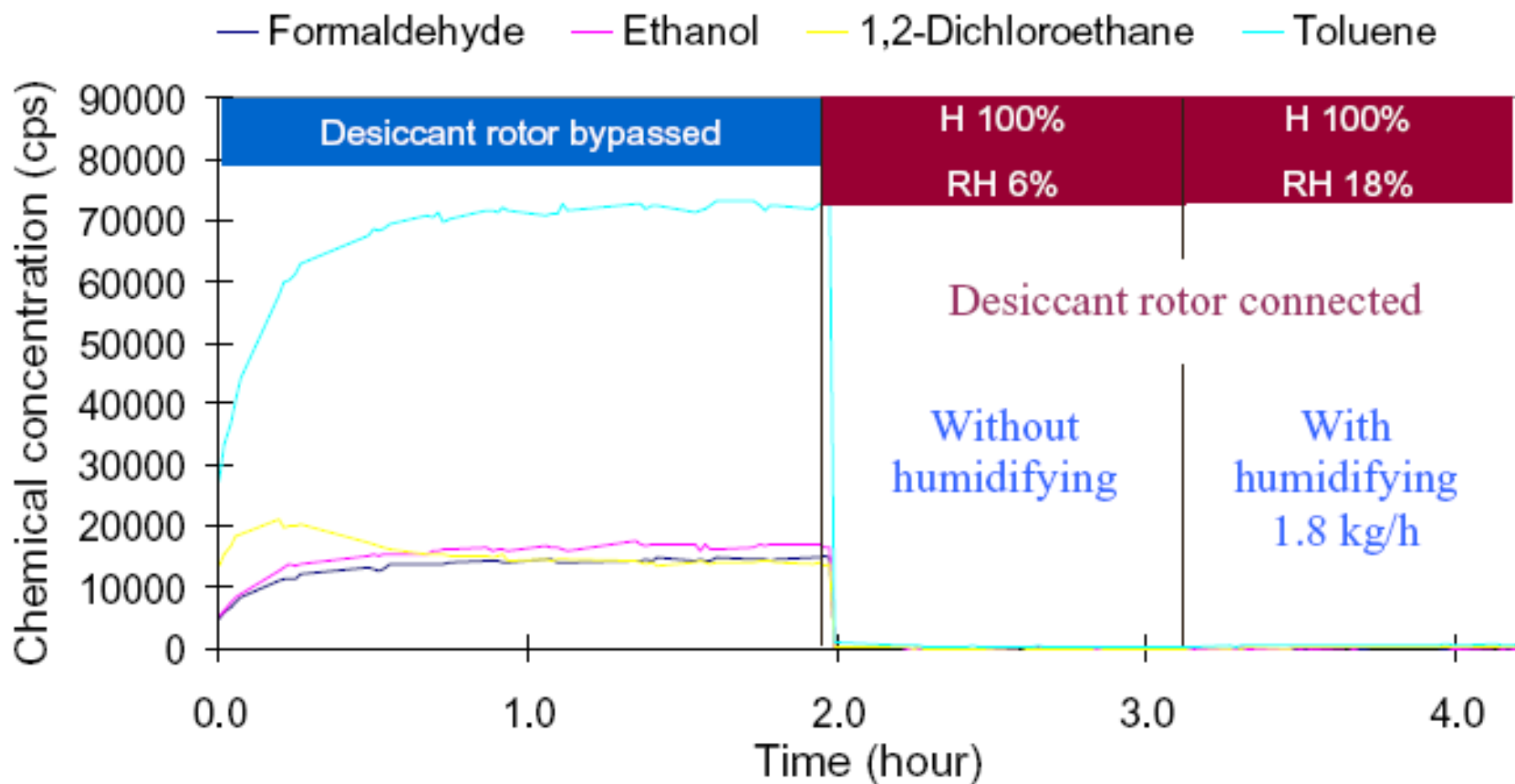


<https://www.munters.com/en/solutions/dehumidification/>

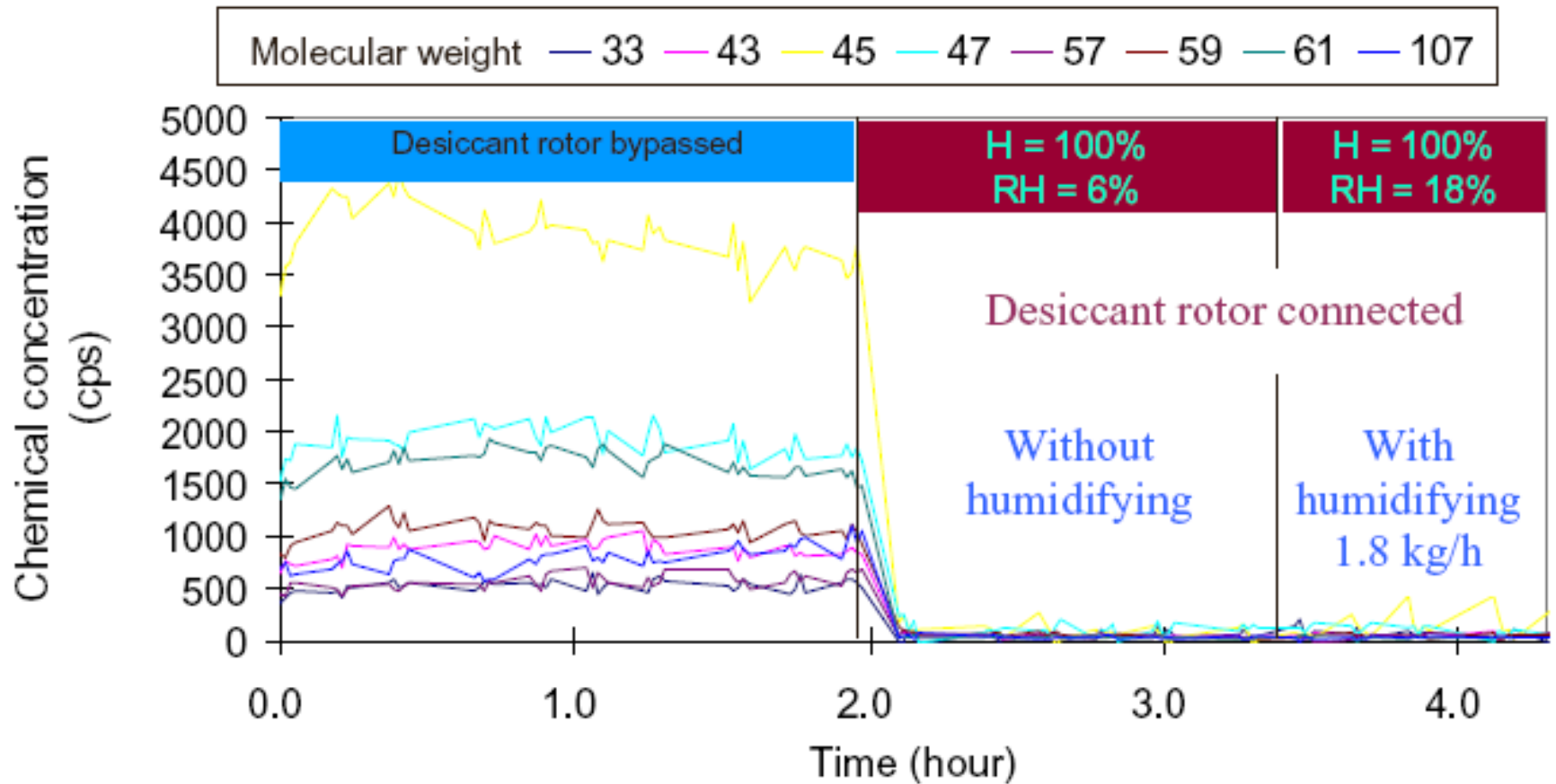
Experimental setup



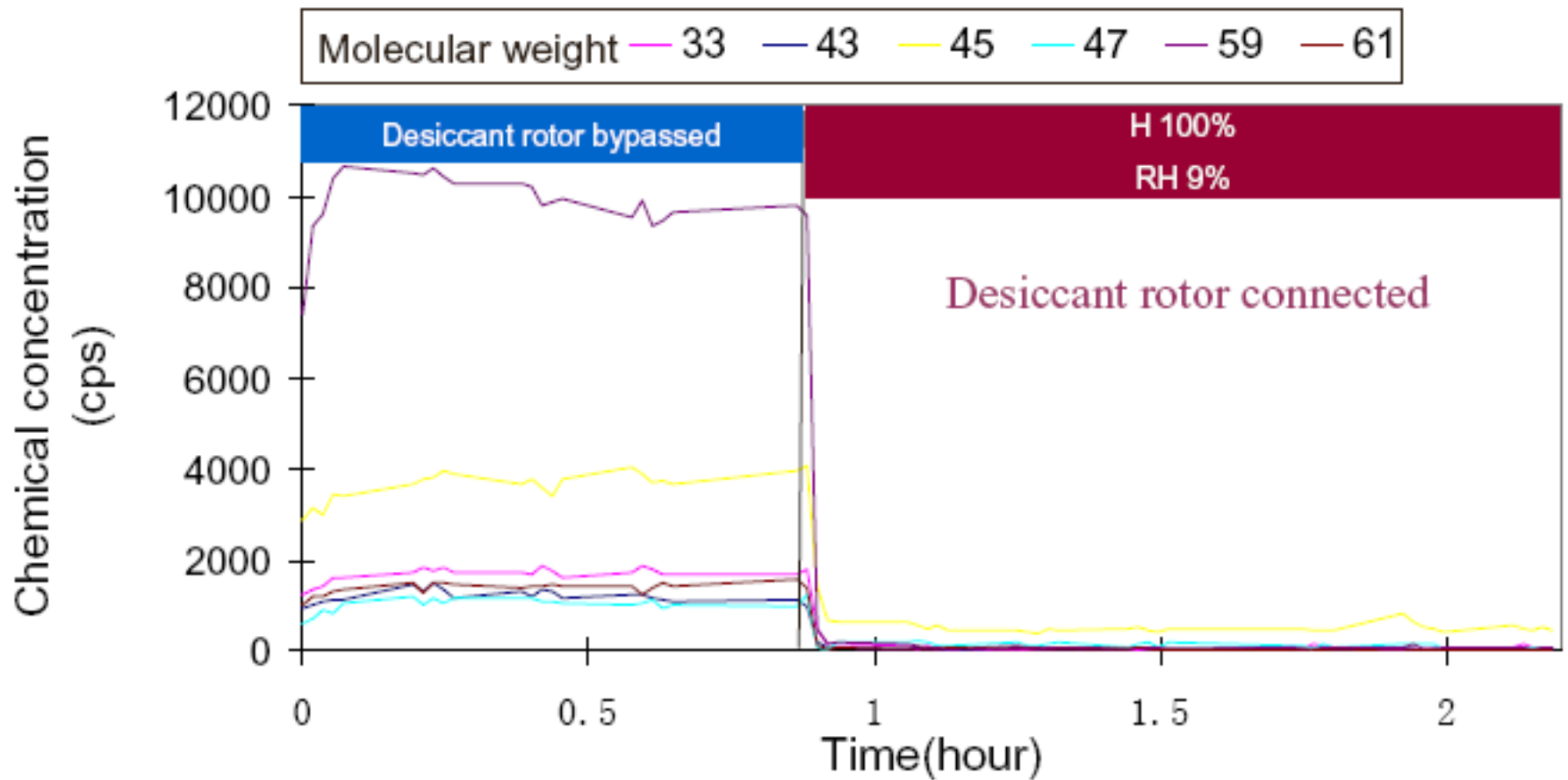
Results when using pure chemicals as pollution source



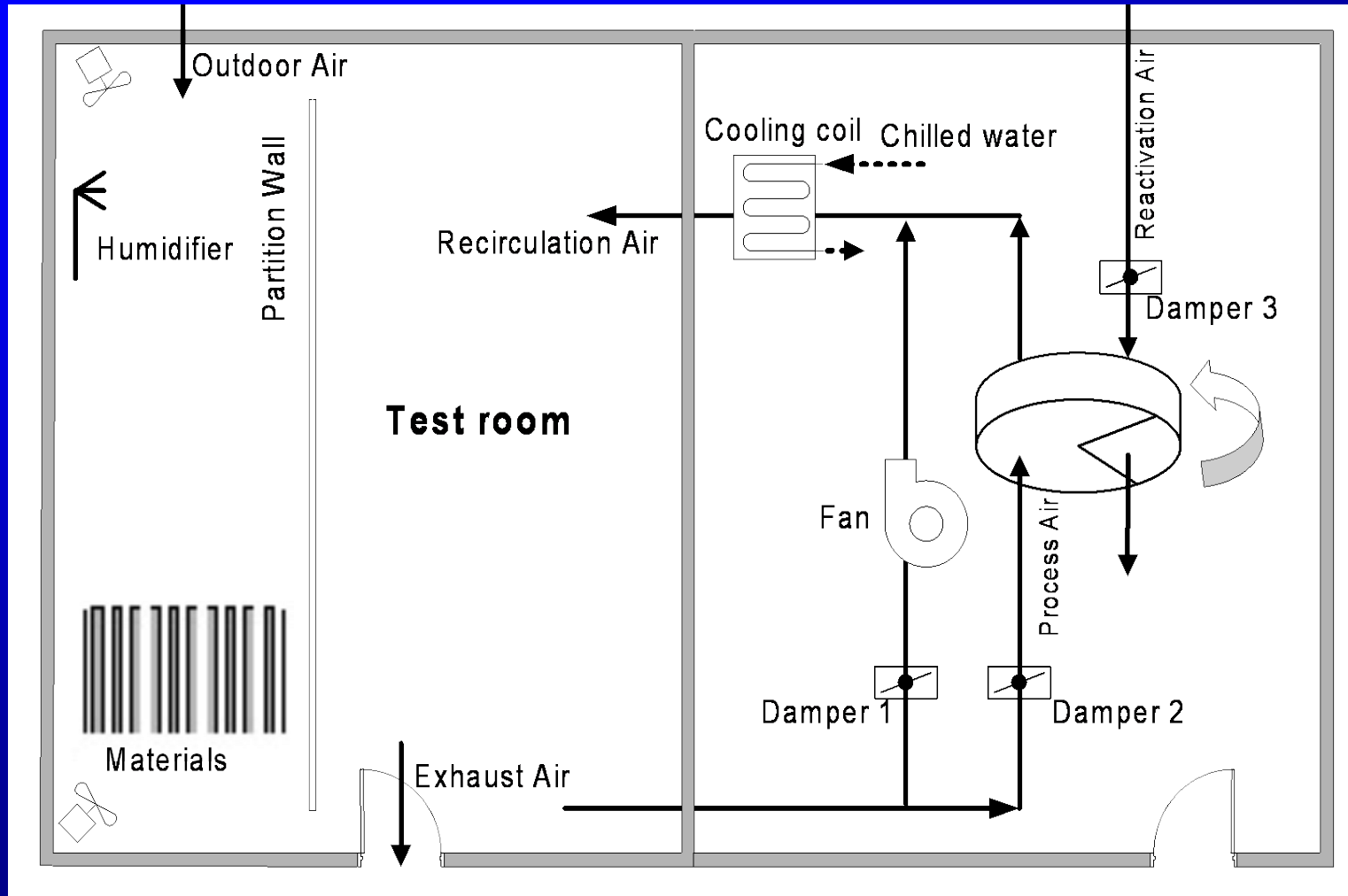
Results when using flooring materials as pollution source



