Hydronic systems - operation

Emission systems

$\dot{C}$ Heat capacity rate

Warm fluid $\dot{C}' = c'\dot{m}'$

Cold fluid $\dot{C}'' = c''\dot{m}''$

$\dot{C}_{min}$ Minimum value of heat capacity rate

$\dot{C}_{max}$ Maximum value of heat capacity rate

ε Efficiency of the heat exchanger

$$\varepsilon = \frac{q}{q_{\max}}$$

q → Actual heat transfer rate

$q_{\max}$ → Ideal maximum heat transfer rate (exploiting the maximum Δt in the heat exchanger)

Ideal heat flow: the fluid with minimum heat capacity rate can heat up from t''_i to t'_i

$$q_{\max} = \dot{C}_{min} (t'_i - t''_i)$$

$$q = \dot{C}' (t'_i - t'_u) \qquad q = \dot{C}'' (t''_u - t''_i)$$

$$\varepsilon = \frac{\dot{C}' (t'_i - t'_u)}{C_{min} (t'_i - t''_i)} = \frac{\dot{C}'' (t''_u - t''_i)}{C_{min} (t'_i - t''_i)}$$

$\dot{C}_{min} = \dot{C}'$ $\Longrightarrow$ $\varepsilon = \frac{(t_i^{'} - t_u^{'})}{(t_i^{'} - t_i^{''})}$

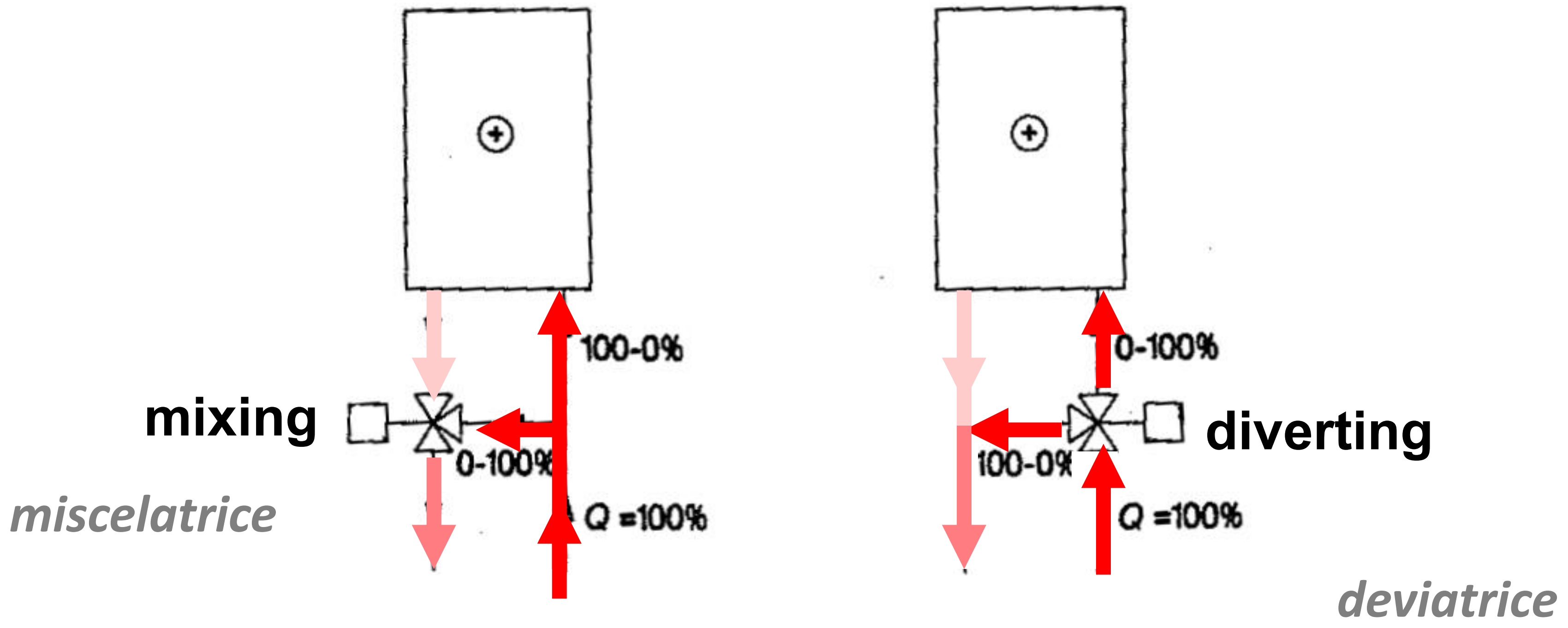
$\dot{C}_{min} = \dot{C}''$ $\Longrightarrow$ $\varepsilon = \frac{(t_u^{''} - t_i^{''})}{(t_i^{'} - t_i^{''})}$

In general:

$$\varepsilon = \frac{\left|(t_i - t_u)_{\max}\right|}{t_i^{'} - t_i^{''}}$$

$\longrightarrow$ The greatest absolute value temperature variation in the heat exchanger (fuid with minimum heat transfer rate)

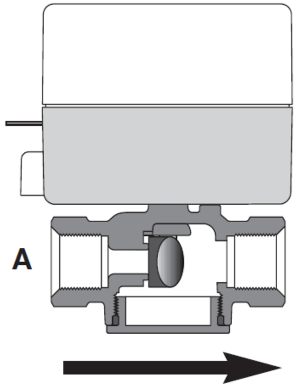
Some basic notions on the valves



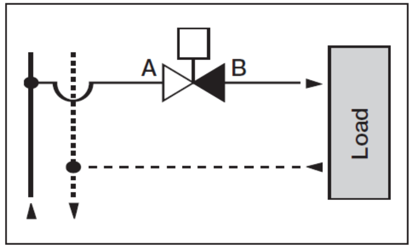
Mixing valve: it allows a mixing between the 2 entering fluids: the outflowing fluid = Σ (entering flows). The outlet temperature is a function of the mass flow rates enering the valve.

Diverting valve: one input, 2 outputs. The entering temperature of the fluid will be the same than the 2 outputs.

