Heat and Cold Energy Demands of Buildings

Module 2.4
Building side hydronic systems

SHaKE – Sharing Heat and Knowledge on Energy Communities
Erasmus+ KA220-HED Cooperation Partnerships in HE
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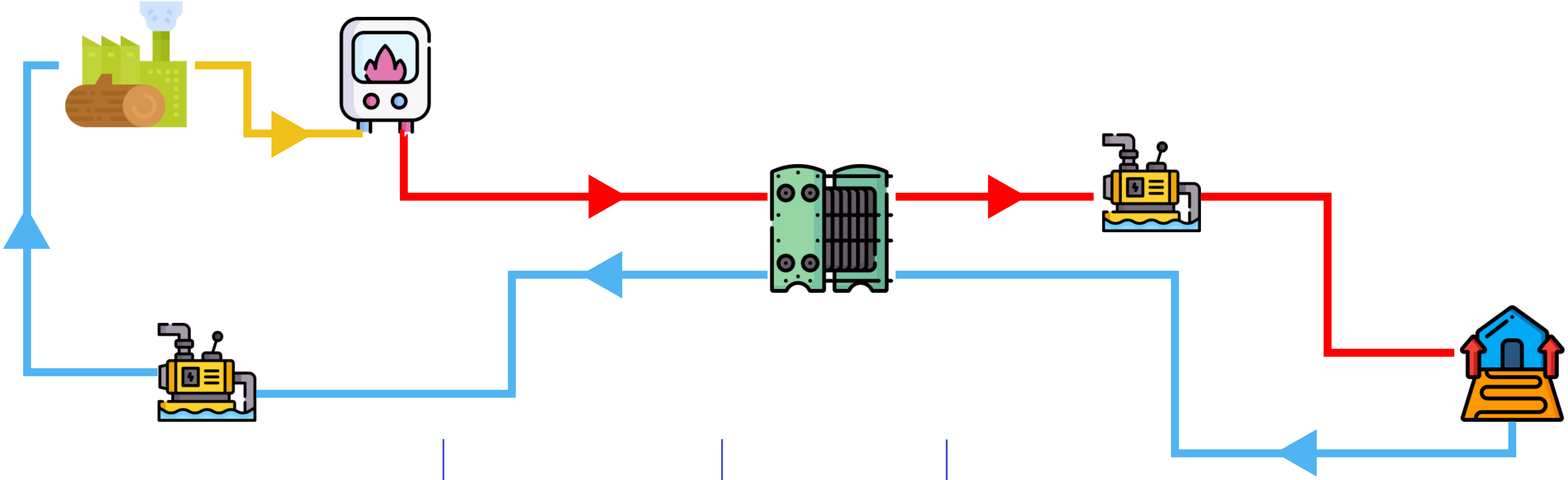
SHaKE
Sharing Knowledge on Energy Communities

1. Introduction

Once the consumption of the buildings has been determined, it is necessary to choose and size the distribution system



Heat generation plant | Primary network | Substation | Secondary network / Distribution system

1. Introduction

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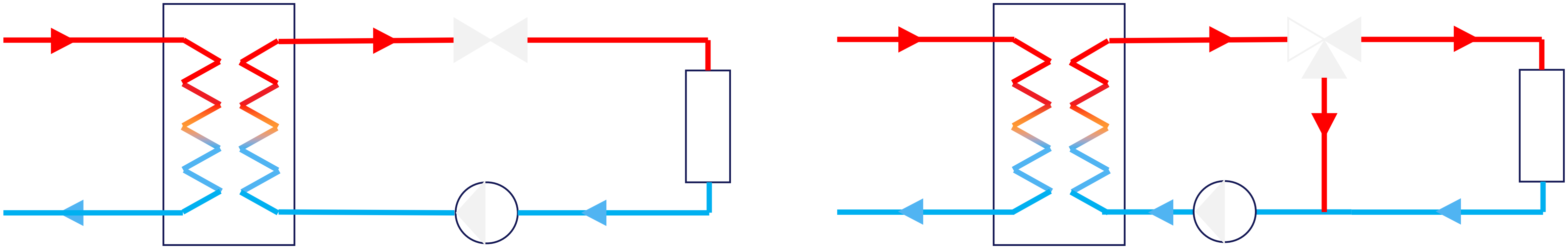


Which emitters ?

Which pump ?

How to design the pipes ?

Which valves ?

1. Introduction

Once the consumption of the buildings has been determined it is necessary to choose and size the distribution system

Calculation of room heating needs

Choice and sizing of the emitters

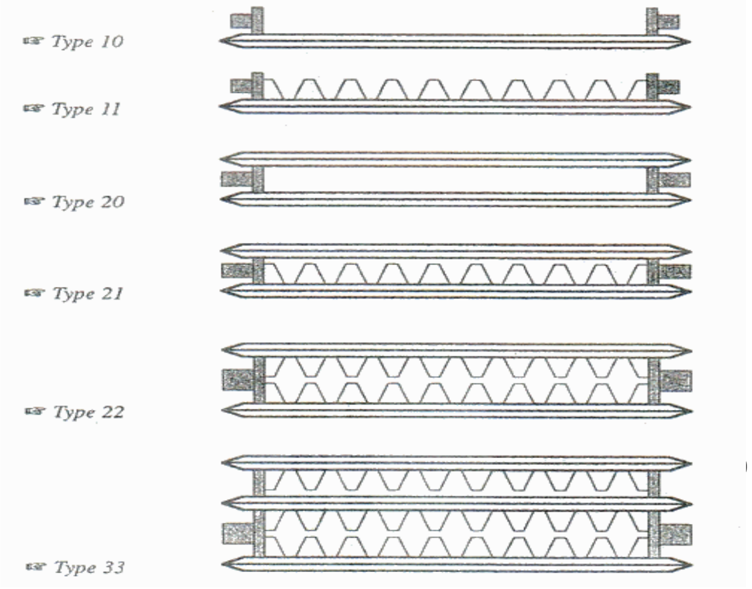
Sizing of the hydronic distribution

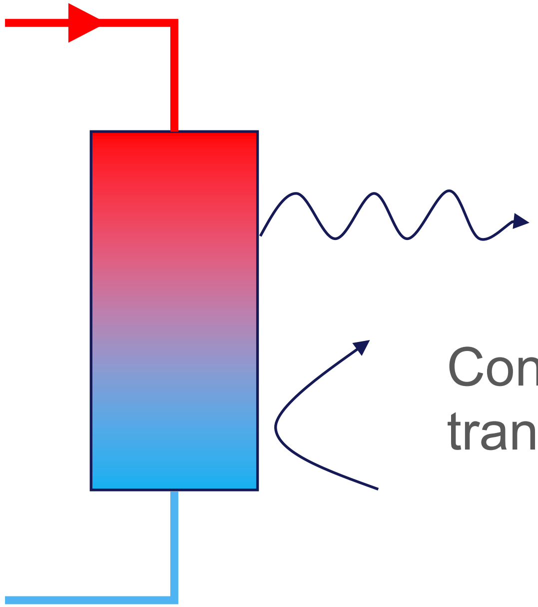
2. Heat emitters

Which distribution systems and emitters are usually used with a DH network?

Radiator	Heating floor	Fan coil
		
+ Price	+ Space	+ Space
+ Easy to install	+ Comfort	+ Reversible
– Space	– Price	– Comfort
– Non-reversible	– Inertia	– Performance

2.1 Radiators





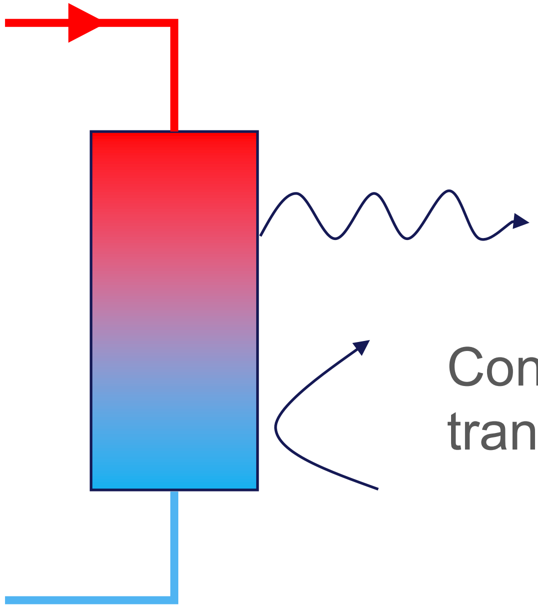
Radiative transfer

Convective transfer

$$\dot{Q}_{con} = h_{conv} A \left(\frac{T_{in}+T_{out}}{2} - T_{air}\right)$$

Natural convection depending on the geometry and flow regime

2.1 Radiators



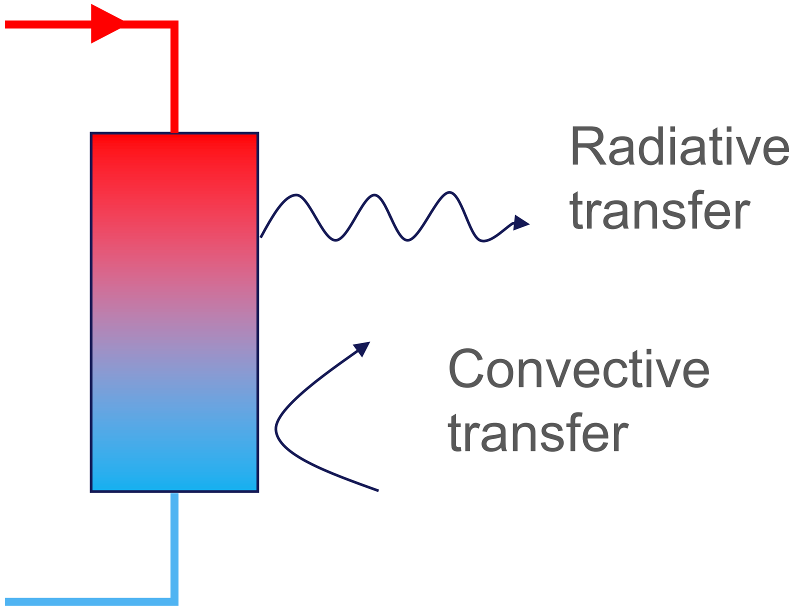
$$\dot{Q}_{con} = h_{conv}\, A \left(\frac{T_{in}+T_{out}}{2} - T_{air}\right)$$

$$\dot{Q}_{rad} = 4\sigma\varepsilon \left(\frac{T_{moy,rad}+T_{op}}{2}\right)^3 A \left(\frac{T_{in}+T_{out}}{2} - T_{op}\right)$$

$$\dot{Q}_{rad} = h_{rad}\, A \left(\frac{T_{in}+T_{out}}{2} - T_{air}\right)$$

$$\dot{Q}_{radiator} = \underbrace{\dot{Q}_{con}}_{\approx 70\%} + \underbrace{\dot{Q}_{rad}}_{\approx 30\%}$$

2.1 Radiators



According to European Norm EN-442 :

$$\dot{Q}_{radiator} = UA\,\Delta T^{n} = UA\left(T_{moy,rad} - T_{air}\right)^{n}$$

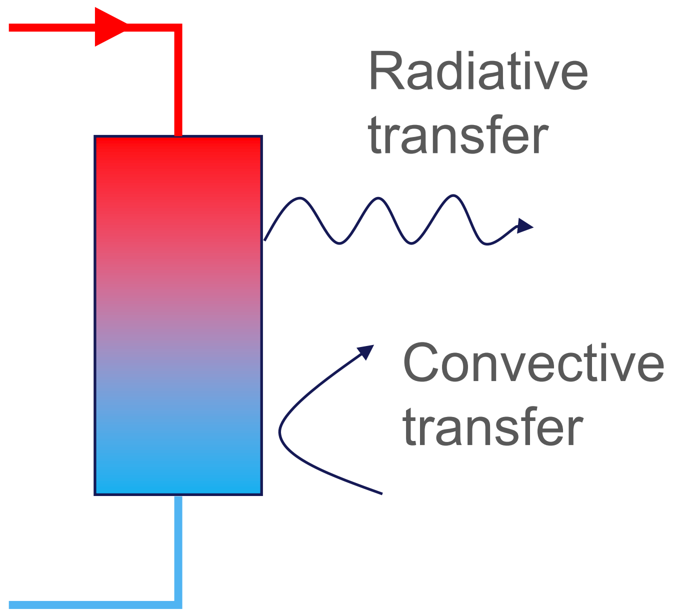
Determined through standards based-test

$1,3 < n < 1,5$

$T_{in,rad}$	$T_{out,rad}$	$T_{moy,rad}$
80	60	70
75	55	65
60	40	50
55	45	50

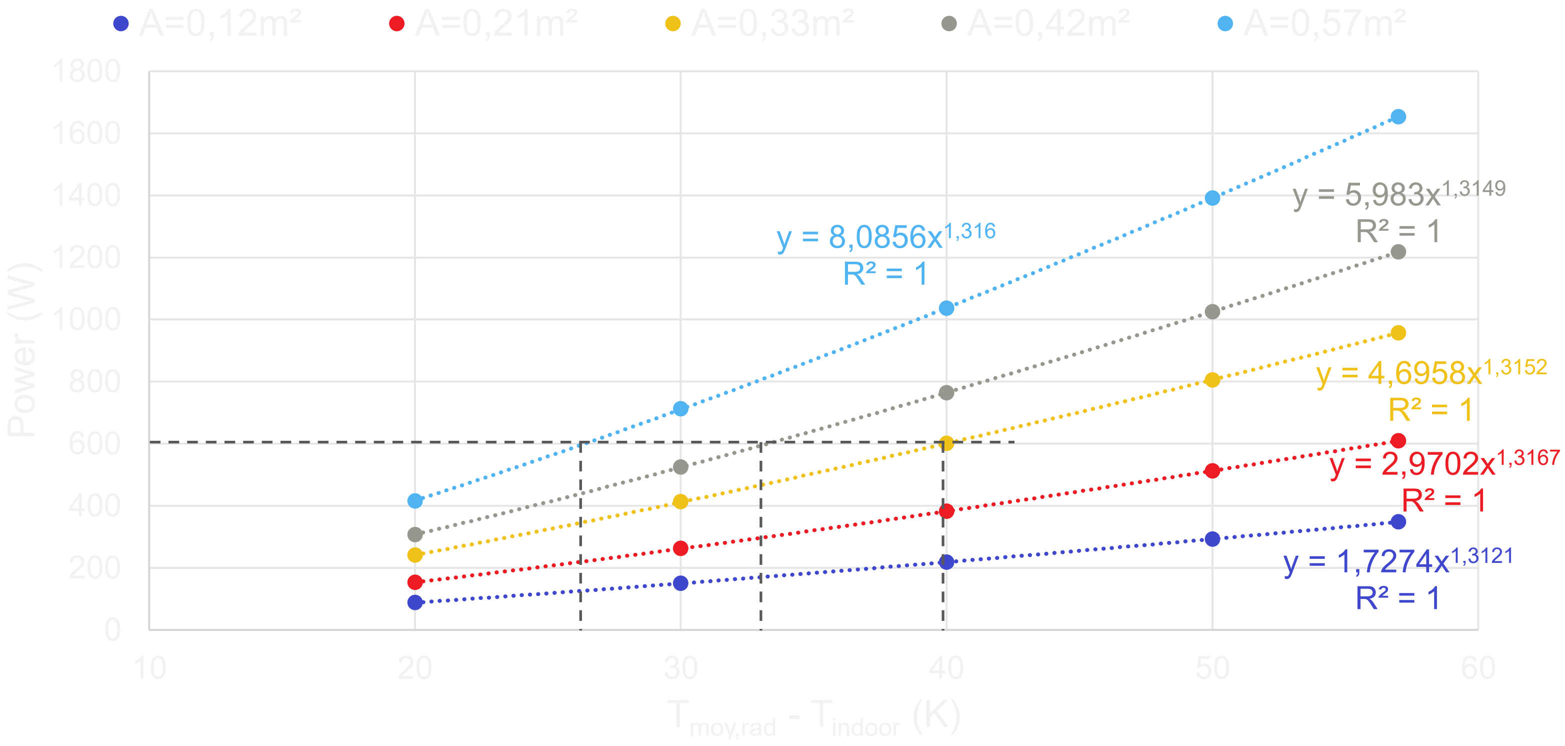
Different temperature regimes are possible. A temperature regime is the inlet and outlet water temperature of a radiator at the design point (for example for $T_{outdoor} = -7°C$)

2.1 Radiators



According to European Norm EN-442 :

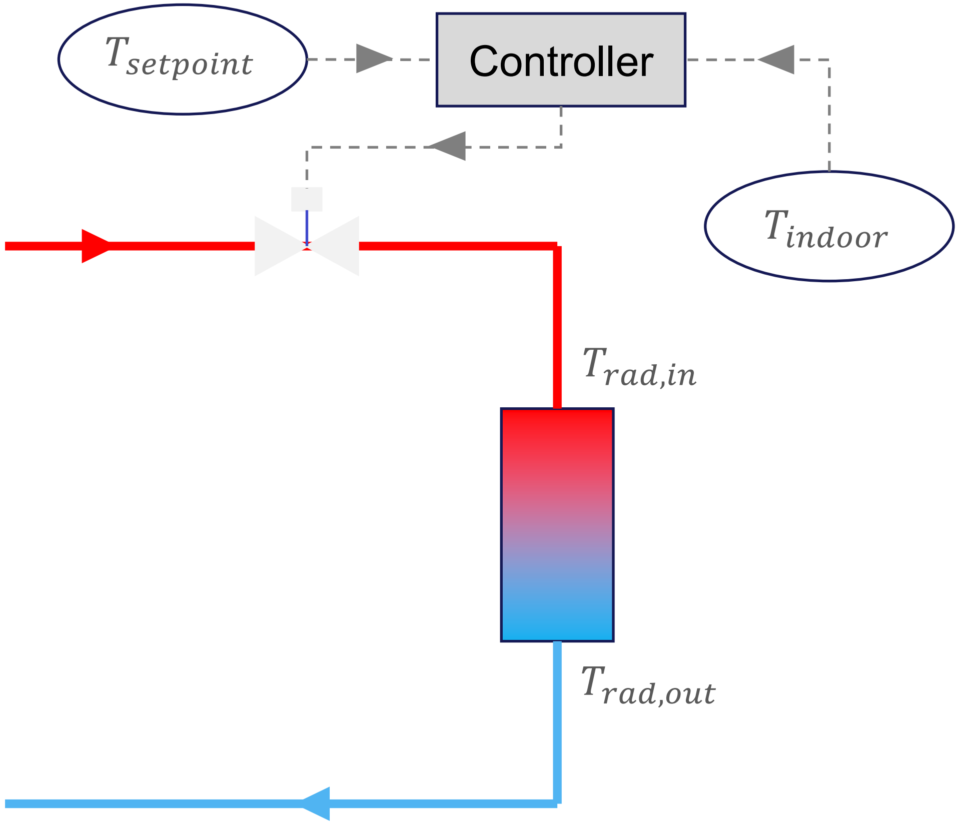
$$\dot{Q}_{radiator} = UA\,\Delta T^{n} = UA\left(T_{moy,rad} - T_{indoor}\right)^{n}$$

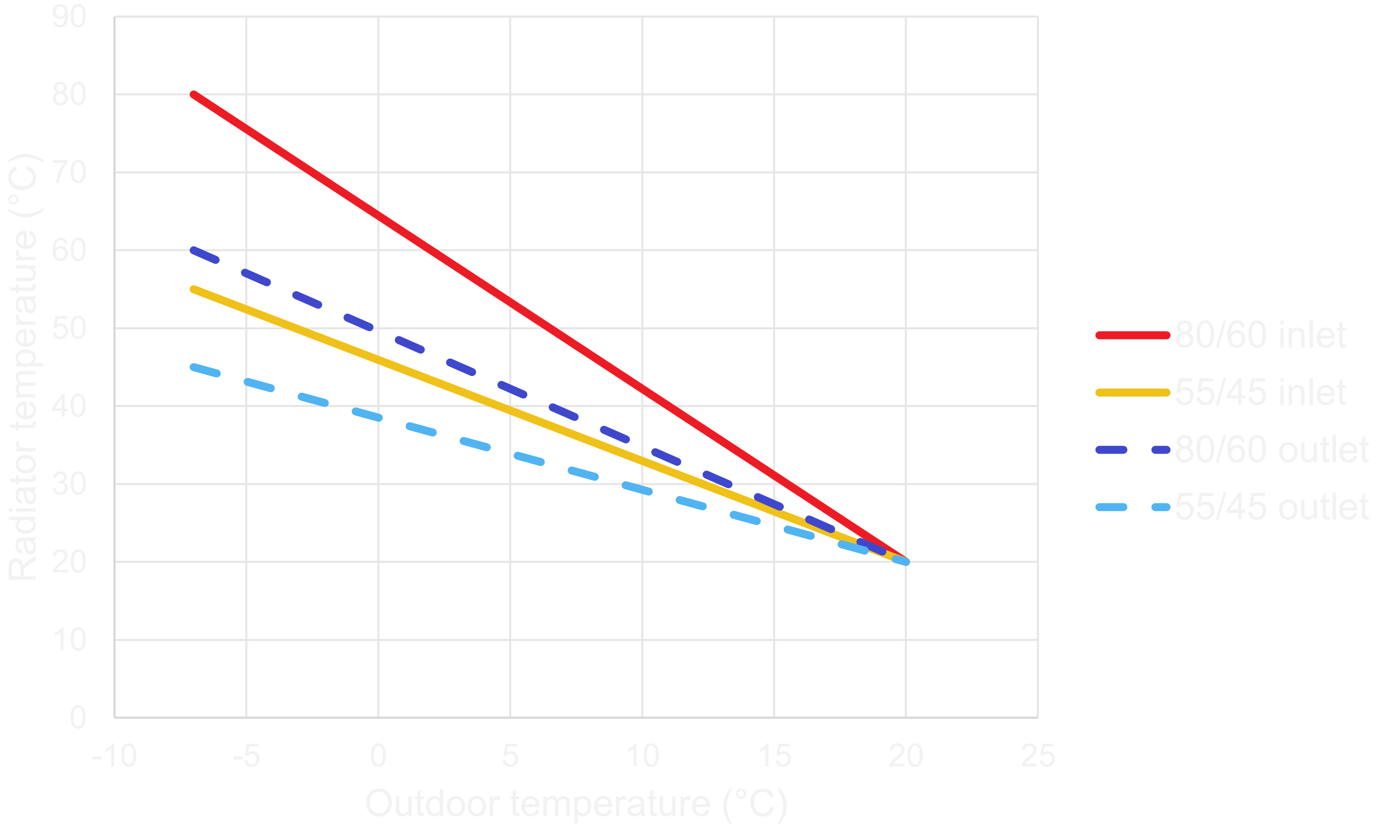


For the same heating power, a radiator with lower mean temperature has a larger area

2.1 Radiators

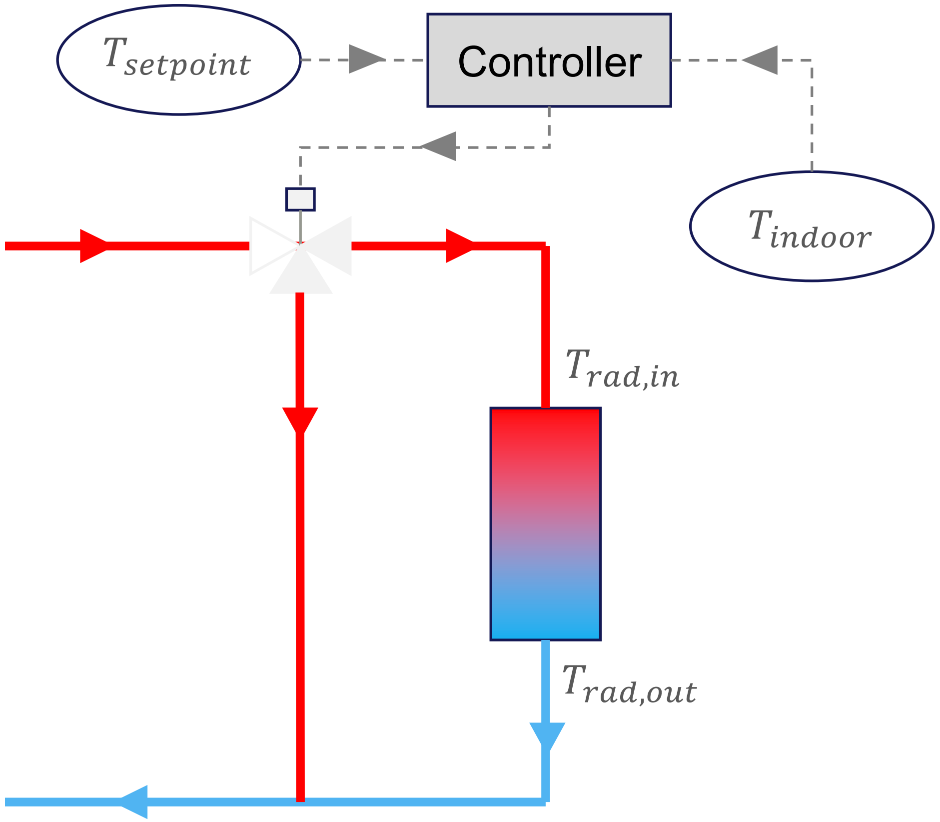
$$\dot{Q}_{radiator} = UA\,\Delta T^{n} = UA\left(T_{moy,rad} - T_{indoor}\right)^{n} = \dot{m}_{rad}\,Cp\left(T_{rad,in} - T_{rad,out}\right)$$