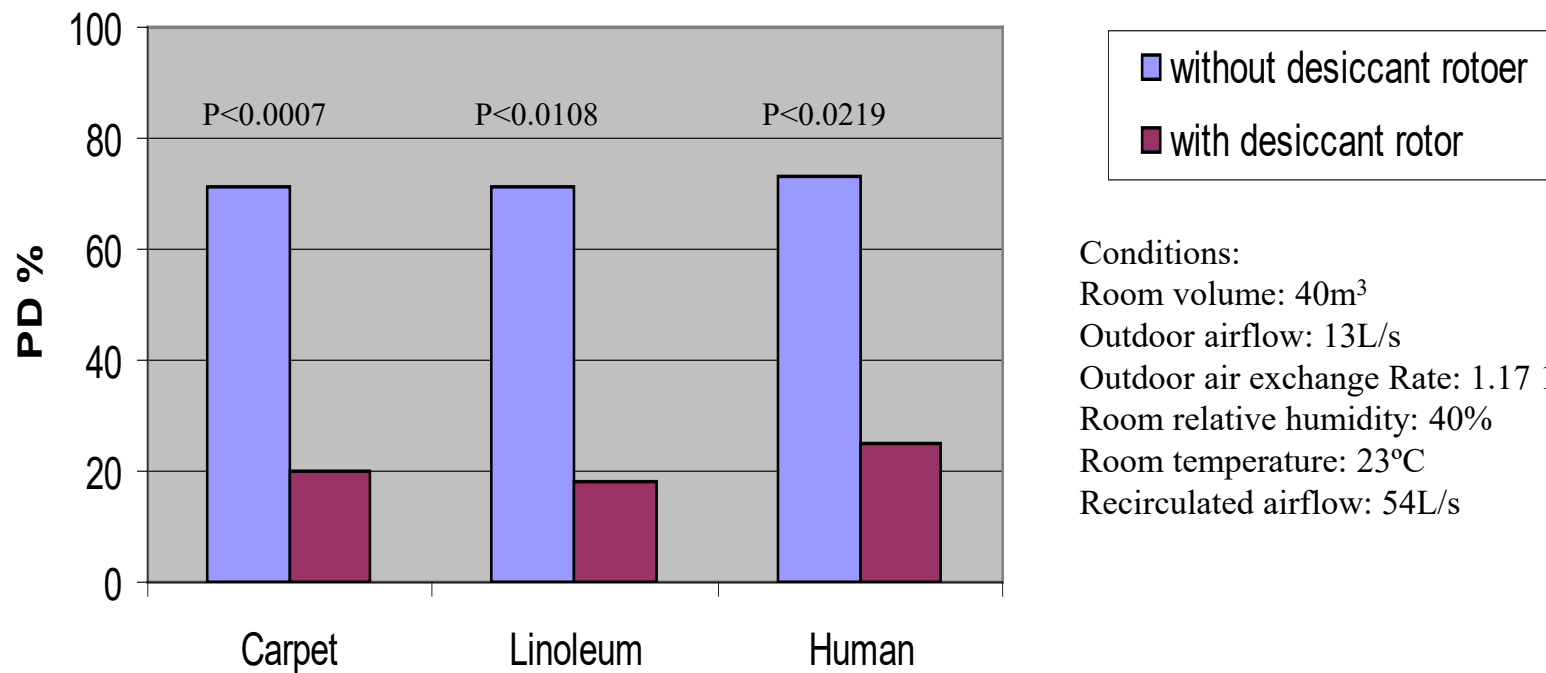
Results when using human bioeffluents as pollution source

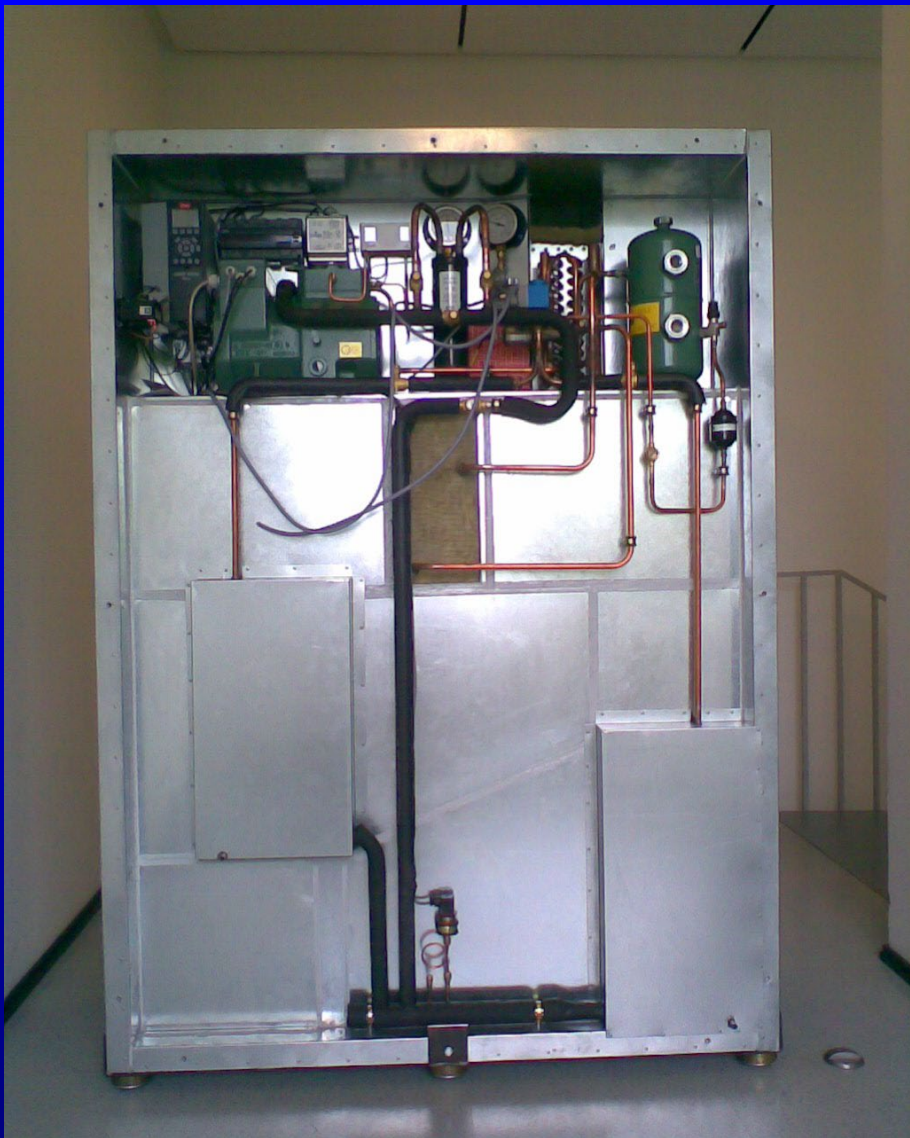


Experimental set-up



PAQ in PD% with and without desiccant rotor

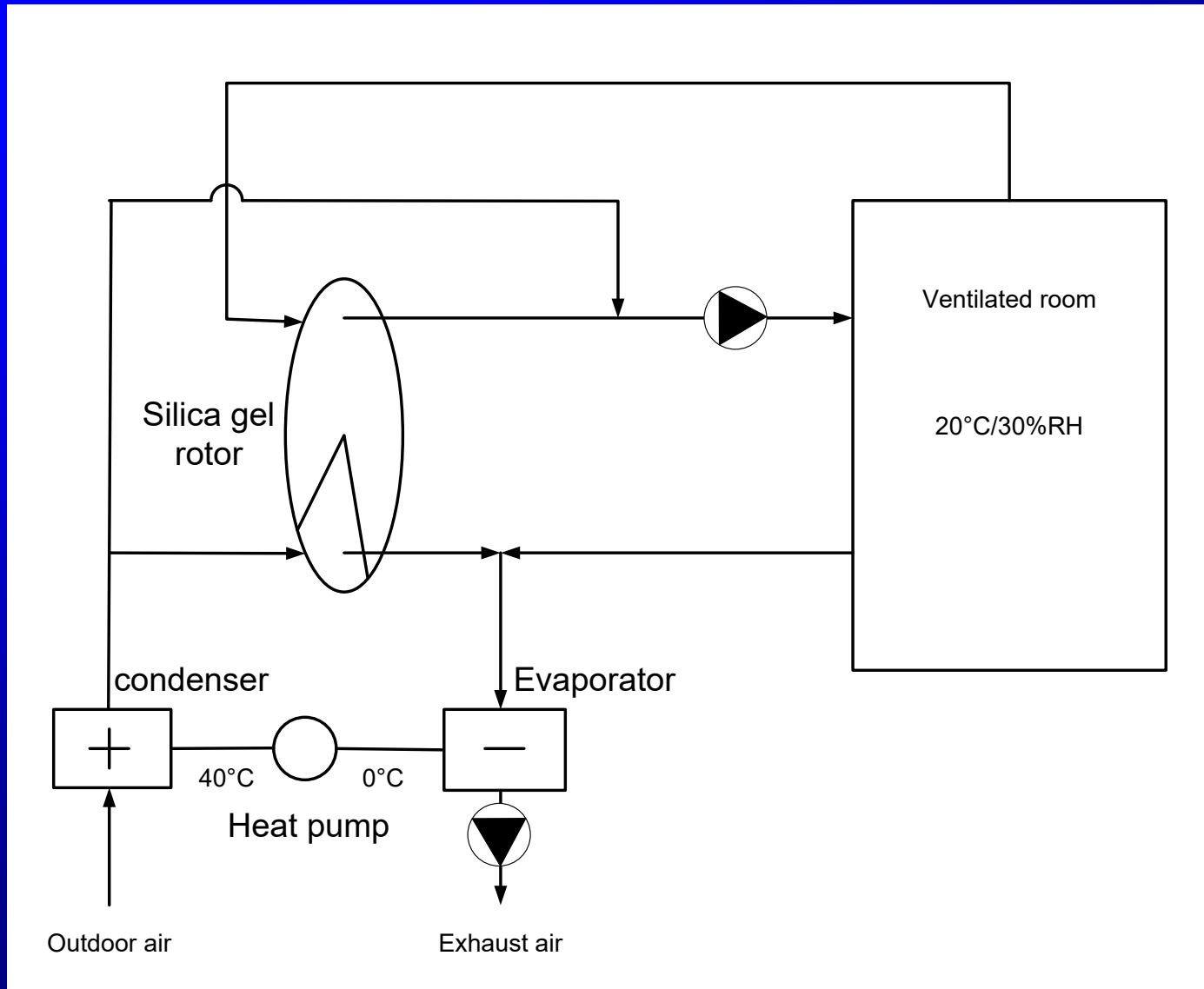




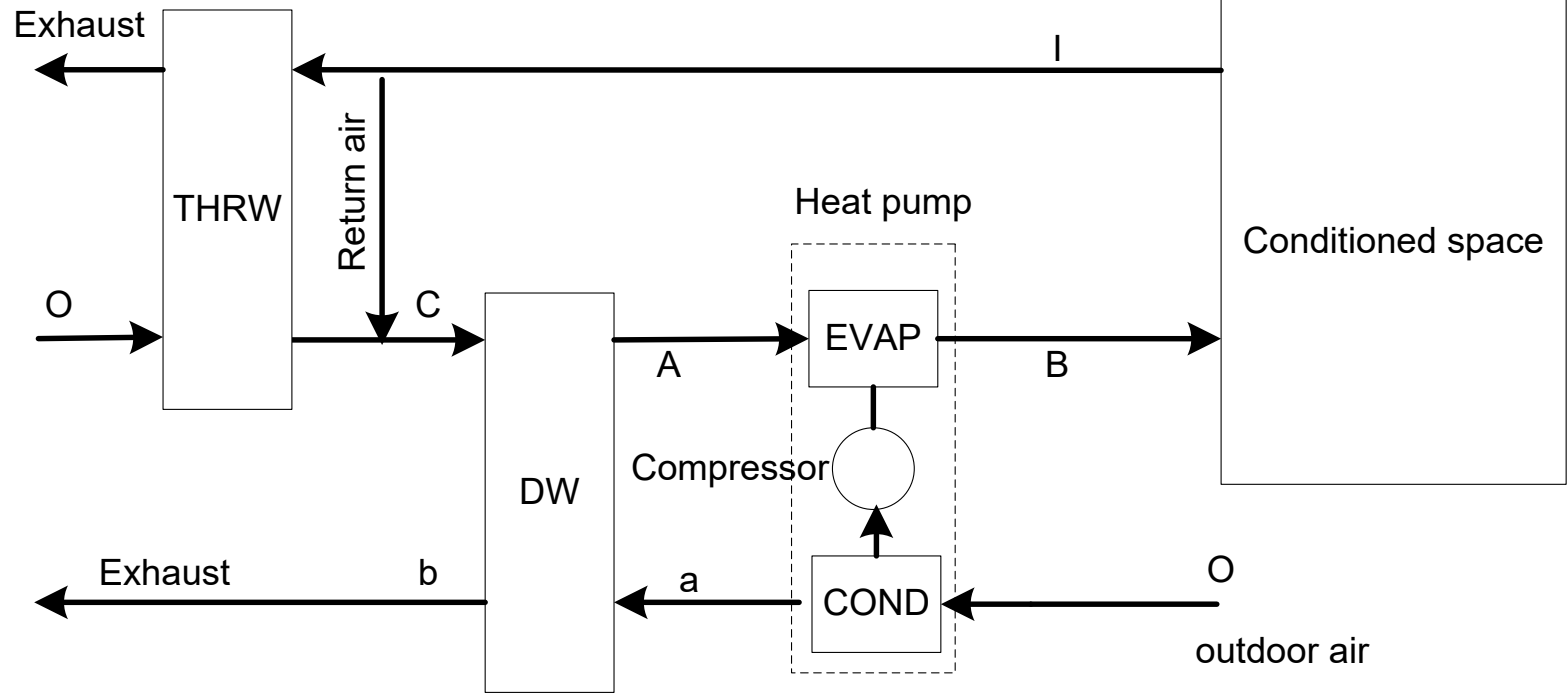
Practical applications

- In winter combined with heating
- In summer combined with cooling and dehumidification

Desiccant wheel and heat pump hybrid air-conditioning system (winter application)