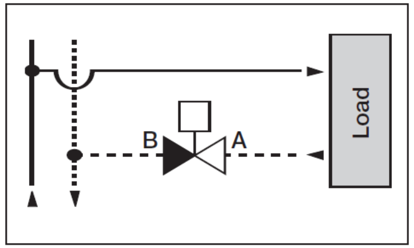
2 ways valve



2-way valve
normally closed actuator

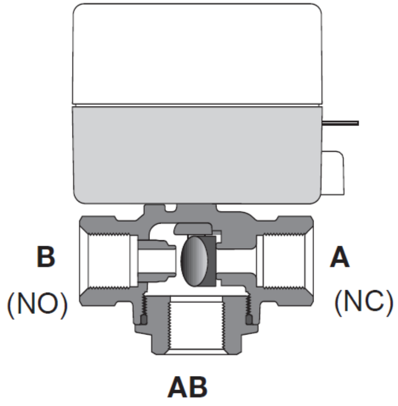


2-way installed on the supply



2-way installed on the return

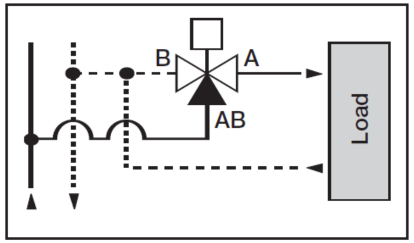
3 ways valve



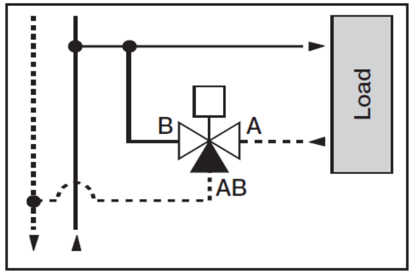
3-way valve normally closed actuator

3-way Zone valves can be fitted with NC actuators only.

Note! Rotate 180° the valve body for NO applications



3-way installed on the supply in diverting configuration



3-way installed on the return

Thermal output of a terminal unit

q^*: design peak power

q: partial load

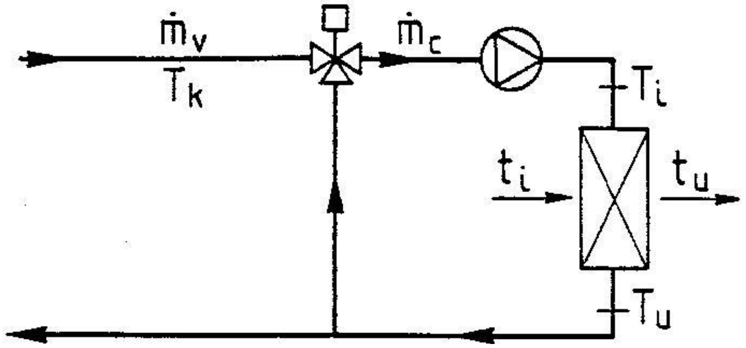
3 ways:

1. Variation of the temperature maintaining the water flow rate constant.

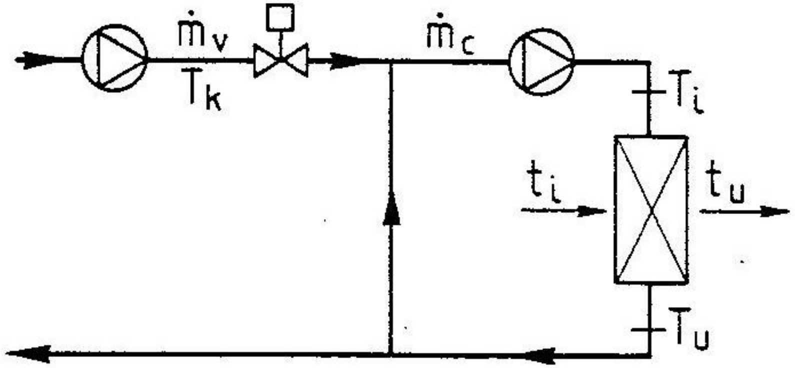
2. Variation of flow rate of the water keeping the supply temperature constant

3. Variation of flow rate and supply temperature

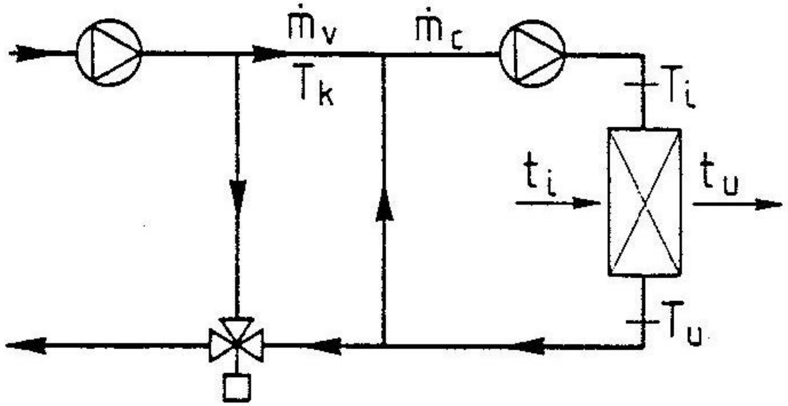
Case 1 (variable temperature, constant flow rate)



3-ways valve

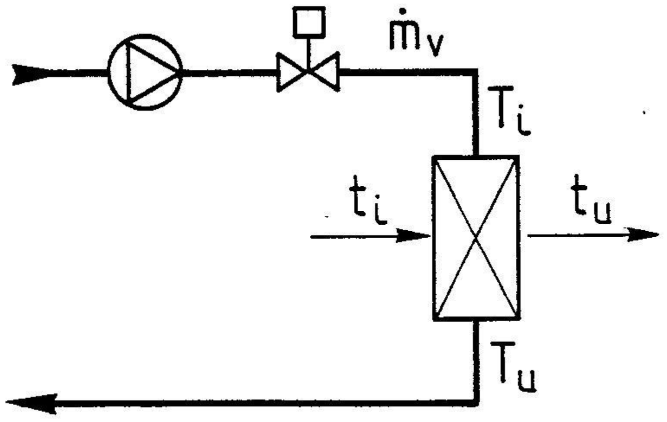


Main circuit with variable flow rate

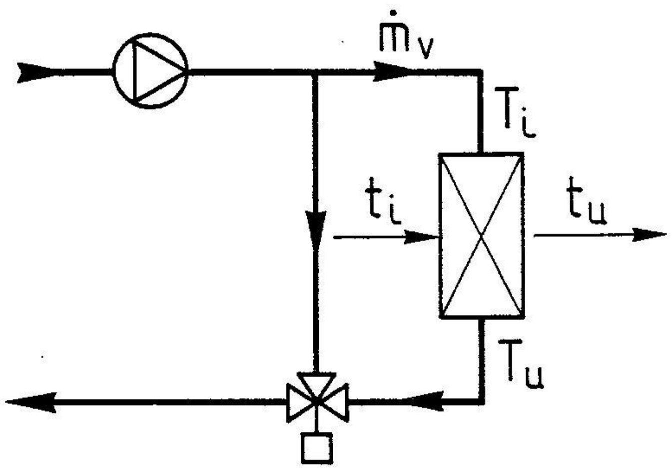


Main circuit with constant flow rate

Case 2 (variable flow rate, constant temperature)



