Ventilation

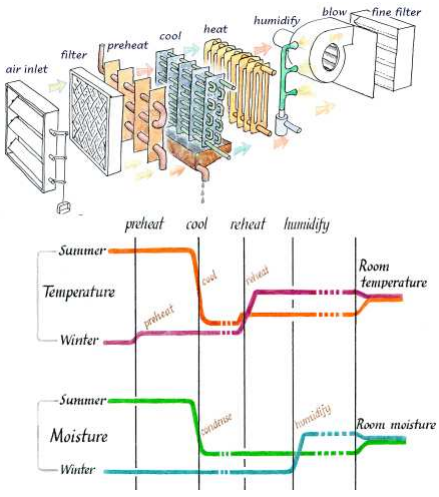
6 Heat Exchangers

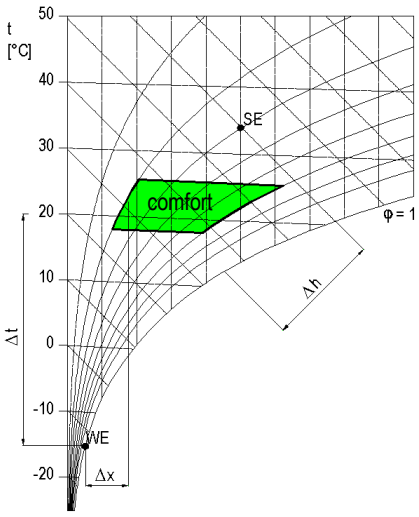
Vladimír Zmrhal (room no. 814)

http://users.fs.cvut.cz/~zmrhavla/index.htm

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
FAKULTA STROJNÍ
Dpt. Of Environmental Engineering

Air-conditioning processes





Dimensioning of air-conditioning

Outdoor air conditions (Czech Republic)

WINTER

$t_e = t_{e,loss}$ – 3 °C, φ_e = 100 % ($t_{e,loss}$ = -12, -15, -18 °C)

SUMMER

t_e = 32 °C, h_e = 58 kJ/kg

Indoor air conditions (for air-conditioned spaces)

Indoor air temperature t_i = 18 to 26 °C

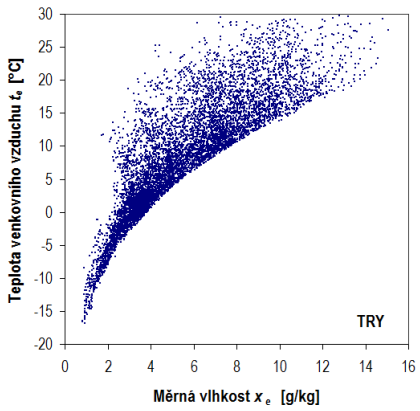
Relative humidity φ_i = 30 to 70 %

Example 1: Find the summer and winter extreme in the diagram

3

Air-conditioning processes

Typical climatic data (Czech Republic)



TRY – test reference year

t_e – ambient air temperature [°C]

x_e – humidity ratio [g/kg]

