Air Conditioning Systems

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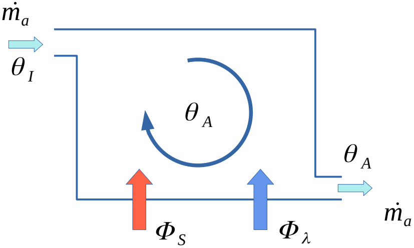
All Air systems

Energy and mass space balance



energy and mass balance

$$
\begin{aligned}
(\dot{m}_a)_u &= (\dot{m}_a)_e \\
(\dot{m}_{av})_u &= (\dot{m}_{av})_e + \dot{m}_v \\
m_a \cdot x_A &= m_a \cdot x_I + \dot{m}_v \\
\dot{m}_a \cdot h_u &= \dot{m}_a \cdot h_I + \Phi_S + \Phi_\lambda
\end{aligned}
$$

Space condition line

Pendenza Retta

$$\begin{aligned}
\Phi_{tot} &= \dot{m}_a \cdot (h_A - h_I) \\
\dot{m}_v &= \dot{m}_a \cdot (x_A - x_I) \\
\frac{\Phi_{tot}}{\dot{m}_v} &= \frac{h_A - h_I}{x_A - x_I}
\end{aligned}$$

Winter

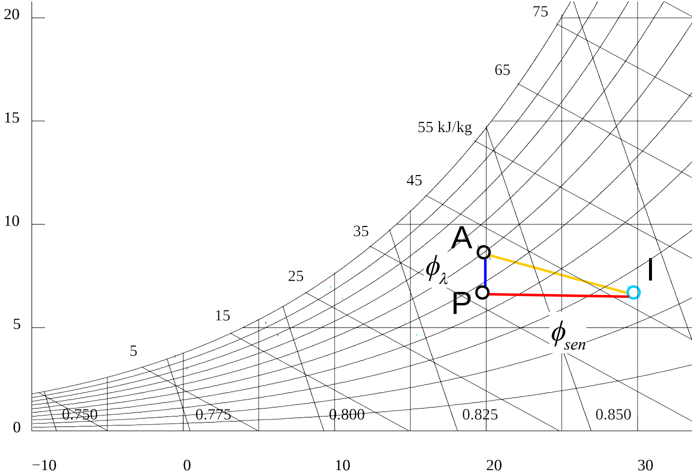
$$\Phi_S < 0;\ \Phi_\lambda > 0 \Longrightarrow \Phi_{tot} < 0; \qquad \frac{h_A - h_I}{x_A - x_I} = \frac{\Phi_{tot}}{\dot{m}_v} < 0$$

Summer

$$\Phi_S > 0;\ \Phi_\lambda > 0 \Longrightarrow \Phi_{tot} > 0; \qquad \frac{h_A - h_I}{x_A - x_I} = \frac{\Phi_{tot}}{\dot{m}_v} > 0$$

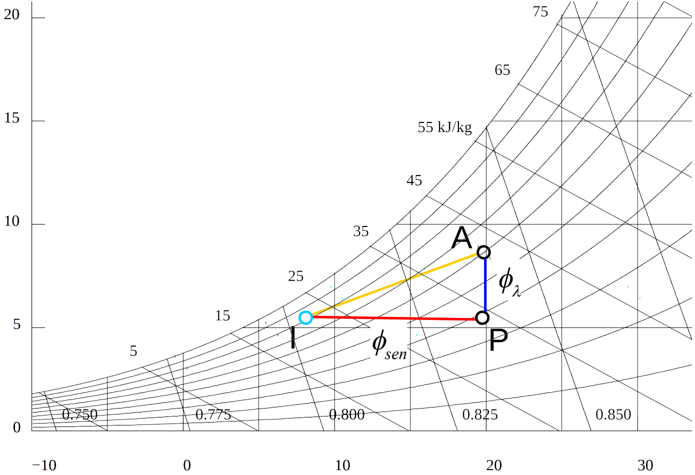
sensible and latent load

winter



Sensible and latent load

summer



Sensible and latent load

Balance

total load

$$\Phi_{tot} = \dot{m} \cdot (h_A - h_I)$$

auxiliary point

$$\theta_P = \theta_A$$

$$x_P = x_I$$

loads

$$\dot{m} \cdot (h_A - h_I) = \dot{m} \cdot (h_A - h_P) + \dot{m} \cdot (h_P - h_I)$$