2-way valve with variable flow rate in the main circuit



3-way valve with constant flow rate in the main circuit

Case 1: constant flow rate, variable temperature

Constant flow rate, hence *KA* does not vary, hence the characteristic parameters do not change:

$$\dot{C}_{\min} / \dot{C}_{\max}, NTU$$

Thus ε can be considered constant

Design consitions:

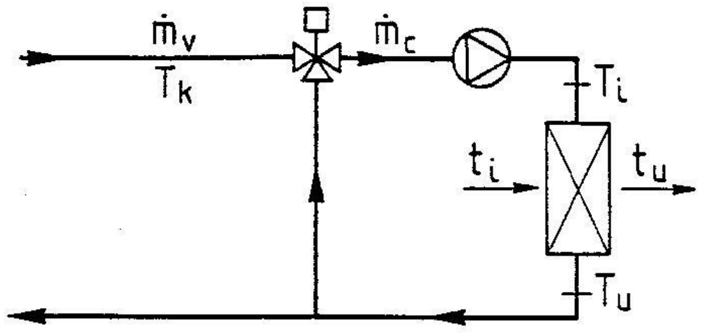
$$q^* = \varepsilon \dot{C}_{\min} (T_i^* - t_i)$$

In general actual conditions:

$$q = \varepsilon \dot{C}_{\min} (T_i - t_i)$$

Named $q_R = q/q^*$:

$$q_R = \frac{T_i - t_i}{T_i^* - t_i}$$



It linearly depends on the inlet temperature T_i.

The valve modulates the flow rate $\dot{m}_v$

$$\dot{m}_R = \dot{m}_v / \dot{m}_v^*$$

Heat exchange characteristic *E*:

$$E = \frac{T_i - T_u}{T_i - t_i} = \frac{T_i^* - T_u^*}{T_i^* - t_i}$$

$E = \varepsilon$ when the flow rate is: $\dot{C}_{\min}$

When $\dot{m}_v{}^* = \dot{m}_c$

$$m_R = \frac{\dot{m}_v}{\dot{m}_v{}^*} = \frac{\dot{m}_v}{\dot{m}_c} = \frac{T_i - T_u}{T^*{}_i - \boldsymbol{T_u}}$$

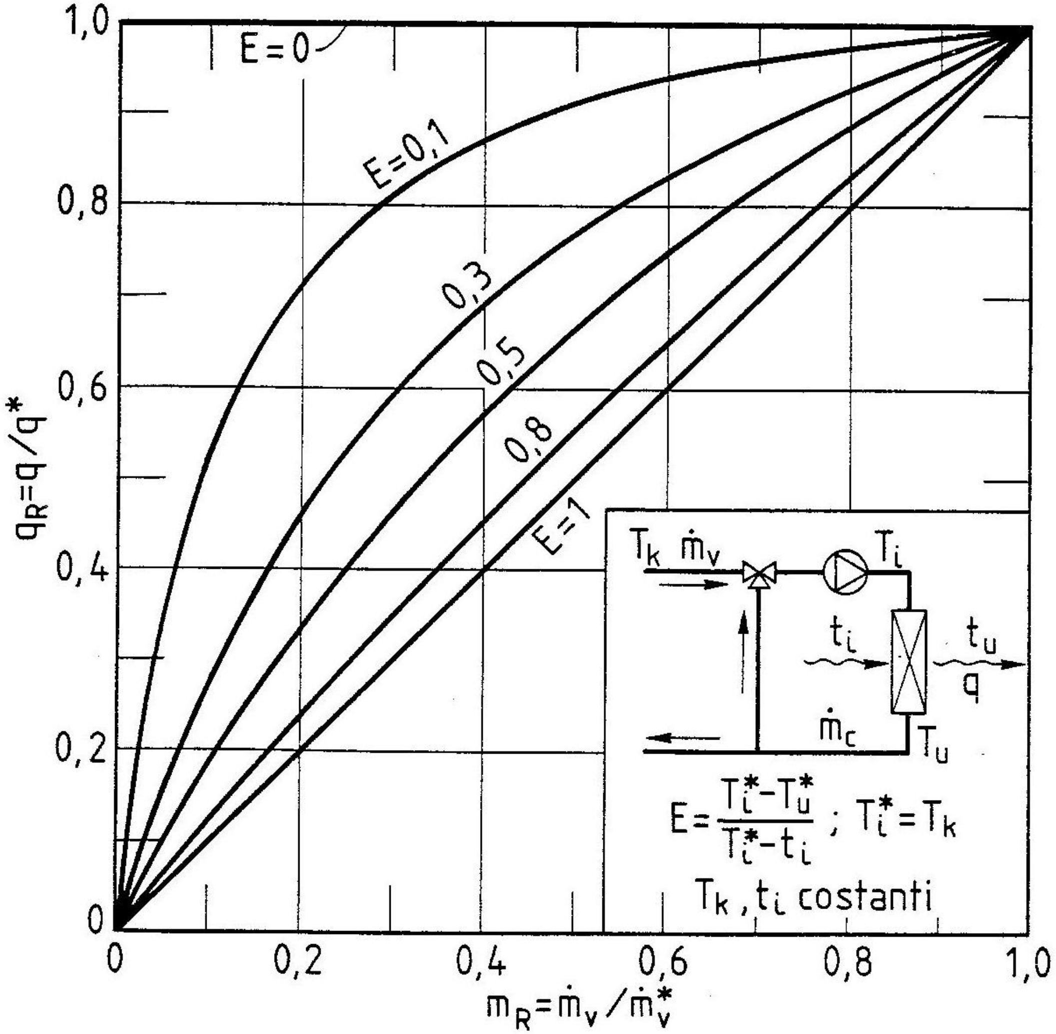
$$\frac{E}{m_R} = \frac{T_i{}^* - T_u}{T_i - t_i}$$