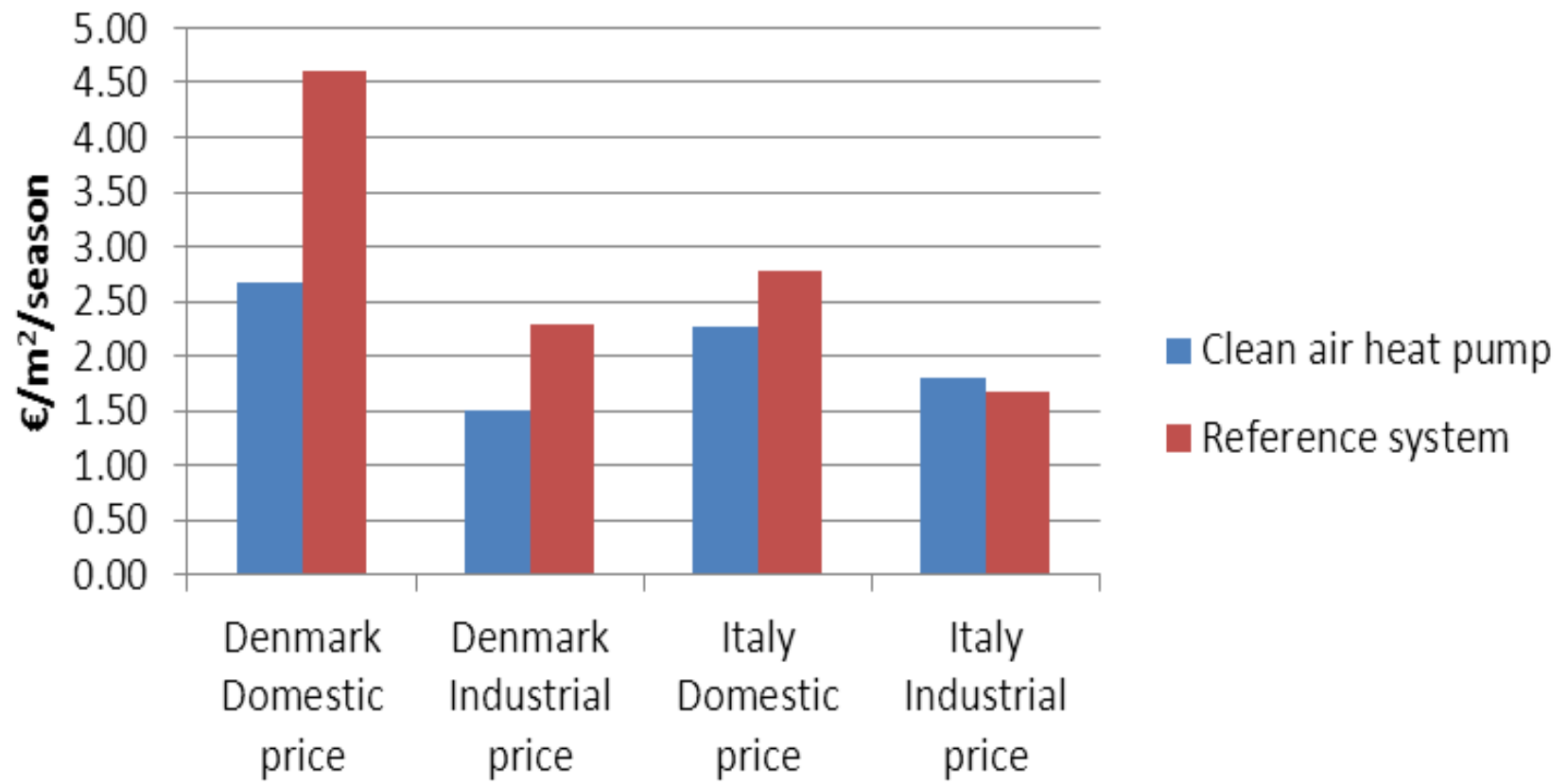
Desiccant wheel and heat pump hybrid air-conditioning system (summer application)



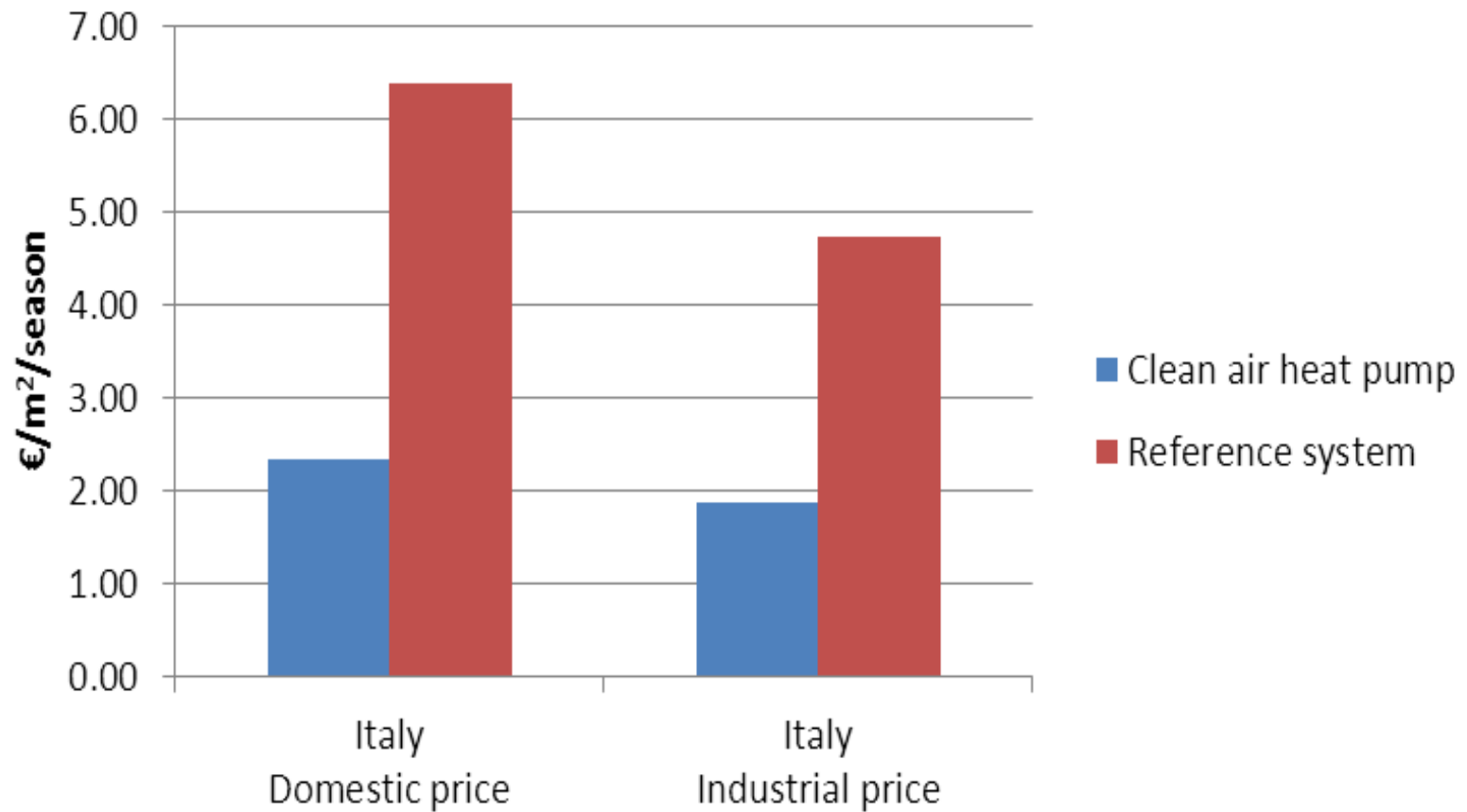
DW: Rotary dehumidifier;
EVAP: Evaporator;

THRE: Total heat recovery equipment
COND: Condenser

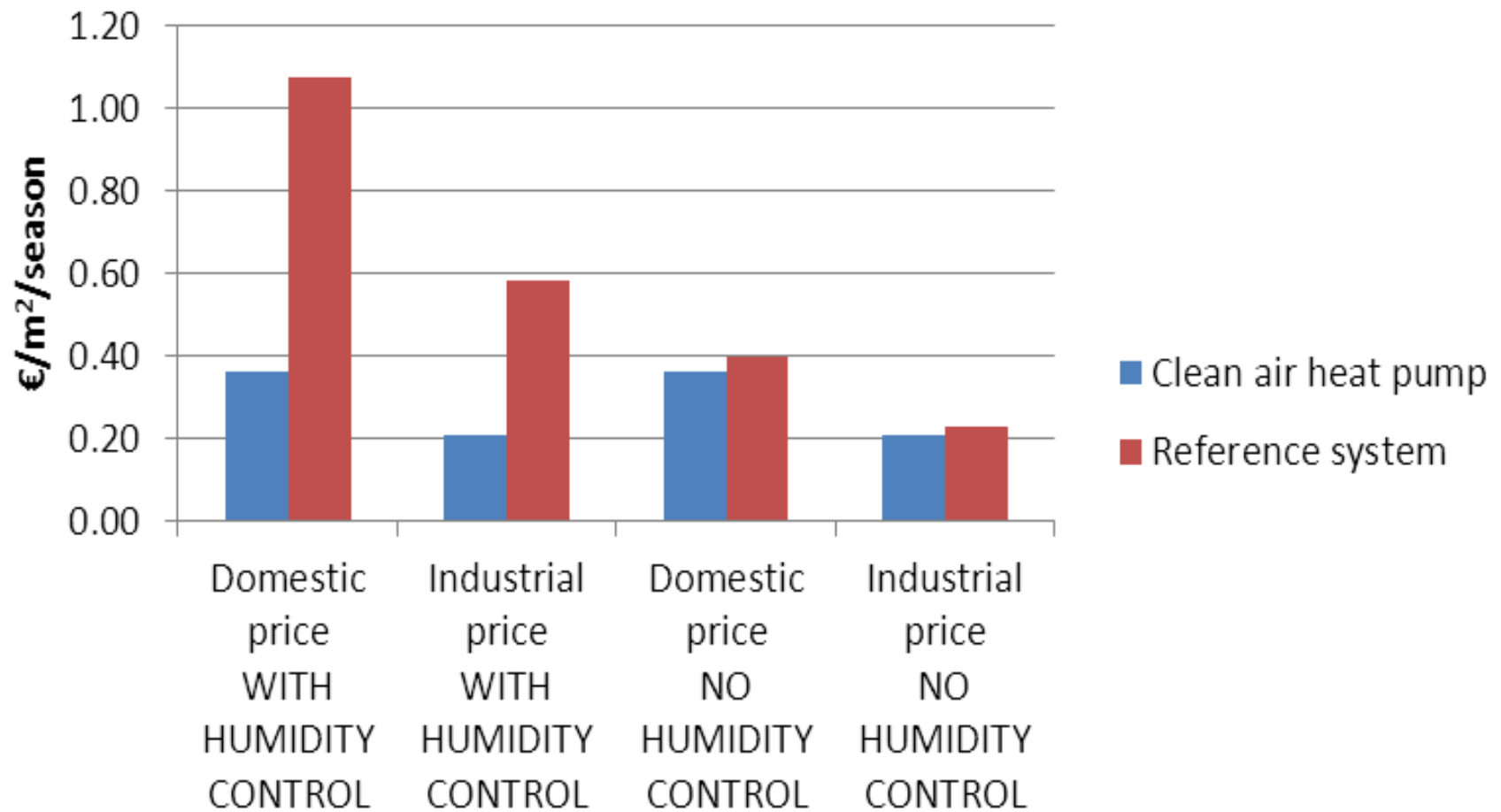
Denmark & Italy - Winter season - "Ventilation Only"



Italy - Summer Season - "Ventilation + Cooling "



Denmark - Summer Season - "Ventilation + Cooling"

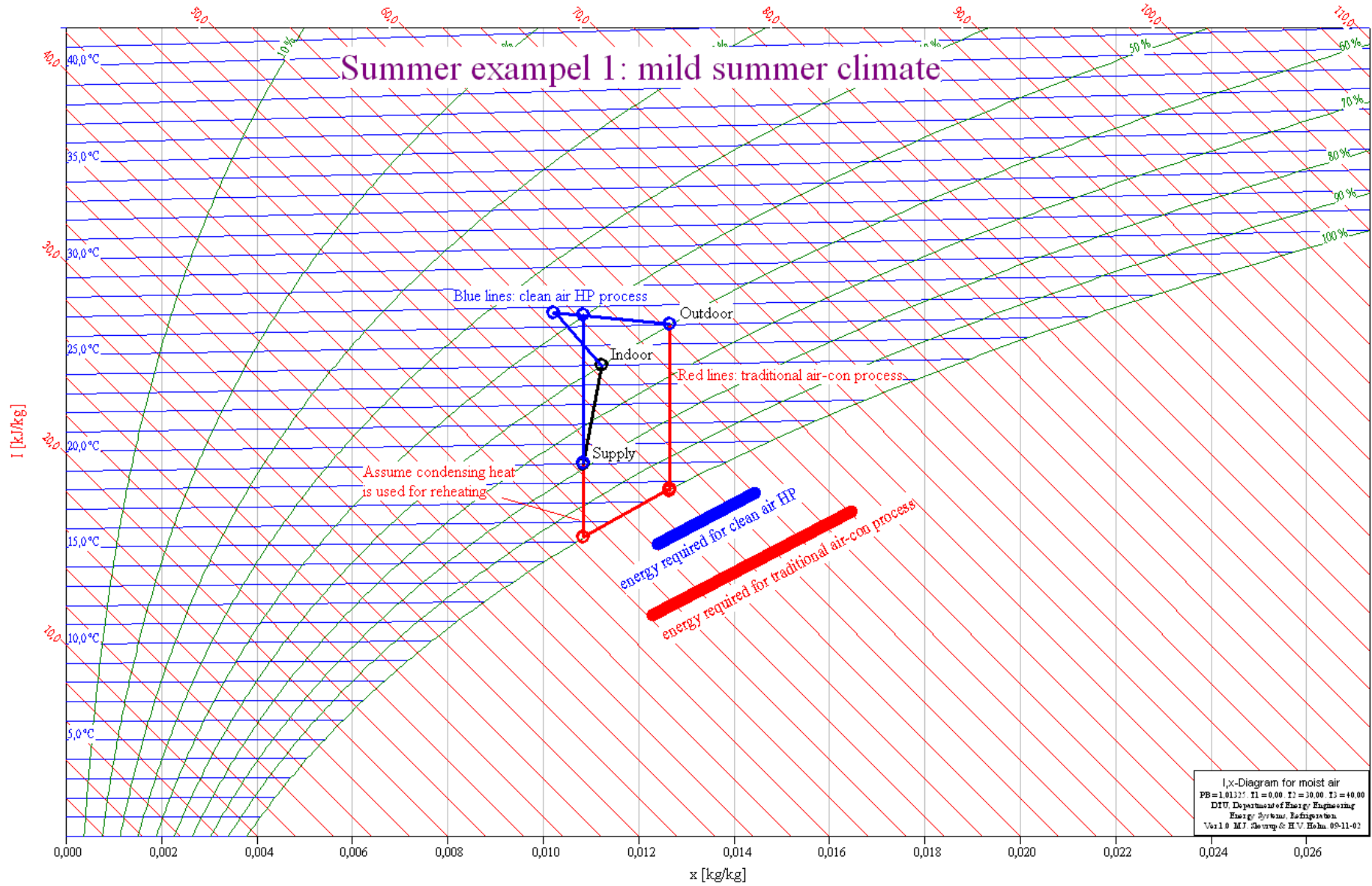


Advantages

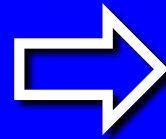
- Make full use of the energy on both sides of the heat pump
- The system is working in a completely dry environment
- High clean air delivery rate without extra energy consumption
- Humidity control
- Energy recovery

Thank You

Summer example 1: mild summer climate



I,x-Diagram for moist air
 PB=1.013; T1=0.00; T2=30.00; T3=40.00
 DTU, Department of Energy Engineering
 Energy Systems Refrigeration
 Niels Bohr Center for Energy Research
 Niels Bohr Institute, Copenhagen, Denmark