$$\dot{m} \cdot (h_A - h_P) = \dot{m}_v \cdot (cp_v \cdot \theta_A + r_0) \simeq \dot{m}_v \cdot r_0 = \Phi_\lambda$$

$$\dot{m} \cdot (h_P - h_I) = \dot{m} \cdot (cp_a + x_I \cdot cp_v) \cdot (\theta_P - \theta_I) = \dot{m} \cdot c_{pau} \cdot (\theta_A - \theta_I)$$

$$\dot{m} \cdot (h_P - h_I) = \Phi_{sen}$$

Sensible Heat Ratio

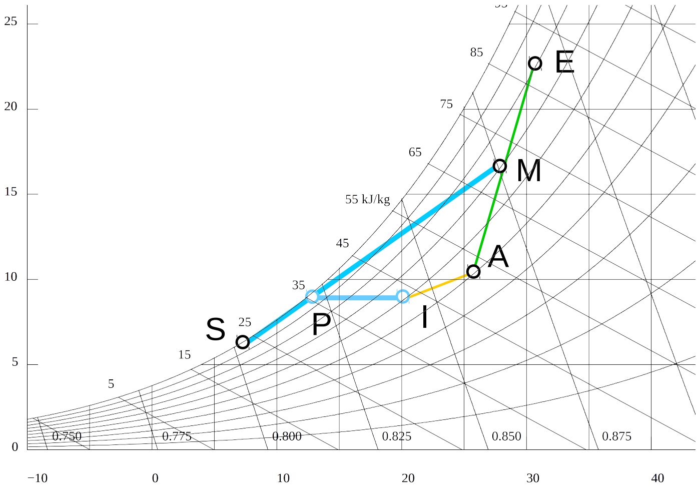
SHR

The sensible heat ratio (SHR) of an air conditioning process is defined as the ratio of the absolute value of sensible heat to the absolute value of total heat

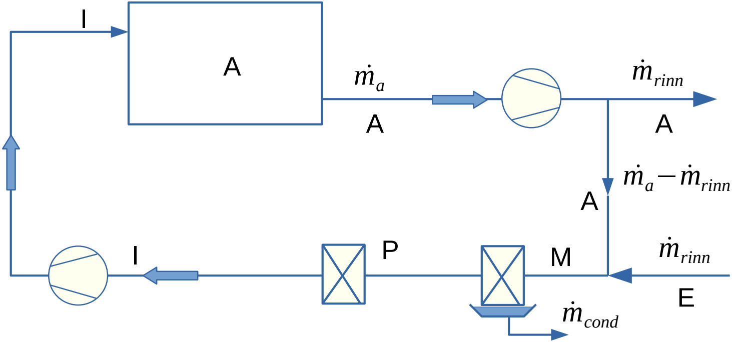
SHR

$$
\begin{aligned}
SHR &= \frac{\phi_s}{\phi_{tot}} \\
&= \frac{\phi_s}{\phi_s + \phi_\lambda}
\end{aligned}
$$

Summer air conditioning cycle

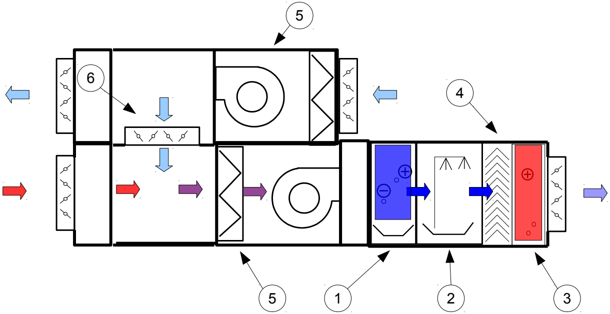


Summer condition



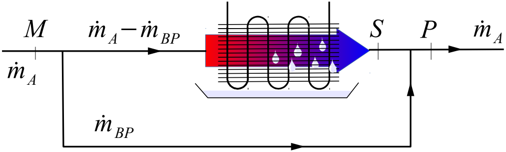
Air handling unit (AHU)

summer condition



1. cooling coil
2. humidifier (disabled)
3. heating coil
4. droplet eliminator
5. filter
6. recirculation