2.1 Radiators

$$\dot{Q}_{radiator} = UA\,\Delta T^{n} = UA\left(T_{moy,rad} - T_{indoor}\right)^{n} = \dot{m}_{rad}\,Cp\left(T_{rad,in} - T_{rad,out}\right)$$



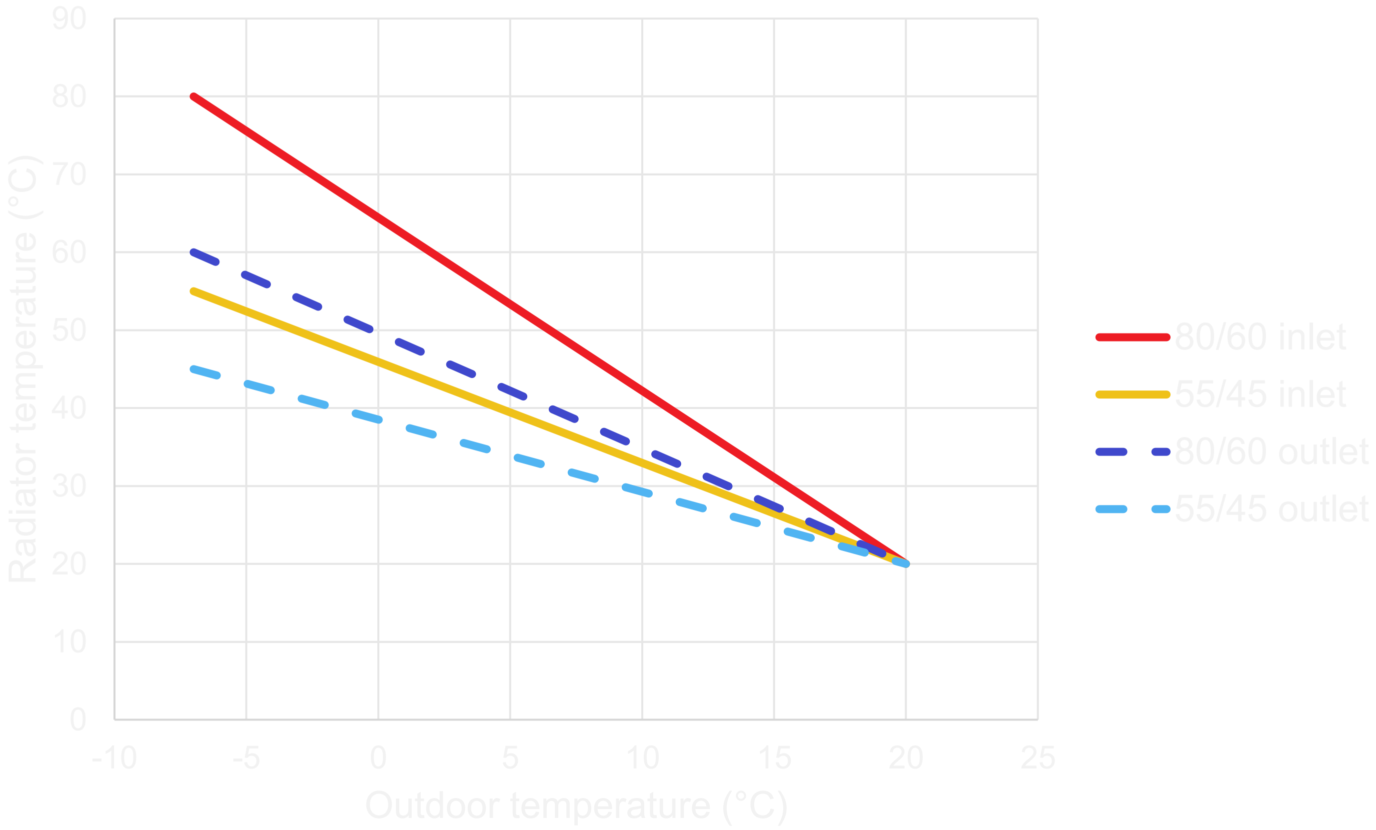
$T_{setpoint}$

Controller

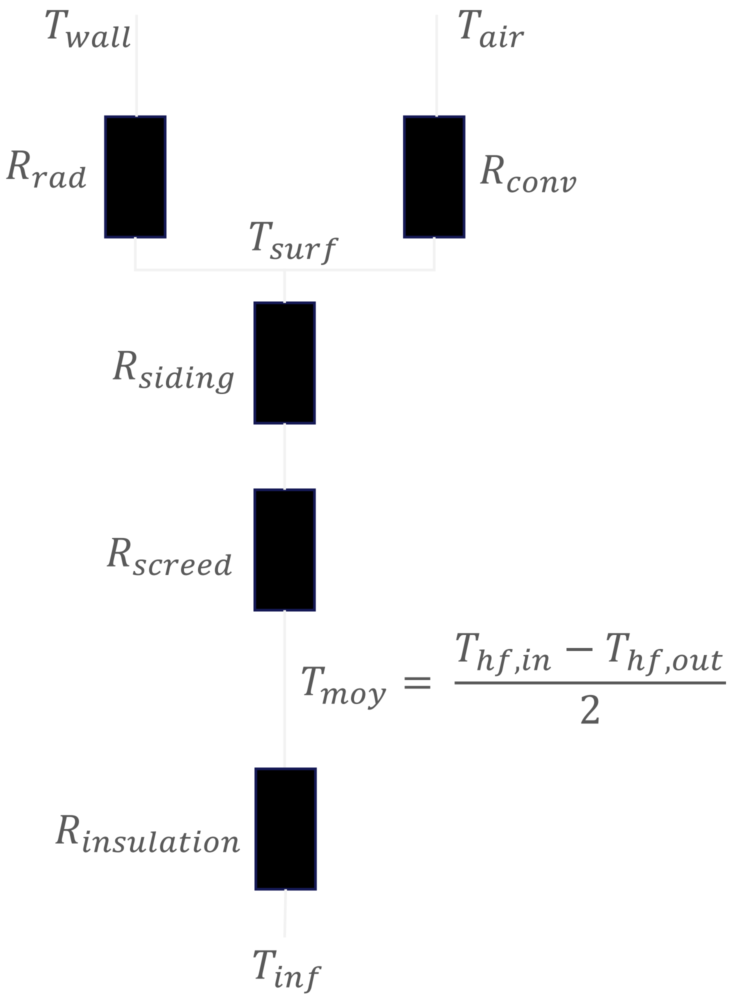
T_{indoor}

$T_{rad,in}$

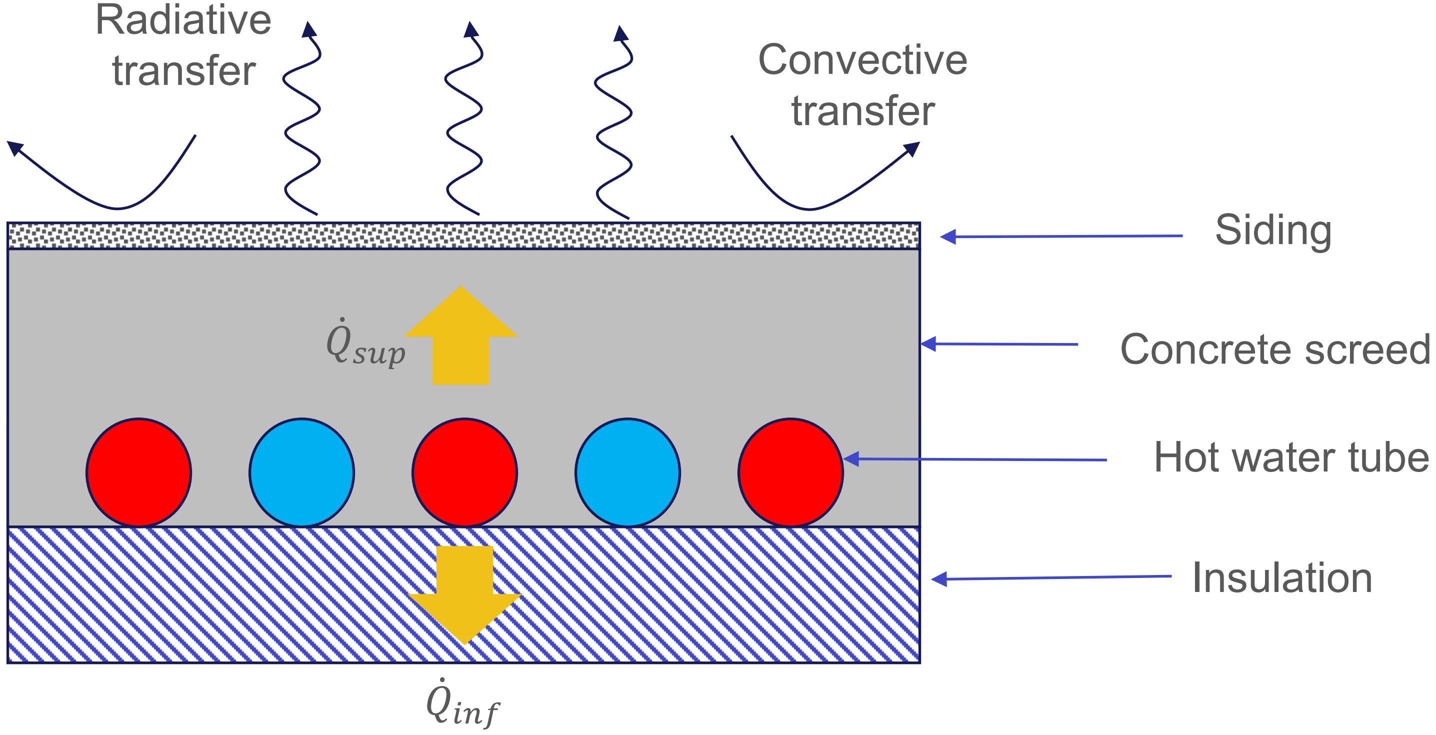
$T_{rad,out}$



2.2 Heating floor



$$T_{moy} = \frac{T_{hf,in} - T_{hf,out}}{2}$$



$$\dot{Q}_{water} = \dot{m}_{water}\, Cp\,\left(T_{hf,in} - T_{hf,out}\right) = \dot{Q}_{sup} + \dot{Q}_{inf}$$

$$\dot{Q}_{water} = \frac{T_{moy} - T_{surf}}{R_{siding} + R_{screed}} + \frac{T_{moy} - T_{inf}}{R_{insulation}}$$

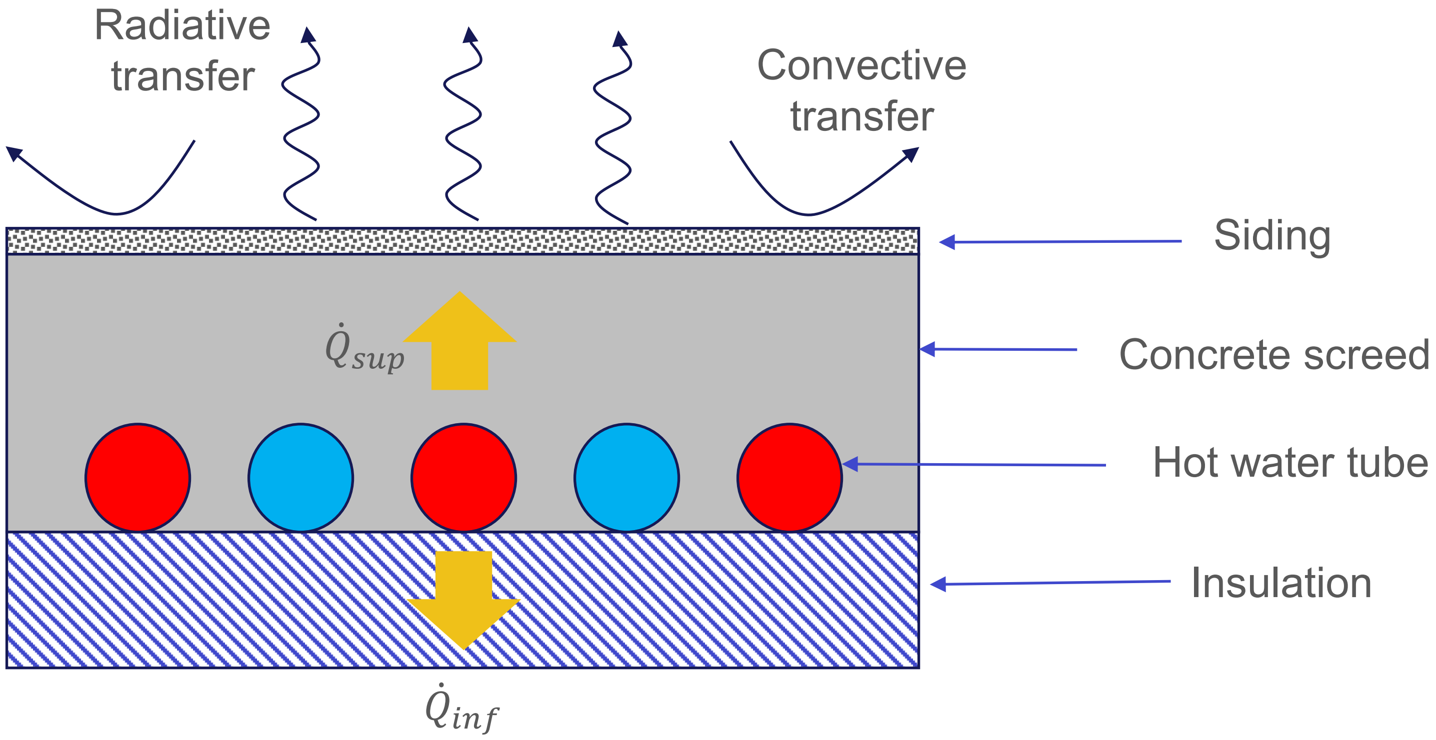
2.2 Heating floor

$$\dot{Q}_{sup} = \dot{Q}_{hf} = \overset{\approx 70\%}{\dot{Q}_{rad}} + \overset{\approx 30\%}{\dot{Q}_{conv}}$$

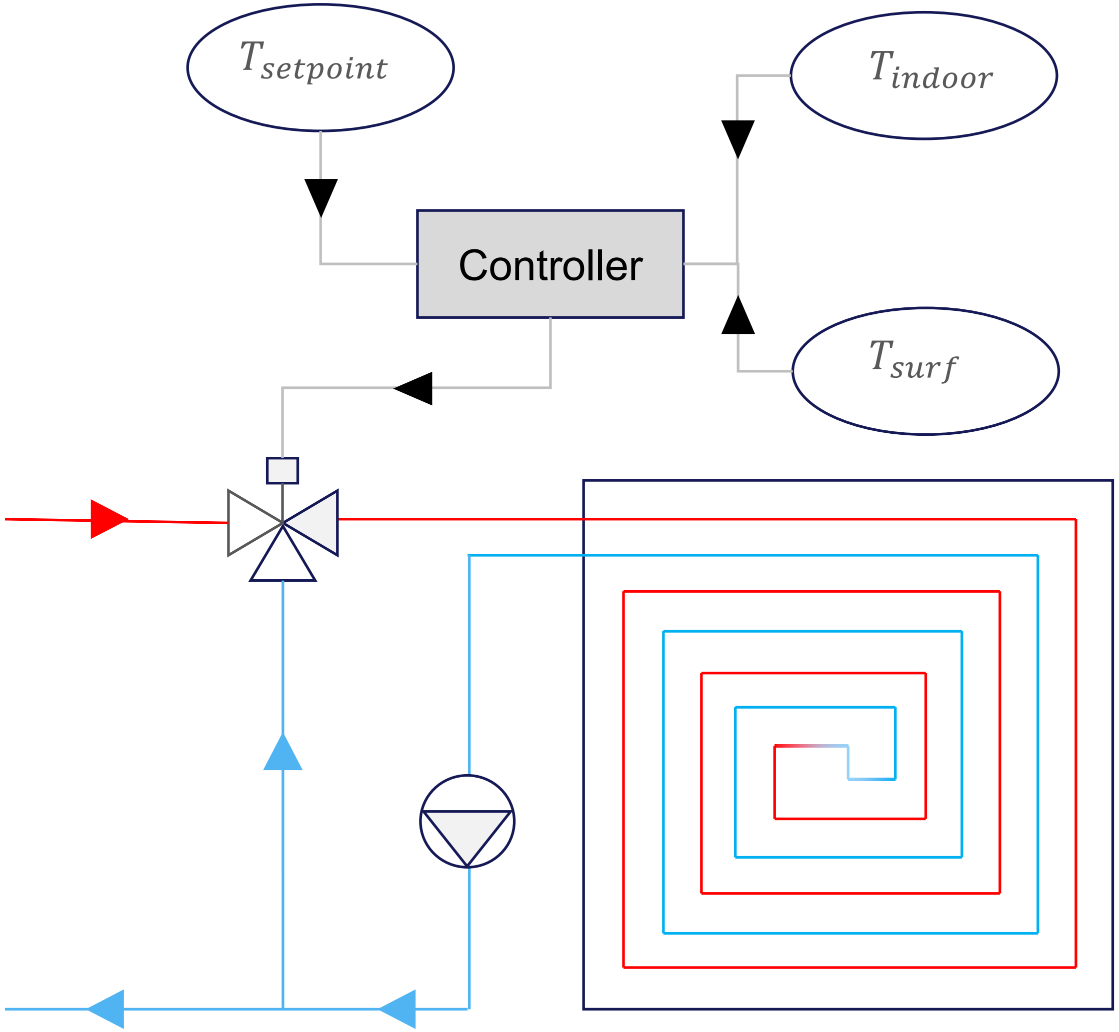
$$\dot{Q}_{rad} = h_{rad}\, A \left(T_{surf} - T_{op}\right)$$

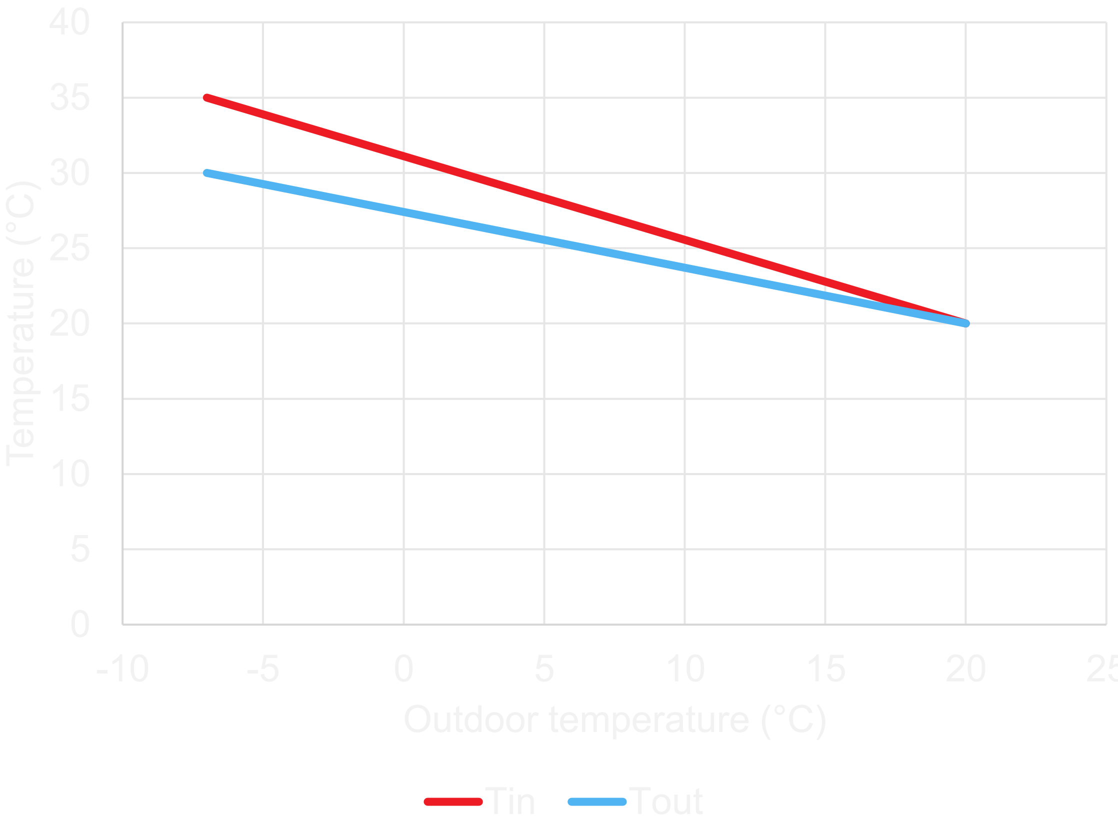
$$\dot{Q}_{conv} = h_{conv}\, A \left(T_{surf} - T_{air}\right)$$

Limited to 28°C for health reason



2.2 Heating floor

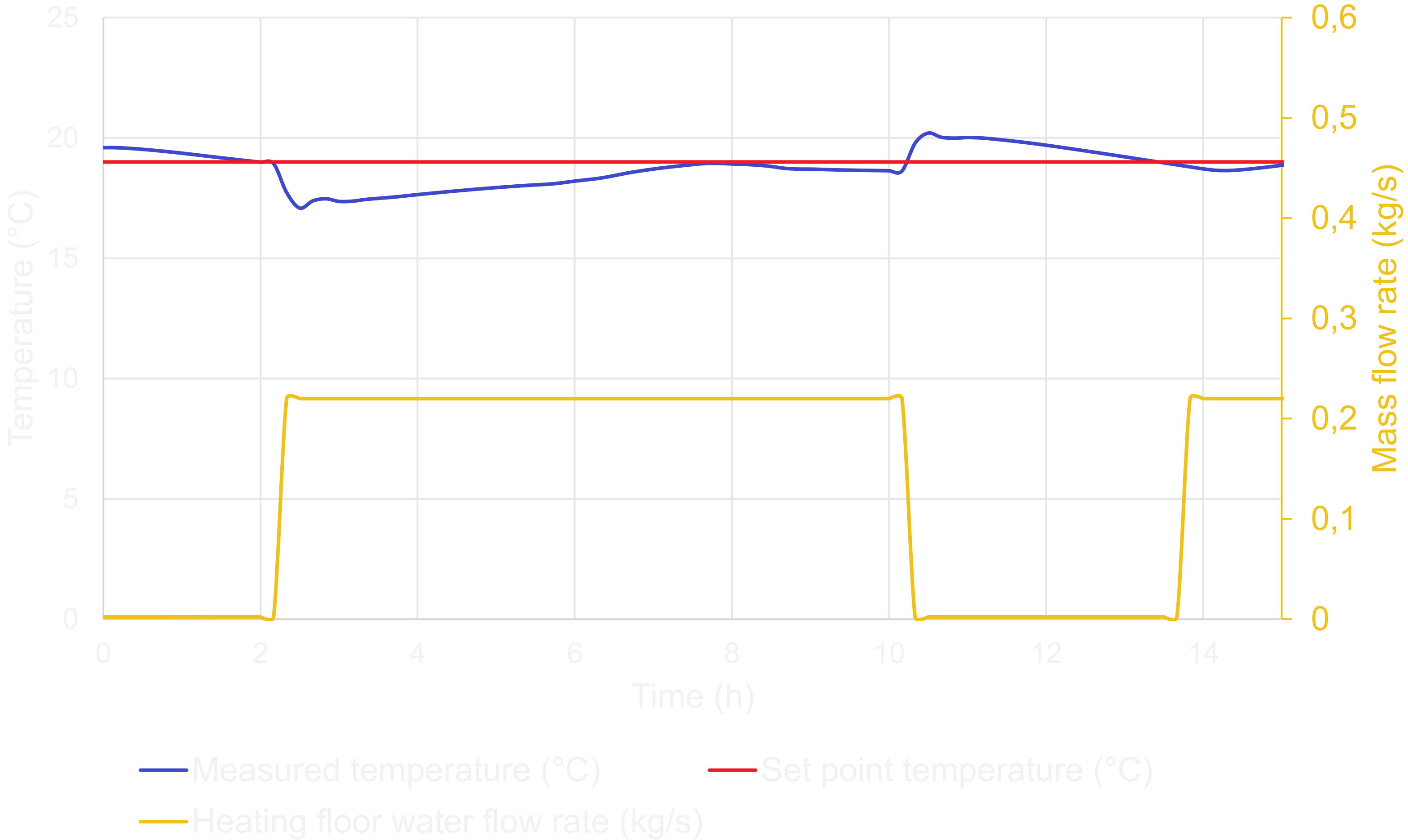




2.2 Heating floor

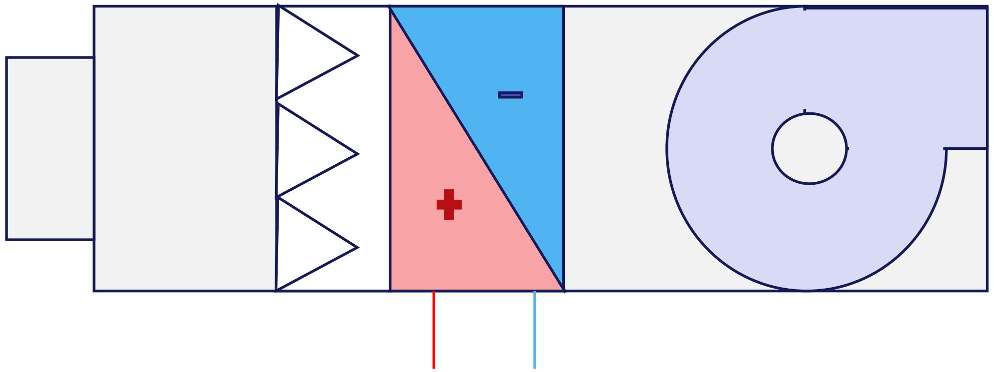
Contrary to the radiators, the heating floor has a certain inertia due to mass of the floor (concrete, …) and the diffusion of the heat into the pipe