$$(1 - E) = \frac{T_u - t_i}{T_i - t_i}$$

$$q_R = \frac{1}{(E / m_R) + (1 - E)}$$

In general

0.1 < E < 0.4

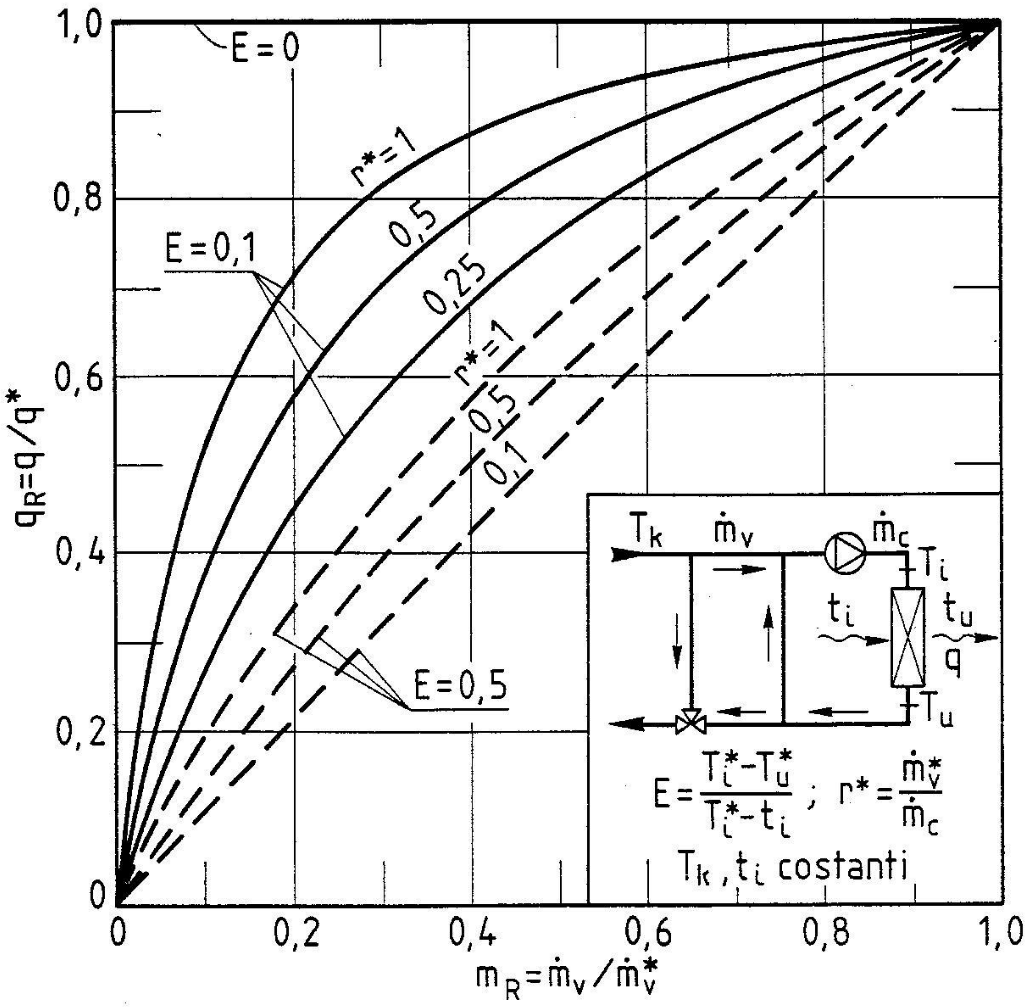


Named:

$$r^* = \frac{\dot{m}_v{}^*}{\dot{m}_c} = \frac{T_i{}^* - T_u{}^*}{T_k - T_u{}^*}$$

Also in this case the equation is solved in a mathematical way:

$$q_R = \frac{E + r^*(1-E)}{(E/m_R) + r^*(1-E)}$$



Case 2 (variable flow rate, constant temperature)

In this case by varying the flow rate, also K would vary. Anyway let us suppose that K does not vary.

Hence ε does not vary:

$$q^* = c\dot{m}_v{}^* E^* (T_i - t_i) \qquad q = c\dot{m}_v E (T_i - t_i)$$

$$q_R = q / q^* \qquad m_R = \dot{m}_v / \dot{m}_v{}^*$$

$$q_R = m_R (E / E^*)$$

$$E = \varepsilon \dot{C}_{\min} / \dot{C}_{\max}$$

Radiators, with thermostatic valves.

$$t_i = t_u = t_a$$

$$\dot{C}_{min} / \dot{C}_{max} = 0$$

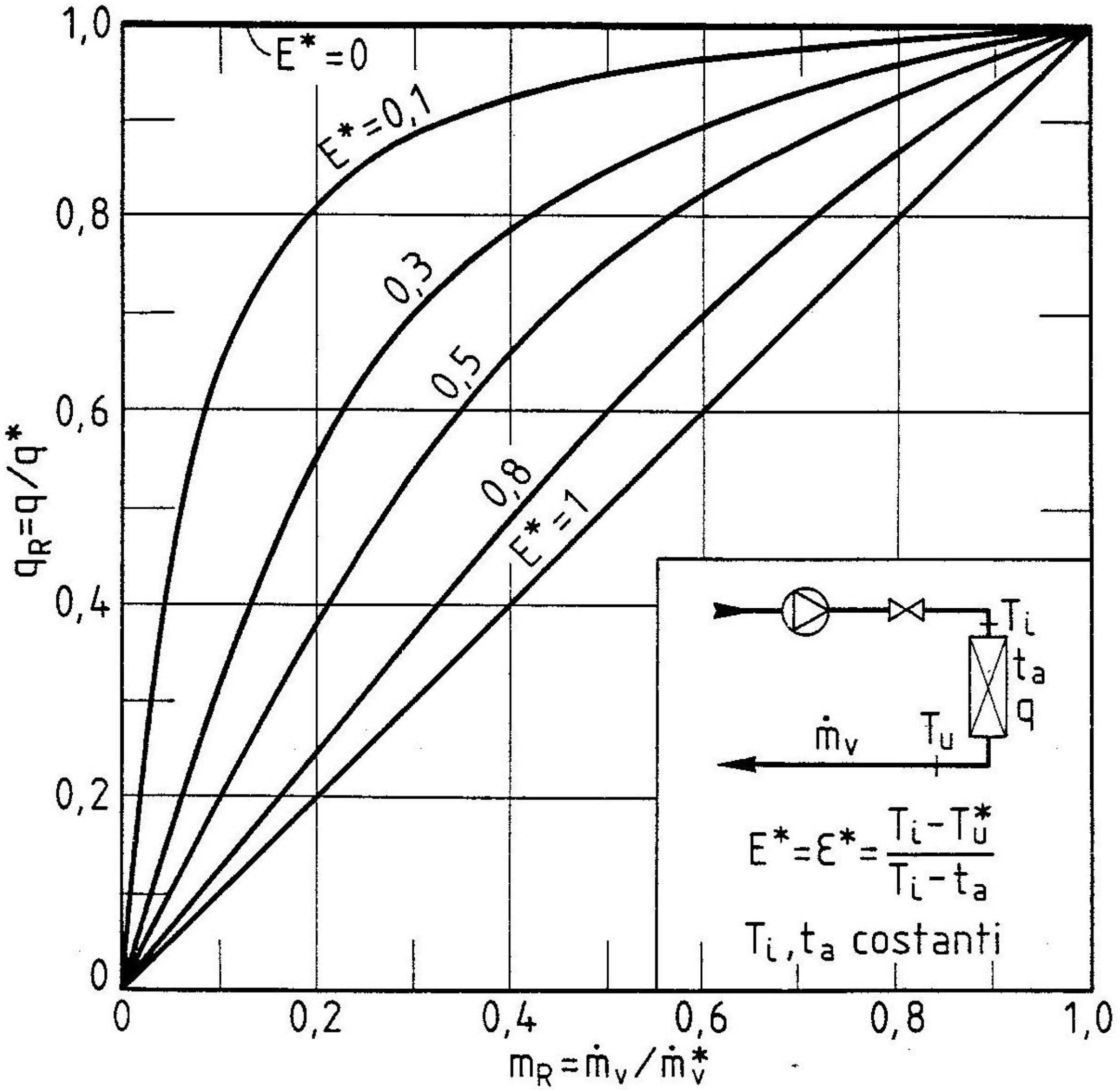
$$E^* = \varepsilon^* = 1 - e^{-NTU^*}$$