Bypass Factor



Mixing

$$BF = \frac{\dot{m}_{BP}}{\dot{m}_{AI}}$$

$$\dot{m}_{AI} h_P = \dot{m}_{BP} h_M + h_S(\dot{m}_{AI} - \dot{m}_{BP})$$

$$\dot{m}_{AI}(h_P - h_S) = \dot{m}_{BP}(h_M - h_S)$$

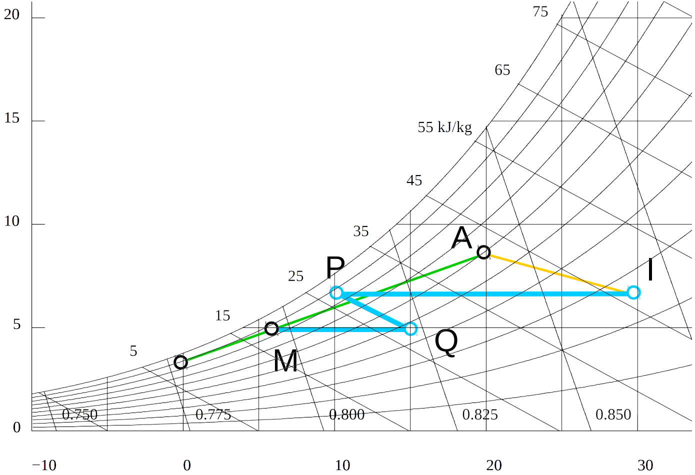
$$BF = \frac{(h_P - h_S)}{(h_M - h_S)} \approx \frac{(\theta_P - \theta_S)}{(\theta_M - \theta_S)}$$