When the set point temperature is reached, the water flow rate into the pipes is stopped but the indoor temperature continue to increase

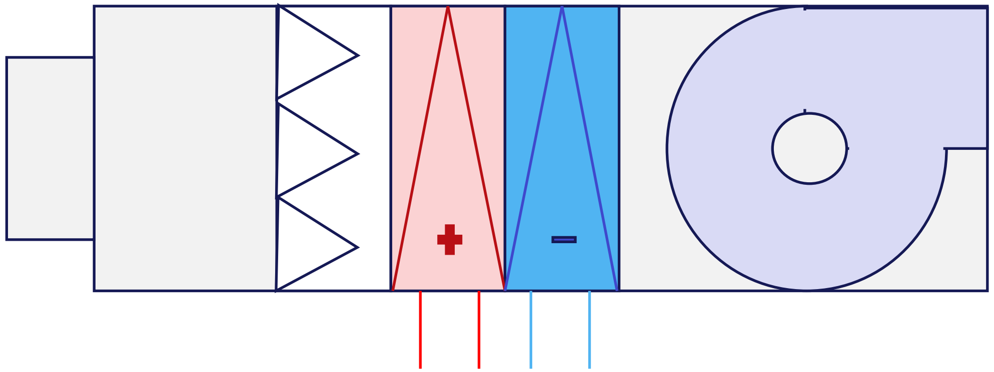


2.3 Fan coil

- A fan coil can be composed of:
  - A filter
  - A fan
  - One or two heat exchangers
  - Electrical resistance
  - Condensate drip tray

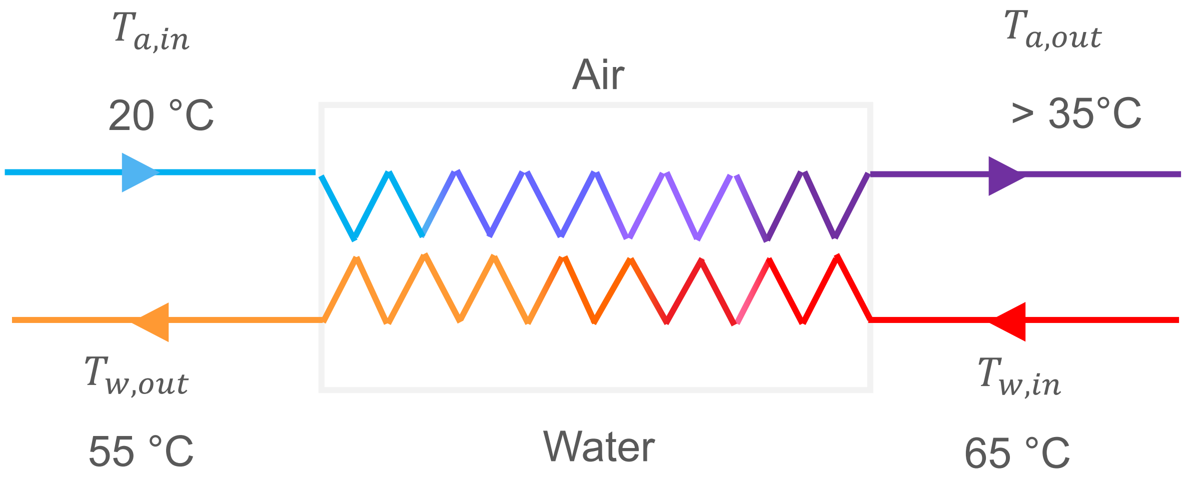


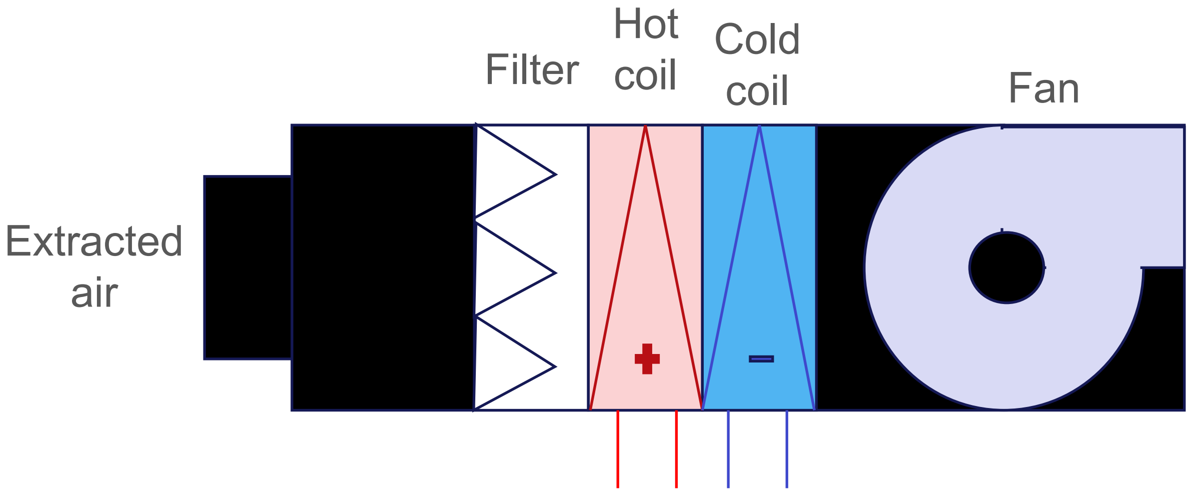
2-pipe reversible fan coil unit



4-pipe fan coil unit

2.3 Fan coil





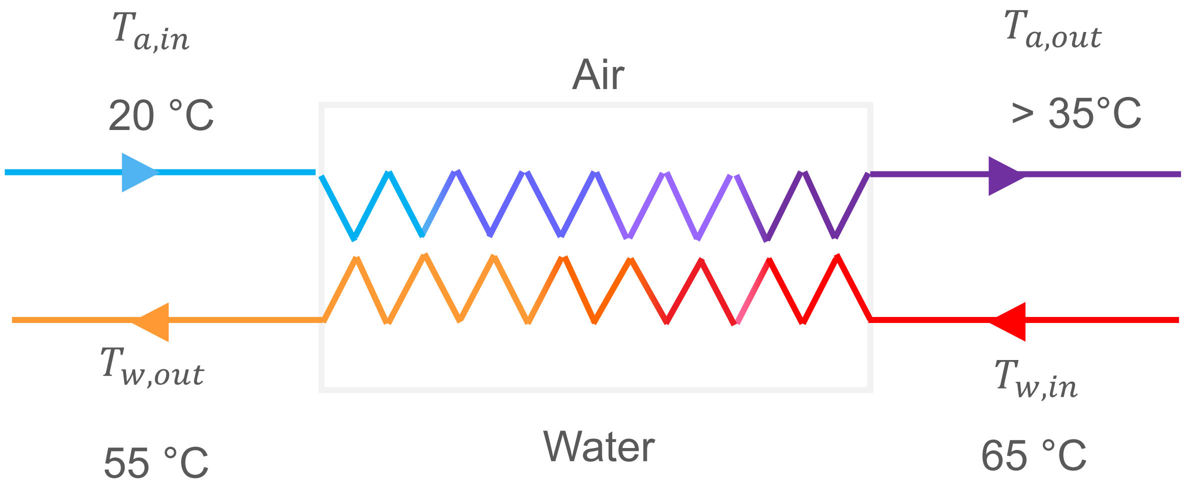
Compared to the radiator, the heat exchange is better with the fan coil. Indeed, the latest works in forced convection leading to better heat convection coefficient

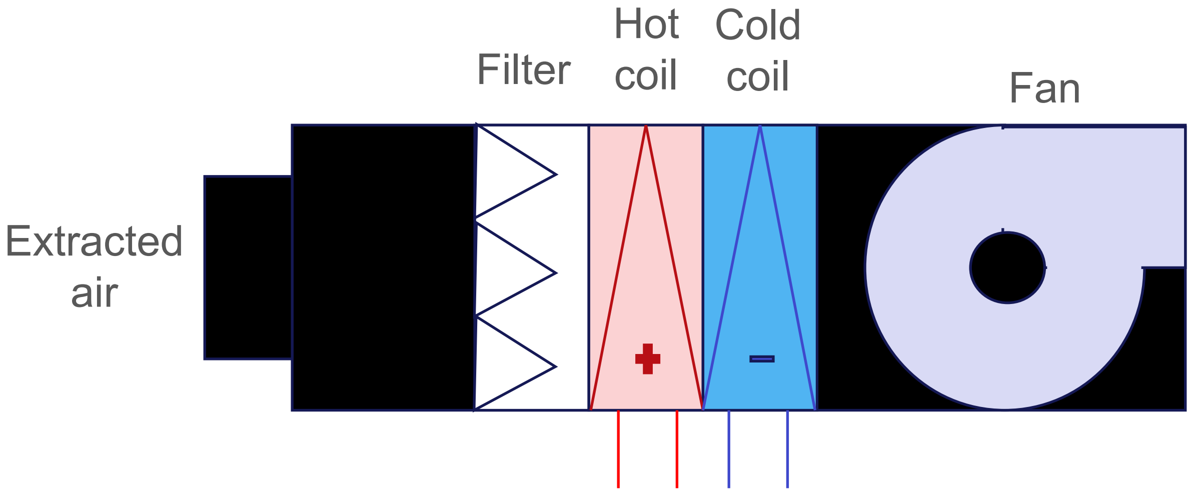
$$\dot{Q} = \dot{m}_a Cp_a \left(T_{a,out} - T_{a,in}\right)$$

$$\dot{Q} = \dot{m}_w Cp_w \left(T_{w,in} - T_{w,out}\right)$$

$$E = \frac{\dot{Q}}{\min(\dot{m}_a Cp_a;\ \dot{m}_w Cp_w)\left(T_{w,in} - T_{a,in}\right)}$$

2.3 Fan coil





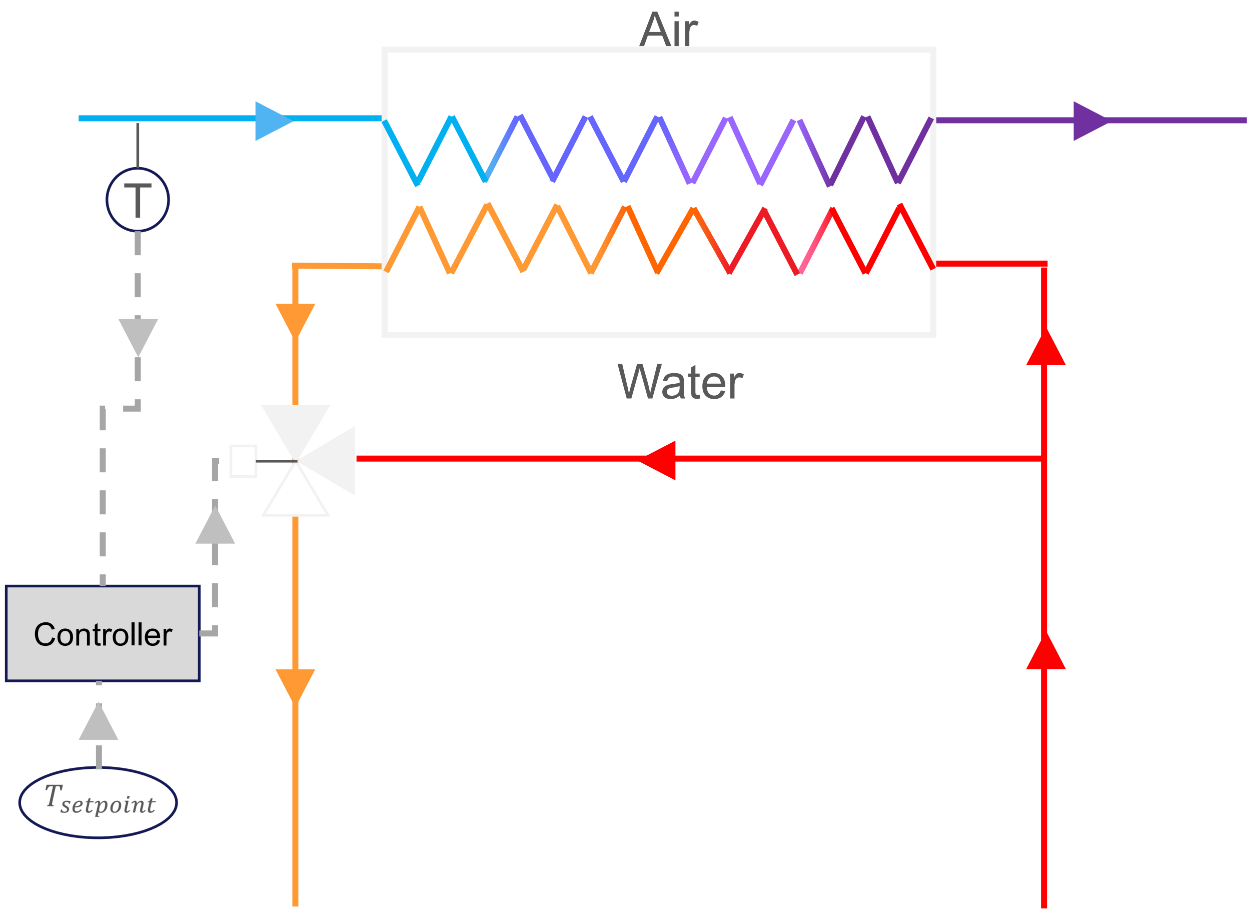
As only one HEX is used to supply heat and cold. For the cooling mode the temperature regime is 7°C/12°C. So, to avoid a lack of performance due to a HEX oversizing in heating mode the temperature regime must be lower

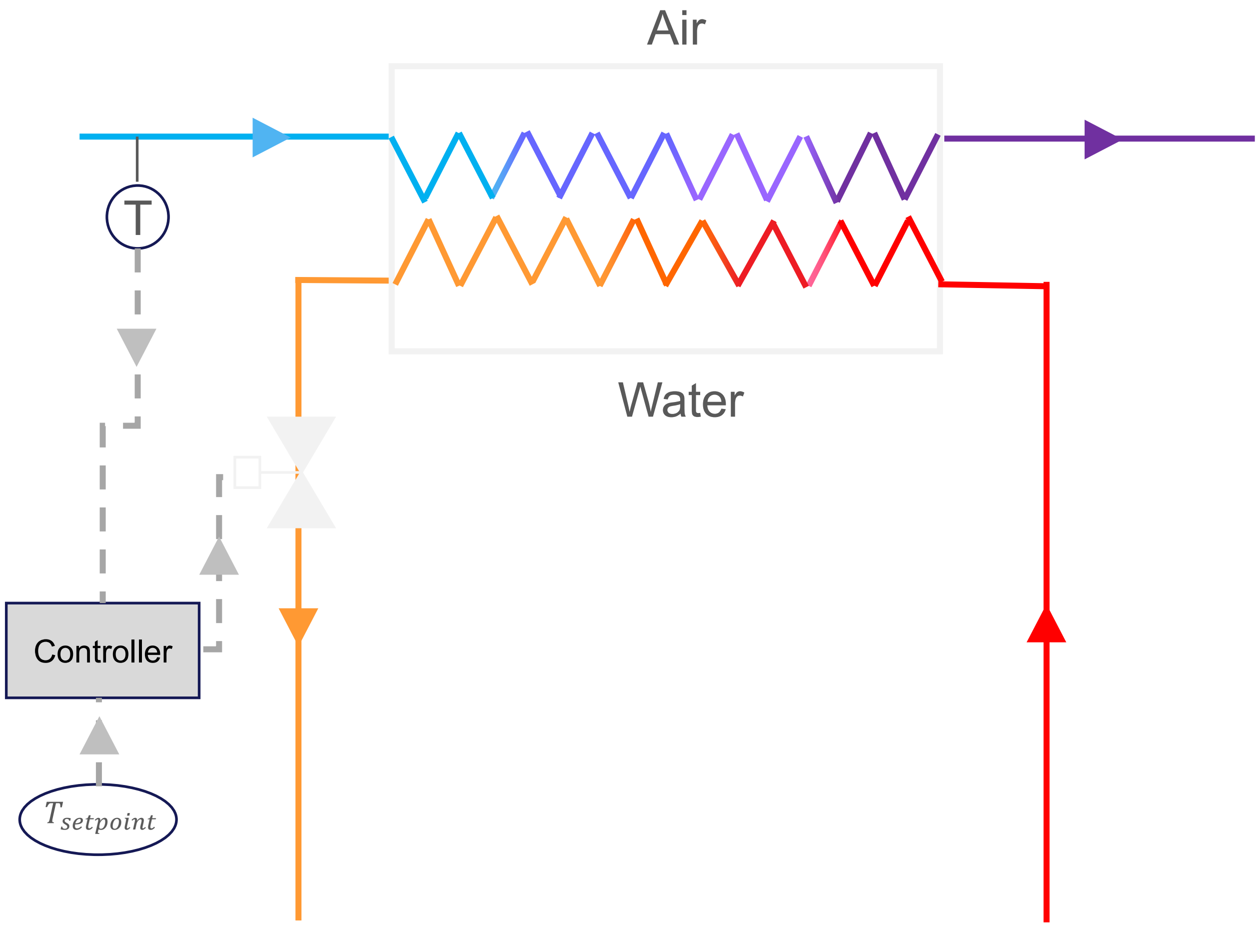
$$\dot{Q} = \dot{m}_a Cp_a \left(T_{a,out} - T_{a,in}\right)$$

$$\dot{Q} = \dot{m}_w Cp_w \left(T_{w,in} - T_{w,out}\right)$$

$$E = \frac{\dot{Q}}{\min(\dot{m}_a Cp_a;\ \dot{m}_w Cp_w)\left(T_{w,in} - T_{a,in}\right)}$$

2.3 Fan coil


Air
T
Water
Controller
$T_{setpoint}$


Air
T
Water
Controller
$T_{setpoint}$

3. Cold emitters

Which distribution systems and emitters are usually used with a DH network?

Cooling ceiling

- + Comfort
- + Reversible
- − Price
- − Limited power

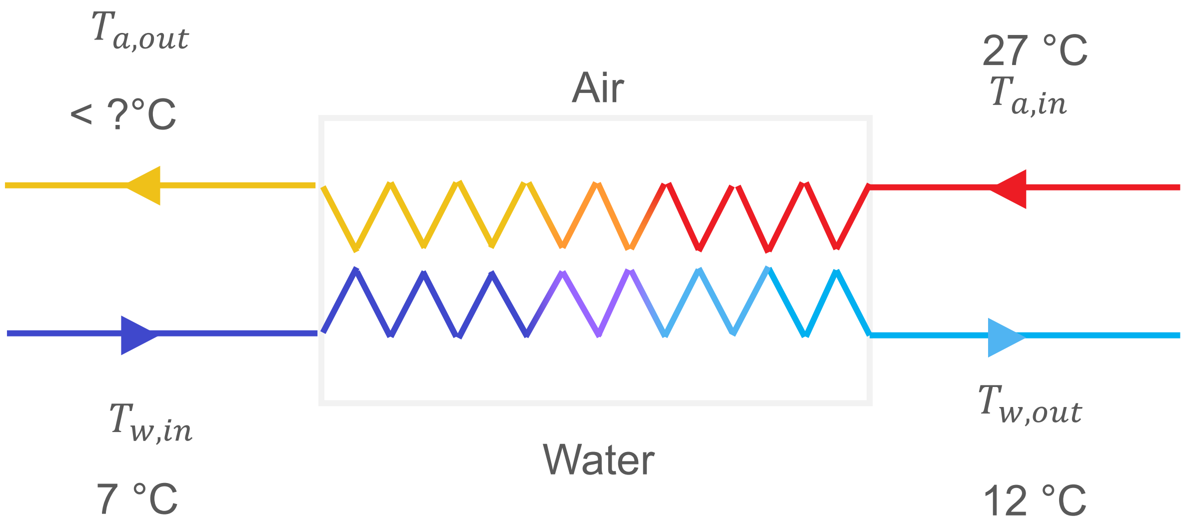
Cooling floor

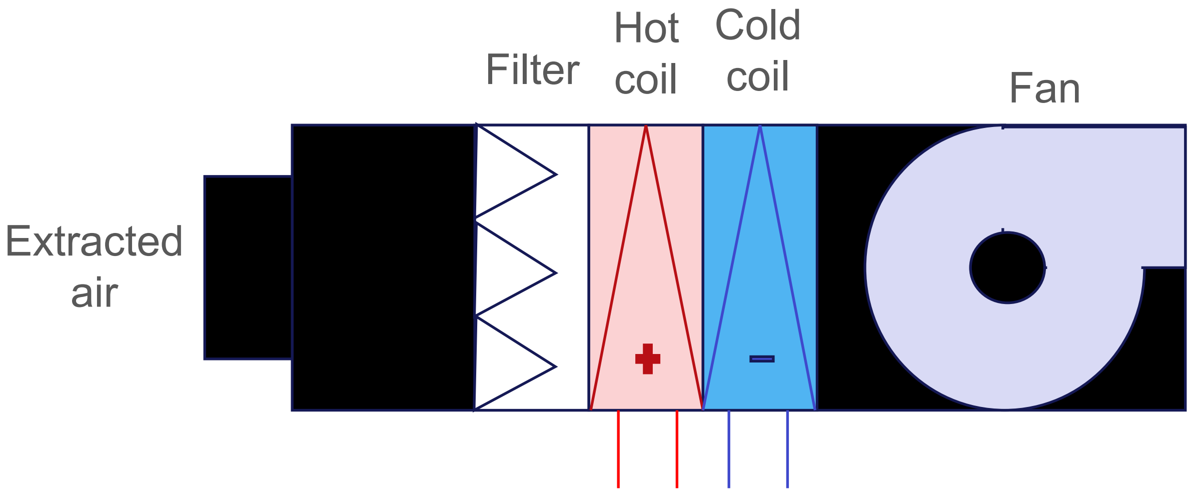
- + Comfort
- + Reversible
- − Price
- − Limited power

Fan coil

- + Space
- + Reversible
- − Comfort
- − Noise

3.1 Fan coil





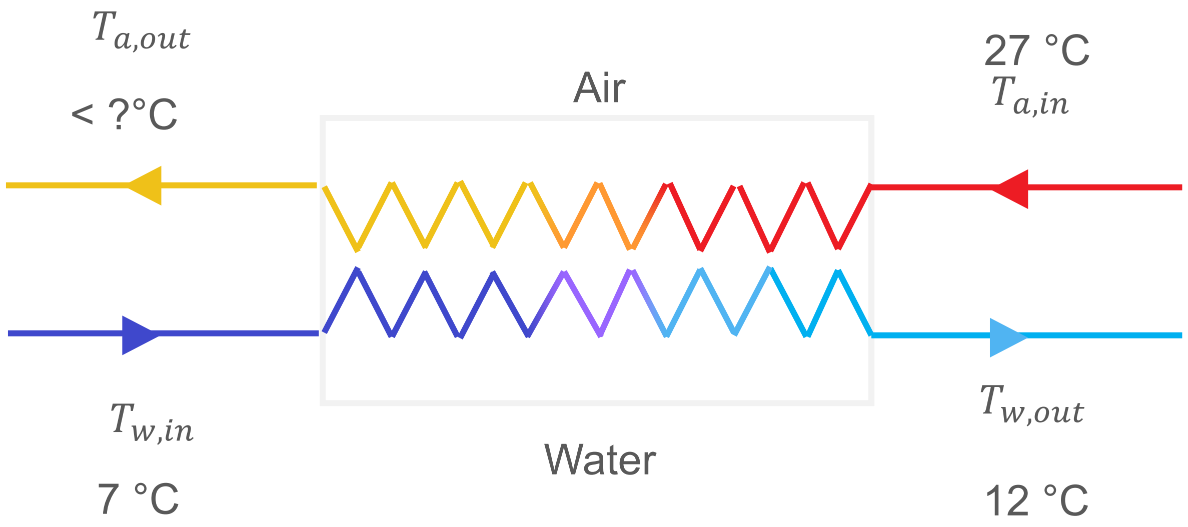
$$\dot{Q} = \dot{m}_a Cp_a \left(T_{a,out} - T_{a,in}\right)$$

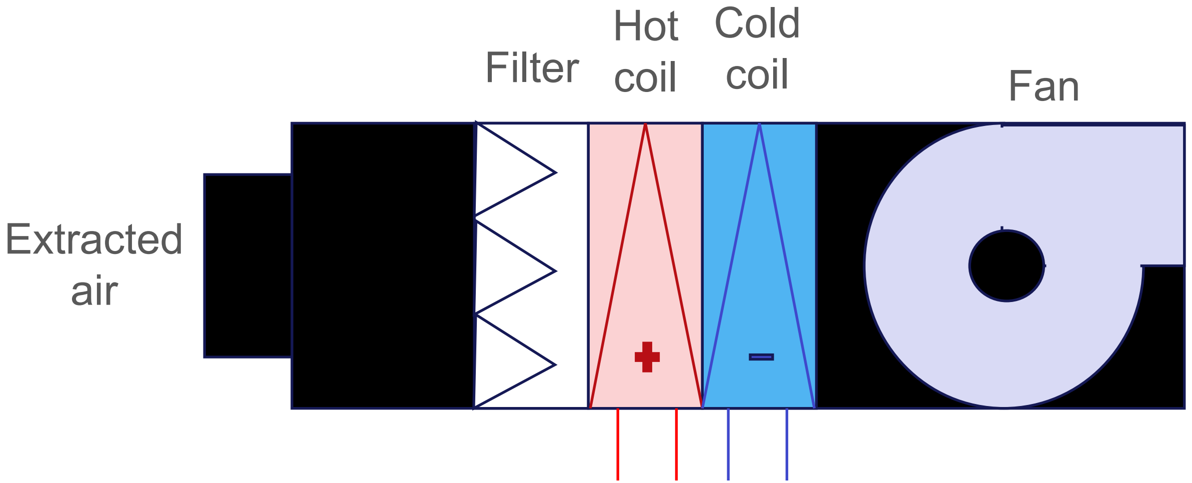
$$\dot{Q} = \dot{m}_w Cp_w \left(T_{w,in} - T_{w,out}\right)$$