$$E \;\; = \varepsilon = 1 - e^{-NTU}$$

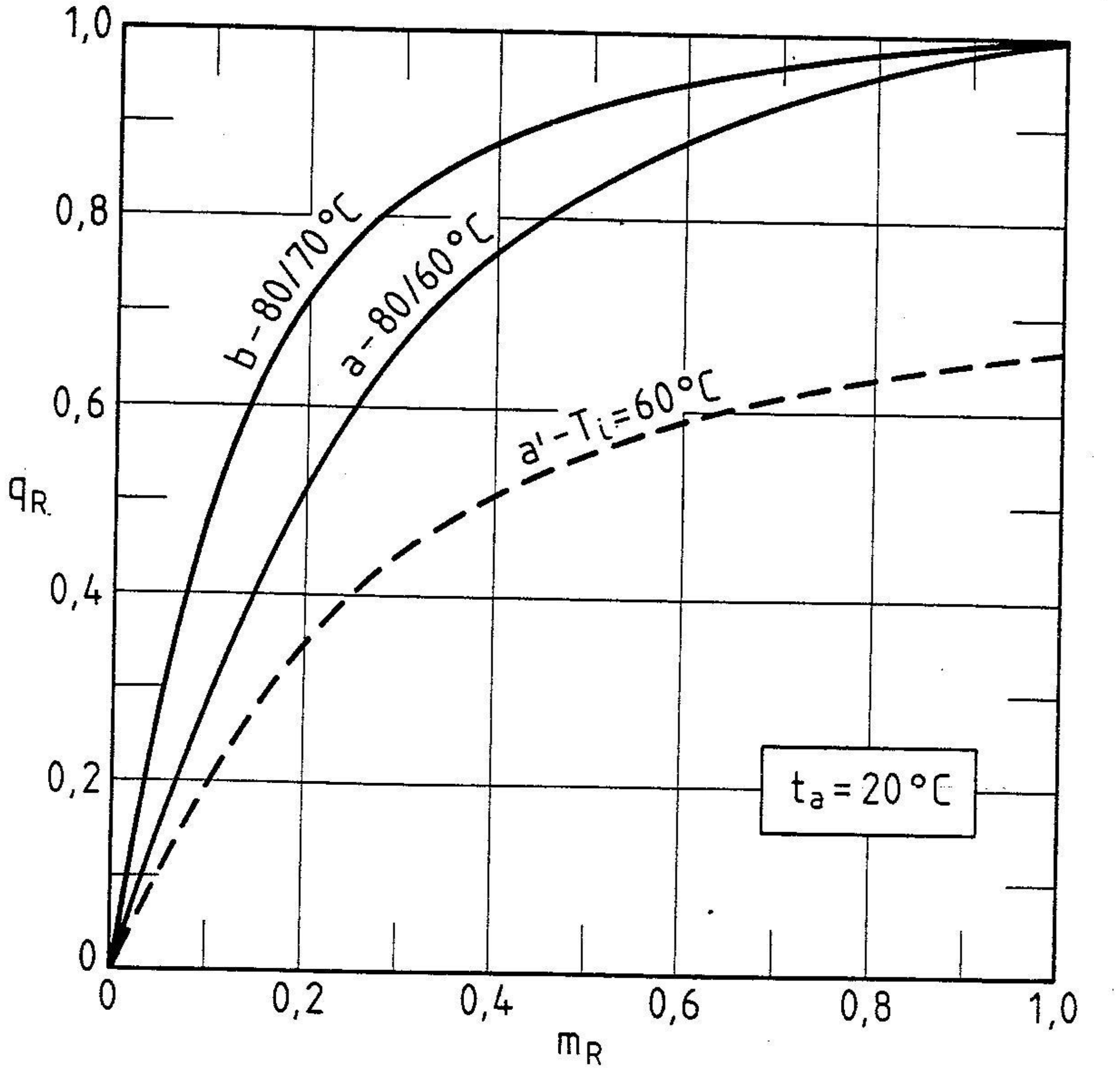
$$NTU = NTU^* / m_R$$

$$q_R = m_R \frac{1 - e^{-NTU^*/m_R}}{1 - e^{-NTU^*}}$$

$$q_R = m_R \frac{1 - (1 - \varepsilon^*)^{1/m_R}}{\varepsilon^*}$$



Case 3: Example of a radiator with variable temperature and flow rate



Valves

Regulation

Adjusting temperature/flow rates in a hydronic circuit so that users are satisfied in different operating conditions (e.g. partial loads)

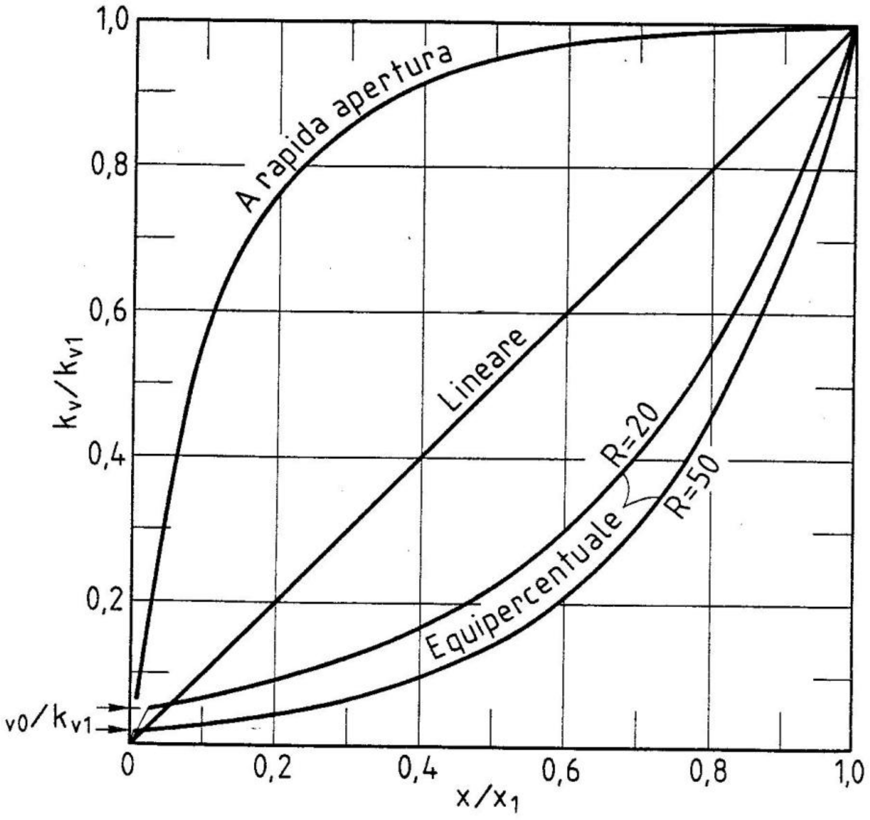
Balancing

Adjusting pressures/flow rates in a hydronic circuit so that flow/heat is evenly distributed at full load.