$$BF = 0,67^n \quad 0 < BF < 1$$

n number of coil rows

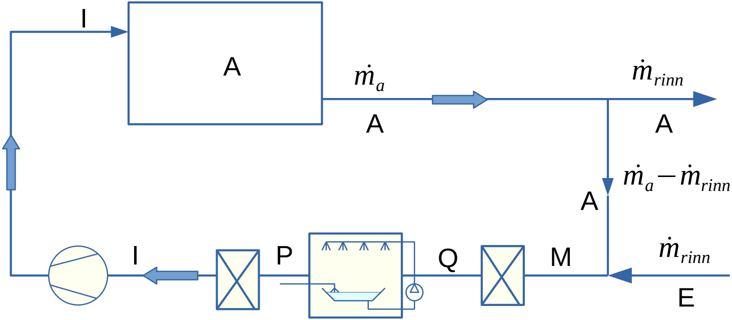
Winter air conditioning cycle

Design condition



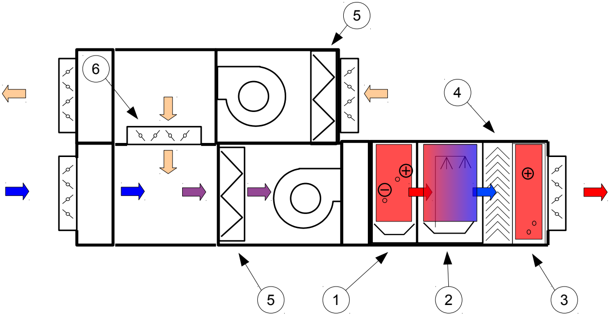
Winter air conditioning scheme

Adiabatic humidification



Air handling unit - AHU

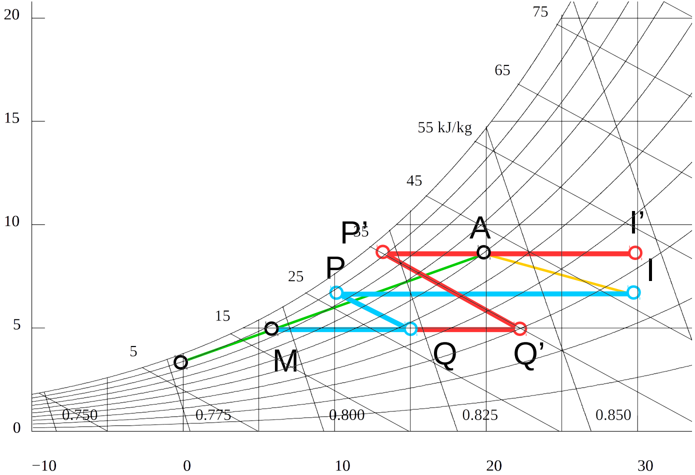
winter condition



1. Heating coil
2. Humidifier
3. Heating coil
4. droplet eliminator
5. filters
6. recirculation

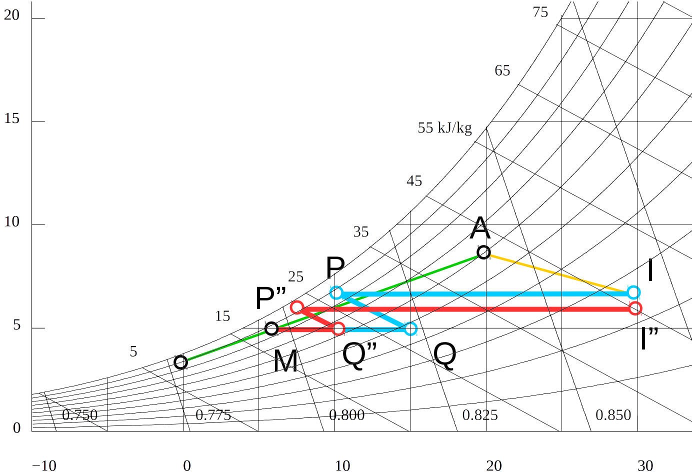
Winter air conditioning cycle

zero latent load



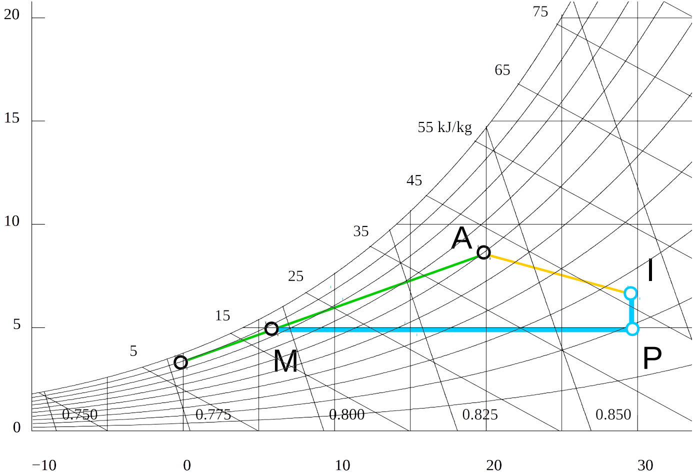
Winter air conditioning cycle

Maximum latent load



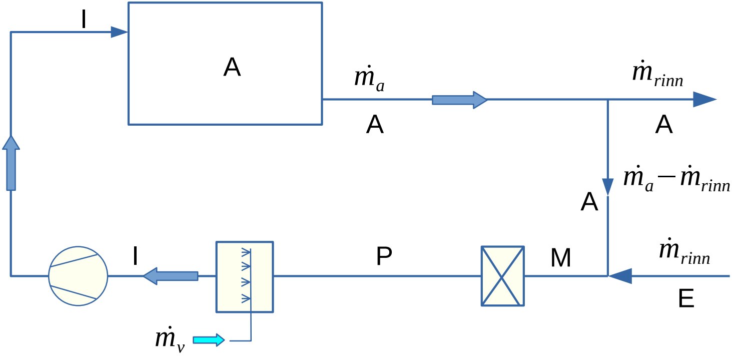
Winter air conditioning cycle

steam humidifier



winter working scheme

Steam humidifier



heating coil

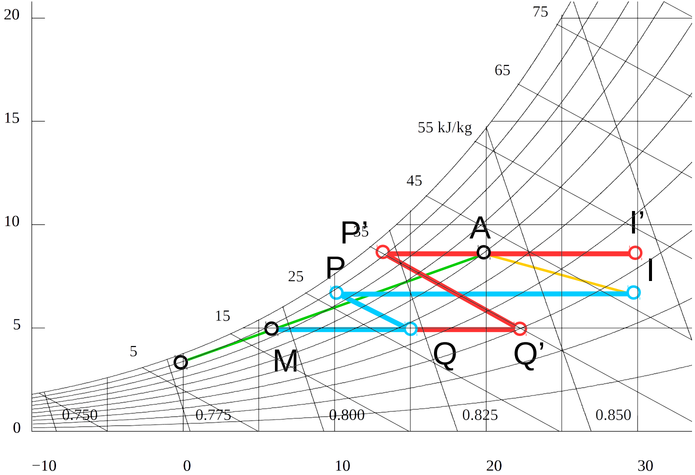
winter

Characteristics

- heating coil, can be used as a cooling coil during summer season
- hot water provided by a boiler
- drives the humidity of point *I*
- it is driven by an humidity sensor in the conditioned space