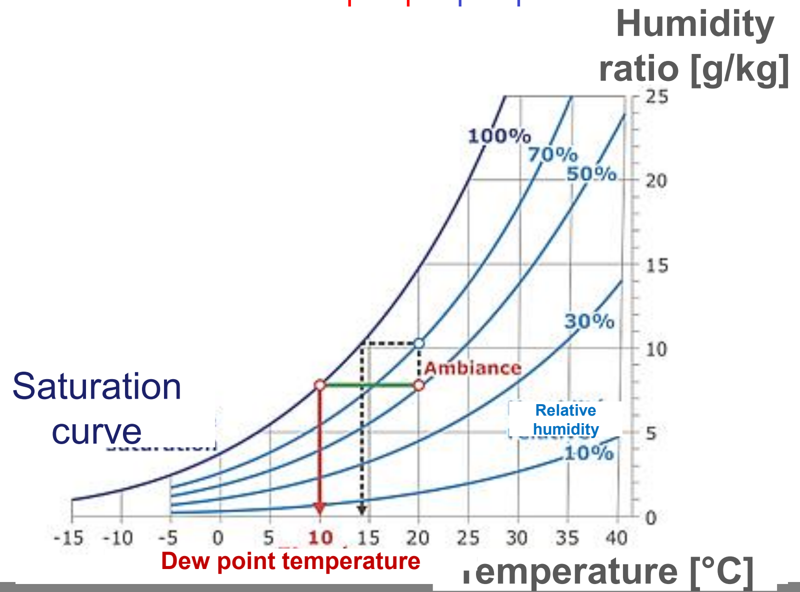
$$E = \frac{\dot{Q}}{\min(\dot{m}_a Cp_a;\ \dot{m}_w Cp_w)\left(T_{w,in} - T_{a,in}\right)}$$

The cold battery operates the same way as the hot one (HEX). Nevertheless, indoor air is humid and given the dew point temperature, the condensation is possible

3.1 Fan coil







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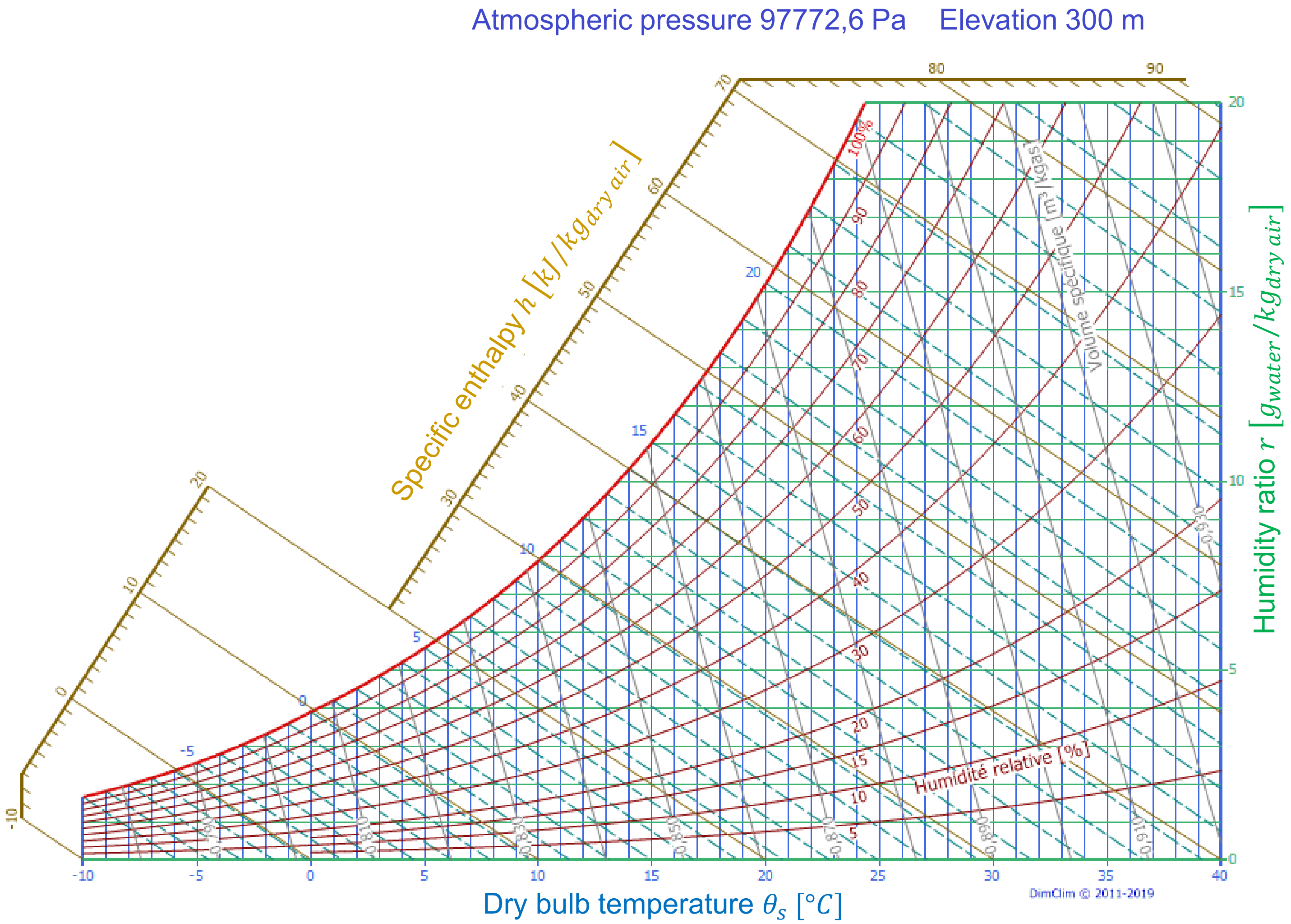


Dry bulb temperature $\theta_s\ [°C]$: Temperature measured through a simple thermometer

Humidity ratio $r\ \left[kg_{water}/kg_{dry\ air}\right]$

$$r = \frac{m_{water}}{m_{dry\ air}} = 0{,}622\,\frac{p_v}{p - p_v}$$

Specific enthalpy $h\ \left[kJ/kg_{dry\ air}\right]$

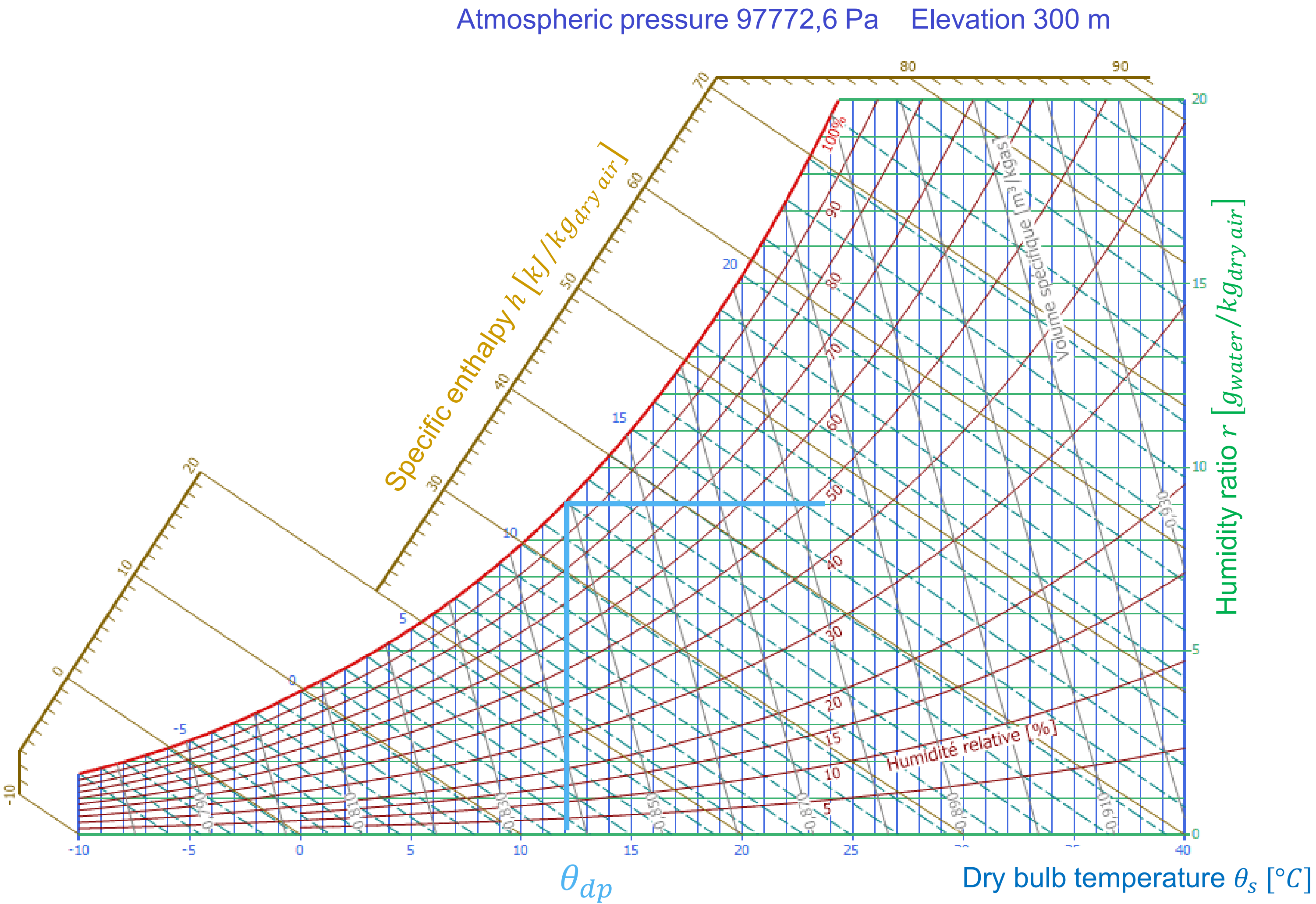
$$h = h_{dry\ air} + r\ h_{vapour}$$

$$h = Cp_{dry\ air}\ \theta_s + r\left(L_v + Cp_{vapour}\ \theta_s\right)$$

Relative humidity φ [%] :

$$\varphi = p_{v,\theta}/p_{vs,\theta}$$

3.1 Fan coil



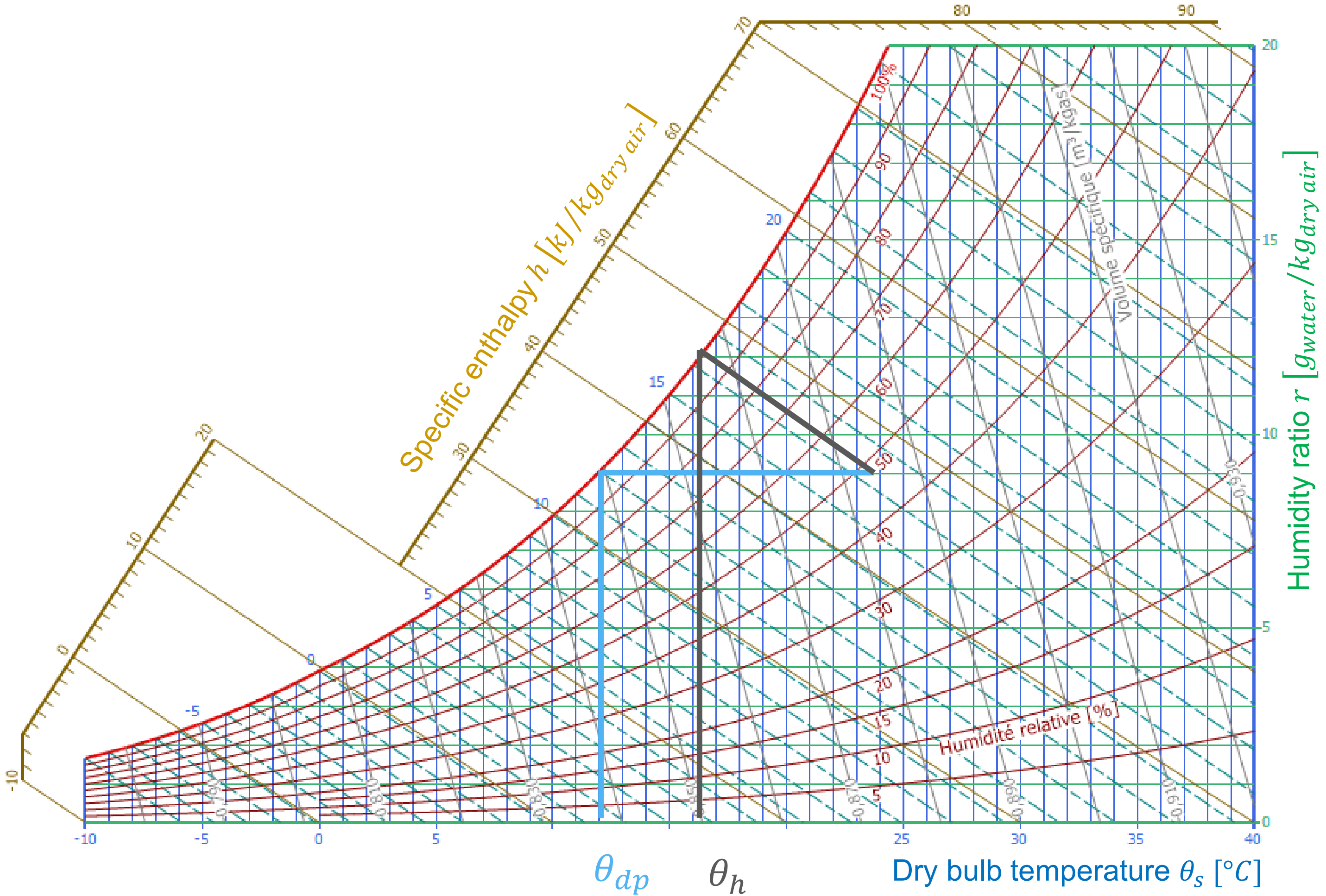
Specific volume $v\ [m^3/kg_{dry\ air}]$

Dew point temperature $\theta_{dp}\ [°C]$: This is the temperature at which humid air would have to be cooled for water vapor to begin condensing

Wet bulb temperature $\theta_h\ [°C]$: This is the temperature measured by a thermometer whose bulb is covered with a wet cotton and placed in a stream of air (2 m/s)

3.1 Fan coil

Atmospheric pressure 97772,6 Pa   Elevation 300 m



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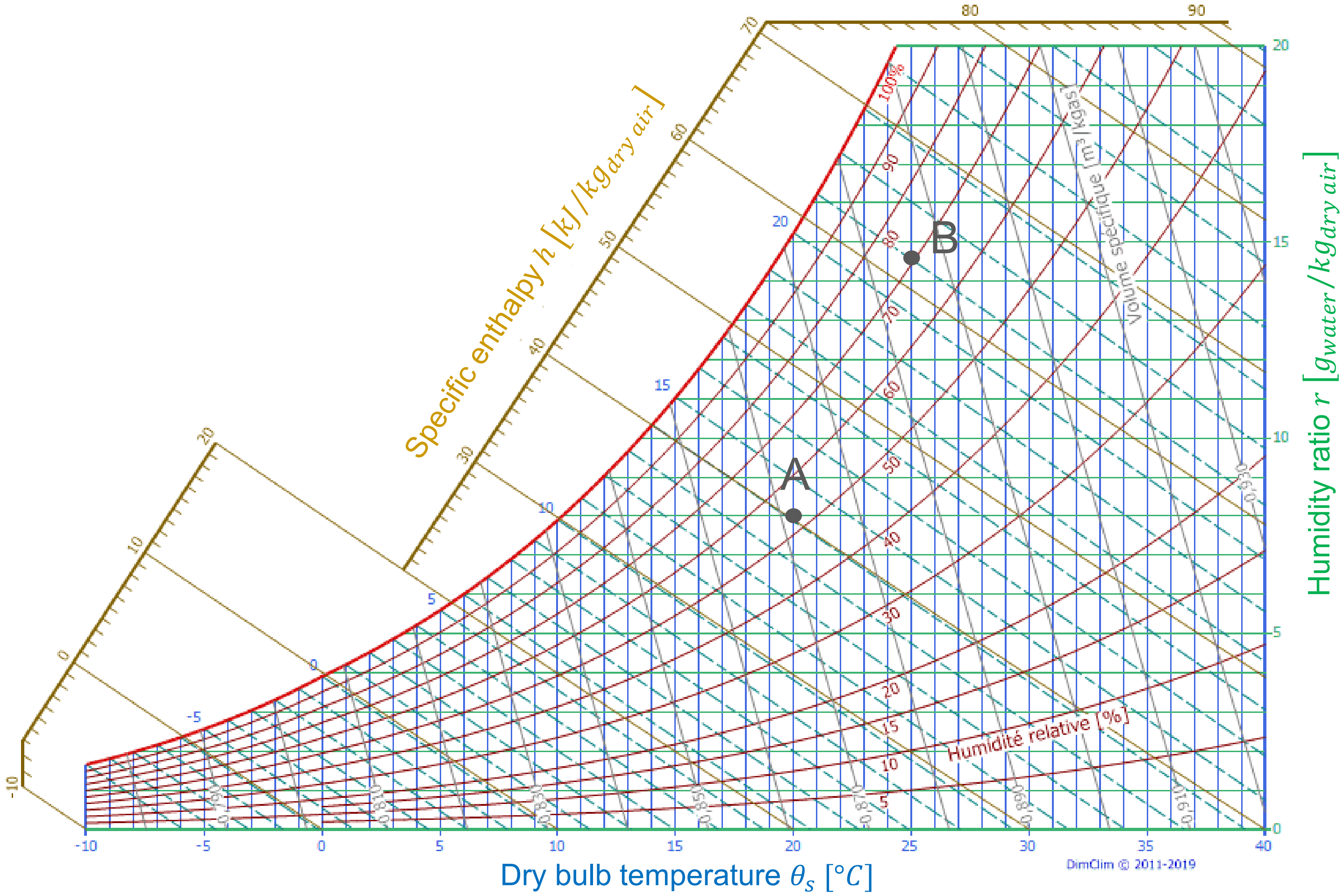
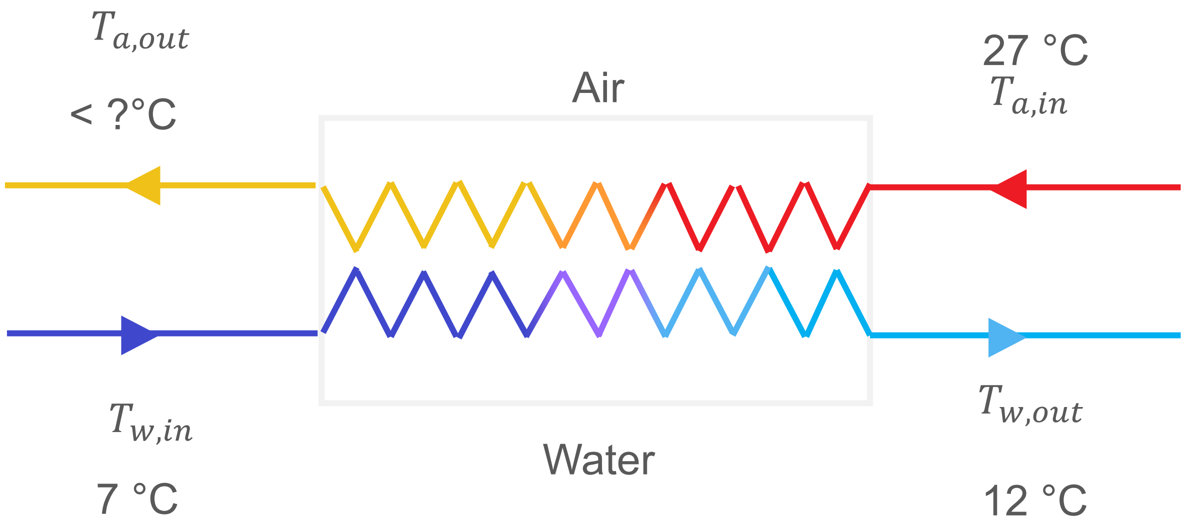


	A	B
θ_s $[°C]$	20	24
θ_{dp} $[°C]$	10	18,5
θ_h $[°C]$	14	20
r $[kg_w/kg_{da}]$	0,008	0,0145
h $[kJ/kg_{da}]$	40	58
φ $[\%]$	52	70
v $[m^3/kg_{dry\ air}]$	0,871	0,891

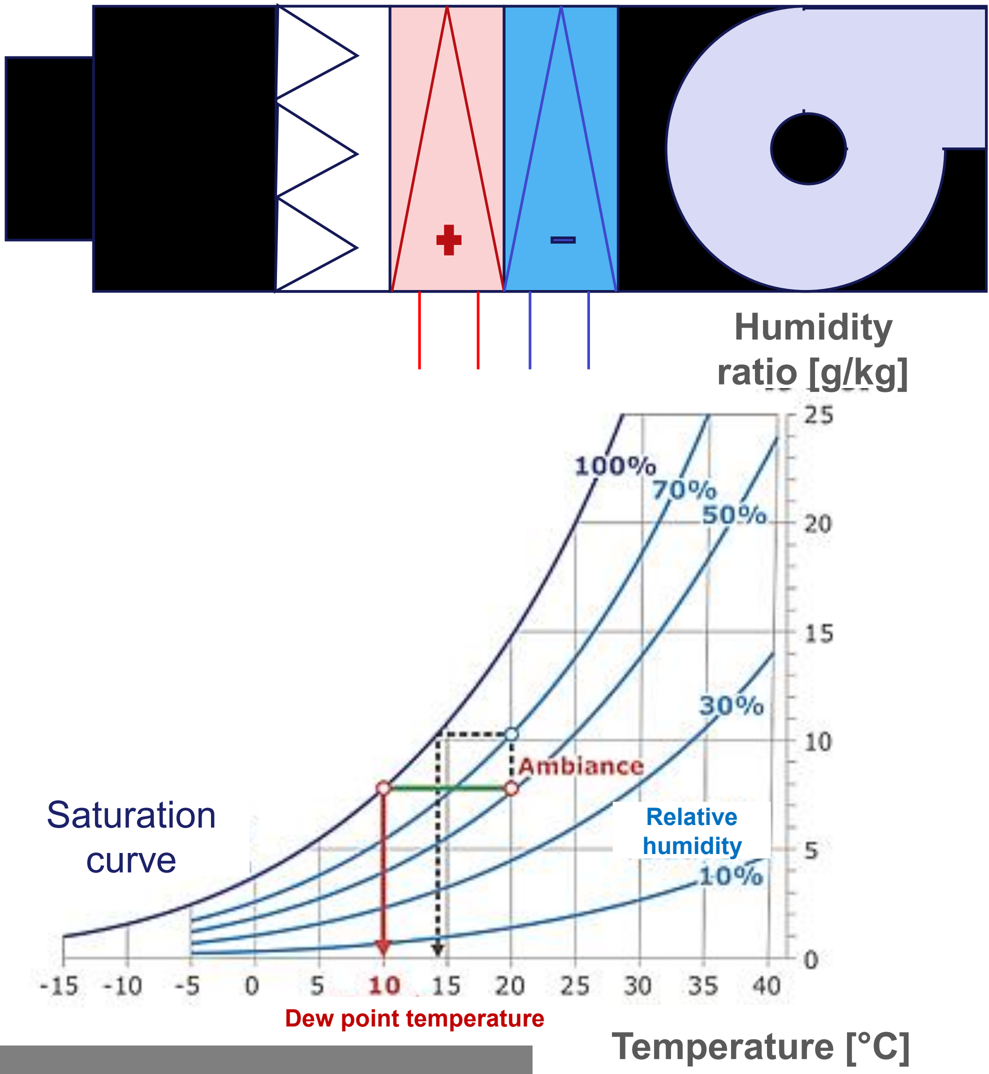
3.1 Fan coil



$$\dot{Q} = \dot{Q}_s + \dot{Q}_l$$

$$\dot{Q} = \dot{m}_{air}\, Cp_{air} \left(T_{a,in} - T_{a,out}\right) + \dot{m}_{cond}\, L_v$$

$$\dot{m}_{cond} = \dot{m}_{air} \left(r_{a,in} - r_{a,out}\right)$$



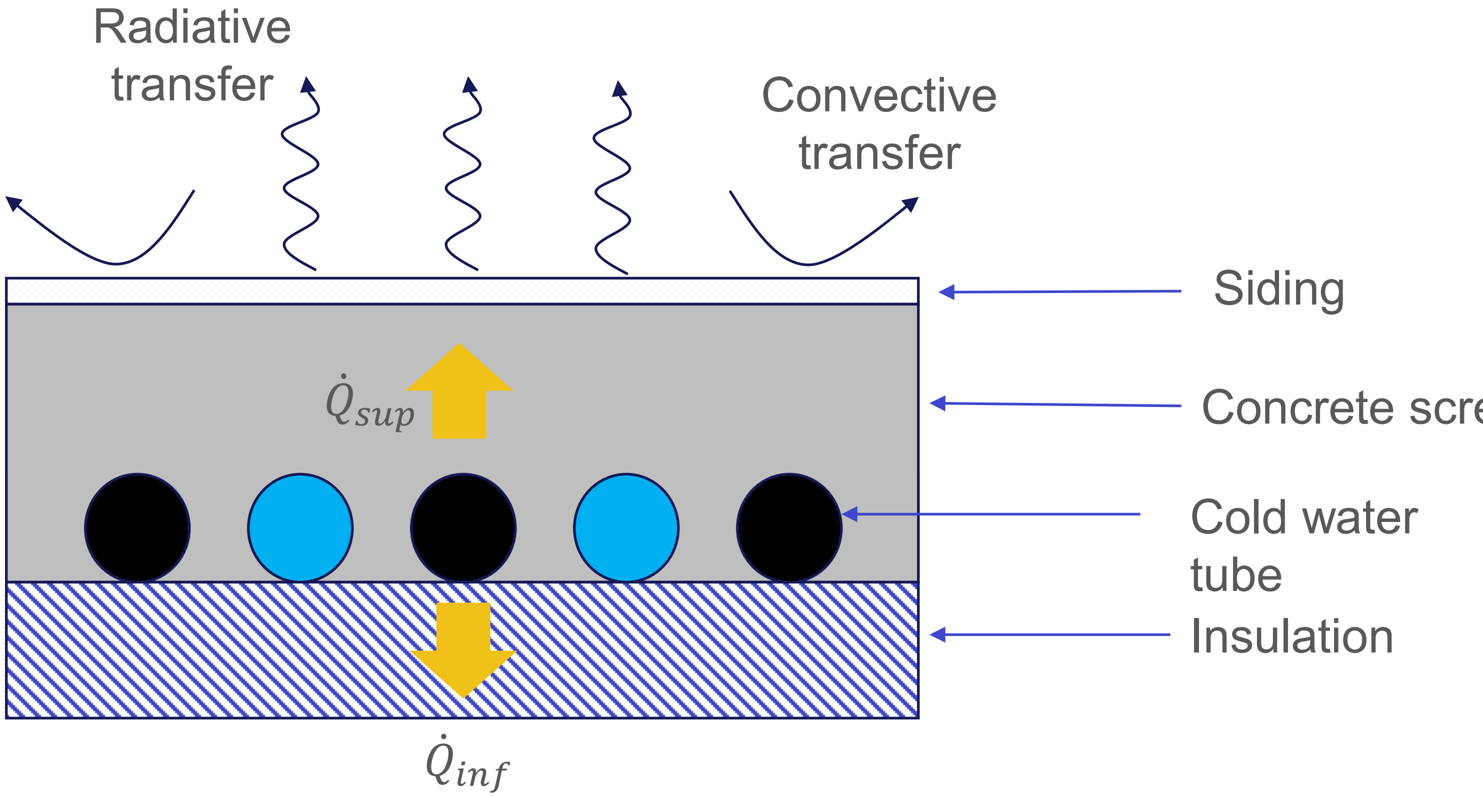
3.2 Cooling floor

$$\dot{Q}_{sup} = P_{hf} = \overset{\approx 70\%}{P_{rad}} + \overset{\approx 30\%}{P_{conv}}$$

$$\dot{Q}_{rad} = h_{rad}\, A \left(T_{surf} - T_{op}\right)$$

$$\dot{Q}_{conv} = h_{conv}\, A \left(T_{surf} - T_{air}\right)$$

Limited to 18°C to avoid condensation
(in temperate climate far from the sea)