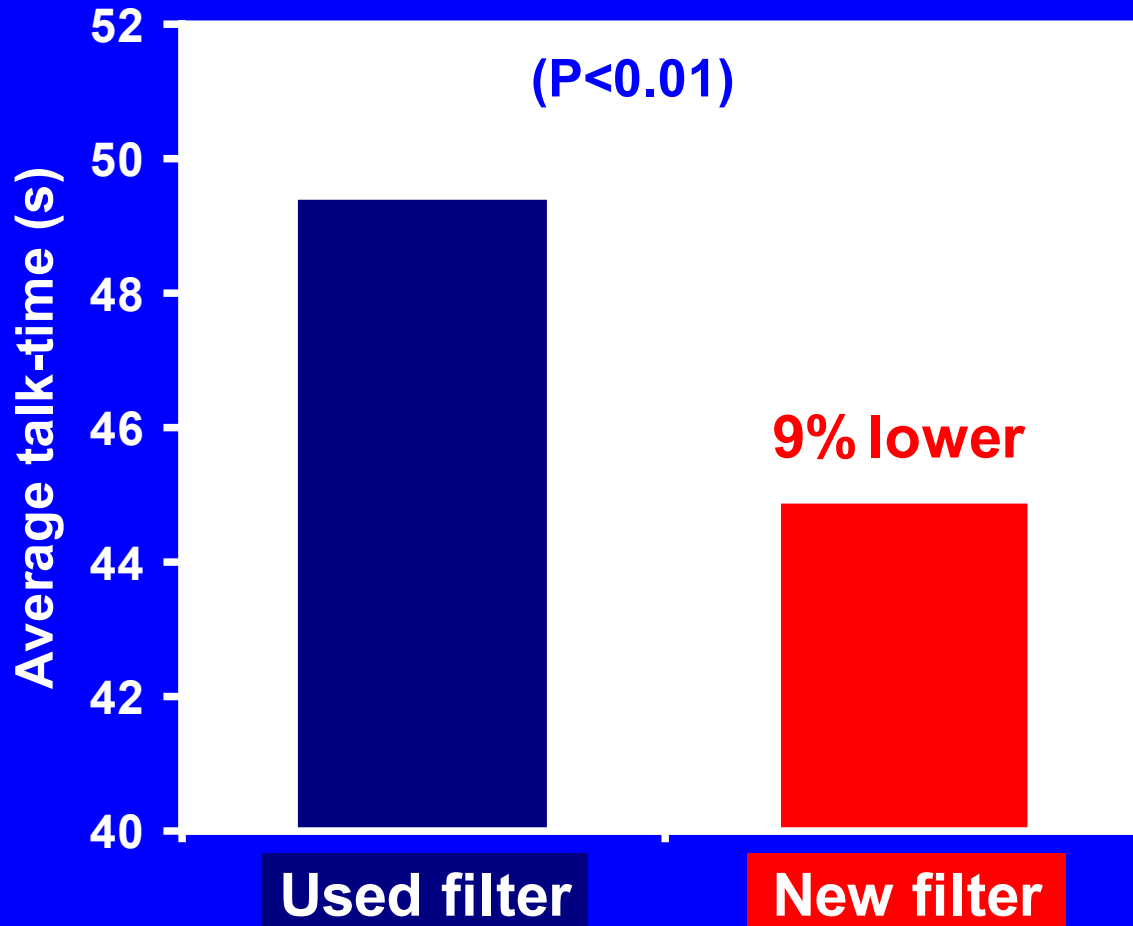


Synthetic-fiber coarse filter

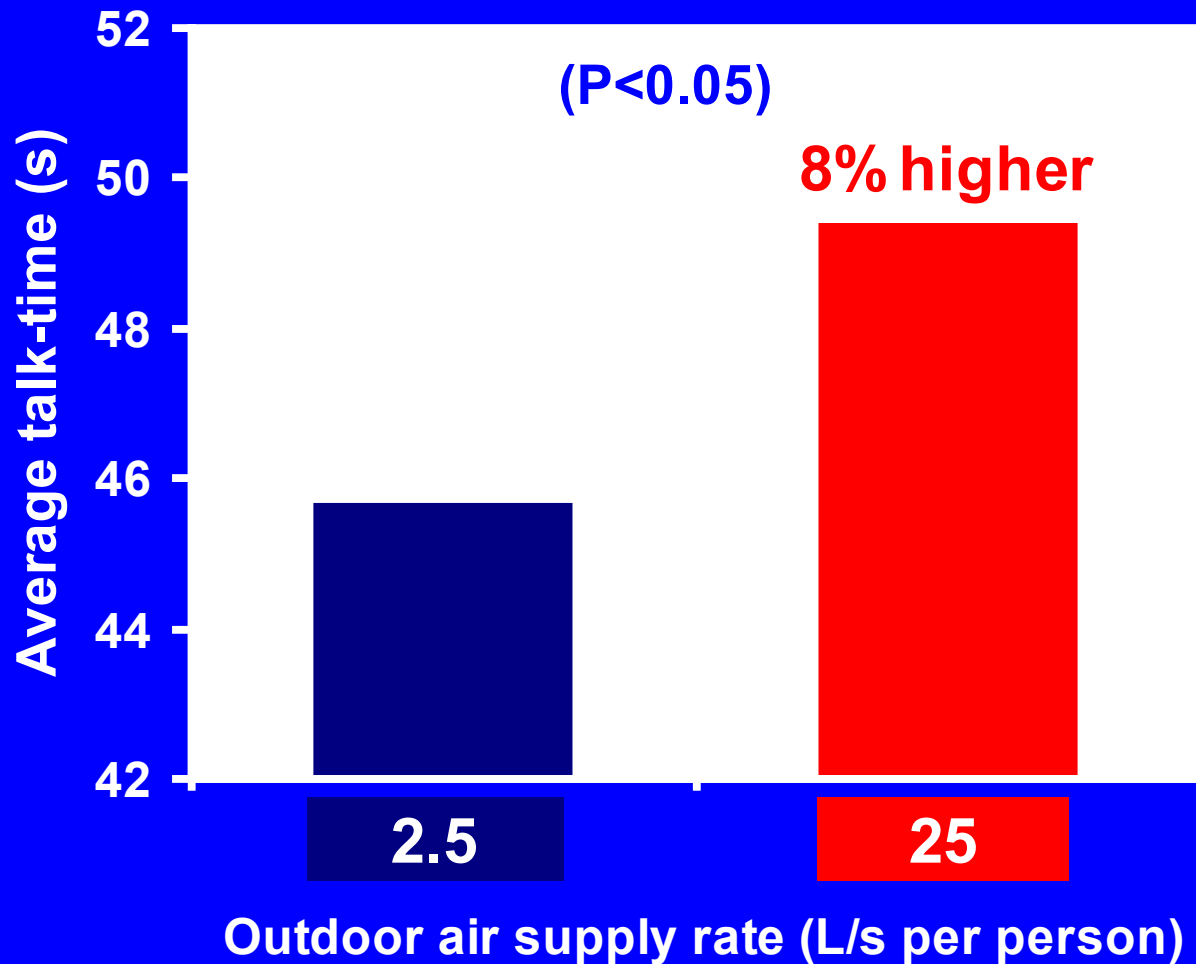
- Number of calls
- Talk-time
- Length of pauses



Automatically and continuously registered for every 30 minutes for each operator during the experimental period



Used filters negatively affect the performance of office work



Increased outdoor air supply rate through used filter:
Negative effect on performance



IYSKE BANK

Air Cleaning

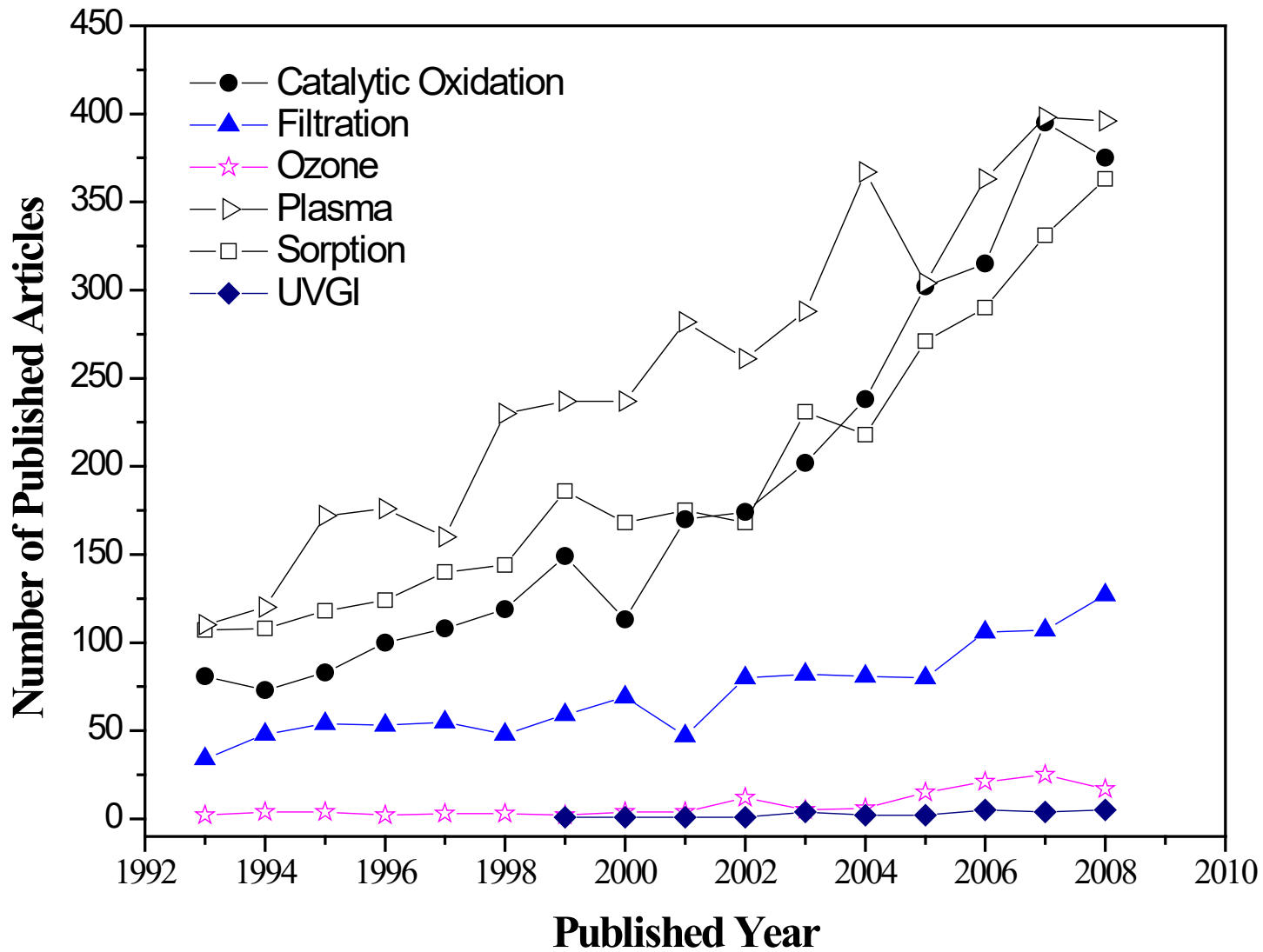
- Particle filtration
- Gas phase pollutants removal

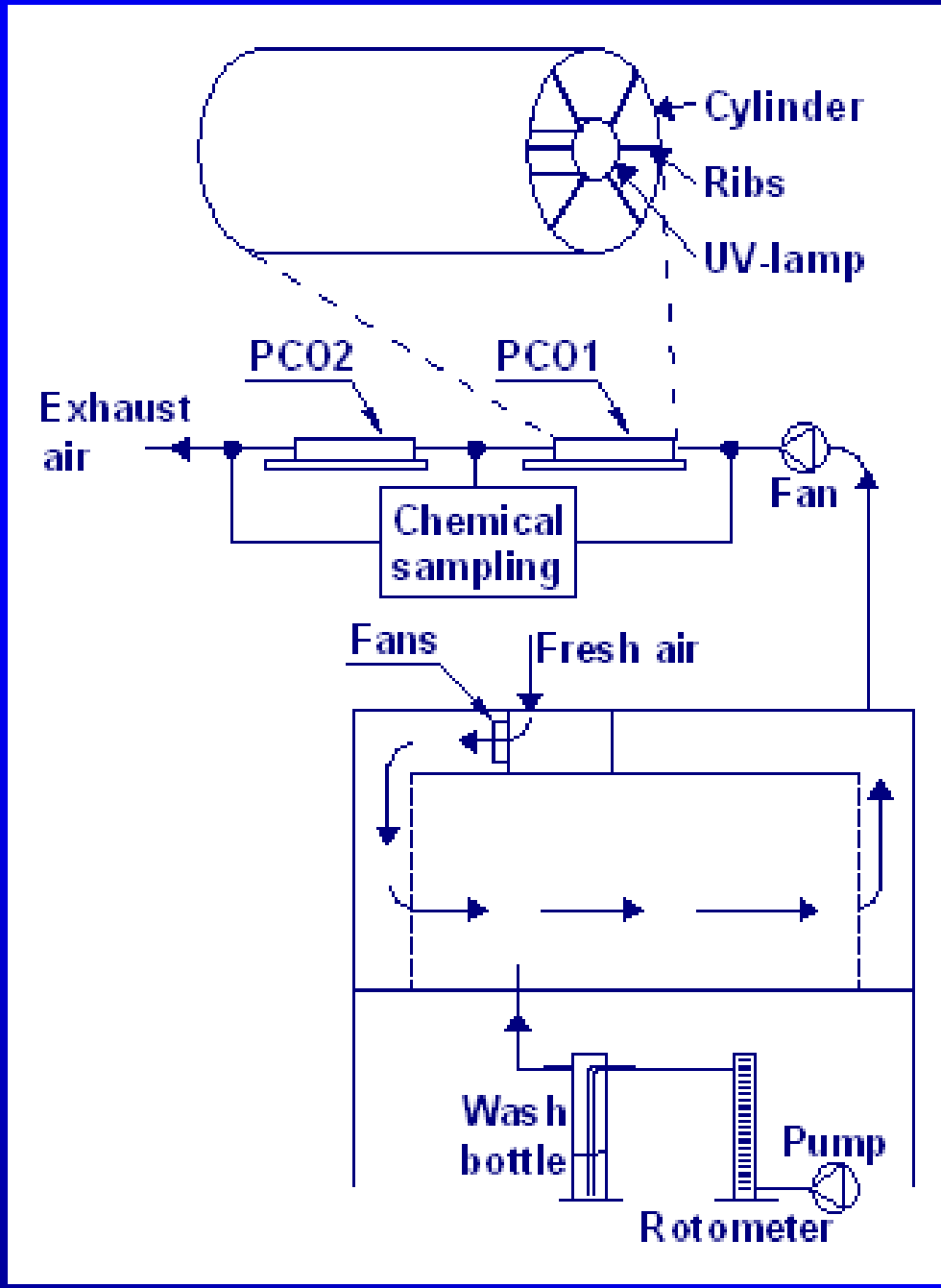
Do we have technology for
gas phase air cleaning?