Winter air conditioning cycle

zero latent load



Heating coil

winter - zero latent load

AIr side

$$\Phi_{pre,MAX} = \dot{m}_{AI}(h_{Q'} - h_M) = \dot{m}_{AI} \cdot c_{p,aria}(\theta_{Q'} - \theta_M)$$

$$\Phi_{pre,MAX} = \dot{m}_{AI}\left[c_{pa}\theta_{P'} + x_M(r_o + c_{pv}\theta_{P'}) - c_{pa}\theta_M - x_M(r_o + c_{pv}\theta_M)\right]$$

$$\Phi_{pre,MAX} = \dot{m}_{AI}\left[c_{pa}(\theta_{Q'} - \theta_M) + x_M c_{pv}(\theta_{Q'} - \theta_M)\right]$$

$$\Phi_{pre,MAX} = \dot{m}_{AI}\left[c_{pau}(\theta_{Q'} - \theta_M)\right]$$

Cooling coil

Maximum latent load

coil heat balance

$$|\Phi_{fr}^{-}| = \dot{m}_{AI}(h_M - h_P) - \dot{m}_L \cdot h_L$$

$$\dot{m}_L h_L \ \approx 0 \rightarrow |\Phi_{fr}^{-}| = \dot{m}_{AI}(h_M - h_P)$$

Coil selection

$$BF = \frac{(h_P - h_S)}{(h_M - h_S)}$$

$$(h_M - h_P) = (h_M - h_S) + (h_S - h_P)$$

$$(h_M - h_P) = (h_M - h_S)(1 - BF)$$

BF BPF is selected to obtain $X_p = X_l$

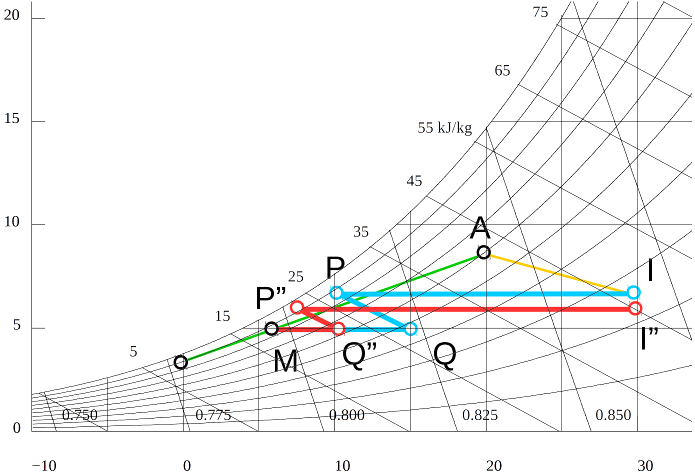
Water side

$$\Delta\theta_{H_2O} = |\theta_m - \theta_r| = 5 \ K, \ \theta_m = 7^o C \ \theta_r = 12^o C$$

$$|\Phi_{fr}^{-}| = \dot{m}_{H_2O} \cdot c_{H_2O} \cdot \Delta\theta_{H_2O}$$

Winter air conditioning cycle

Maximum latent load



heating coil

summer and winter condition

Winter, maximum latent load

$$\Phi_{post,max} = \dot{m}_{AI}(h_I - h_P) \; = \dot{m}_{AI} \cdot c_{pau}(\theta_I - \theta_P)$$

Water side

$$\theta_m = 70^o C, \; \Delta\theta_{H_2O} = (\theta_m - \theta_r) \approx 10 \; K$$

$$\dot{m}_{H_2O} = \frac{\Phi_{post,MAX}}{c_{H_2O} \cdot \Delta\theta_{H_2O}}$$

Flow rate

Limits

1. **outdoor air requirement** for acceptable air quality for occupants, depends on the number of people and activity.
2. **air inlet condition** θ_I
3. **dilute the concentration of the air contaminants**
4. **provide a desirable air velocity** to avoid air stratification:

minimum outdoor air

$$\dot{m}_{AI} \geq \dot{m}_{ext,min}$$

Flow rate

air inlet temperature

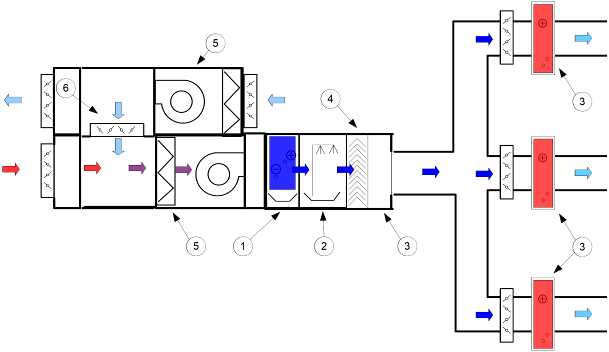
$$
\begin{aligned}
\Phi_{sen} &= \dot{m}_{AI} \cdot c_{pau} \cdot (\theta_A - \theta_I) \\
\dot{m}_{AI} &= \frac{|\Phi_{sen}|}{c_{pau} \cdot \Delta\theta} \\
\Delta\theta &\leq 20\ \mathrm{K}\ \mathit{inverno} \\
\Delta\theta &\leq 10\ \mathrm{K}\ \mathit{estate} \\
\dot{m}_{AI} &\geq \mathit{max}\{\dot{m}_{AI,inverno}, \dot{m}_{AI,estate}\}
\end{aligned}
$$

to avoid stratification

$$
\begin{aligned}
n_{lavaggio} &\geq 3\ \mathit{volumi}/\mathit{ora} \\
\dot{m}_{AI} &\geq 0,34 \cdot 3 \cdot V_{locale}
\end{aligned}
$$

Multizone system

summer condition



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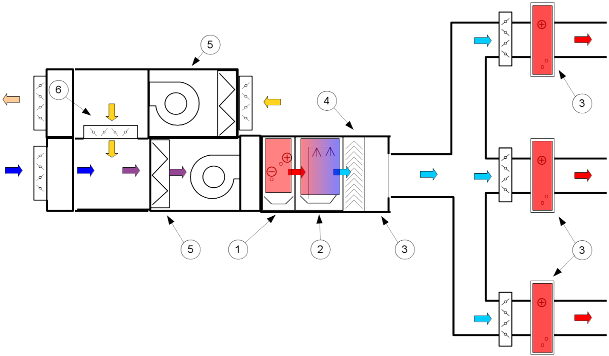
Multizone system

Winter condition



1. Heating coil
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6. recirculation

Multizone system

Characteristics

- inlet temperature is controlled
- can deal with variable sensible loads
- can be applied with uniform latent loads
- must guarantee the external air for the most demanding zone

latent load effect

$$\varphi_j \; increasesif \; \Phi_{\lambda,j} > \Phi_{\lambda,medio}$$

$$\varphi_j \; decreasesif \; \Phi_{\lambda,j} < \Phi_{\lambda,medio}$$

Multizone system

external air

air flow rate required

$$\dot{m}_{AI,j} \;\geq\; max\{\dot{m}_{rinn,min,j}, \dot{m}_{AI,inverno,j}, \dot{m}_{AI,estate,j}, \dot{m}_{lavaggio,j}\}$$

$$\dot{m}_{AI} = \sum \dot{m}_{AI,j}$$

external air flow rate required

$$R_j = \frac{\dot{m}_{rinn,min,j}}{\dot{m}_{AI,j}}$$

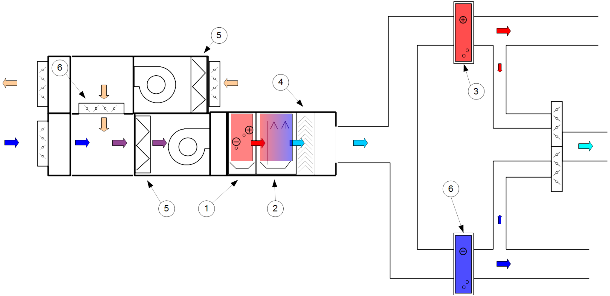
$$R_{j,max} = R_{j,tot} = \frac{\dot{m}_{rinn,tot}}{\dot{m}_{AI}}$$

$$\dot{m}_{rinn,tot} = R_{j,max}\dot{m}_{AI}$$

there is an increase in energy consumption because the external air will be greater than the minimum necessary in

Multizone system

dual-ducts system



1. Heating coil
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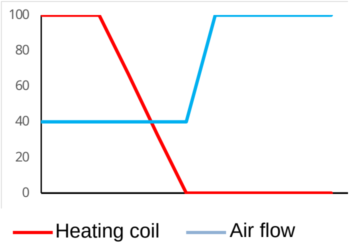
VAV Systems



- Air flow changes with the load
- if the load is reduced first the air flow is reduced
- possible use of variable speed ventilators or using volume dampers
- air flow is reduced up to 40
- a limit value of air flow is required for the correct air distribution
- when the load decreases the control is obtained with the hot coil
- in winter conditions the minimum air flow can be used