4

Air heating

Heating coil

➢ water coil heat exchangers

direct heaters

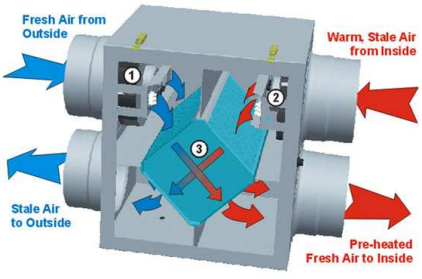
electric heaters

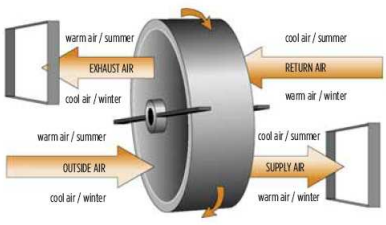
Air heating

Heat recovery

heat recuperation

heat regeneration





Example 2:
$\Phi = 65\ \%$
$t_e = -15\ °C$
$t_i = 20\ °C$
$t_{sup} = ?$

Recovered heat coefficient

$$\Phi = \frac{t_{e2} - t_{e1}}{t_{o1} - t_{e1}}$$

Air heating

Heat flow rate

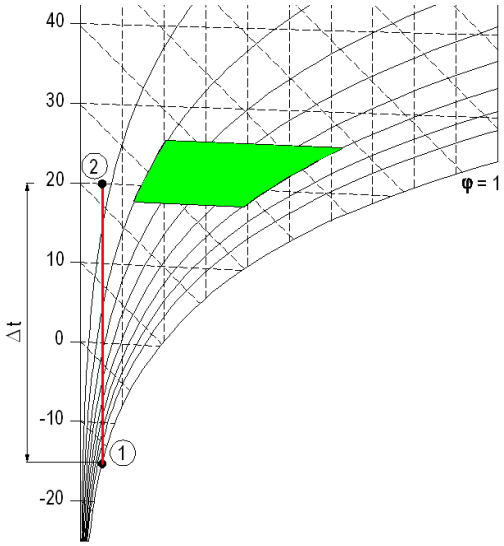
- heating coil capacity

$$Q_h = V\rho c\left(t_2 - t_1\right)$$

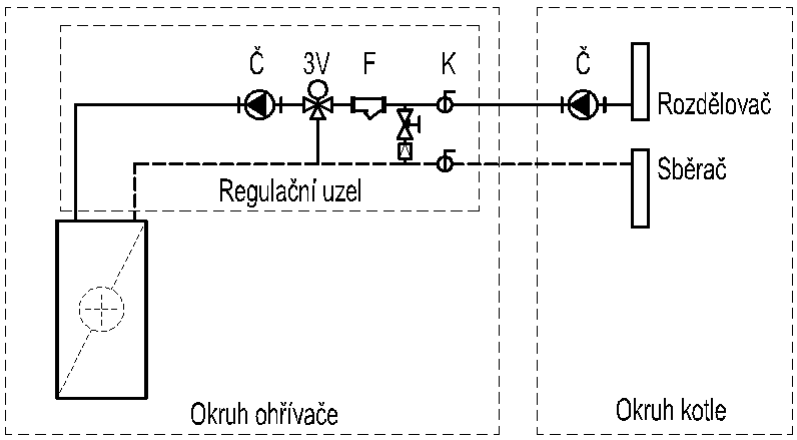
$$\Delta x = 0$$

$$\delta = \infty$$

Example 2:
V = 10 000 m³/h
t_1 = -15 °C
t_2 = 20 °C
Q_h = ?



Air heating



Air cooling

Sensible cooling - without condensation („dry cooling“)

➢ the temperature on a cooling surface is above or equal to the dew point temperature → $t_c > t_{dp}$

Latent cooling - dehumidifying moist air

➢ the temperature on a cold surface is lower than the dew point temperature → $t_c < t_{dp}$

Cold surface temperature

➢ water exchangers e.g. 6/12 °C $t_c = (t_{w1} + t_{w2})/2 = 9$ °C

➢ evaporators $t_c \approx 4 - 5$ °C

Air cooling

Cooling coil capacity

➢ total heat flow rate through the cooling coil

$$Q_c = Q_{sen} + Q_{lat} = V\rho c(t_1 - t_2) + V\rho l(x_1 - x_2)$$

$$Q_c = V\rho(h_1 - h_2)$$

$$\Delta h = c\Delta t + l\Delta x$$

Air cooling

Cooling without condensation

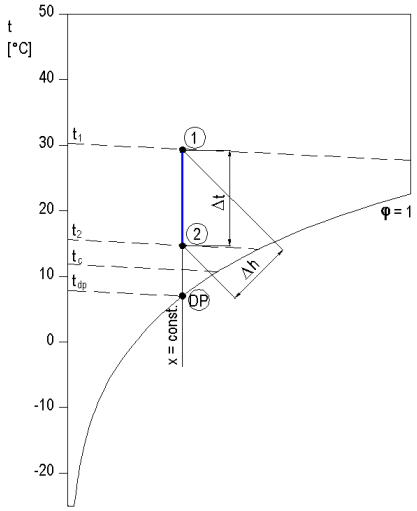
- $t_c > t_{dp}$
- cooling coil capacity