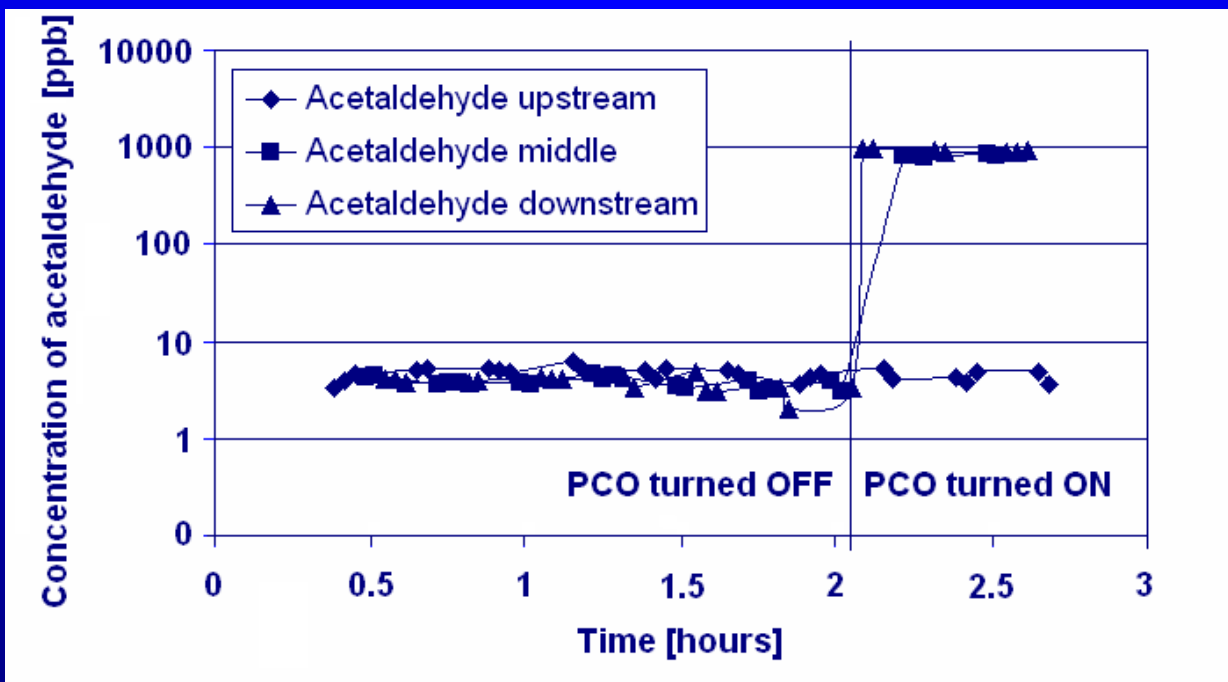
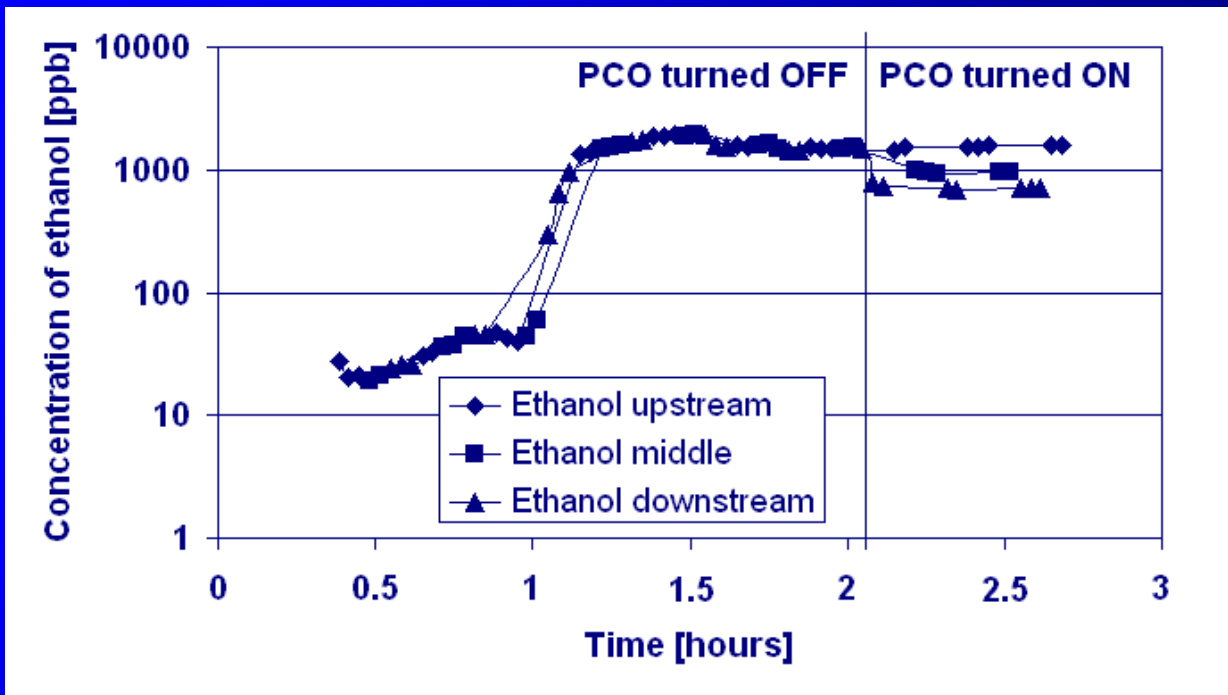


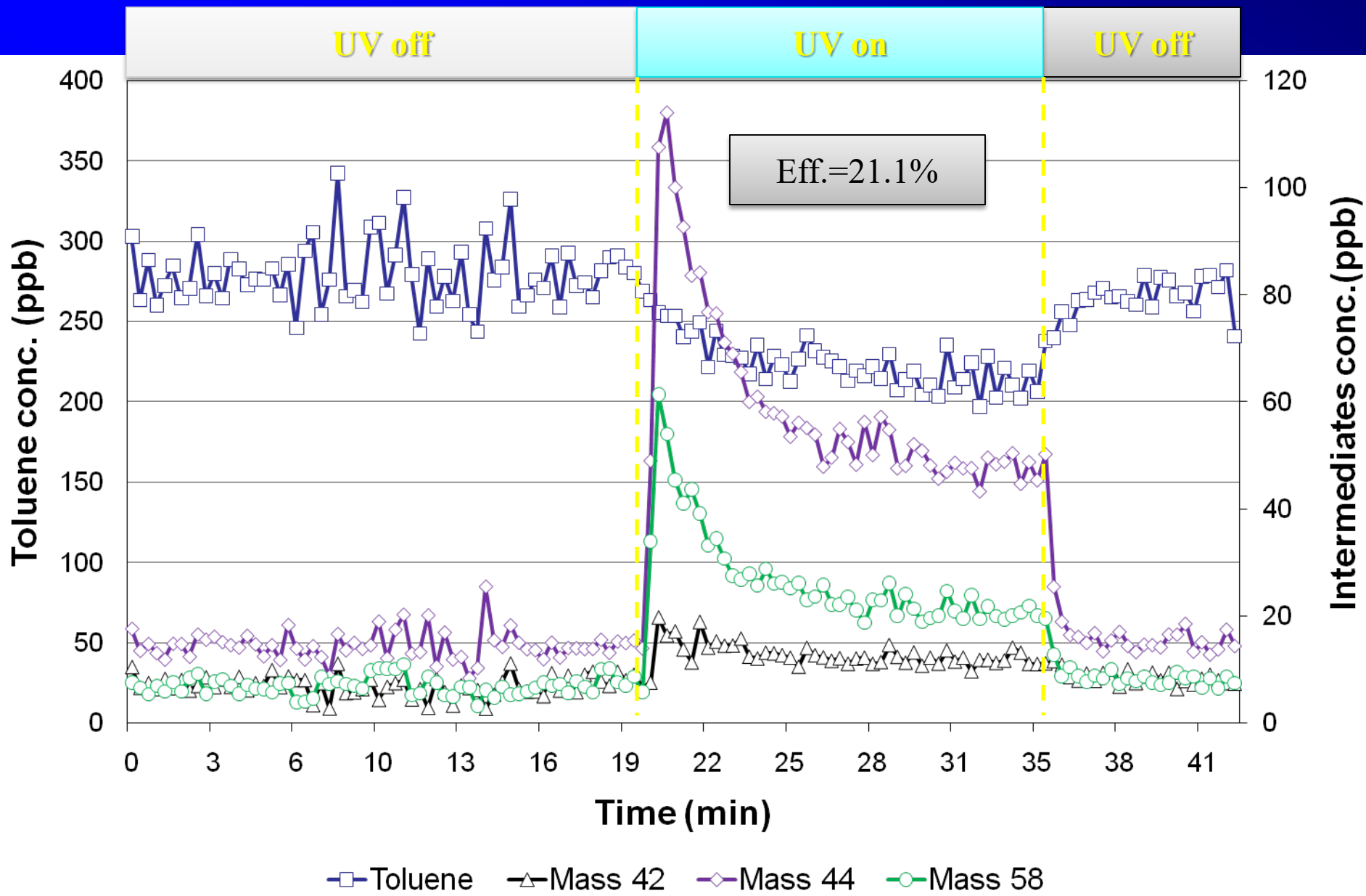
Gas phase air purification technologies

- Photo-catalytic oxidation (PCO)
- Ozone oxidation
- Thermal catalytic oxidation (TCO)
- Plasma oxidation
- Botanic filtration
- Sorption filtration

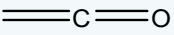
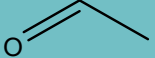


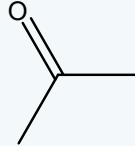
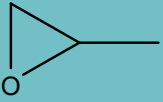




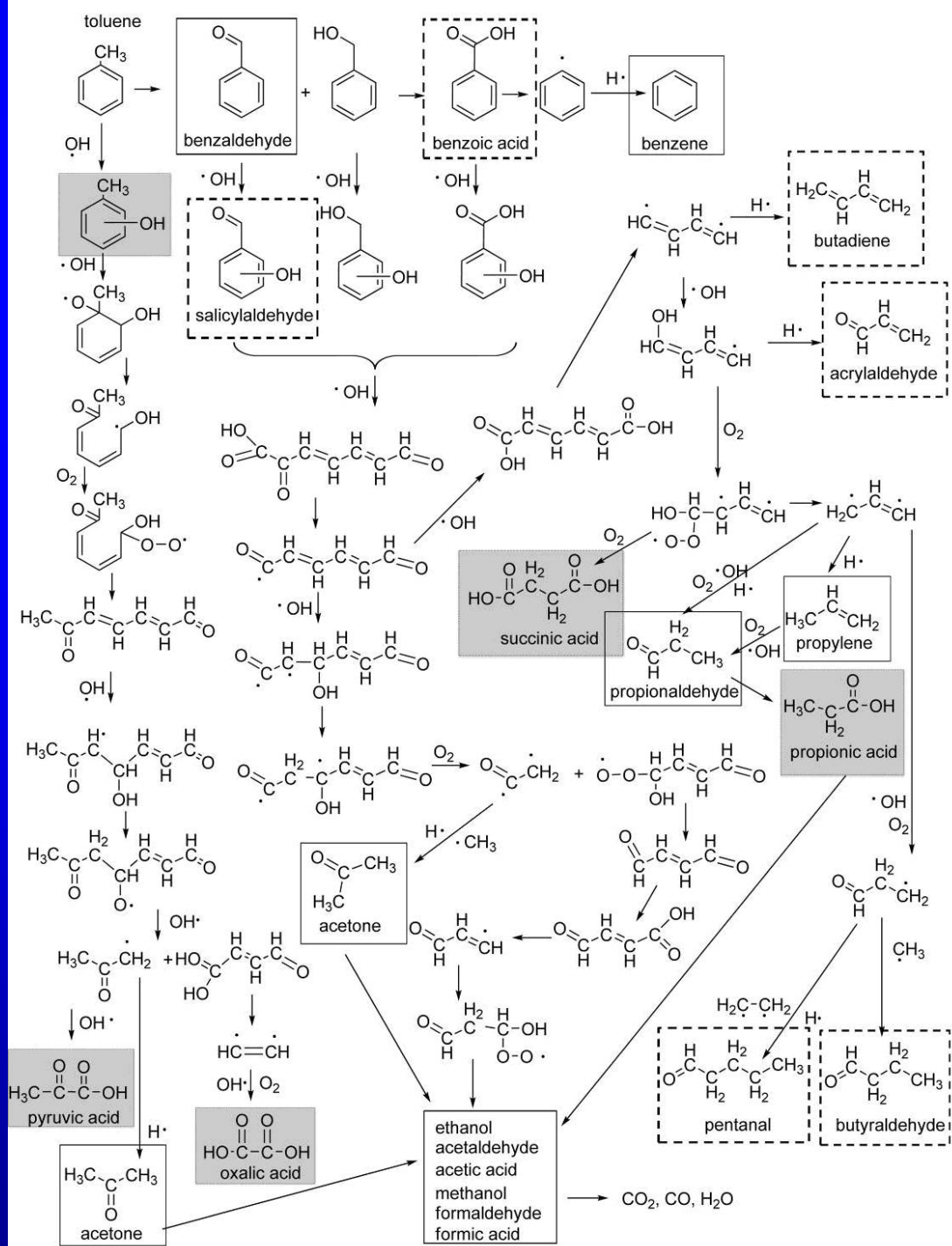




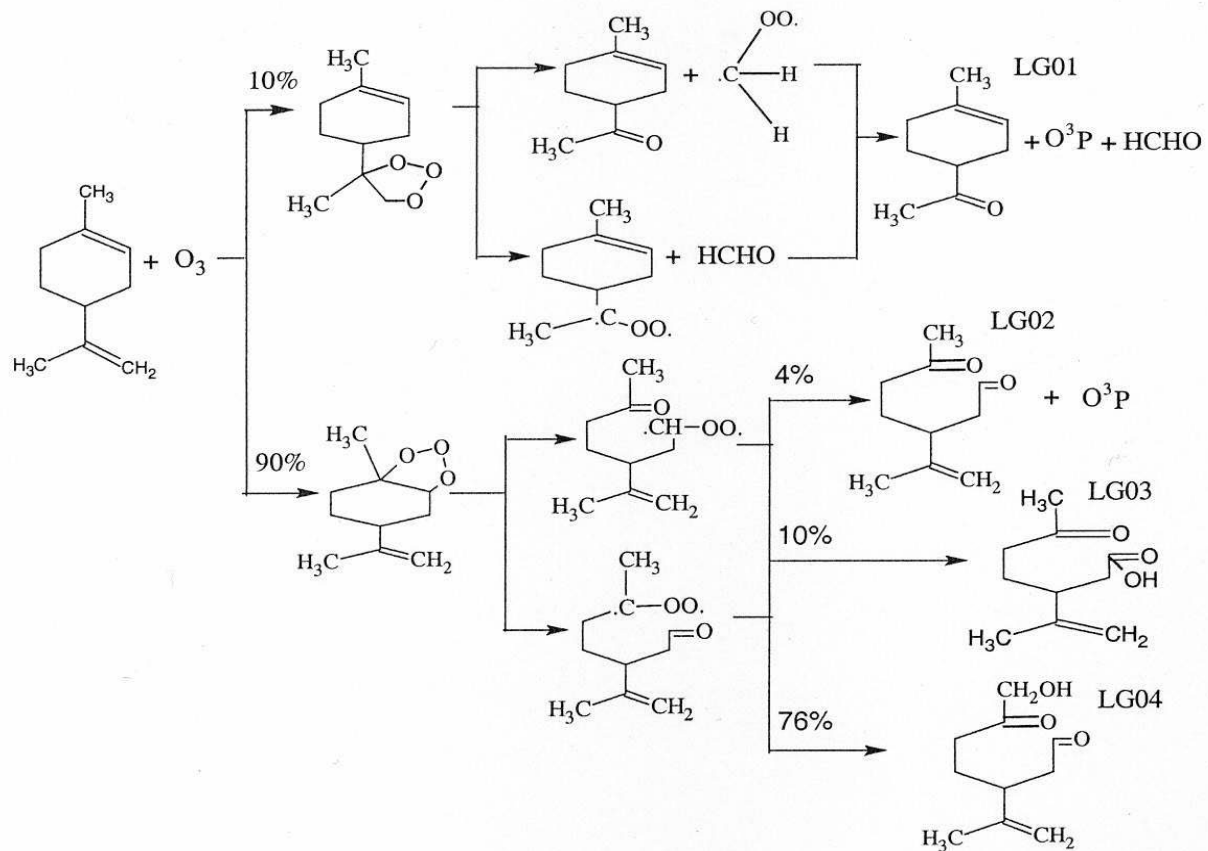
T=25C, RH=50%; UV intensity on TiO₂ surface: 0.43mW/cm²