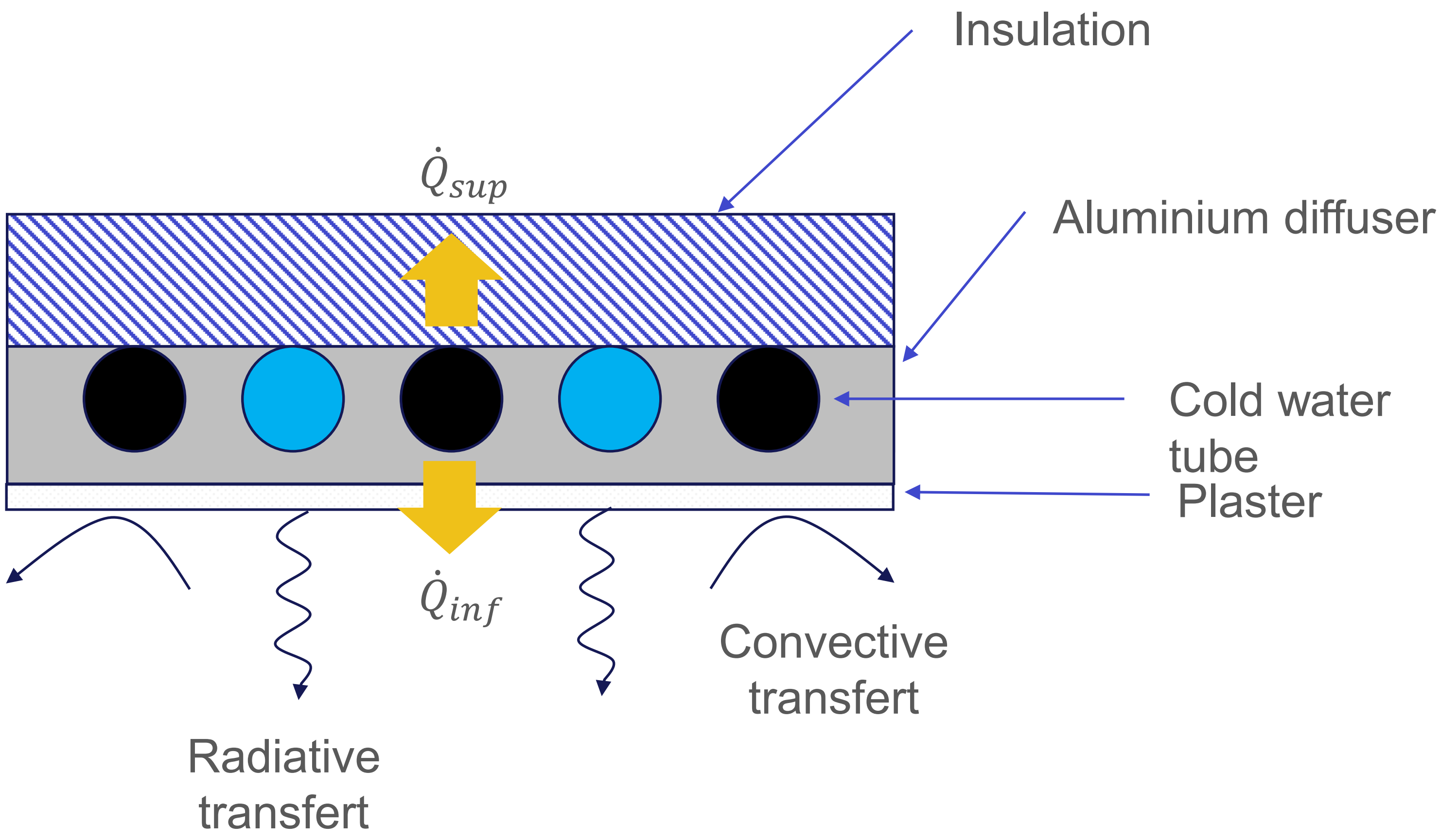
3.3 Cooling floor

$$\dot{Q}_{inf} = \dot{Q}_{cc} = \overset{\approx 70\%}{\dot{Q}_{rad}} + \overset{\approx 30\%}{\dot{Q}_{conv}}$$

$$\dot{Q}_{rad} = h_{rad}\, A\left(T_{surf} - T_{op}\right)$$

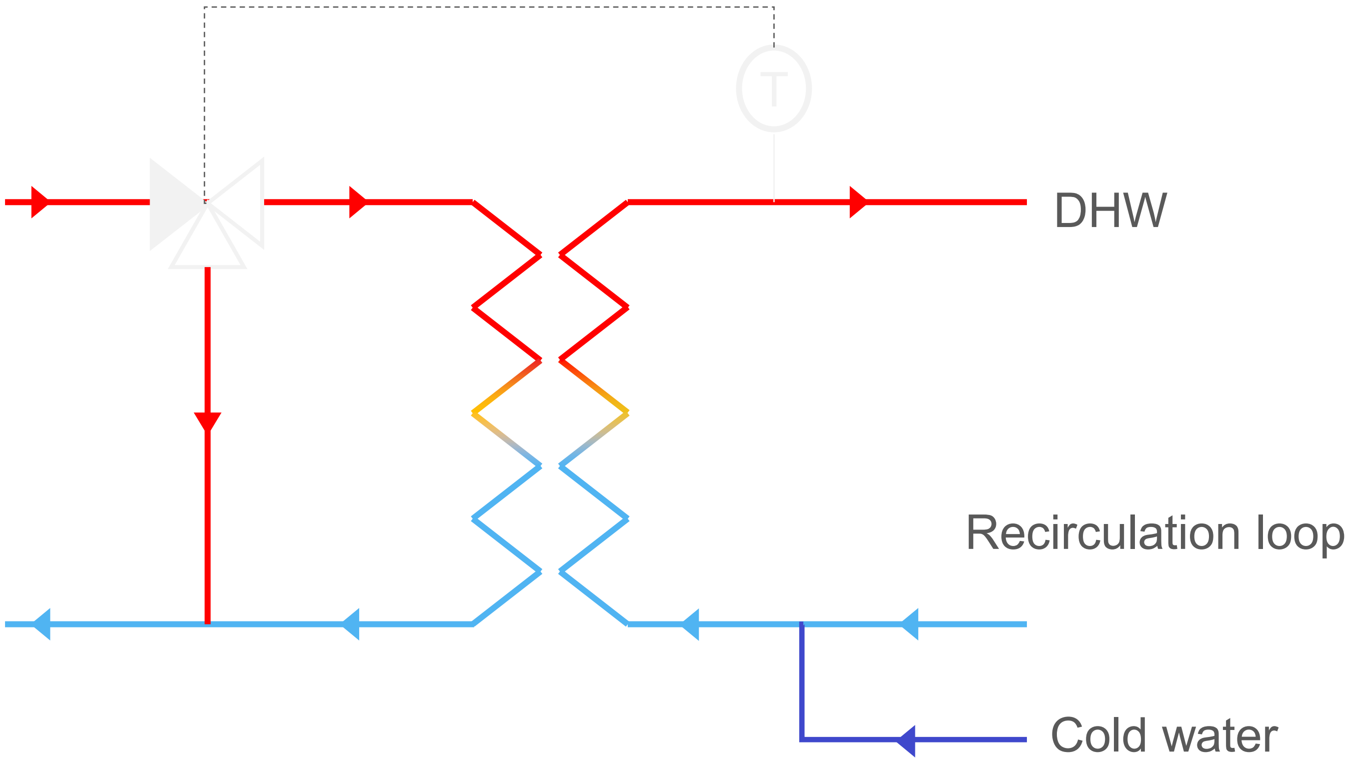
$$\dot{Q}_{conv} = h_{conv}\, A\left(T_{surf} - T_{air}\right)$$

Limited to 18°C to avoid condensation (in temperate climate far from the sea)



4. DHW

How to supply DHW through a DH network?

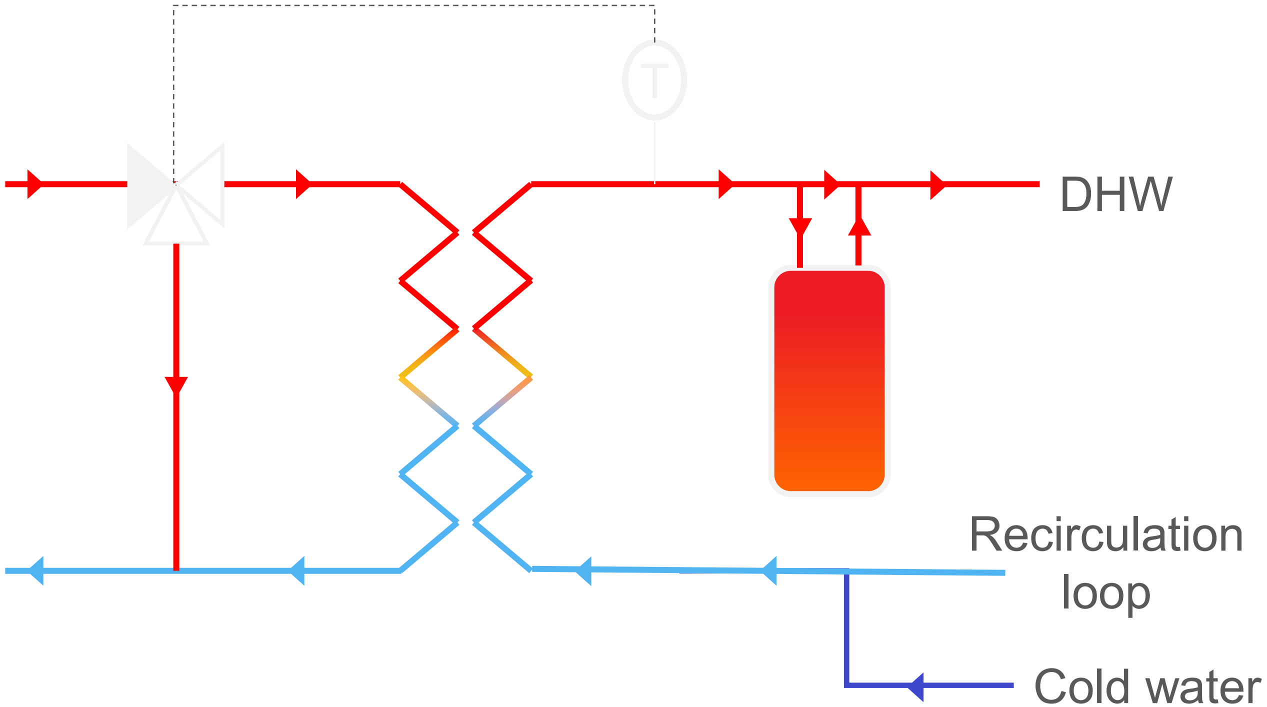


Instantaneous supply:

- Easy to install
- No tank → cheap
- Sizing to supply the maximal needs → Oversized
- Supply temperature up to 60°C
- A constant flow rate on both sides due to the recirculation loop (55°C)

4. DHW

How to supply DHW through a DH network?

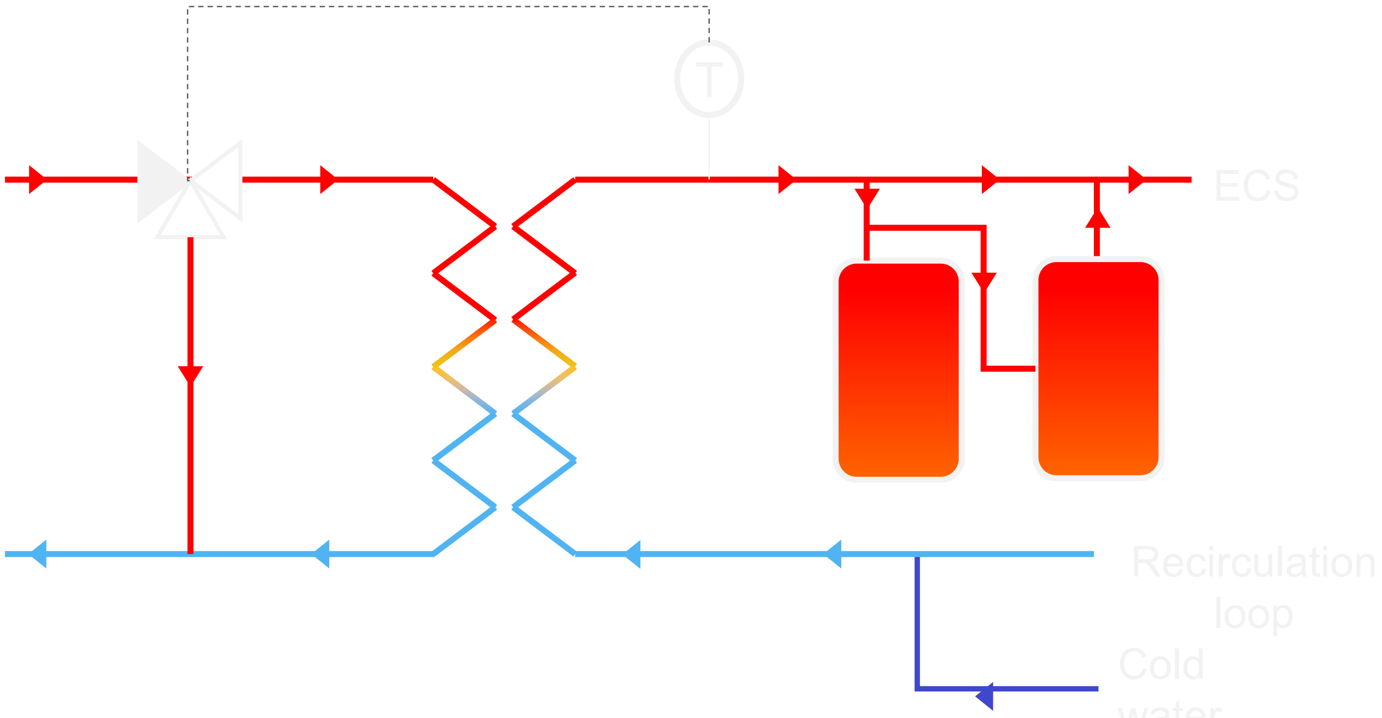


Semi-instantaneous supply:

- Easy to install
- Small tank sized to cover the peak consumption (10 min)
- Supply temperature up to 60°C
- Heat losses through the tank wall
- A constant flow rate on both sides due to the recirculation loop (55°C)

4. DHW

How to supply DHW through a DH network?

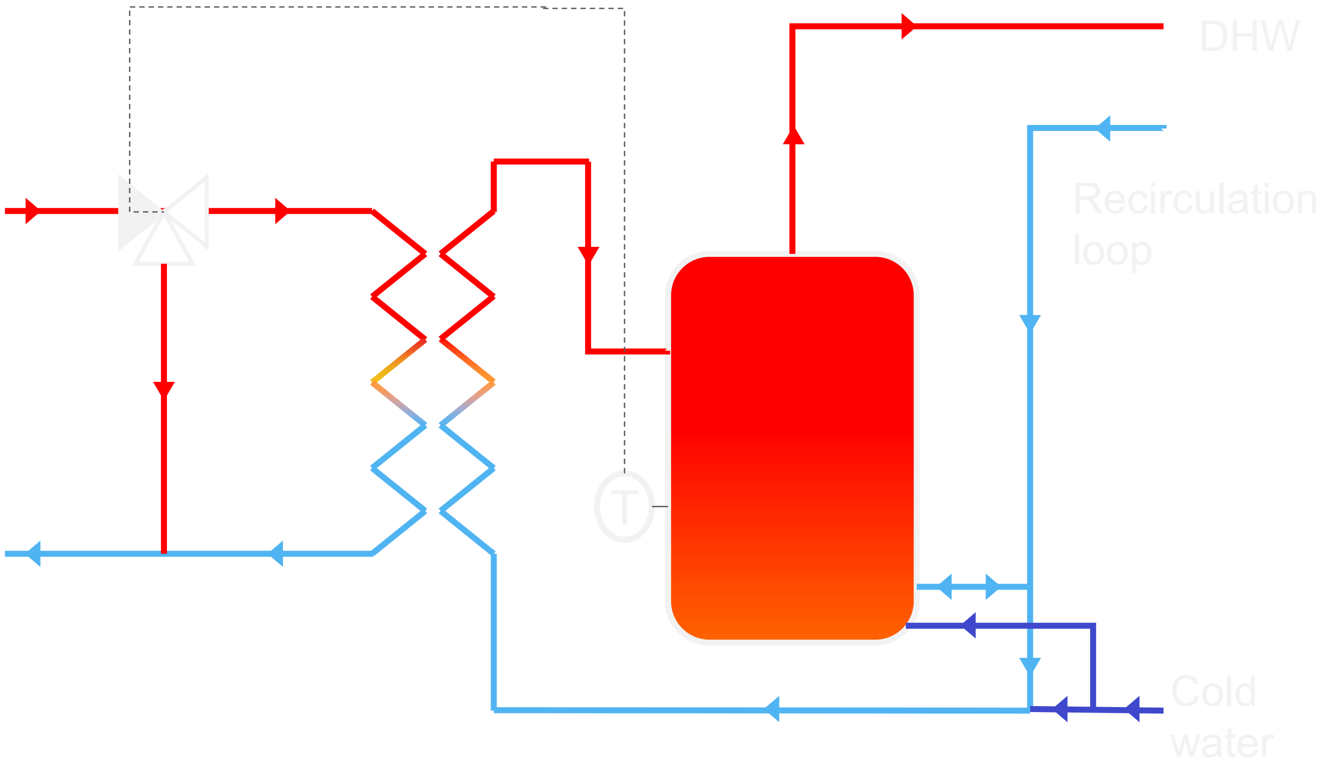


Semi-accumulation supply:

- Space requirement
- Tank sized to cover the consumption for 2-3 hours (10 min)
- Corrosion risk
- Supply temperature up to 60°C
- Heat losses through the tank wall
- A constant flow rate on both side due to the recirculation loop (55°C)

4. DHW

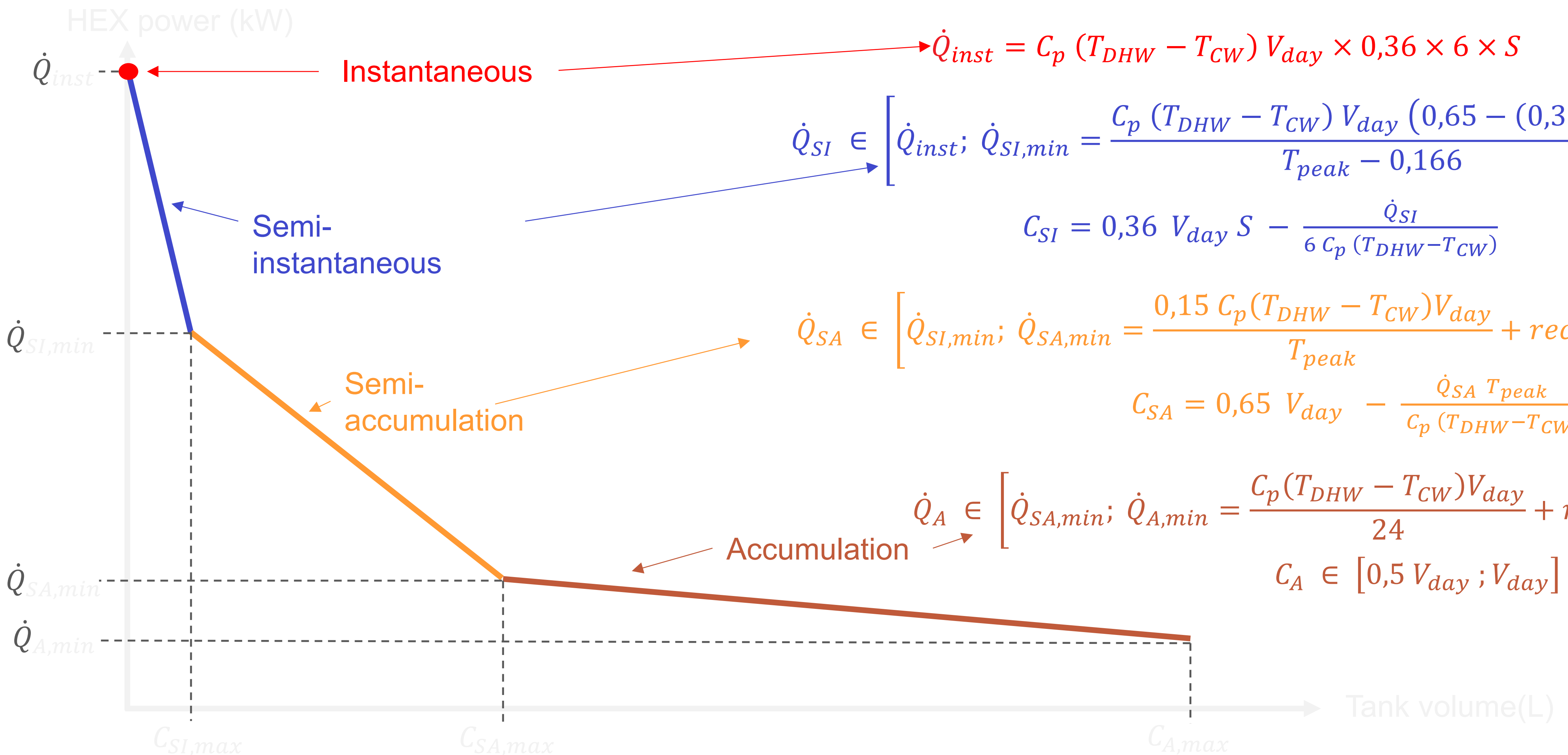
How to supply DHW through a DH network?