$$Q_{sen} = V\rho c(t_1 - t_2)$$

$$Q_{lat} = 0$$

$$Q_c = V\rho(h_1 - h_2) =$$

$$= V\rho c(t_1 - t_2)$$



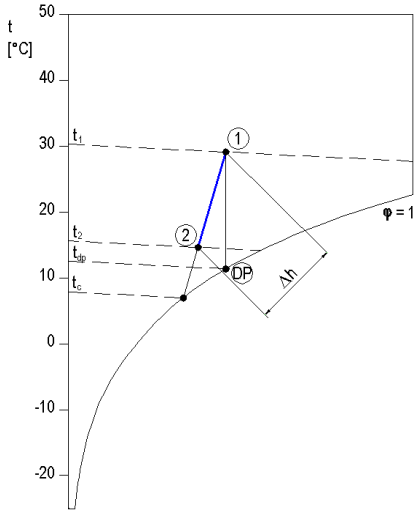
11

Air cooling

Dehumidifying moist air

- $t_c < t_{dp}$
- cooling coil capacity

$$Q_c = V\rho(h_1 - h_2)$$



12

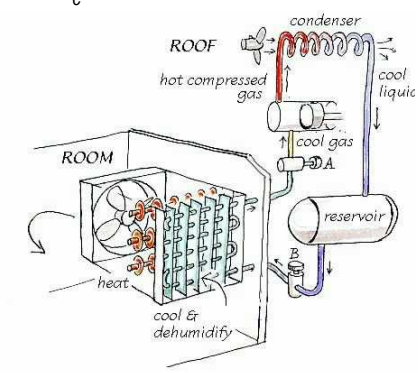
Air cooling

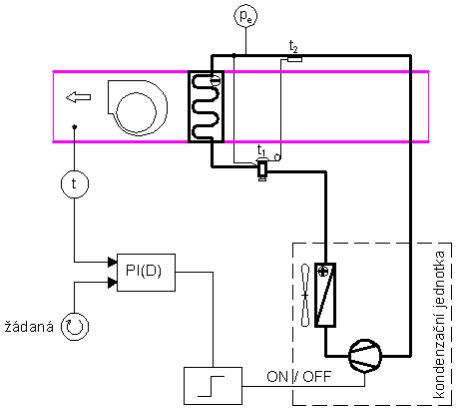
Cooling without condensation	Cooling with dehumidifying
Example 3a: $V = 10\ 000\ m^3/h$ $t_1 = 32\ °C$ $h_1 = 58\ kJ/kg$ $t_2 = 20\ °C$ $t_c = 16\ °C$ $Q_c = ?$	**Example 3b:** $V = 10\ 000\ m^3/h$ $t_1 = 32\ °C$ $h_1 = 58\ kJ/kg$ $t_2 = 20\ °C$ $t_{w1}/t_{w2} = 6/12\ °C$ $Q_c = ?$

Air cooling

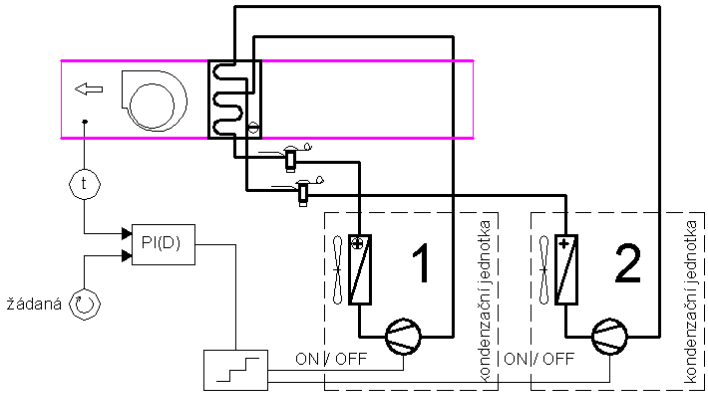
Direct air cooling

- cooling coil = evaporator
- $t_c = 4 - 5\ °C$





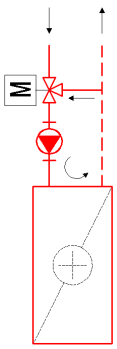
Air cooling



Control of water exchangers

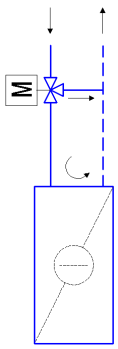
Supply temp. control

- mixing of the flow
- V = const.
- t_w = var.
- heating/cooling coils

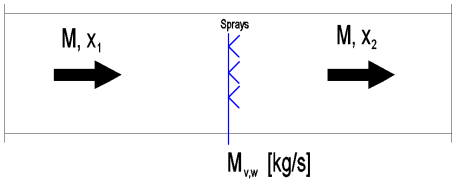


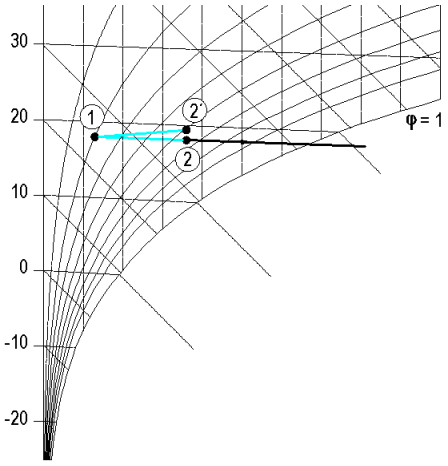
Heat mass flow control

- dividing of the flow
- V = var.
- t_w = const.
- cooling coils



Humidifying (adding steam)