Mass (amu)	Name	Formula	Structure	Concentration		Harmfulness
				mg/cu.m	ppm	
42	Ketene 乙烯酮	C2H2O		0.9	0.5	Irritation eyes, skin, nose, throat, respiratory system; pulmonary edema
44	Acetaldehyde 乙醛	C2H4O		0.05	0.28	Classification — B2; probable human carcinogen
	Ethylene oxide 氧化乙烯	C2H4O		0.18	0.1	Classification — B2; probable human carcinogen
58	Propionaldehyde 丙醛	C3H6O				No harmful health effects in human
	Acetone 丙酮	C3H6O		590	250	Irritation eyes, nose, throat; headache, dizziness, central nervous system depression; dermatitis
	Propylene oxide 氧化丙稀	C3H6O				Irritation eyes, skin, respiratory system; [potential occupational carcinogen]

**US, NIOSH REL: National Institute for Occupational Safety and Health
Recommended Exposure Limit**



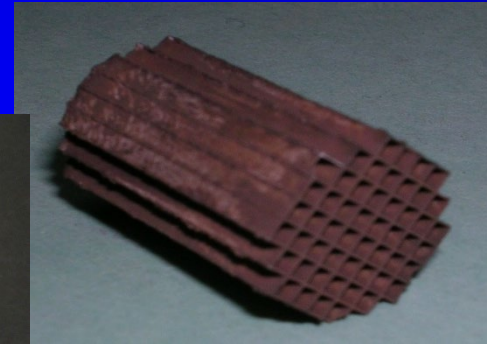
Ozone/Limonene reaction



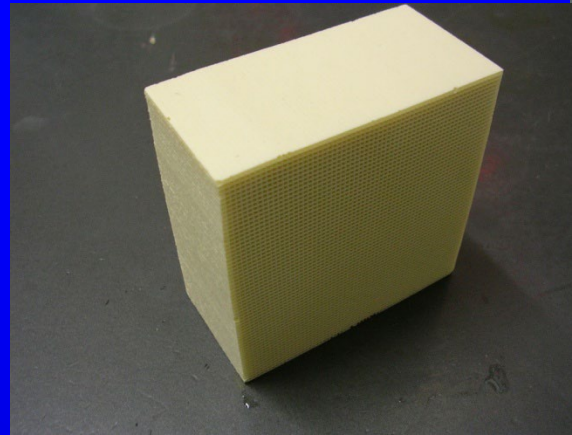
D-LIMONE + O₃ = 0.14 O³P + 0.10 HCHO +

0.1 LG01 + 0.04 LG02 + 0.10 LG03 + 0.76 LG04

TCO materials for formaldehyde decomposition



Honeycomb with
TCO coating

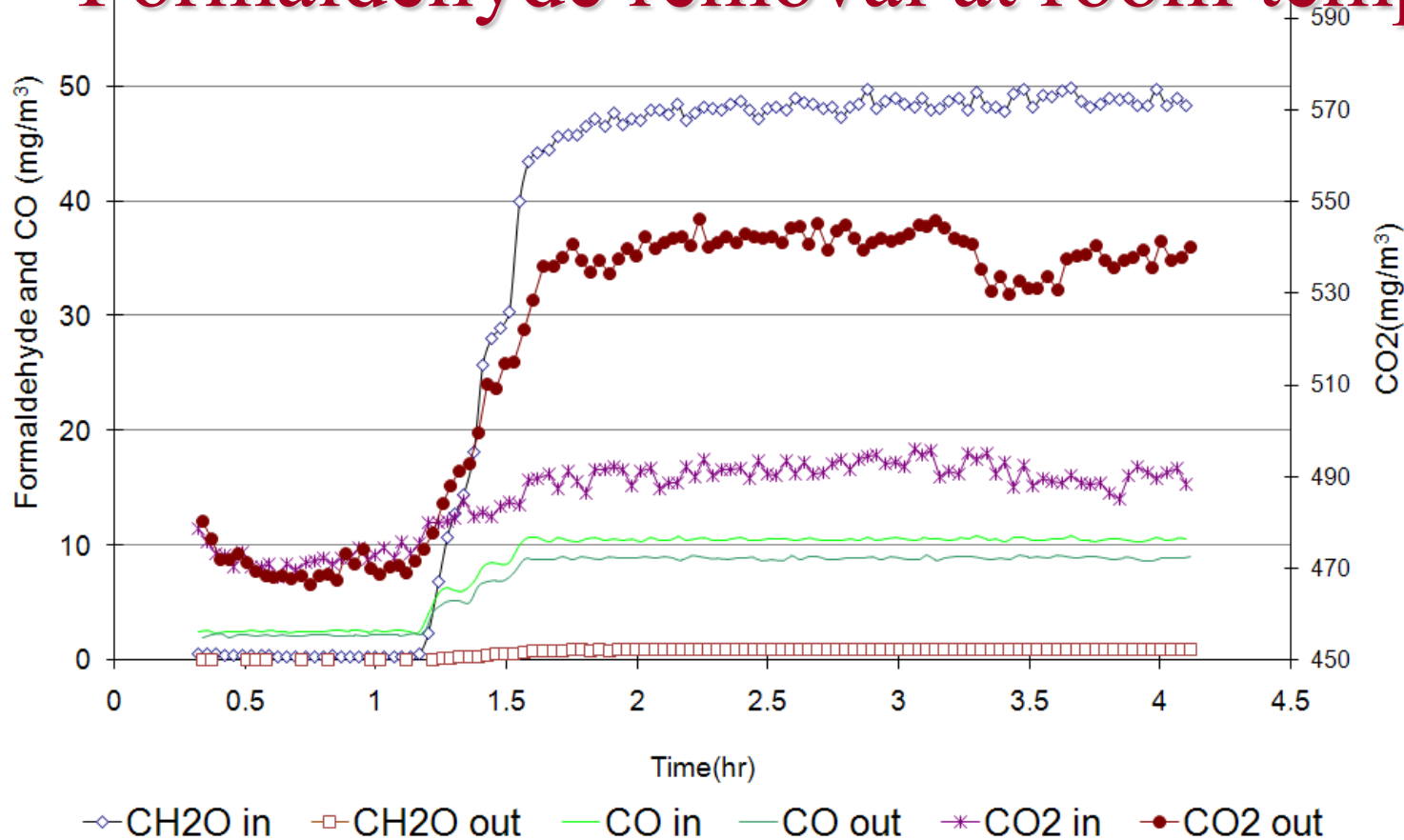


Honeycomb



Thermo-catalyst
powder

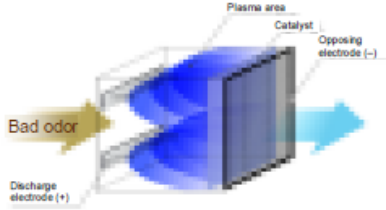
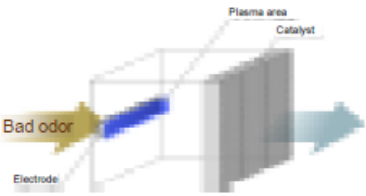
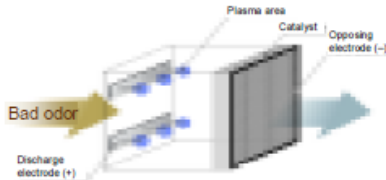
Formaldehyde removal at room temperature



No byproducts

$T=17^{\circ}\text{C}$, $\text{RH}=35\%$, $u=0.5\text{m/s}$

$\text{Eff.}=98\%$, $C_{\text{in}}=48.8\text{ppm}$, $C_{\text{out}}=1.0\text{ppm}$

	Discharge shape	Decomposition area	Decomposition (oxidation)
Streamer discharge	 <p>Oxidation decomposition in 3D space</p>	Wide	1000 times
Barrier discharge	 <p>Discharge only at electrode surface and no discharge in space.</p>		250 times
*Glow discharge	 <p>Discharge only at electrode tip and no discharge in space.</p>	Narrow	1

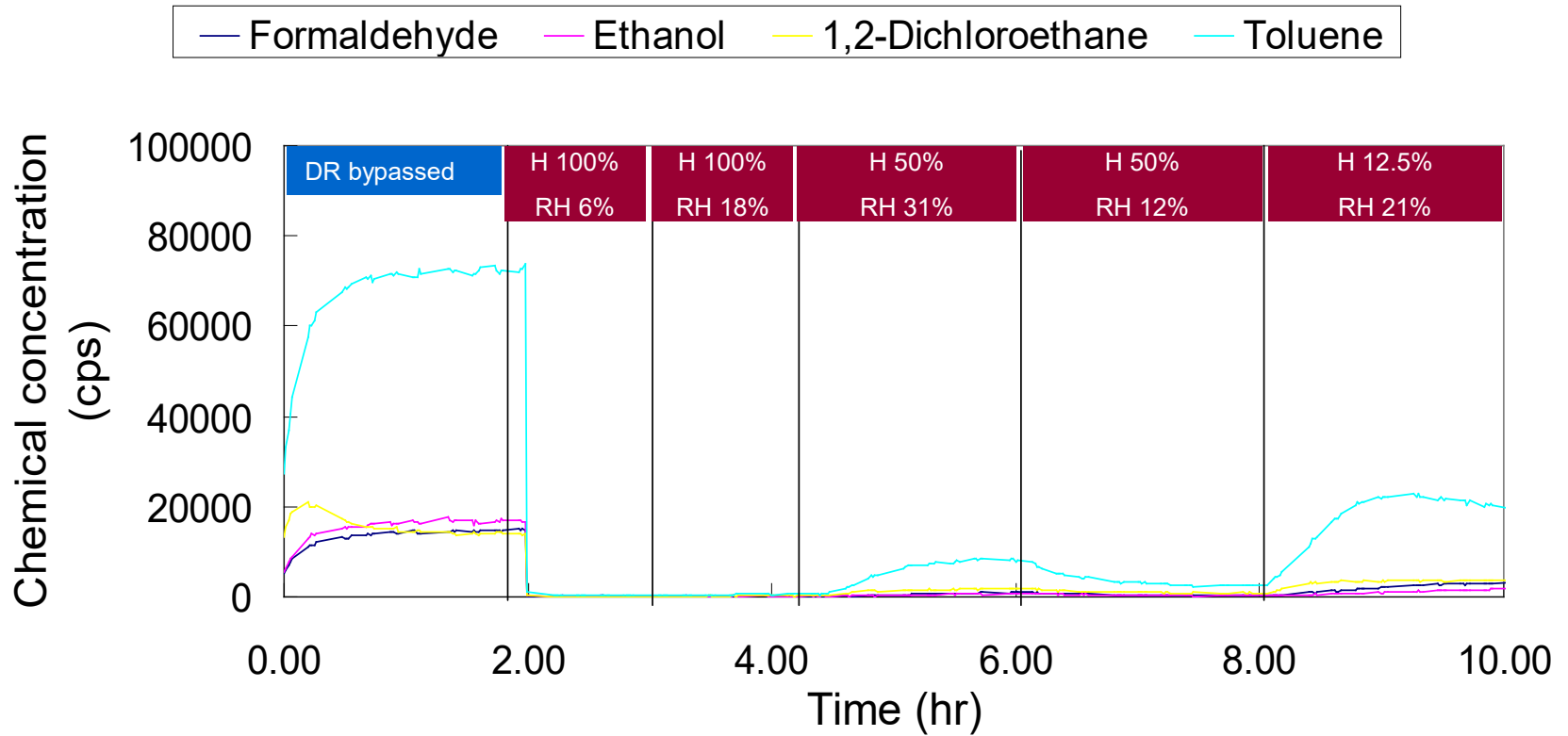


Solid adsorbents

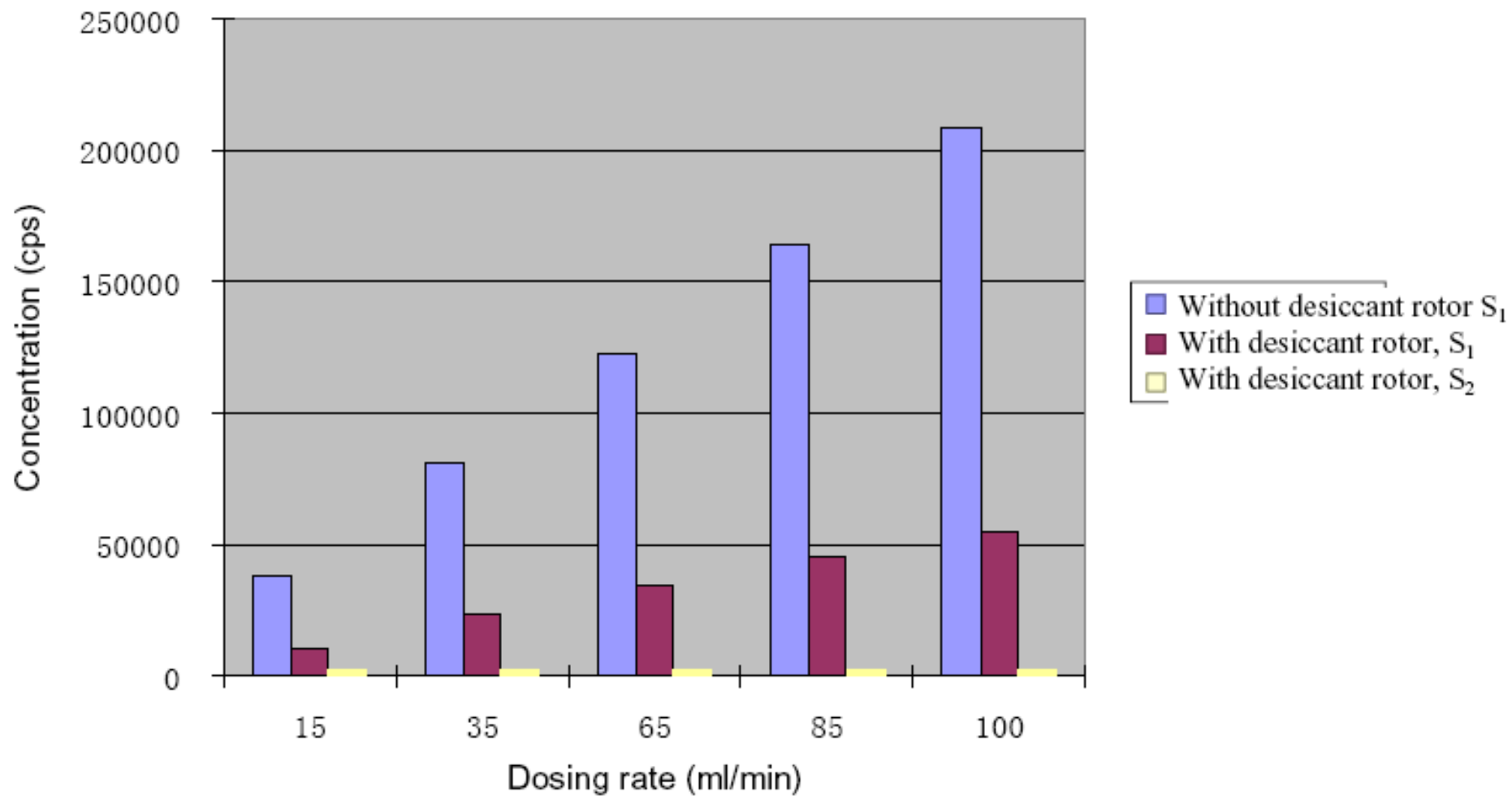
- Activated carbon
- Silica gels
- Activated aluminas
- Zeolites
- Molecular sieves