Accumulation supply:

- High space requirement
- Tank sized to cover the daily consumption
- Corrosion risk
- Supply temperature up to 60°C
- Heat losses through the tank wall

4. DHW



Instantaneous

$$\dot{Q}_{inst} = C_p \, (T_{DHW} - T_{CW}) \, V_{day} \times 0{,}36 \times 6 \times S$$

Semi-instantaneous

$$\dot{Q}_{SI} \in \left[\dot{Q}_{inst};\ \dot{Q}_{SI,min} = \frac{C_p \, (T_{DHW} - T_{CW}) \, V_{day} \left(0{,}65 - (0{,}36 \, S)\right)}{T_{peak} - 0{,}166}\right]$$

$$C_{SI} = 0{,}36 \ V_{day} \, S - \frac{\dot{Q}_{SI}}{6 \, C_p \, (T_{DHW} - T_{CW})}$$

Semi-accumulation

$$\dot{Q}_{SA} \in \left[\dot{Q}_{SI,min};\ \dot{Q}_{SA,min} = \frac{0{,}15 \, C_p (T_{DHW} - T_{CW}) V_{day}}{T_{peak}} + recircu\right]$$

$$C_{SA} = 0{,}65 \ V_{day} - \frac{\dot{Q}_{SA} \, T_{peak}}{C_p \, (T_{DHW} - T_{CW})}$$

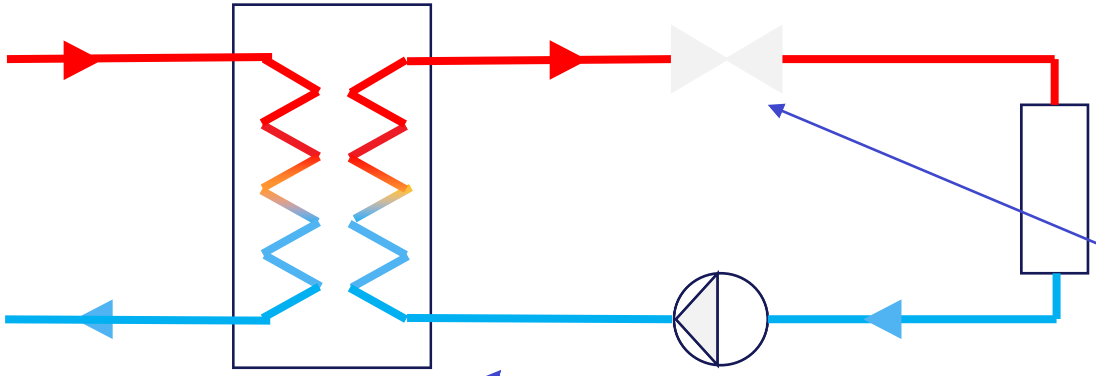
Accumulation

$$\dot{Q}_{A} \in \left[\dot{Q}_{SA,min};\ \dot{Q}_{A,min} = \frac{C_p (T_{DHW} - T_{CW}) V_{day}}{24} + recircu\right]$$

$$C_A \in \left[0{,}5 \, V_{day} \, ; V_{day}\right]$$

5. Distribution

How to design the distribution side also named the secondary side?

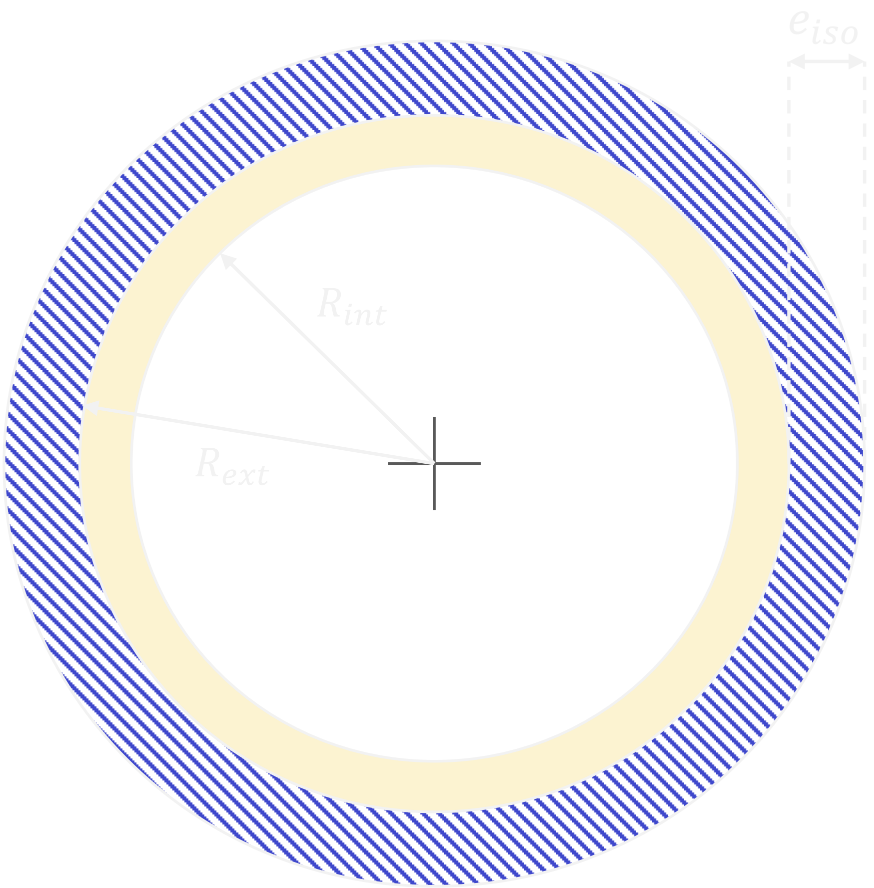


Pipes

Pump

Valves

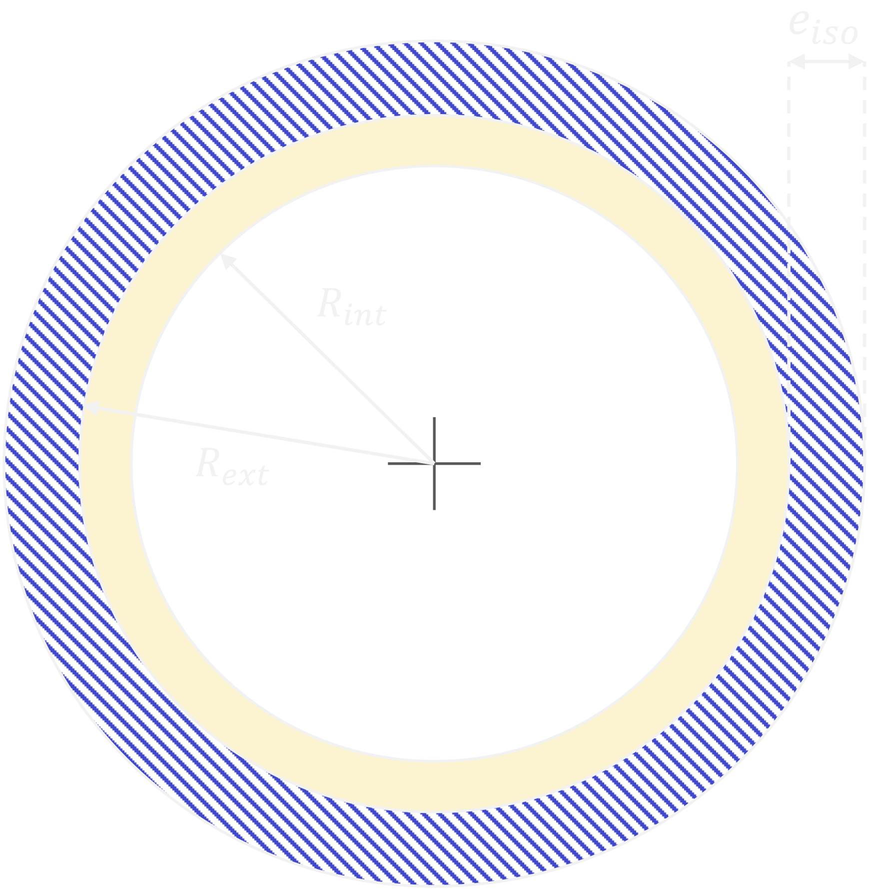
5.1 Pipes



Designing a distribution pipe consists in:

- Calculate the pipe diameter
- Calculate the insulation thickness
- Calculate the pressure losses

5.1 Pipes



Designing a distribution pipe consists in:

- Calculate the pipe diameter

To limit the noise and the vibration the velocity of the water must be limited to $v = 1m/s$

$$\dot{m}_w = \rho\, v\, S = \rho\, v\, \frac{\pi D^2}{4}$$

$$D = \sqrt{\frac{4\, \dot{m}_w}{\pi\, \rho\, v}}$$

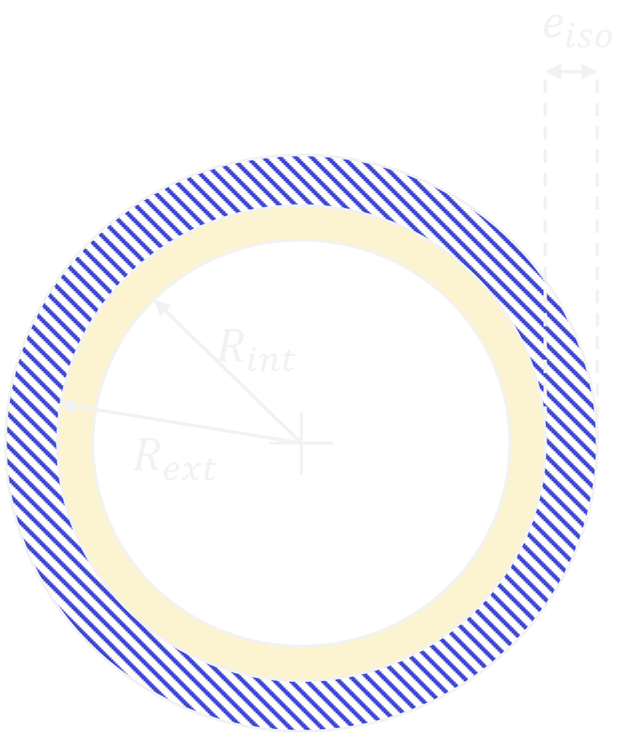
To limit the linear pressure losses $\Delta p = 100\ pa/m$

$$\Delta p = \Lambda\, \rho\, \frac{v^2}{2} = \frac{8\, \Lambda}{\rho \pi^2} \frac{\dot{m}_w^2}{D^4}$$

$$\Lambda = \frac{64}{Re}\ if\ Re < 2300$$

$$\Lambda = 0{,}3164\ Re^{-0{,}25}\ if\ Re > 4000$$

5.1 Pipes



$$\frac{1}{U_l} = \frac{1}{h_{int} 2\pi R_{int}} \frac{\ln\left(\frac{e_{iso}+R_{ext}}{R_{ext}}\right)}{2\pi\ \lambda} + \frac{1}{h_{ext}\ 2\pi\ (e_{iso}+R_{ext})}$$

Designing a distribution pipe consists in:

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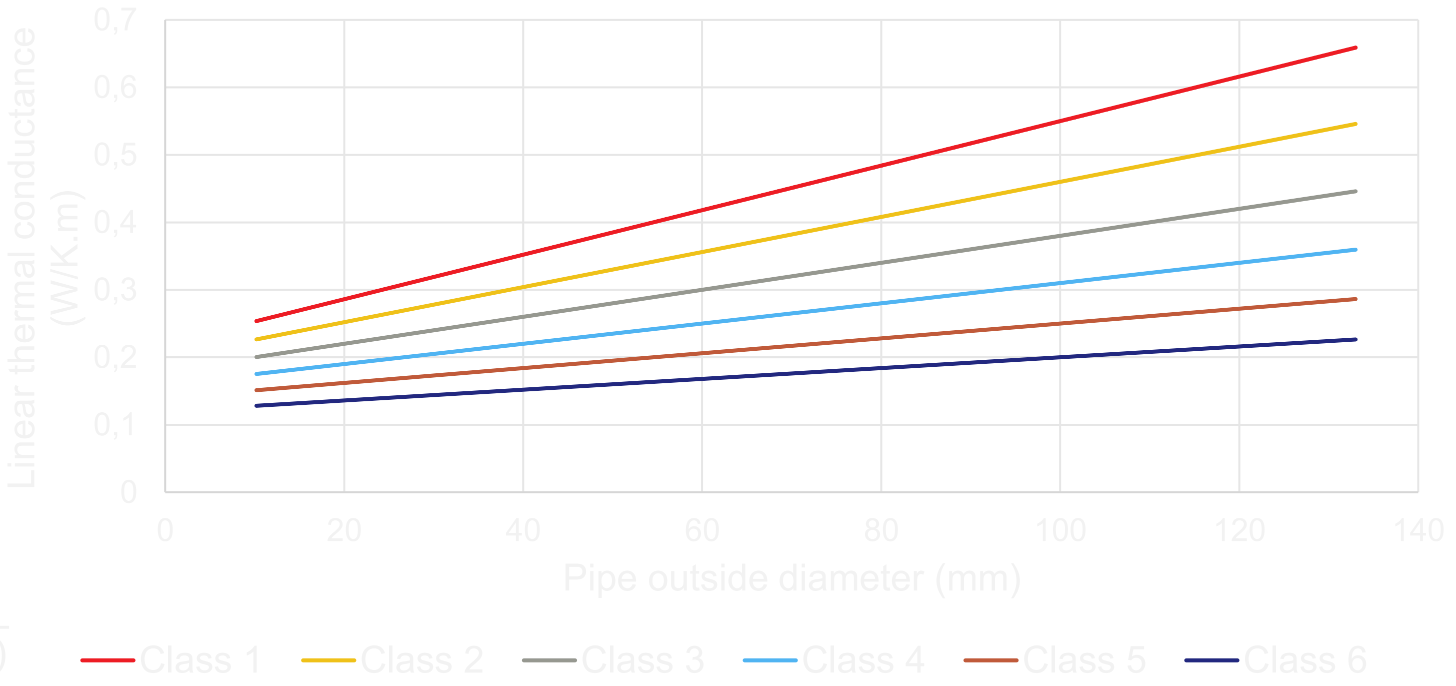
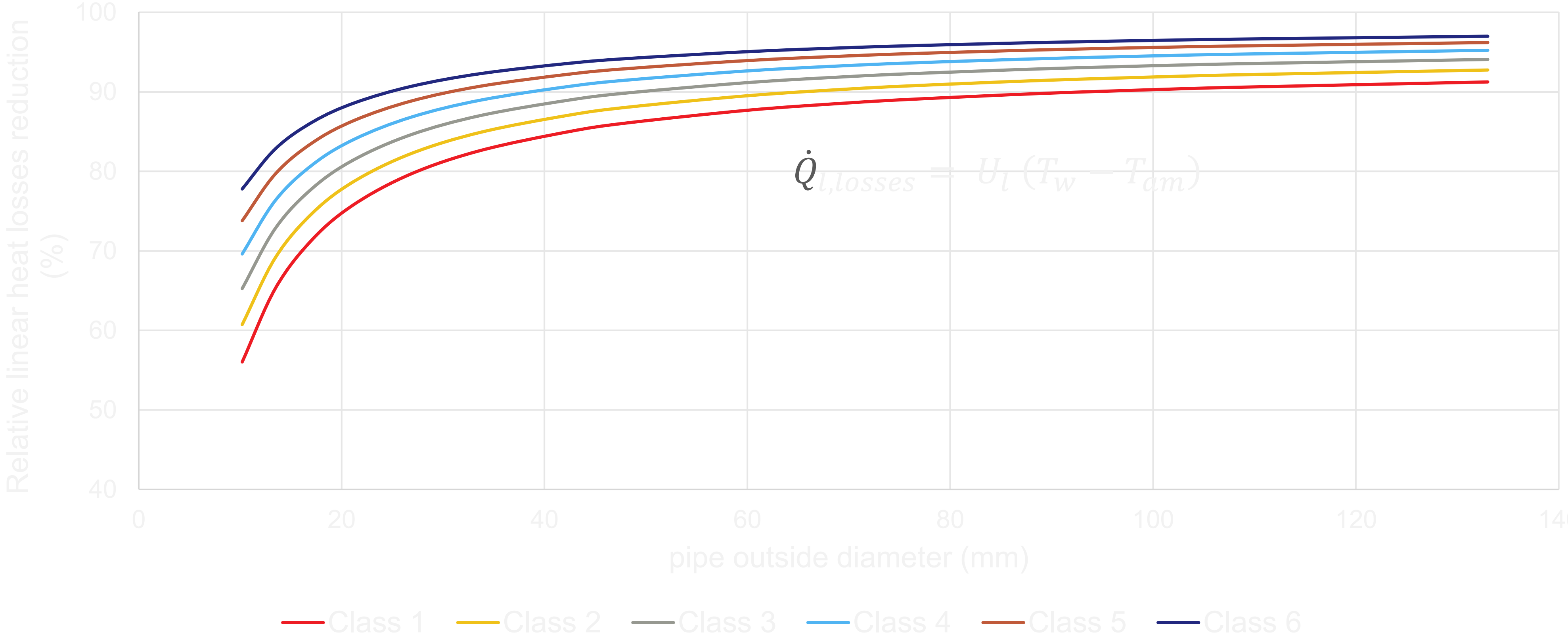
- Calculate the insulation thickness



5.1 Pipes

Relative reduction of linear heat losses for $\lambda_{iso} = 0{,}03\,\frac{W}{k}.m \quad T_w = 60°C \text{ and } T_{amb} = 20°C$



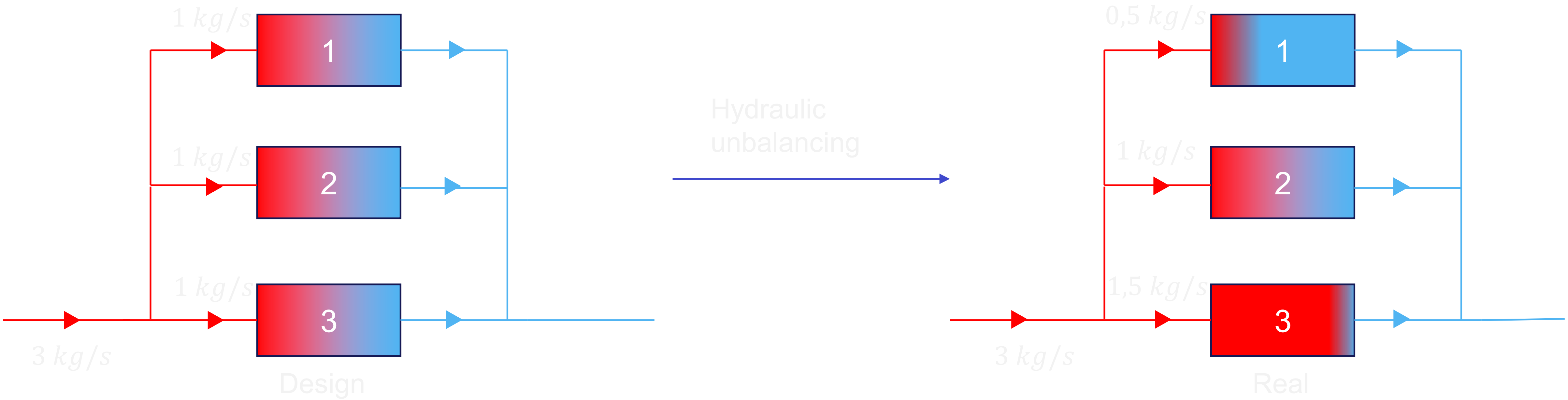
$$\dot{Q}_{l,losses} = U_l\,(T_w - T_{am})$$

5.1 Pipes

$$\Delta p = \Lambda\, \rho\, \frac{v^2}{2} = \frac{8\,\Lambda}{\rho \pi^2}\, \frac{\dot{m}_w^2}{D^4} = Z\, \dot{m}_w^2$$

Designing a distribution pipe consists in:

- Calculate the pipe diameter
- Calculate the insulation thickness
- Calculate the pressure losses



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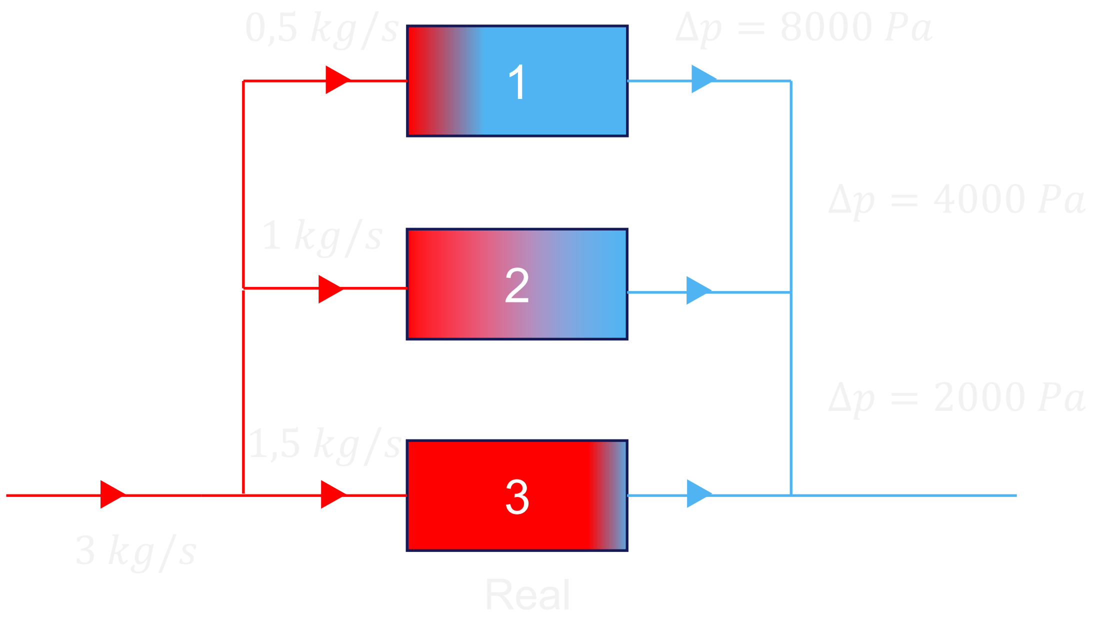
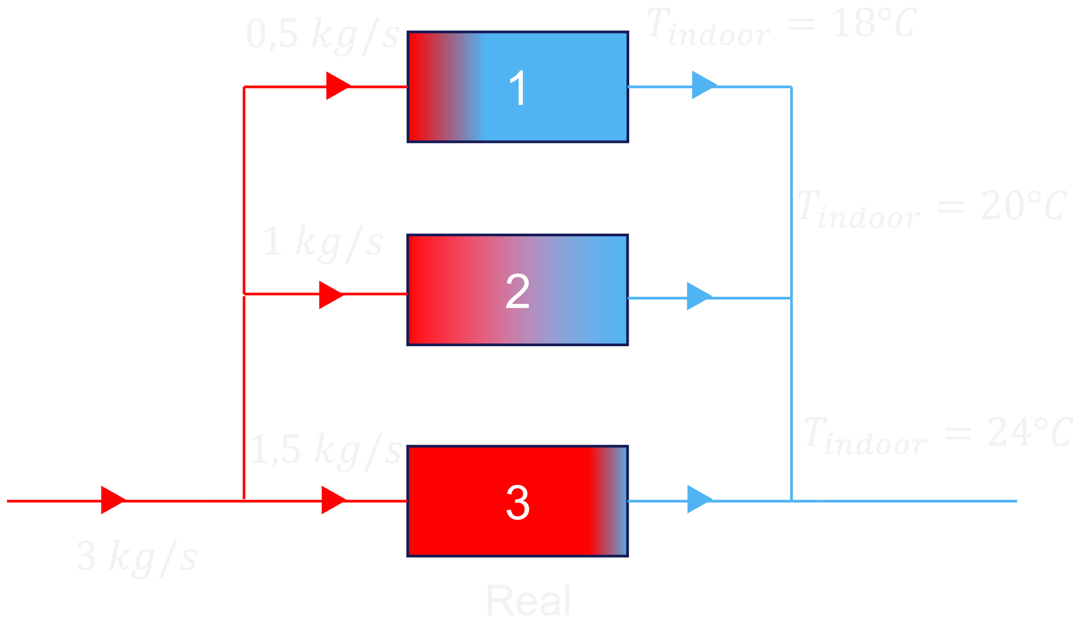
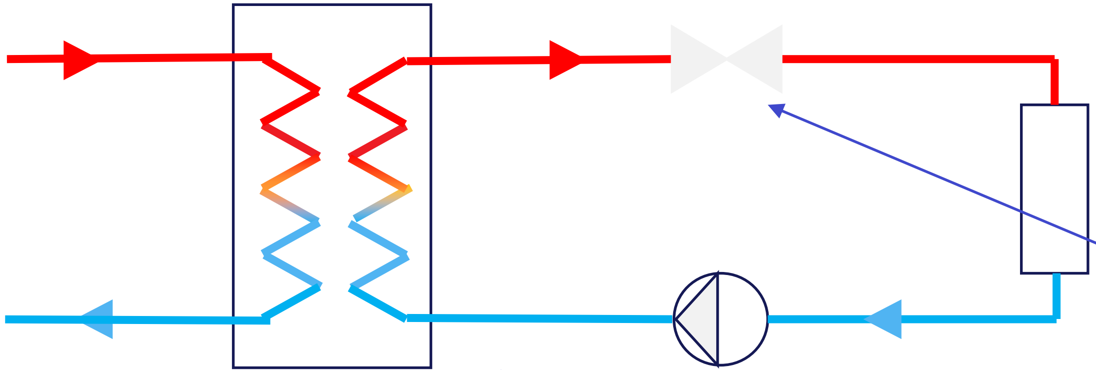




How to control the flow rate through the emitters and ensure the hydraulic balancing?