Moisture balance

$$M\ x_1 + M_v = M\ x_2$$

Heat balance

$$M\ h_1 + M_v h_v = M\ h_2$$

Humidifying (adding steam)

Enthalpy of water vapor

$$h_v = I + c_v t = 2500 + 1.86 \cdot t \cong 2540 \qquad \text{[kJ/kg]}$$

Direction of the process

$$\delta = \frac{\Delta h}{\Delta x} = \frac{h_2 - h_1}{x_2 - x_1} = h_v$$

$$\delta = h_v = 2.5 \qquad \text{[kJ/g]}$$

Humidifying (adding steam)

Enthalpy of water vapor – reality

I = 2500 kJ/kg … for 0 °C

$$h_v = I + c_v t + c_w t = 2500 + 1.86 \cdot 100 + 4.2 \cdot 0 \cong 2680 \quad \text{[kJ/kg]}$$

I = 2257 kJ/kg … for 100 °C

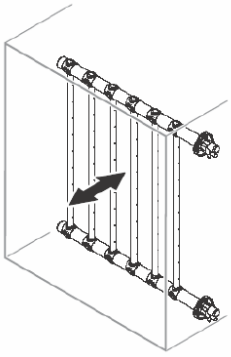
$$h_v = I + c_v t + c_w t = 2257 + 2.08 \cdot 0 + 4.2 \cdot 100 \cong 2680 \quad \text{[kJ/kg]}$$

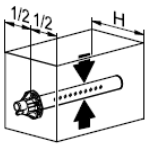
$$\delta = h_v = 2.68 \quad \text{[kJ/g]}$$

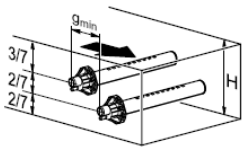
In reality the air is also heated !

Humidifying (adding steam)

Distribution of steam (sprays)







Example 4:
V = 10 000 m³/h
x_1 = 1 g/kg
x_2 = 5 g/kg
M_v = ?
Q_{hum} = ?

Humidifying (adding water - injection)

Adding water (100% evaporation)

$$\delta = \frac{\Delta h}{\Delta x} = \frac{h_2 - h_1}{x_2 - x_1} = h_w$$

Enthalpy of water

$$h_w = c_w t = 4.187t = 0 \text{ to } 420 \quad \text{[kJ/kg]}$$

Direction of the process

$$\delta = h_w \cong 0 \quad \text{[kJ/g]}$$

Humidifying (adding water)

Adiabatic cooling (air washer)

$t_{w1} = t_{w2}$

$Q = 0$

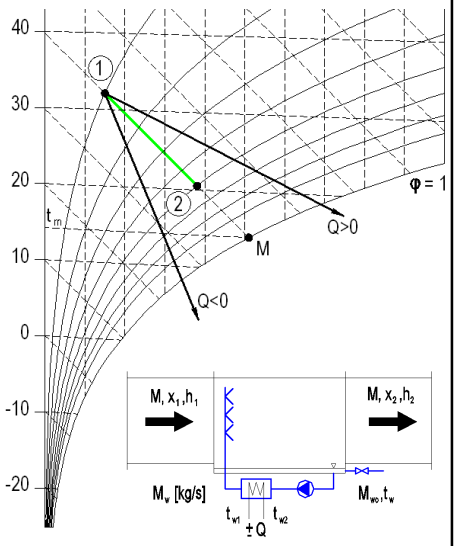
$\delta = c_w t_w = 4.187 t_w \cong 0$ kJ/g

Polytropic change

$t_{w1} \neq t_{w2}$

$Q > 0 \quad \ldots \delta > 0$

$Q < 0 \quad \ldots \delta < 0$



Humidifying (adding water)

Legionella

Legionella acquired its name after a July, 1976 outbreak of a then-unknown "mystery disease" sickened 221 persons, causing 34 deaths. The outbreak was first noticed among people attending a convention of the American Legion - an association of U.S. military veterans. The convention in question occurred in Philadelphia during the U.S. Bicentennial year. This epidemic among U.S. war veterans, occurring in the same city as – and within days of the 200th anniversary of – the signing of the Declaration of Independence, was widely publicized and caused great concern in the United States. On January 18, 1977 the causative agent was identified as a previously unknown bacterium (from air-conditioning) subsequently named *Legionella*. See Legionnaires' Disease for full details.

http://en.wikipedia.org/wiki/Legionella

Humidifying (adding water)

Efficiency of air washer

$$\eta = \frac{x_2 - x_1}{x_{wb} - x_1}$$

Example 5:
η = 60 %
t_1 = 27 °C
φ_1 = 40 %

x_2 = ?
φ_2 = ?