Regulation valves

Flow factor k_v: flow rate (m^3/hr) across the valve at 5-30°C under Δp = 1 bar

k_{v1}: flow rate (m^3/hr) at 5-30°C under Δp = 1 bar with valve fully open (x = x_1)



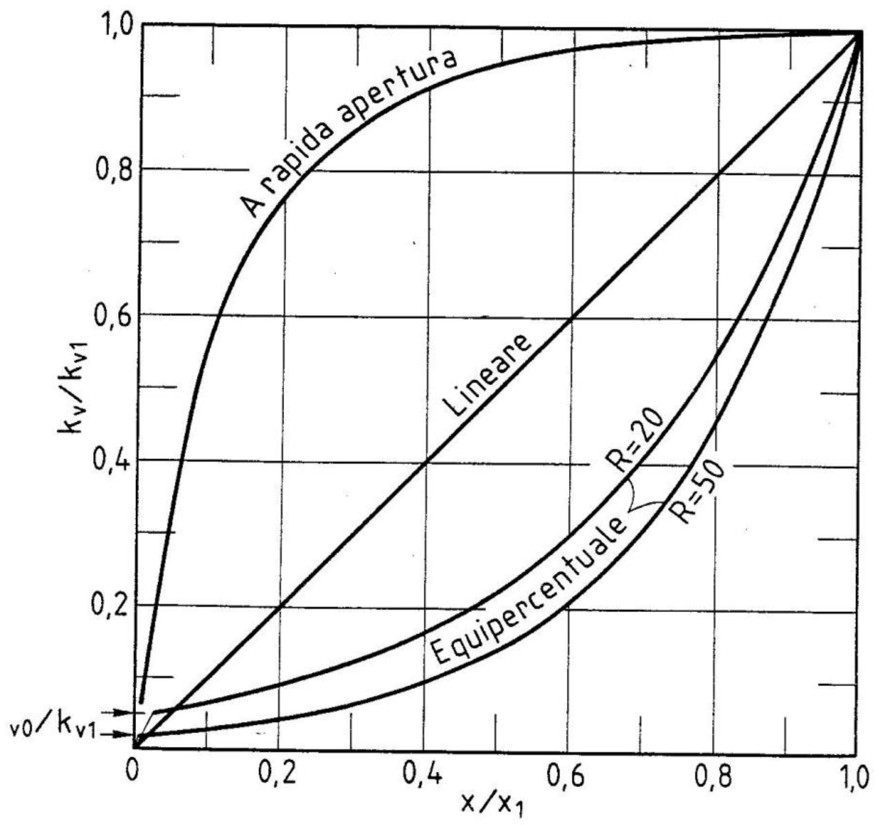
Regulation valves

Characteristic curve of the valves:

$$\frac{k_v}{k_{v1}} = f\left(\frac{x}{x_1}\right)$$

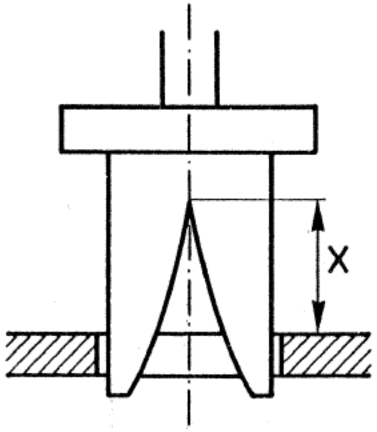
According to the characteristic curve, there are three types of valves:

- **Quick opening**
- **Linear**
- **Equal-percentage**

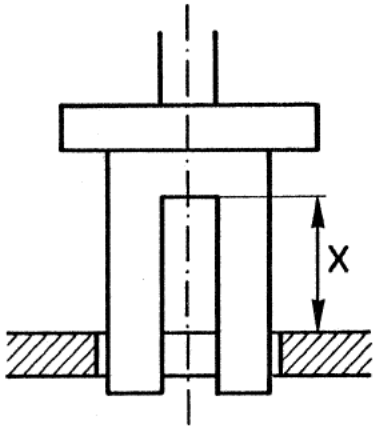


Regulation valves

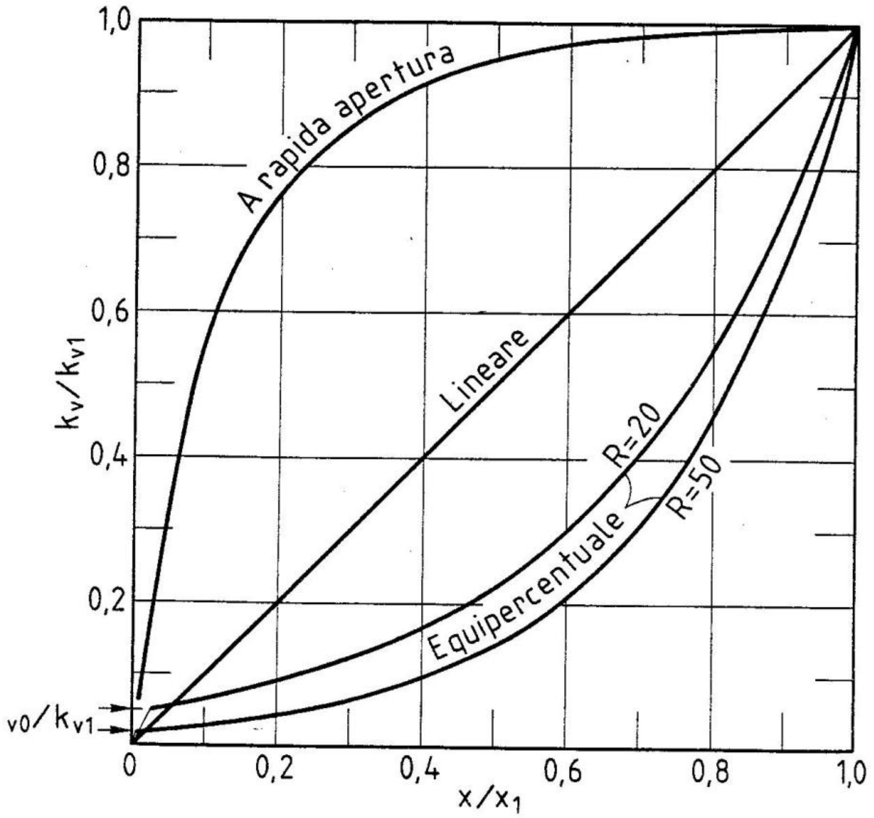
Qualitative shape of the obturators



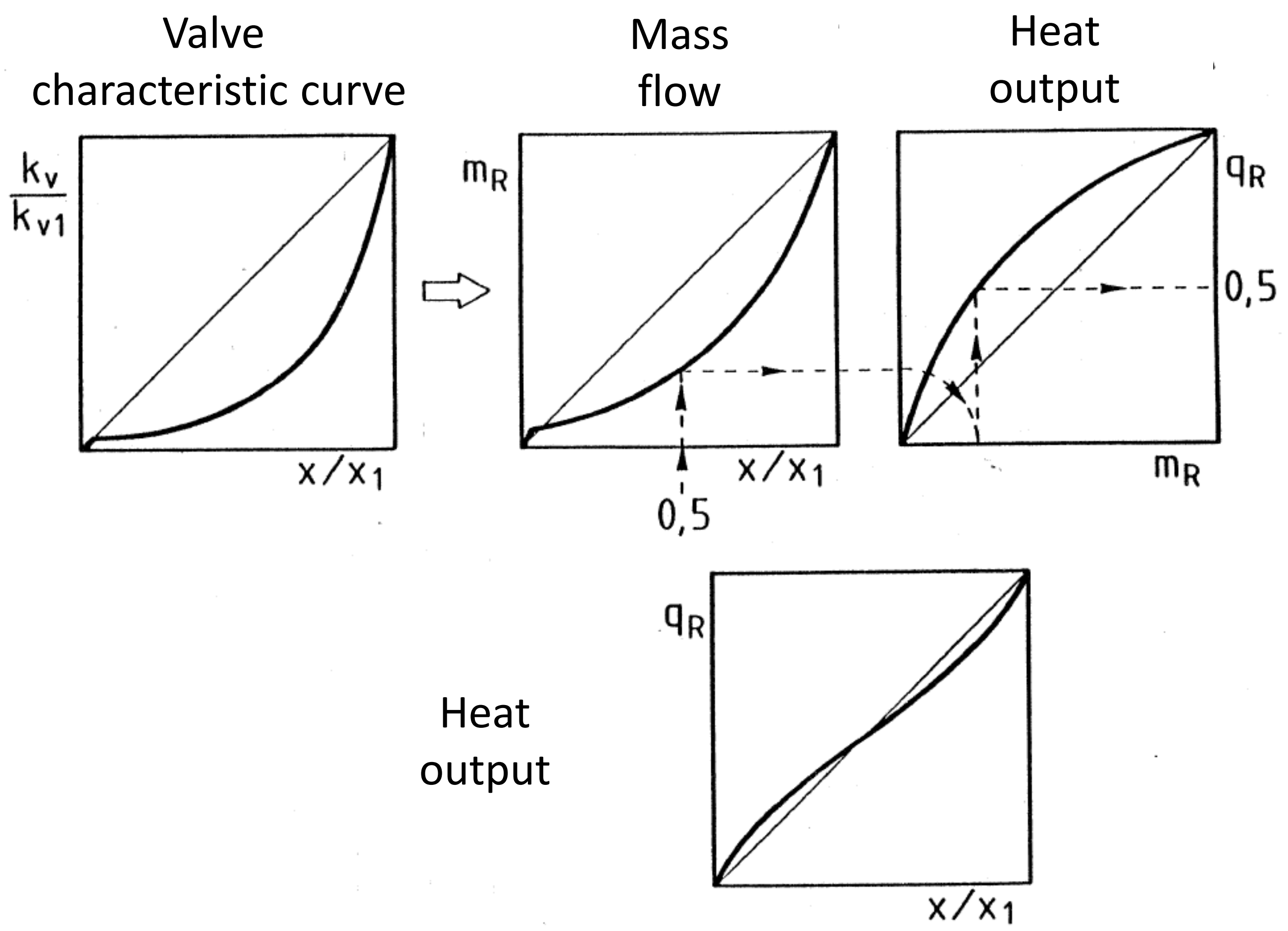
Equal percentage



Linear



Regulation valves



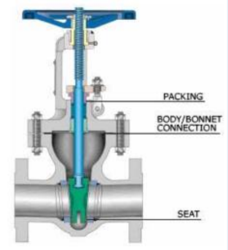
Regulation valves

Classification

Type	Typical applications
Quick-opening control valves	- Frequent on-off systems - Systems where instantaneous supply of large flow rates is needed (e.g. cooling systems, safety circuits..)
Linear control valves	- Liquid level or flow control - Systems where Δp across the valve is expected to remain fairly constant
Equal percentage control valves	- Temperature control - Pressure control - Systems where Δp across the valve is expected to vary significantly

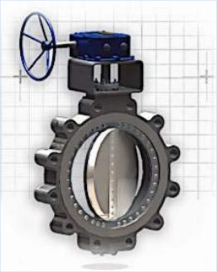
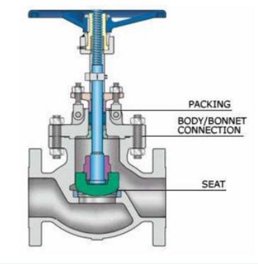
Regulation valves

Quick-opening

Type		Pros	Cons
Ball valves		• Low cost • Versatile (high pressure, high temp, high flow) • Low leakage • Tight sealing with low torque	• Limited throttling • Prone to cavitation • Unsuitable to slurries
Gate valves		• Low cost • Suited to fully open/fully closed operation • Suited to slurries • Tight shut-off	• Poor control • Cavitates at low Δp