5. Distribution



How to design the distribution side also named the secondary side?

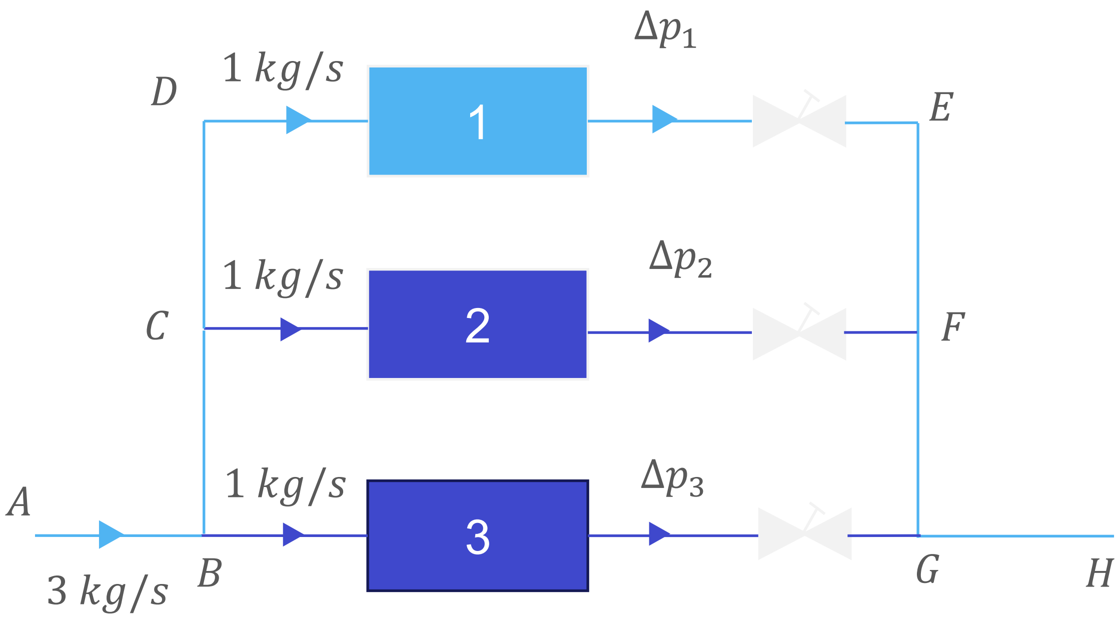
Pipes

Pump

Valves

5.2 Valves

How to control the flow rate through the emitters and ensure the hydraulic balancing?



$$\Delta p_{max} = \Delta p_1 = \Delta p_{AB} + \Delta p_{BC} + \Delta p_{CD} + \Delta p_{DE} + \Delta p_{valve} + \Delta p_{EF} + \Delta p_{FG} + \Delta p_{GH}$$

$$\Delta p_{max} = \Delta p_2 = \Delta p_{AB} + \Delta p_{BC} + \Delta p_{CF} + \Delta p_{valve}\ \Delta p_{FG} + \Delta p_{GH}$$

$$\Delta p_{max} = \Delta p_3 = \Delta p_{AB} + \Delta p_{valve}\ \Delta p_{BG} + \Delta p_{GH}$$

Static hydraulic balancing by adding pressure losses through balancing valves. All the branch must have the same pressure losses.

5.2 Valves

How to control the flow rate through the emitters and ensure the hydraulic

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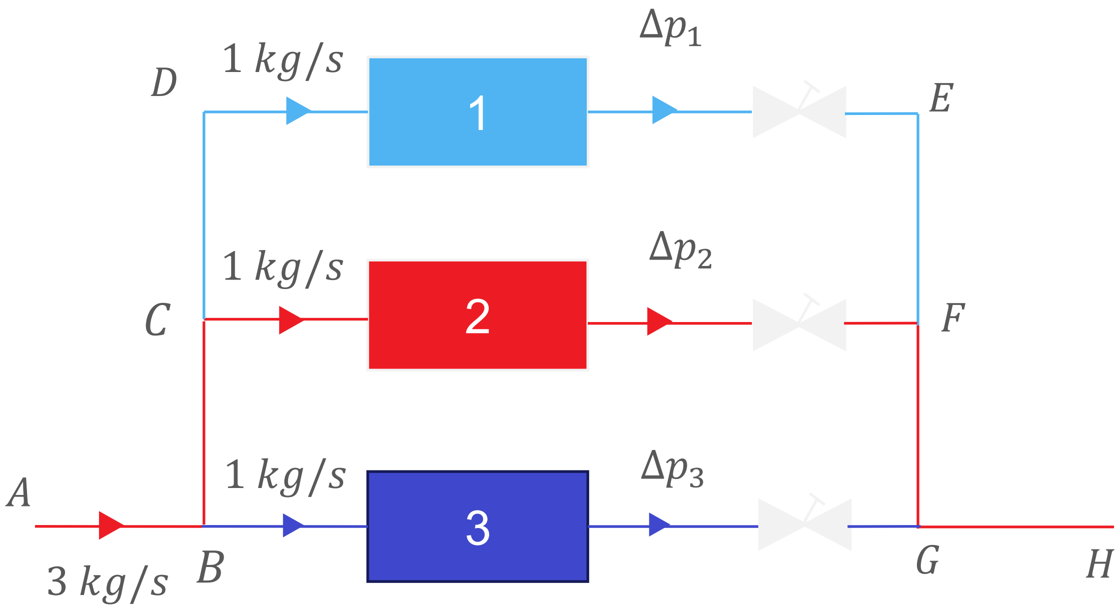

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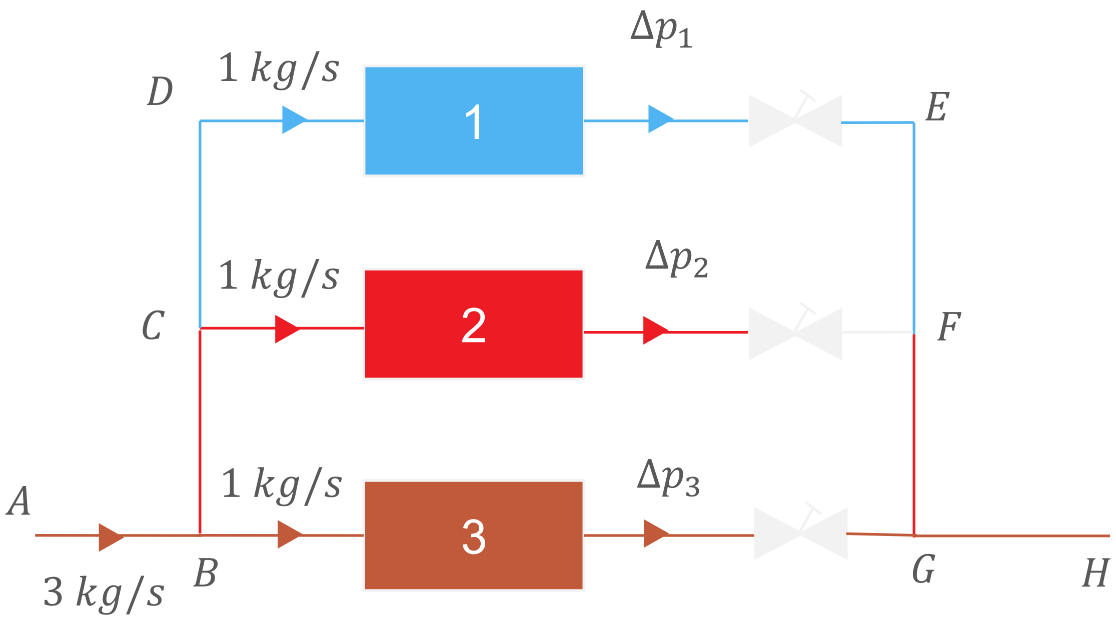

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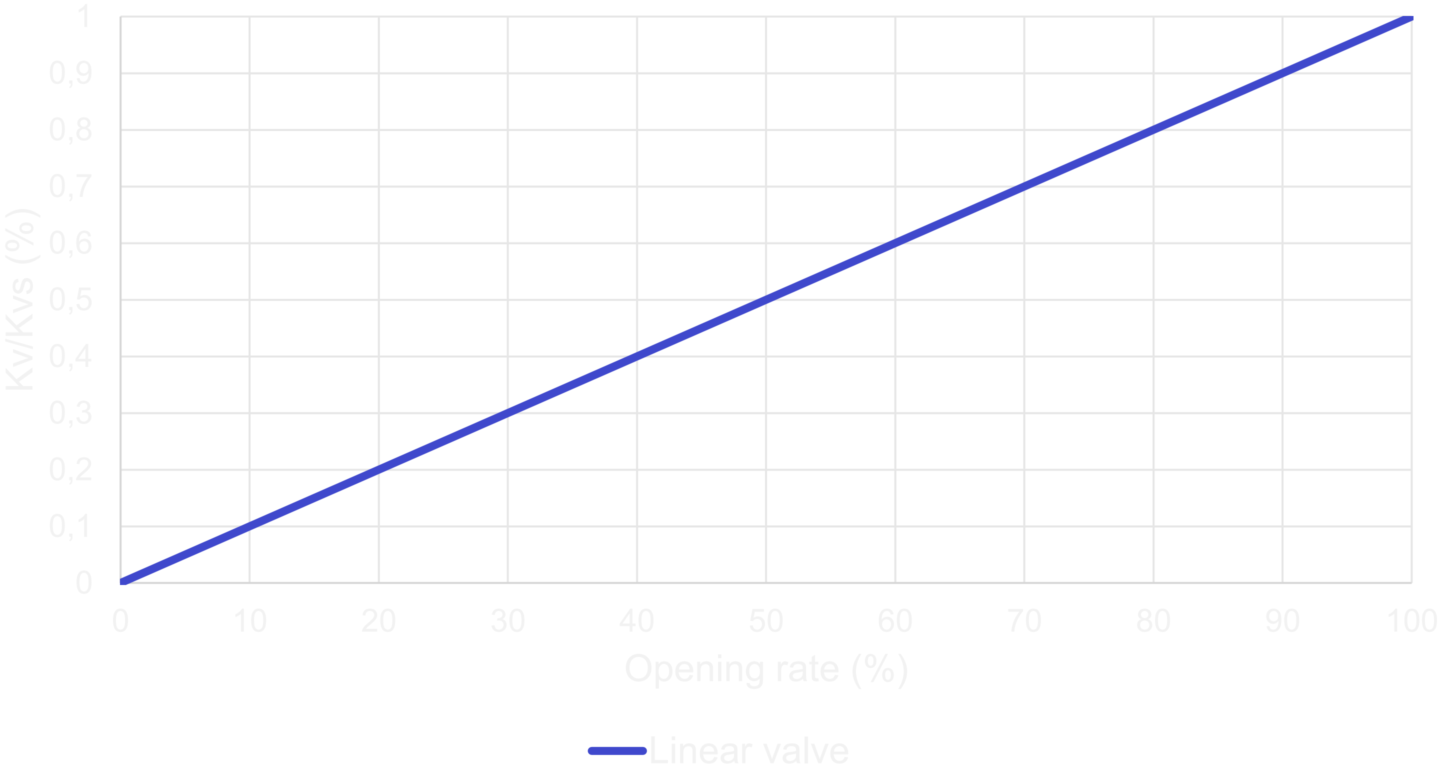

$$\dot{m} = Kv_s \sqrt{\Delta p}\ \ opening$$

$$For\ \Delta p = 1\ bar$$

$$\frac{\dot{m}}{\sqrt{\Delta p}} = \begin{cases} Kv_s & if\ \ opening = 1 \\ Kv & if\ opening \neq 1 \\ Kv_0 & if\ \ opening = 0 \end{cases}$$

Linear valve : $\frac{Kv}{Kv_s} = opening$

5.2 Valves

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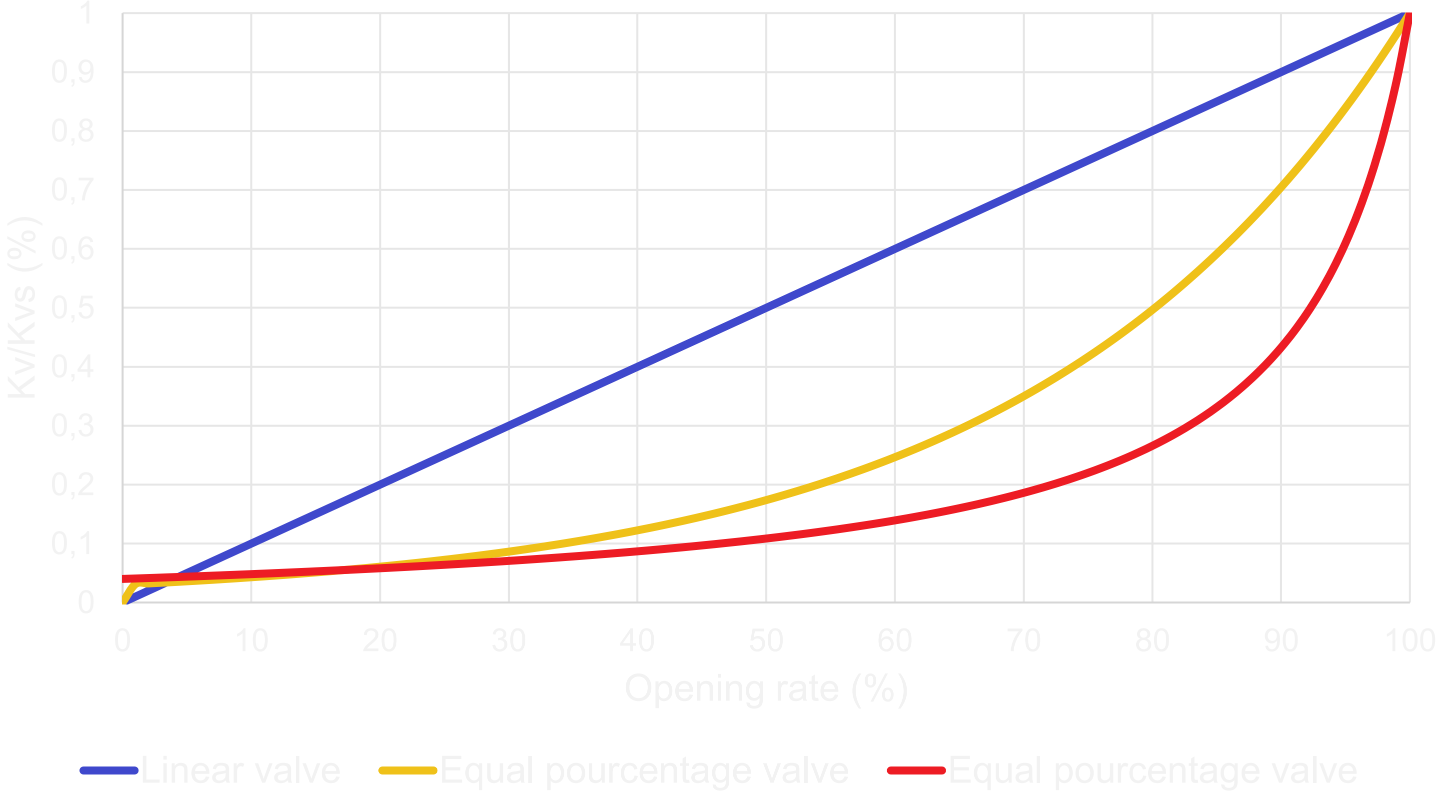

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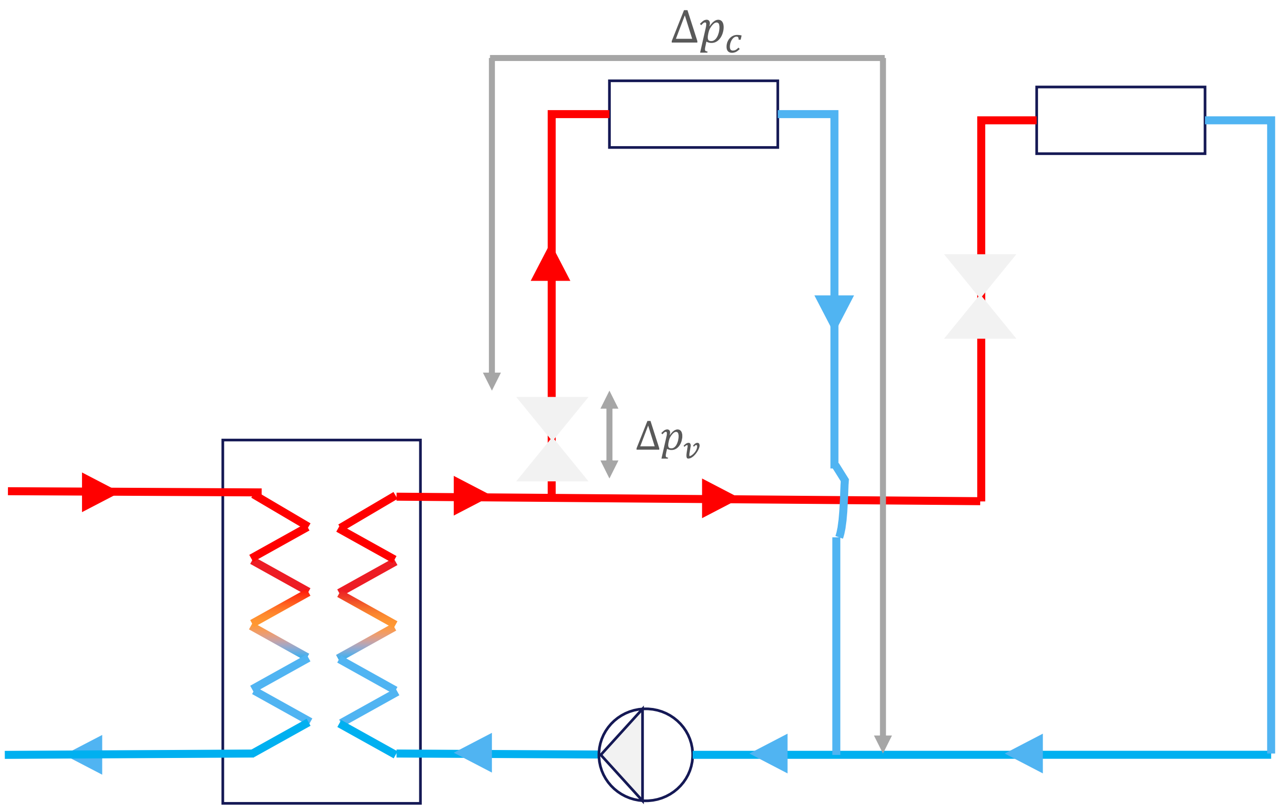
Linear valve : $\frac{Kv}{Kv_s} = opening$

Equal percentage:

$$\frac{(Kv-Kv_0)/(Kv+Kv_0)}{(Kv_s-Kv_0)/(Kv_s+Kv_0)} = opening$$

5.2 Valves

Authority: The valve authority is the capacity of the valve to ensure the progressiveness of the flow rate.



$$Authority\ :\ a = \frac{\Delta p_v}{\Delta p_v + \Delta p_c}$$

Δp_v : The fully open pressure loss of the valve

Δp_c : Pressure loss of the loop to regulate

The authority must be between 0.3 and 0.7 for a correct valve operation. Often the valve is sized for $a = 0.5$

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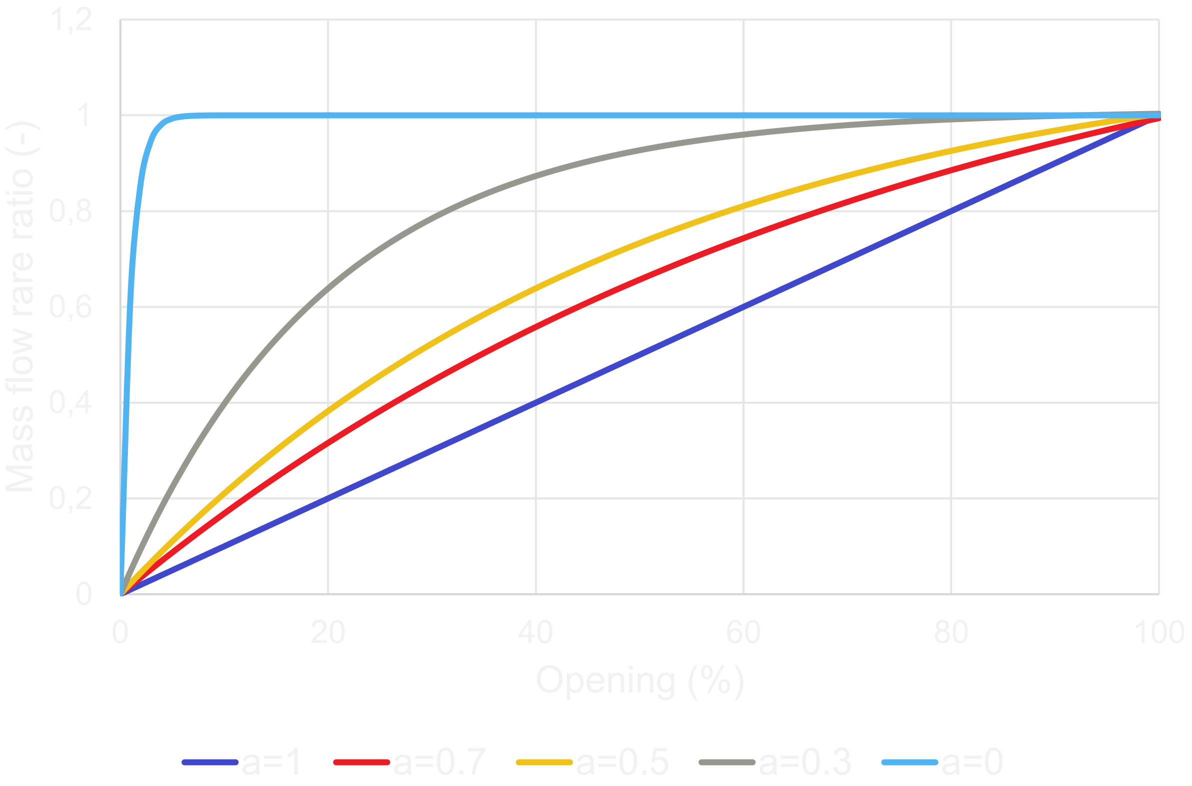

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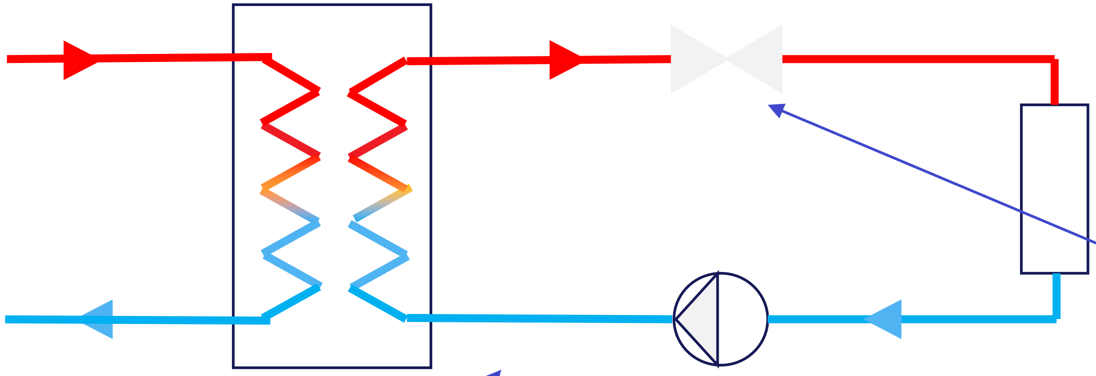
5. Distribution



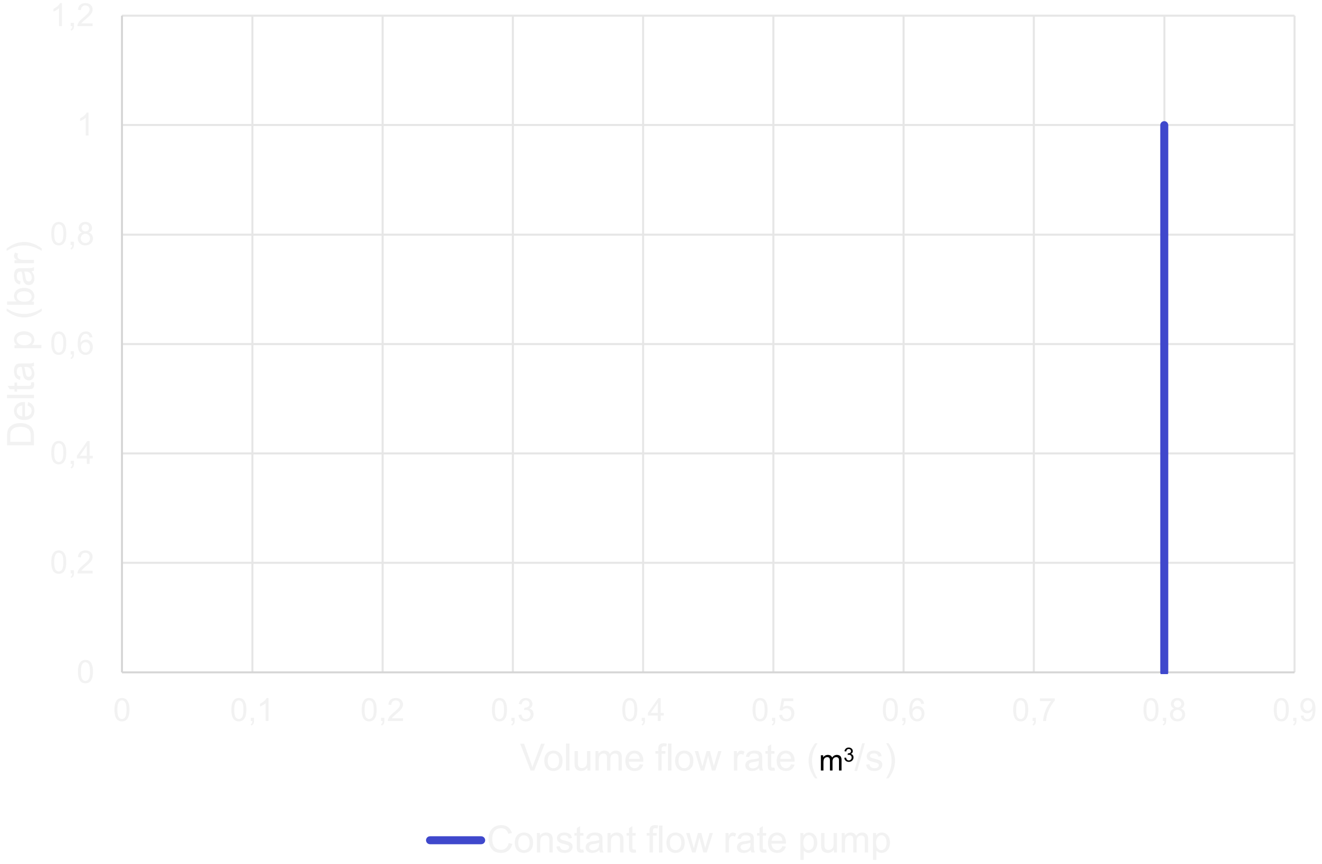
How to design the distribution side also named the secondary side?