More results when using pure chemicals as pollution source

Concentration of dosed chemicals at outlet of desiccant rotor

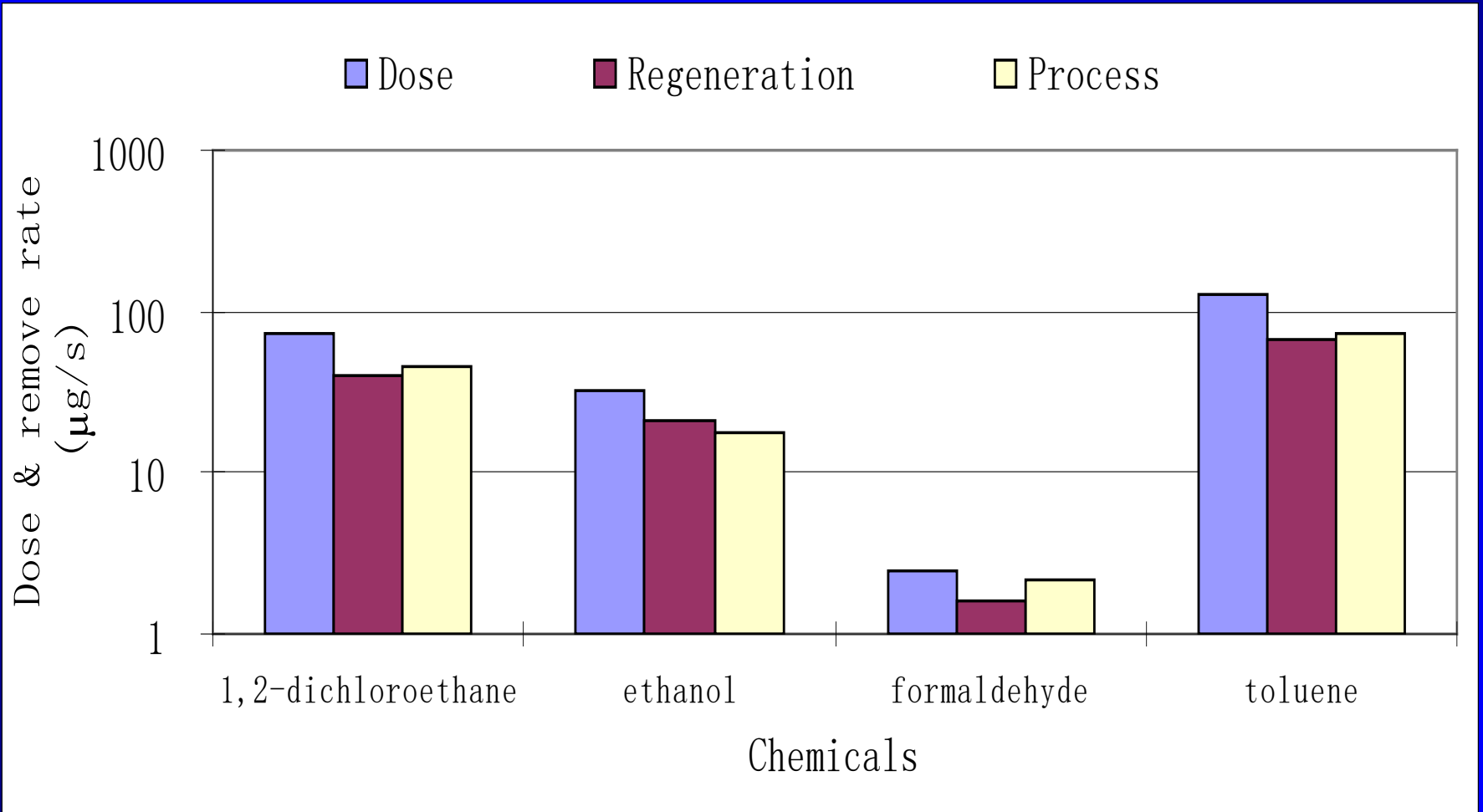


Effect of air purification at different dosing rate of toluene

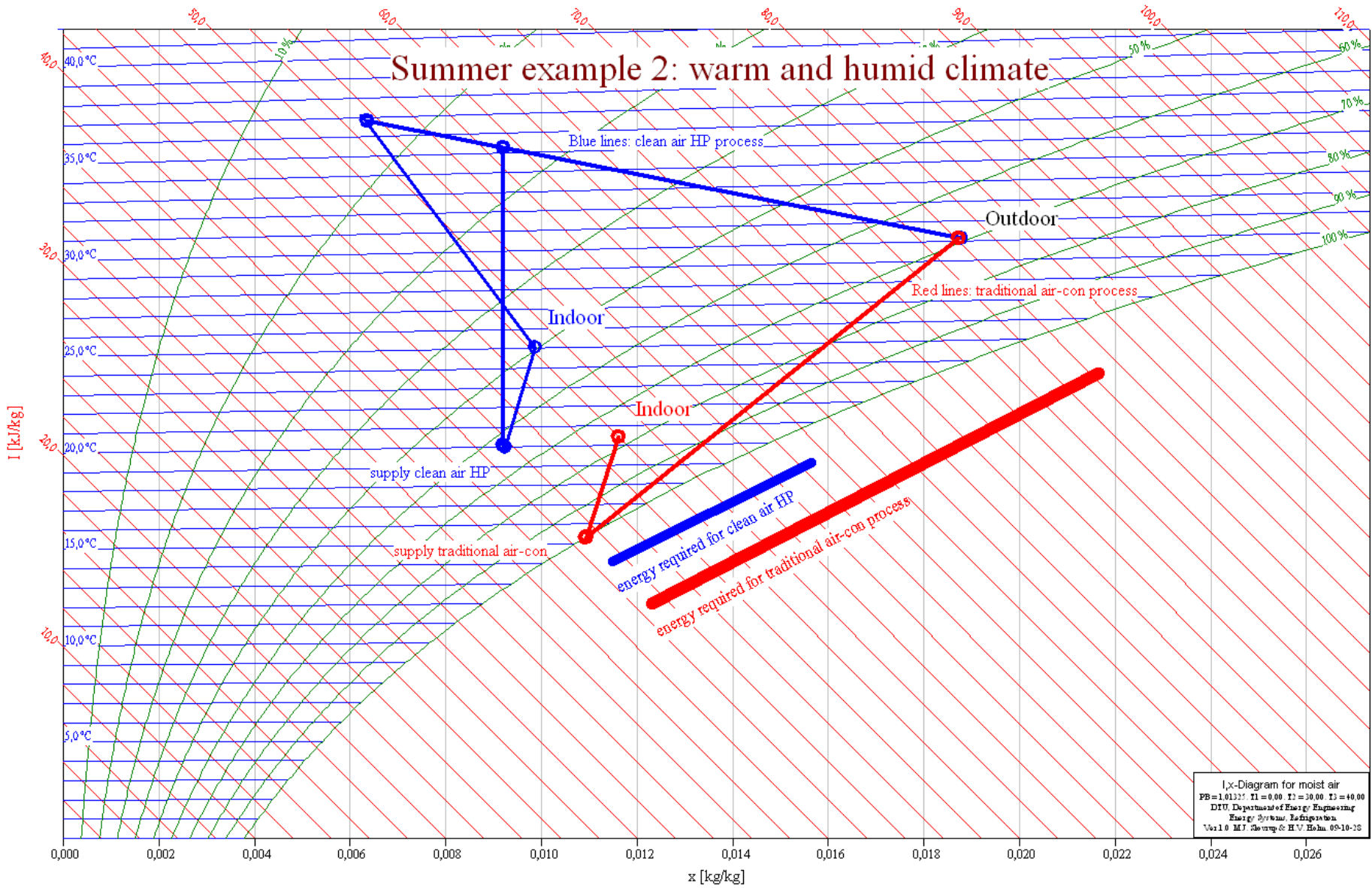


DR – Desiccant rotor

Mass balance between process and regeneration of a desiccant wheel

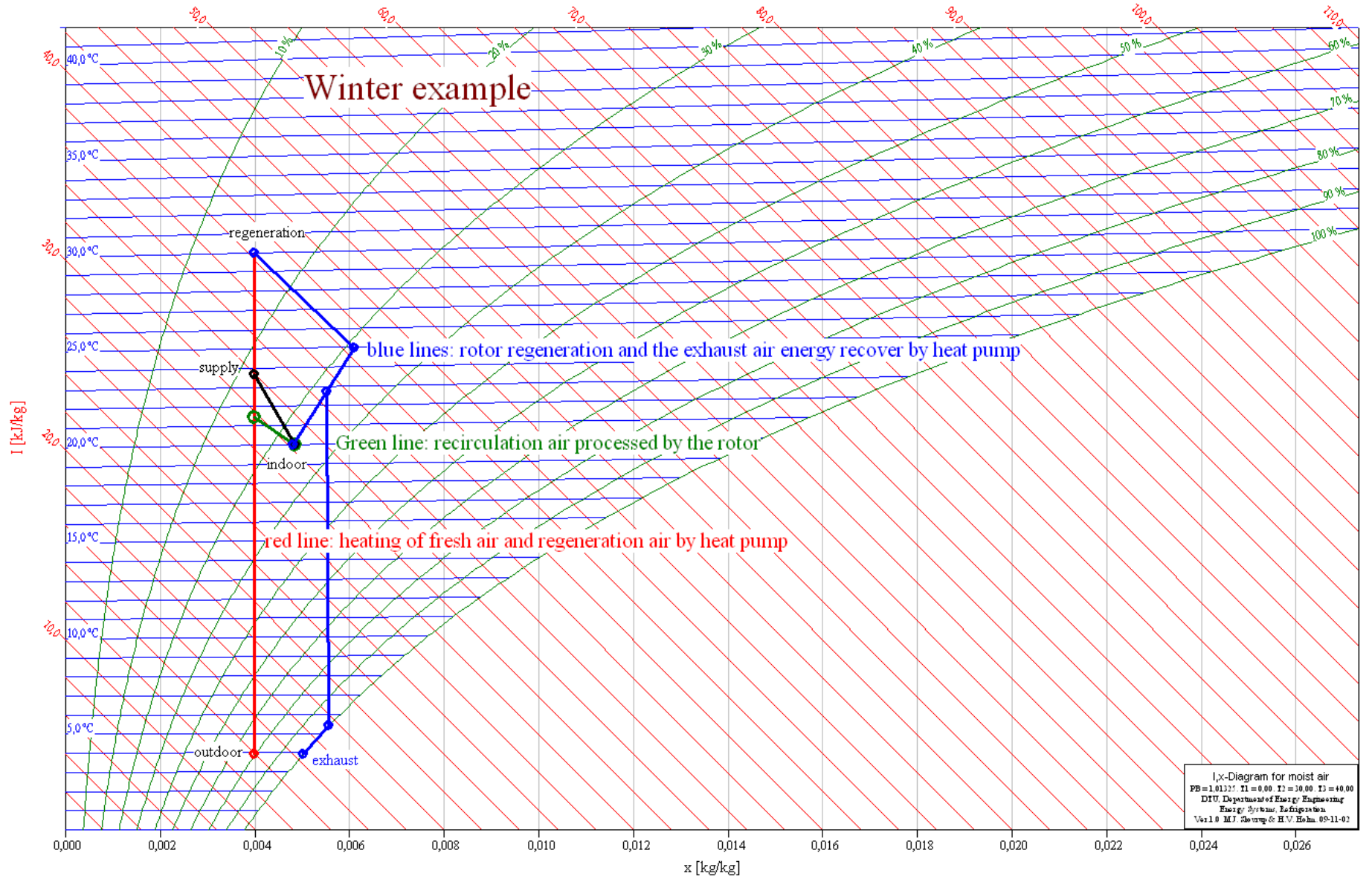


Summer example 2: warm and humid climate



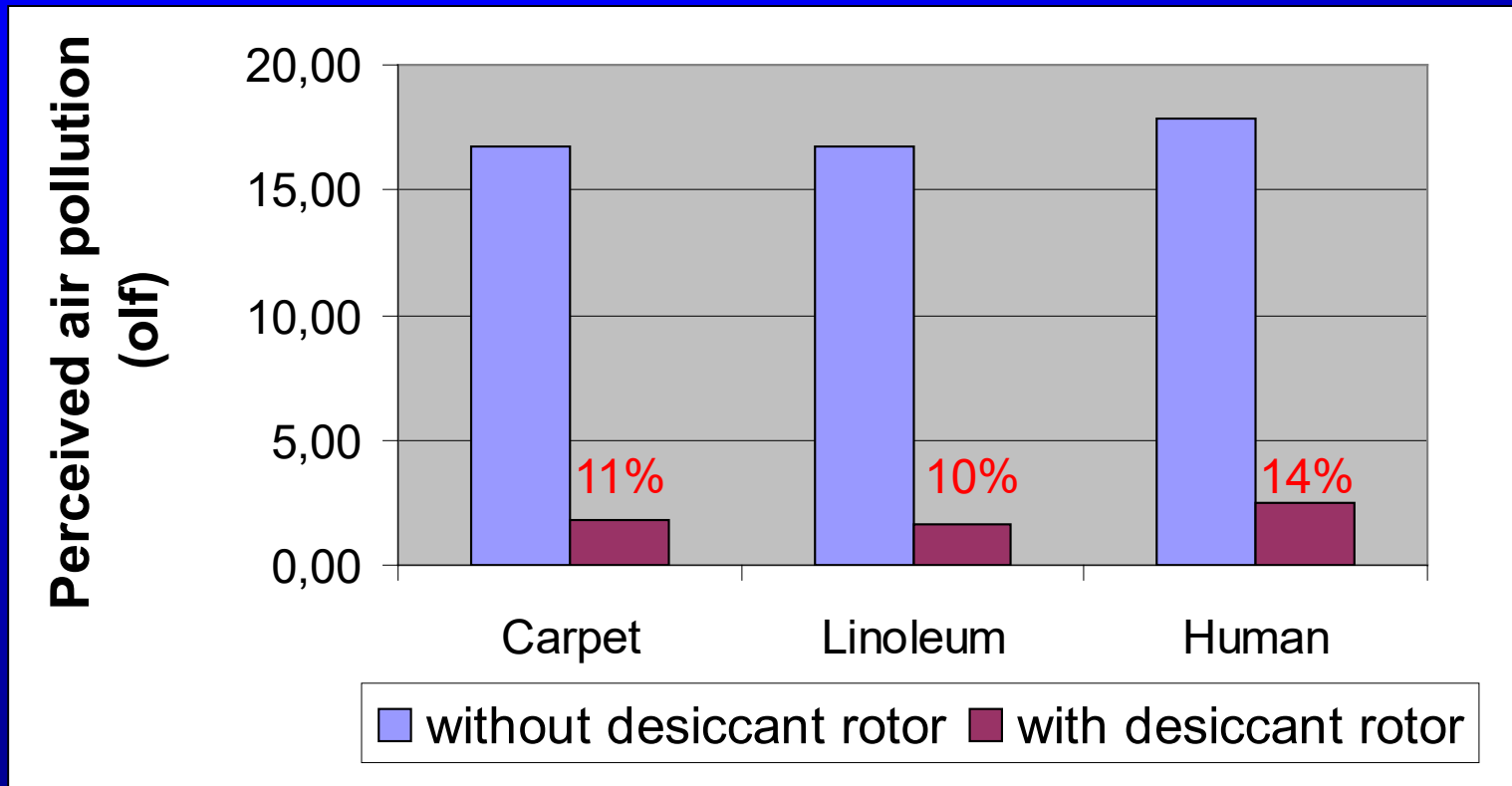
I,x-Diagram for moist air
 PB=1.013; T1=0.00; T2=10.00; T3=10.00
 DTU, Department of Energy Engineering
 Energy Systems, Esbjergsøsten
 Version: M.J. Steyvers & H.V. Ehm, 09-10-20