Dehumidifying

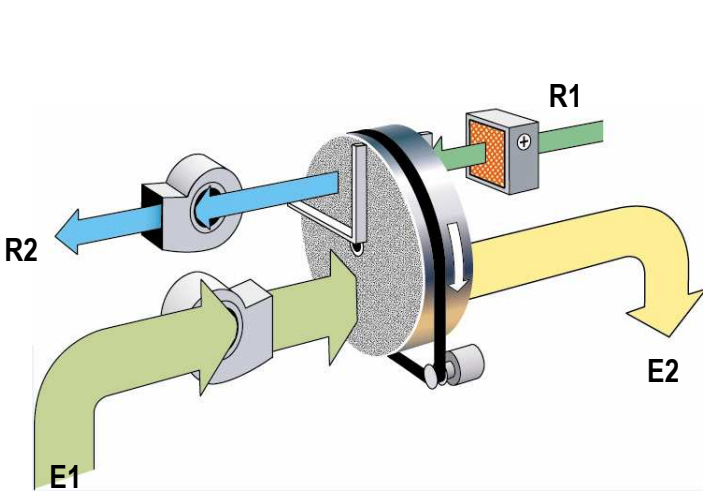
Cooling of air - vapor condensation

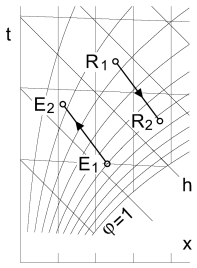
- $t_c < t_{dp}$

Adsorption dehumidifying

- rotary heat recovery exchangers
- rotor with hygroscopic material as silica gel or activated alumina
- the sorbent material contains a vast number of microscopic pores where water is absorbed
- moisture is condensed and held on the surface of the material
- the adsorbent material can be reactivated by heat - regeneration

Dehumidifying

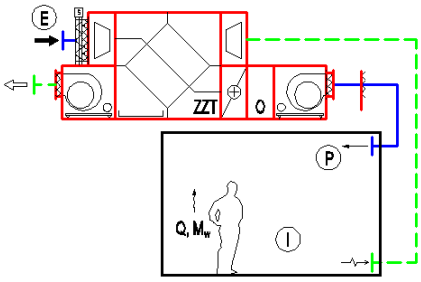


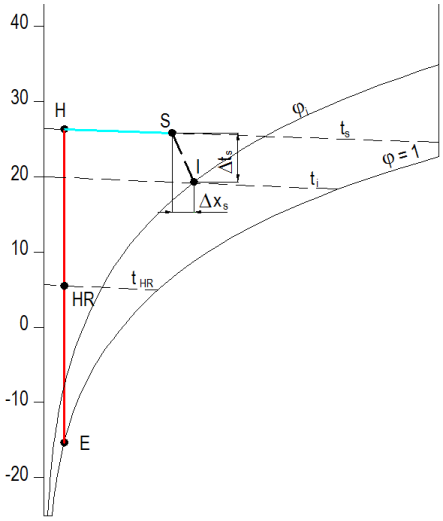


Example of winter process

Single duct air system

- heat recovery
- heater
- humidifying (steam)
- conditioning in the room



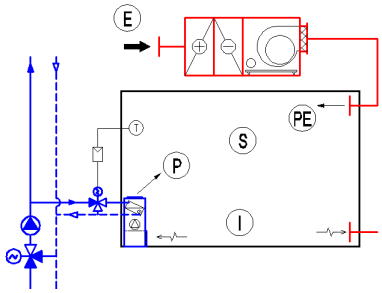


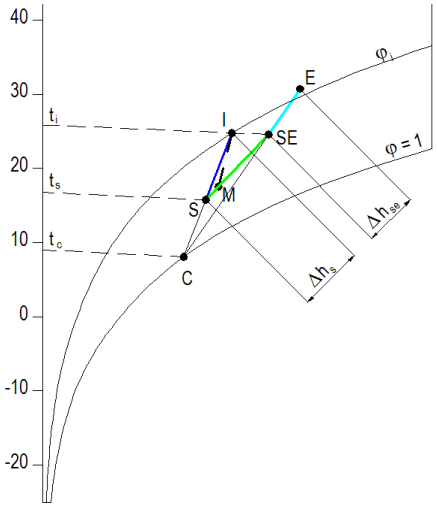
27

Example of summer process

Fan coil units

- outdoor air cooling
- recirculation of air
- mixing in the room
- conditioning in the room





28

Thank you for your attention