Pipes

Pump

Valves

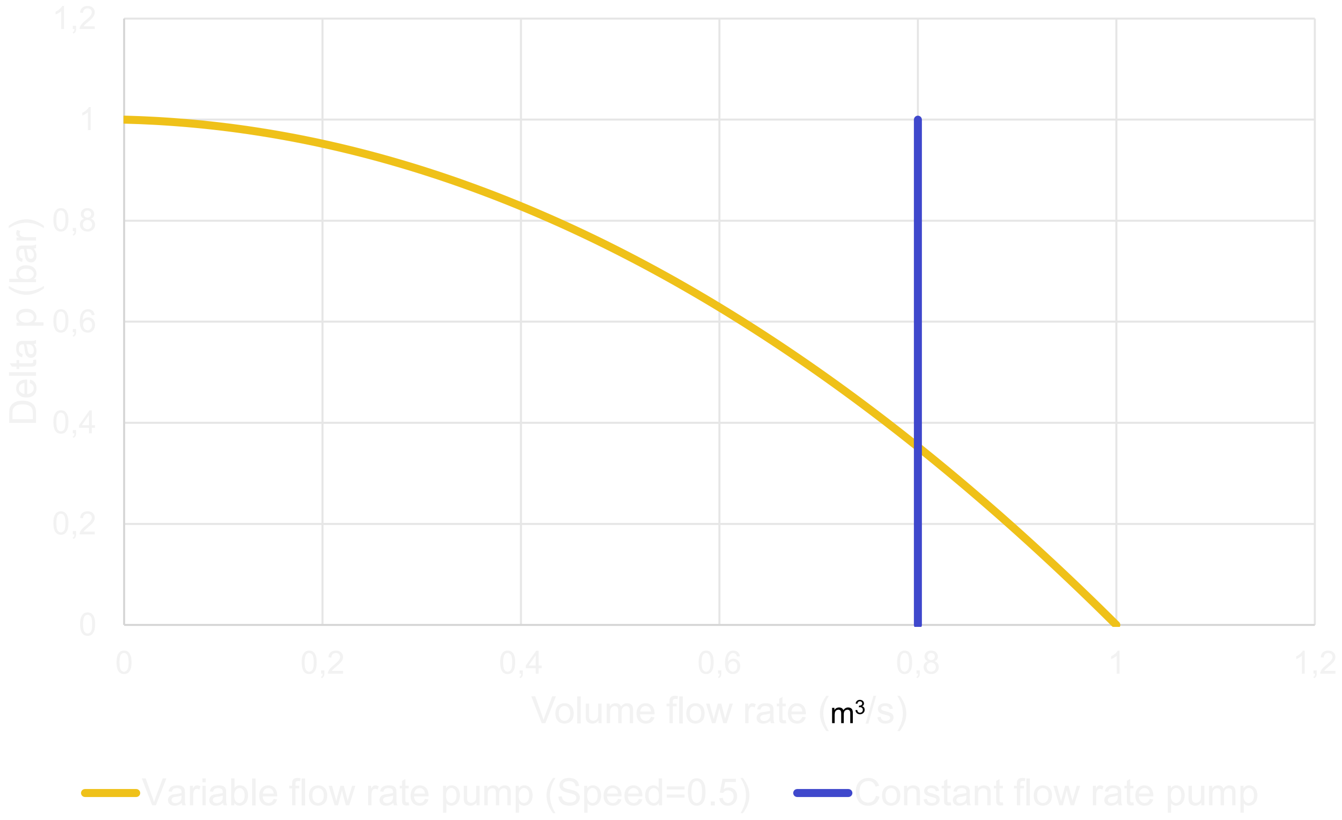
5.3 Pumps



3 types of pumps:

Constant flow rate pump

5.3 Pumps



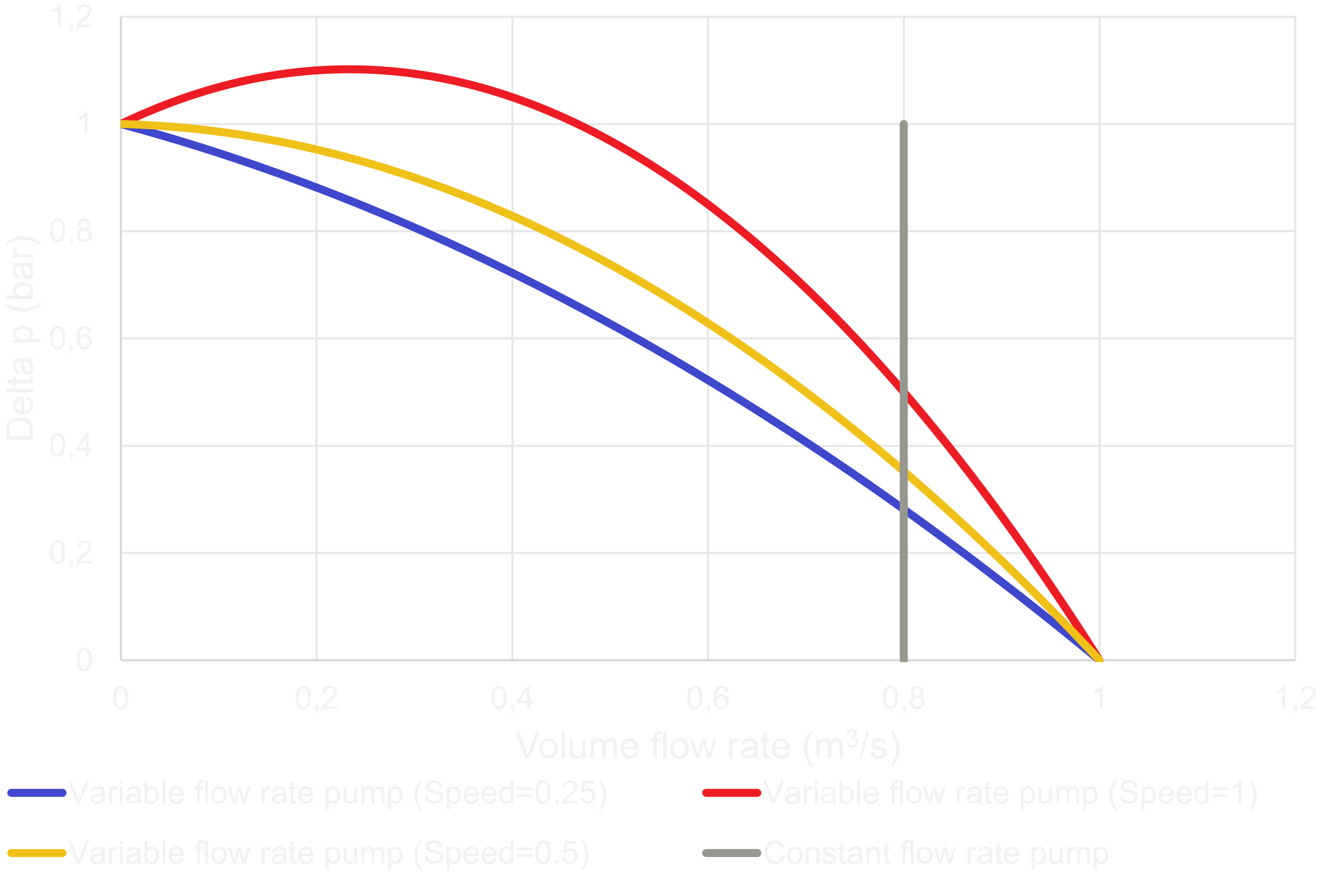
3 types of pumps:

Constant flow rate pump

Variable flow rate pump with constant speed :

$$\Delta p = A\,\dot{V}^2 + B\dot{V} + C$$

5.3 Pumps



3 types of pumps:

Constant flow rate pump

Variable flow rate pump with constant speed :

$$\Delta p = A\,\dot{V}^2 + B\,\dot{V} + C$$

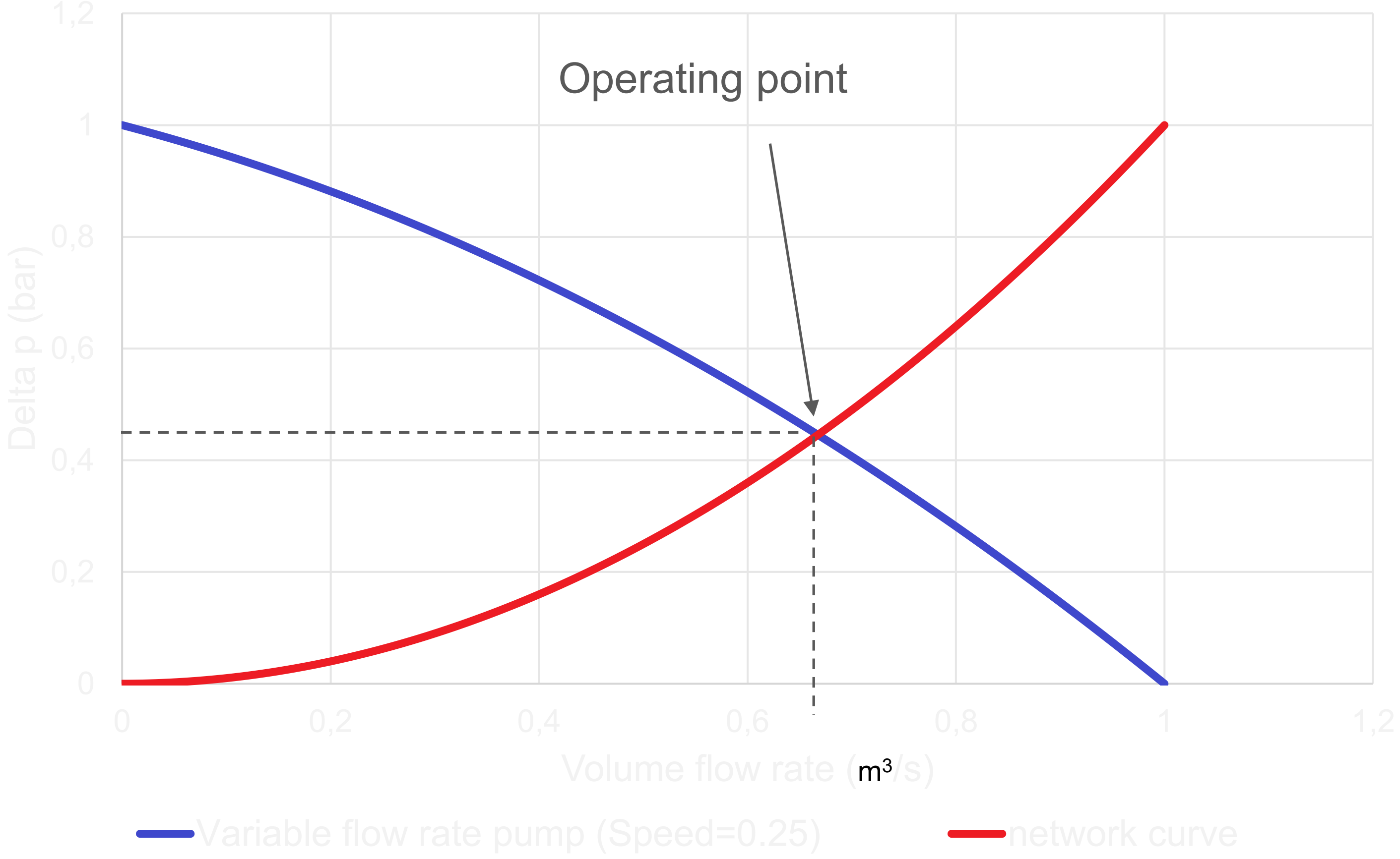
Variable flow rate pump and speed

$$\Delta p = A\,\dot{V}^2 + B\,\dot{V} + C$$

With $A, B \ and \ C$ depending on the speed

Pump electrical power : $P_{elec} = \frac{\Delta p\,\dot{V}}{\eta_{elec}\,\eta_{hydro}}$

5.3 Pumps

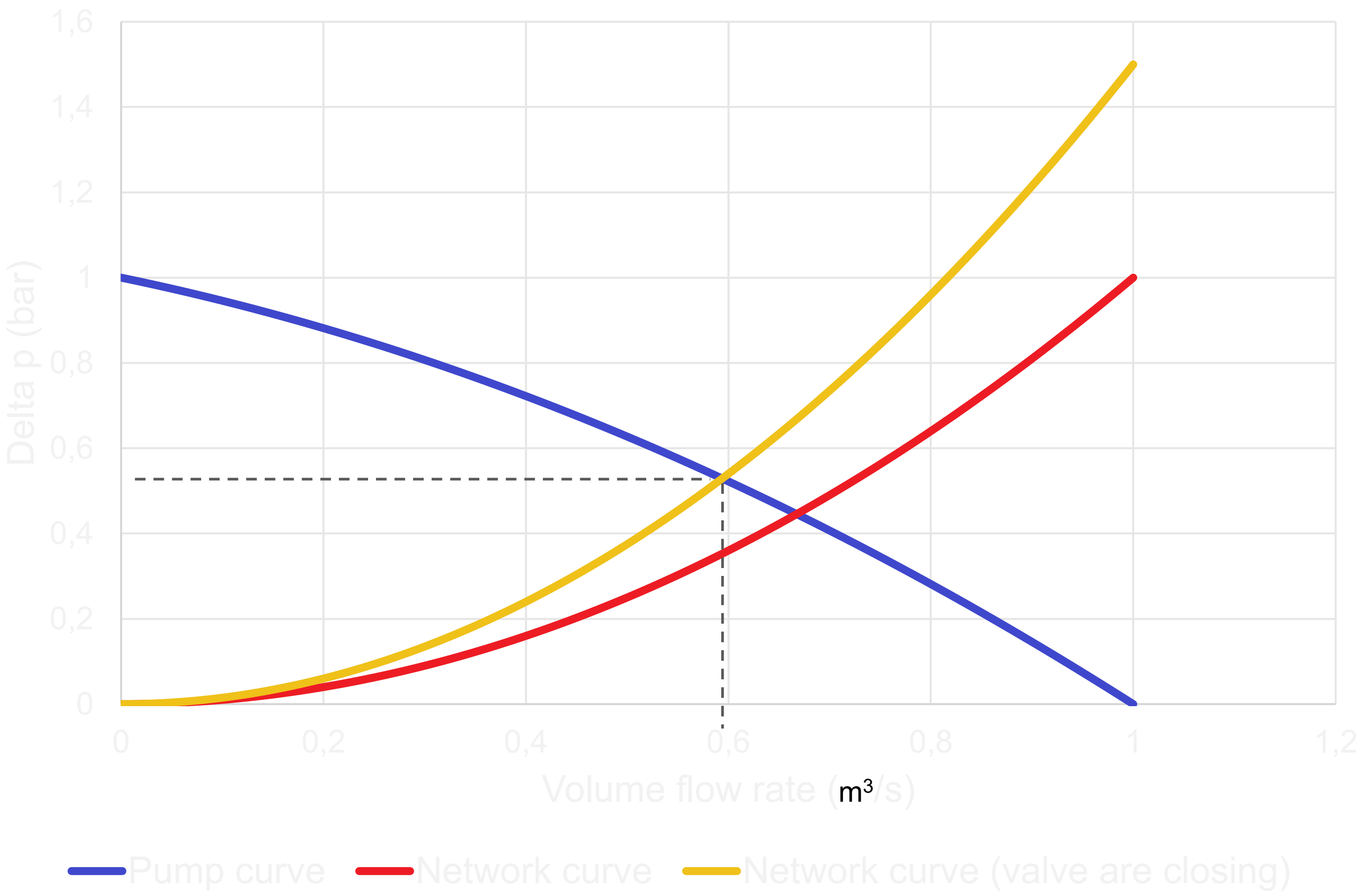


The network characteristic curve depends on:

- The pressure losses through the pipe
- The pressure losses due to the valve opening

The mass flow rate of a network is the crossover between the pump and network curve. This point is called the operating point

5.3 Pumps



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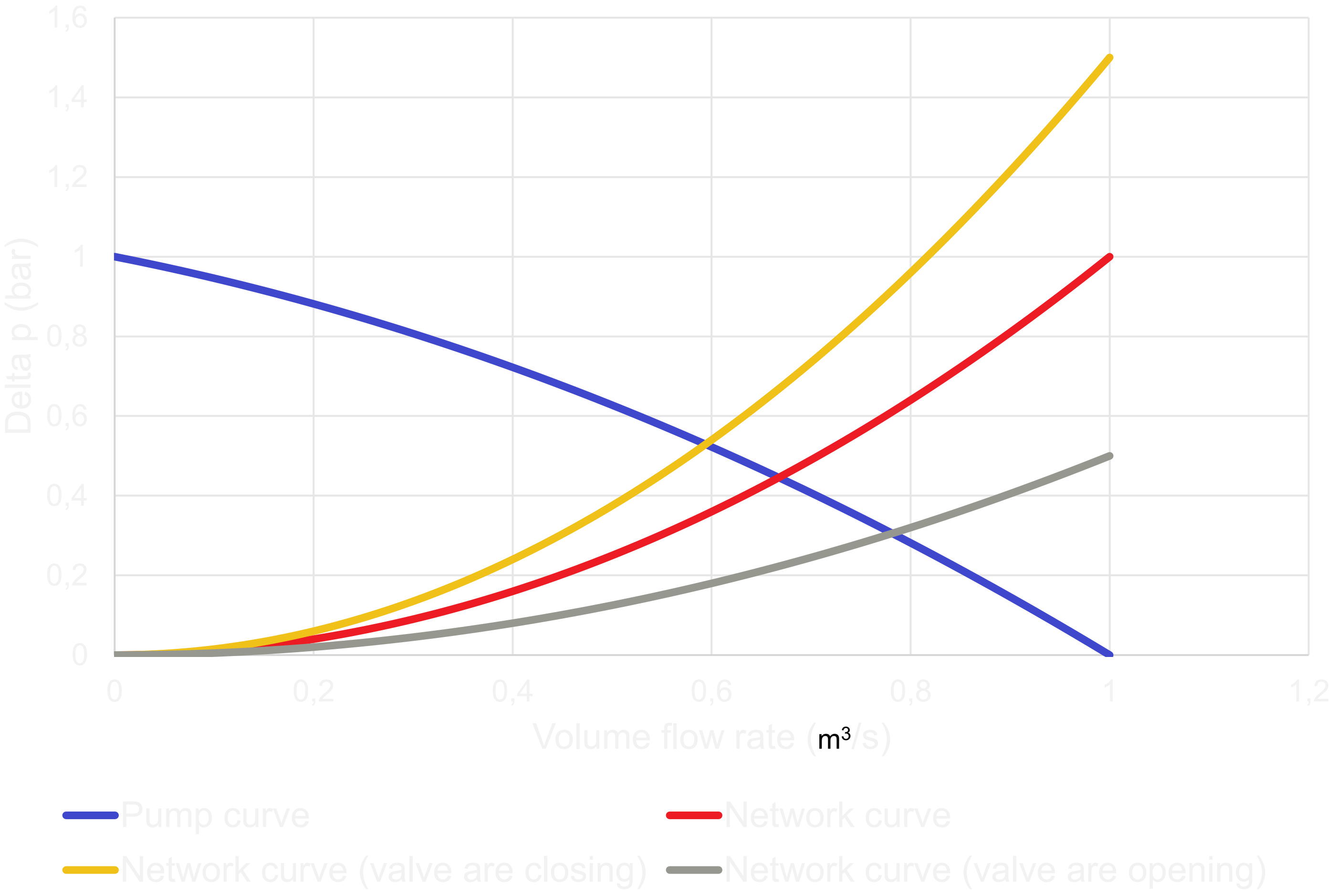
5.3 Pumps



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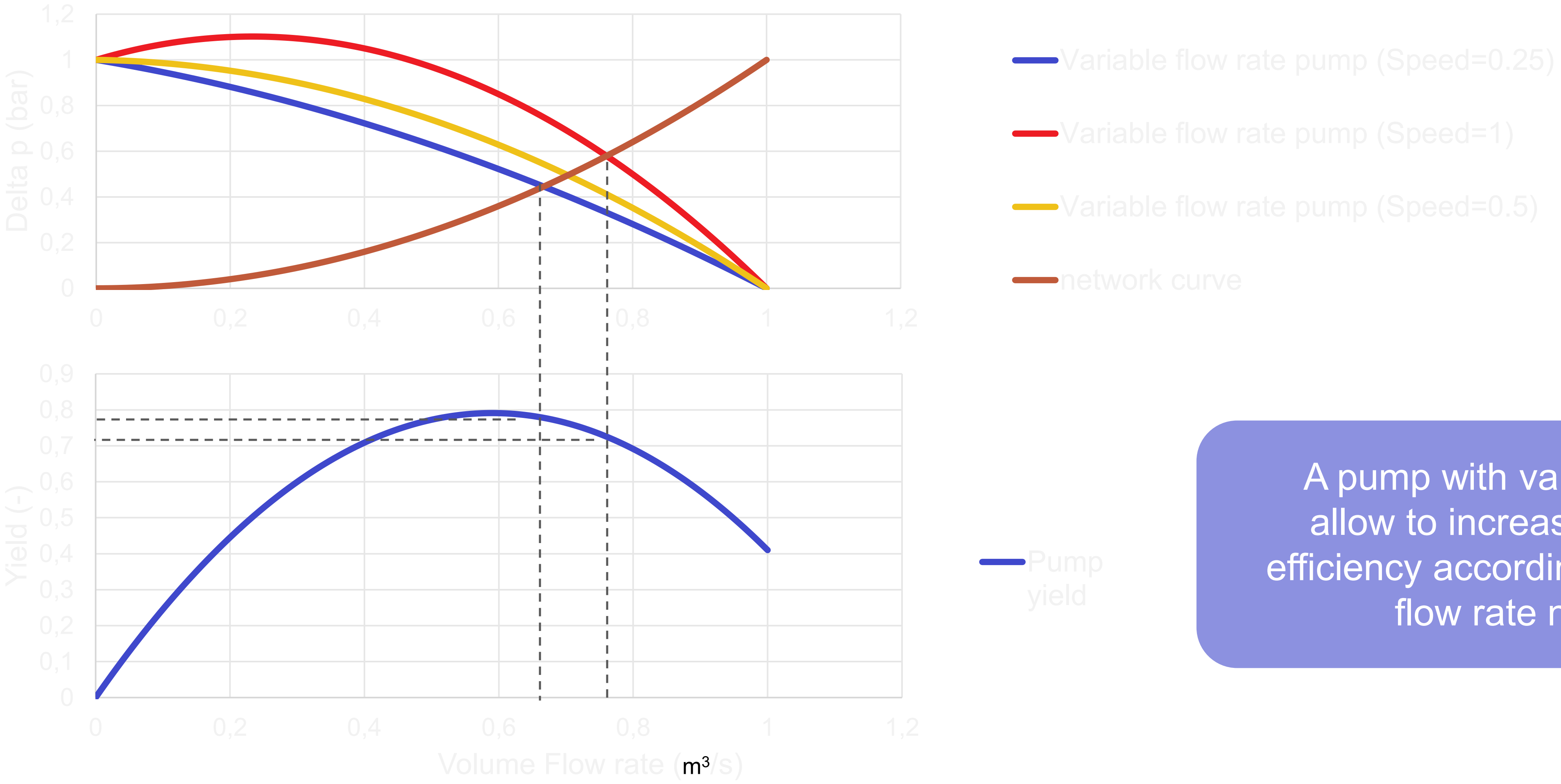
Idem when the valve is opening

5.3 Pumps



A pump with variable speed allow to increase the pump efficiency according to the mass flow rate needed

SHaKE
Sharing Knowledge on Energy Communities

Thank you!

Module 2.4 - Building side hydronic systems

SHaKE – Sharing Heat and Knowledge on Energy Communities

https://www.shakeproject-dhc.eu/

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