Winter example

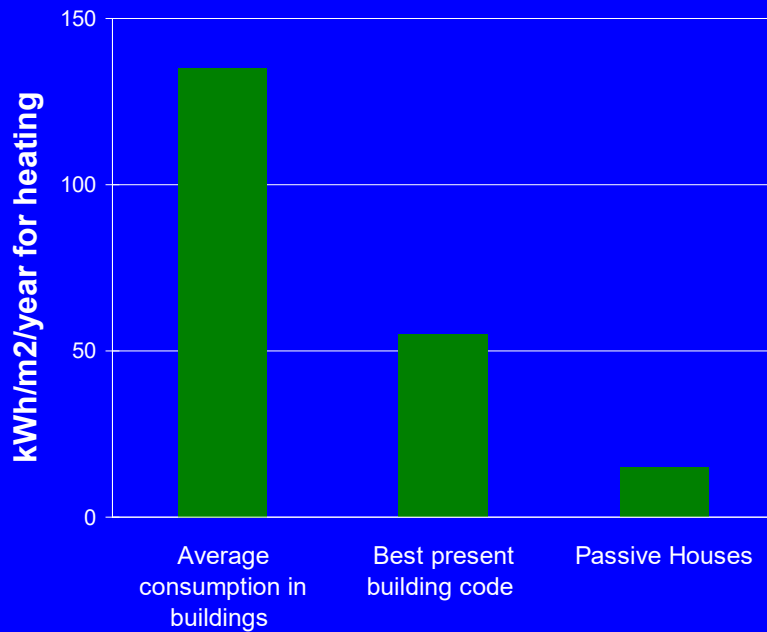


I, x -Diagram for moist air
PB=1.013; $t_1=0.00$; $t_2=30.00$; $t_3=40.00$
DTU, Department of Energy Engineering
Energy Systems Refrigeration
Ved10 M.J. Steyvers & H.V. Boels 09-11-02

Sensory pollution load with and w/o desiccant rotor



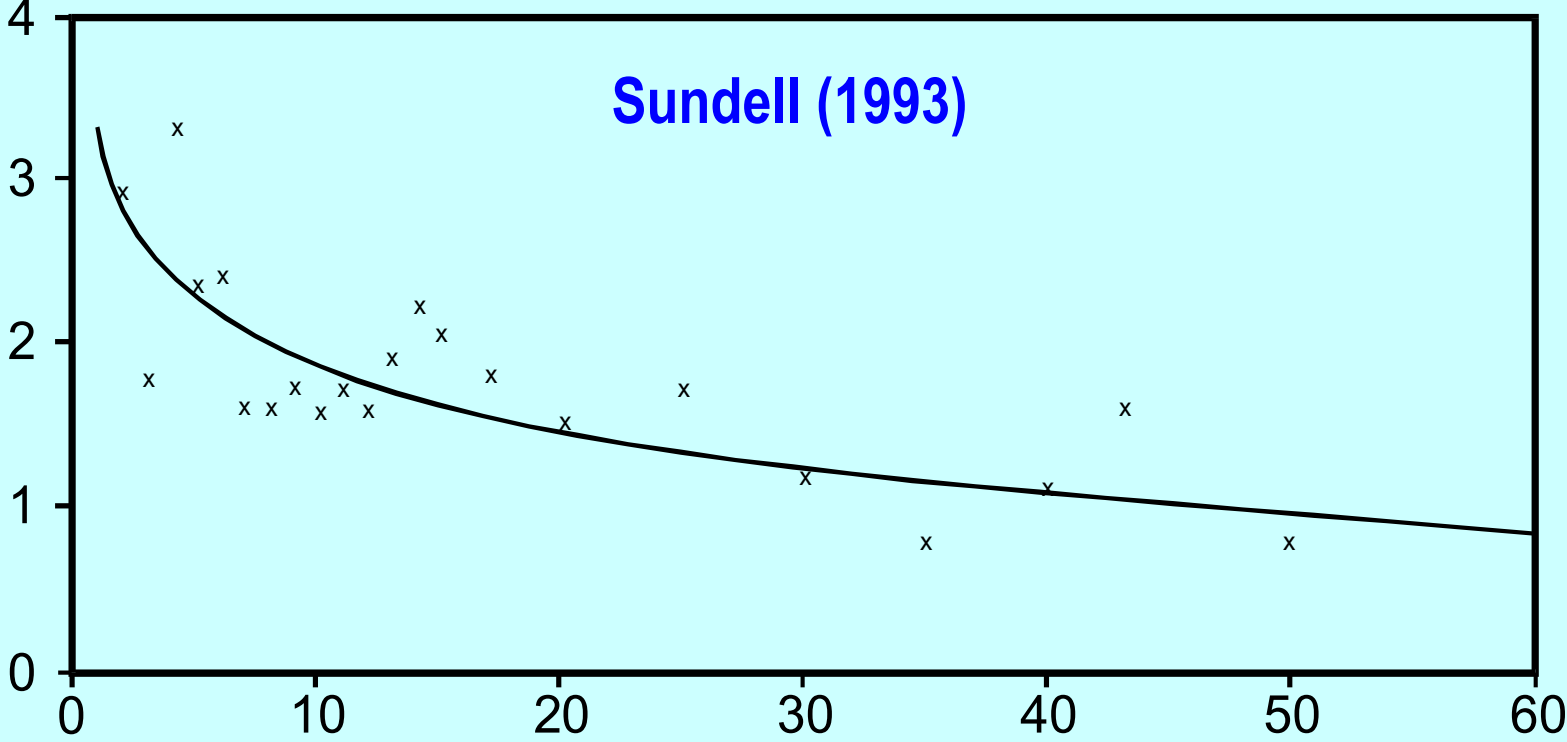
Thermal insulation in buildings



Sources: EU Commission, DK building regulations and www.passivhaus.de

Odds Ratio of SBS-symptoms

Sundell (1993)



Outdoor air flow rate, L/s,p

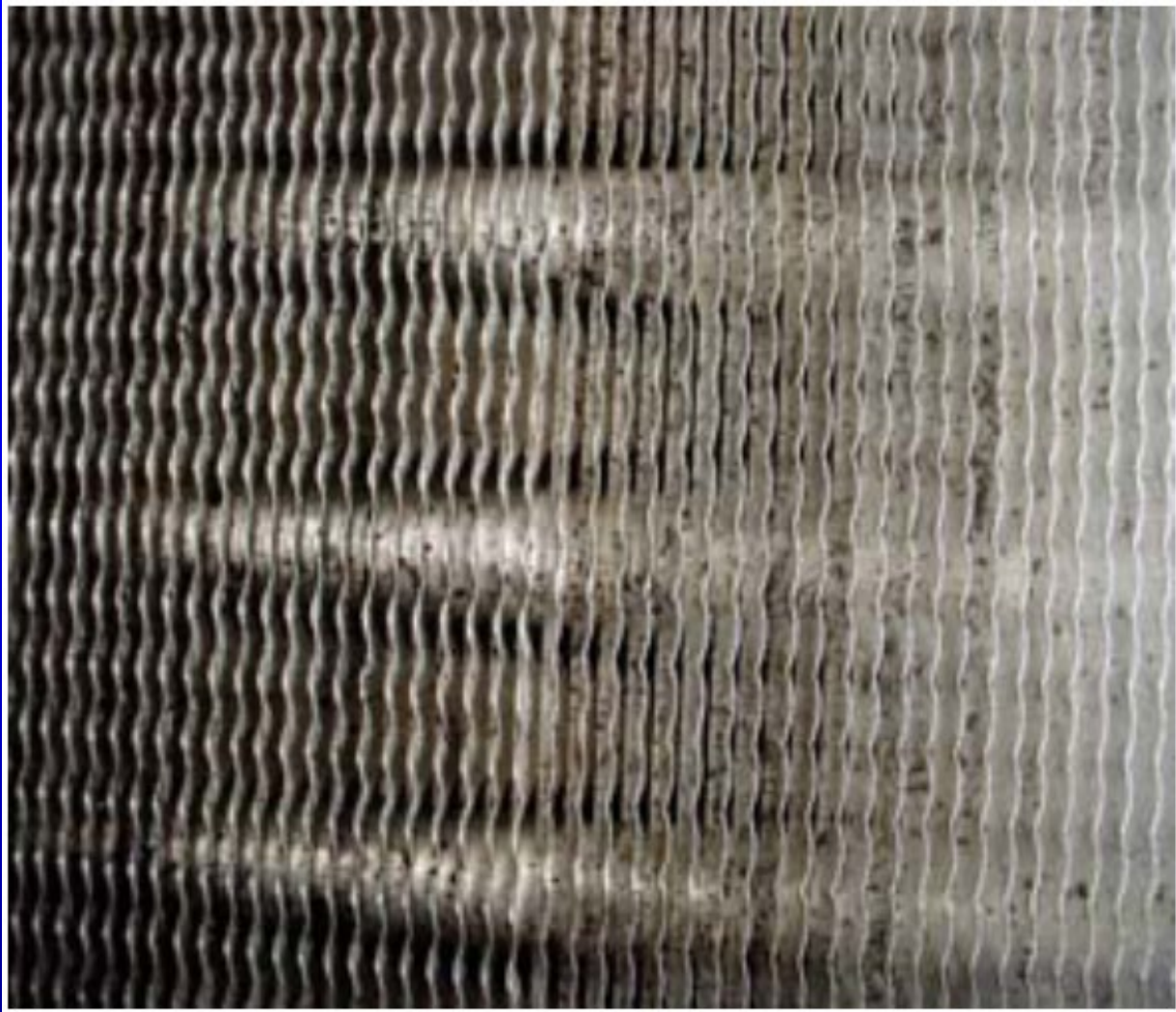
56 Office Buildings Were Investigated in the European Audit Project

- Mean outdoor air supply rate: 25 L/s
- 27 – 32 percent occupants found the indoor air quality not acceptable
- 31 – 52 percent occupants had different SBS symptoms

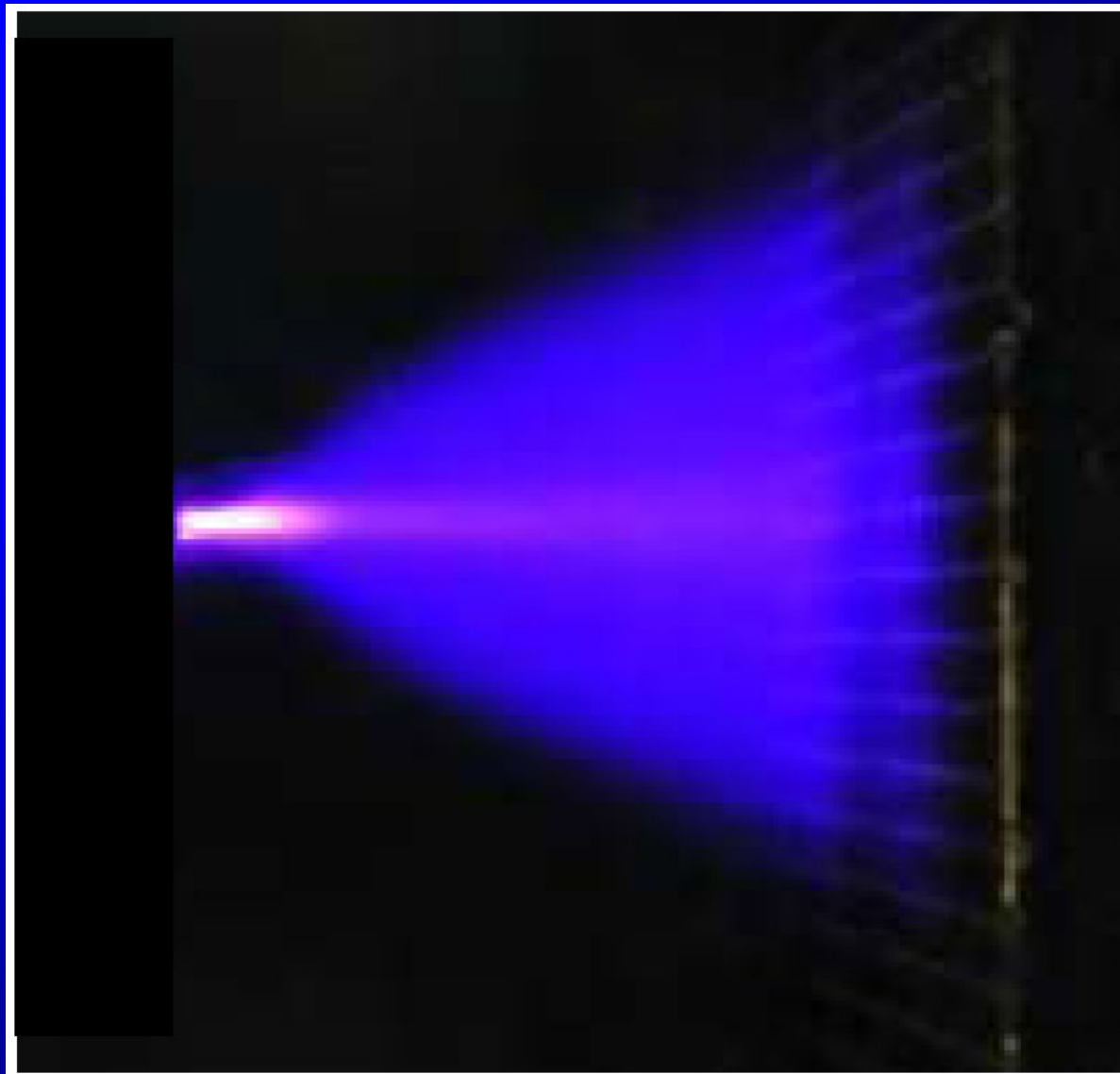
Dirty cooling coil



Mold on cooling coil



Plasma



How can a desiccant rotor remove pollutants?

- Adsorption of chemicals from the process air by the desiccant rotor
- Desorption of chemicals from the desiccant rotor by reactivation air