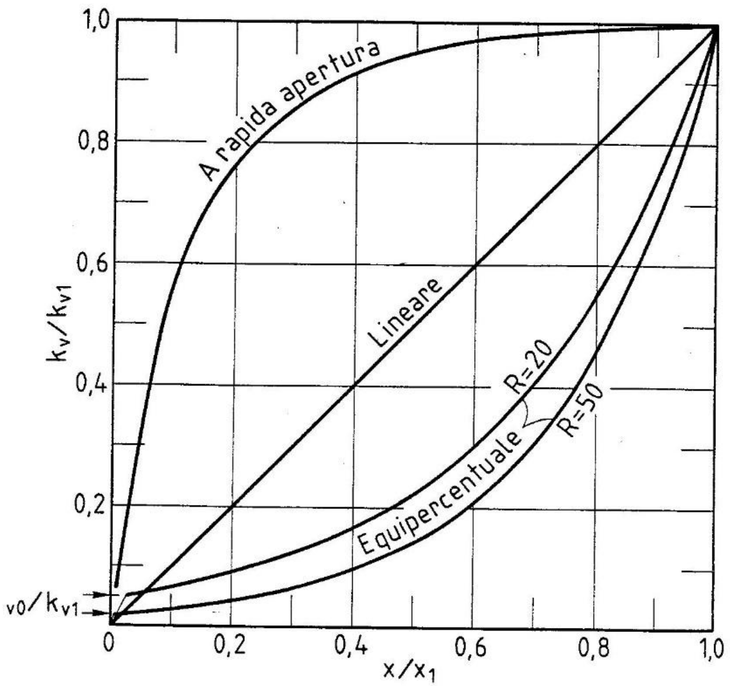
Regulation valves

Linear/equal-percentage control

Type		Pros	Cons
Butterfly valves		• Reliable for frequent operation with low Δp • Cheap solution for high flow applications (water treatment, fire protection)	• High torque required for control (poor throttling characteristics) • Prone to cavitation at low flow
Globe valves		• Precise flow regulation • Frequent and wide throttling • Suited to high Δp	• Expensive • Low shut-off capability

Regulation valves

k_{v0}: Minimum flow rate (m³/hr), below which regulation is not possible: curve deviates from equal percentage law due to «noisy» shut-off



Rangeability

$$R = \frac{k_{v1}}{k_{v0}}$$

Rangeability is an important metric of in **equal-percentage valves** because:

1) It determines the minimum controllable flow k_{v0}
2) It gives the curvature of the characteristic curve

$$\frac{k_v}{k_{v1}} = R^{[(x/x_1)-1]}$$

Regulation valves

Valve authority

It describes how well a throttling valve will control flow under the influence of other elements in the HVAC system

$$\alpha = \frac{\Delta p_v(x_1)}{\Delta p_v(x_1) + \Delta p_c}$$

- $\alpha < 30\%$ unstable to fair control with low Δp
- **$30\% < \alpha < 50\%$** fair to good control with reasonable Δp
- $\alpha > 50\%$ very good control with high Δp

Regulation valves

Note

- Flow factor k_v: flow rate (m^3/hr) across the valve at 5-30°C under Δp = 1 bar
- Δp ≈ f(Q^2)

$$\Delta p\ [mm] = 0.01\left(\frac{Q\ [l/hr]}{k_v[m^3/hr]}\right)^2$$

Regulation valves

Two-way valves

Typical use

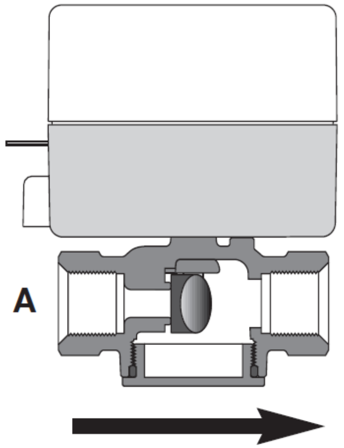
Adapting flow rate to local energy demand in hydraulic circuits with variable flow

Examples

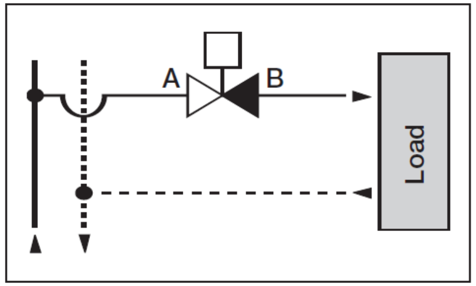
- Thermostatic valves in radiator systems
- 2-way valves in fancoil circuits
- 2-way valves in substations of DH networks with variable flow rate

Regulation valves

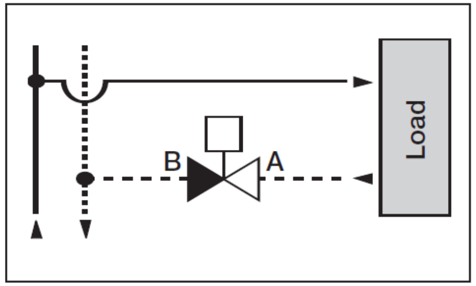
Two-way valves



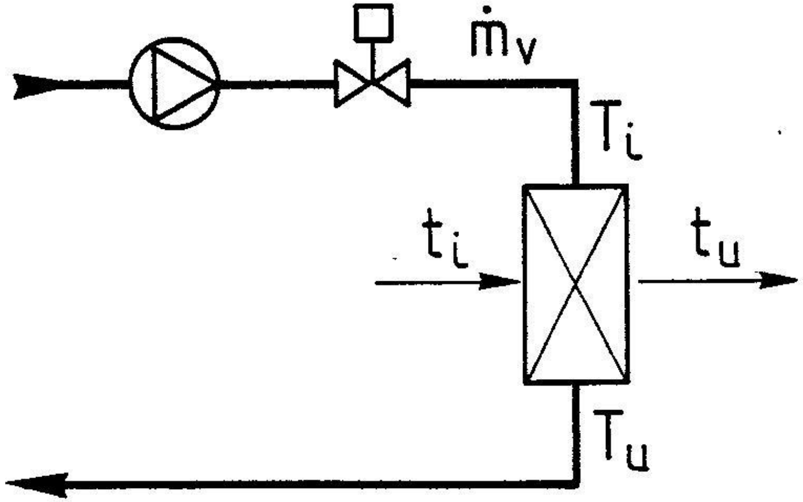
2-way valve
normally closed actuator



2-way installed on the supply



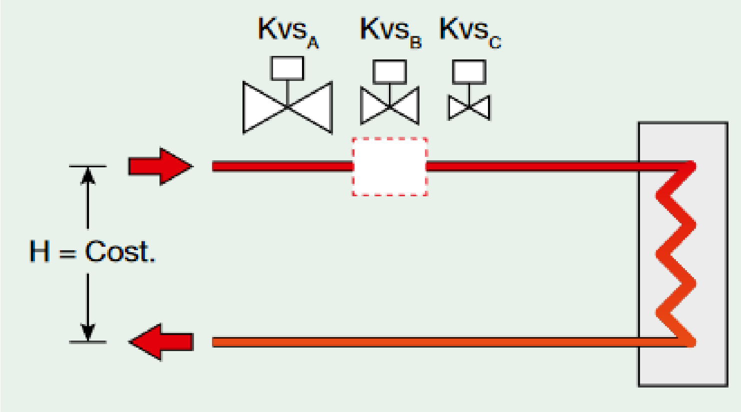
2-way installed on the return



Regulation valves

Example: selection of a two-way valve

Choose between valve A ($k_{v1} = 18\ m^3/hr$), valve B ($k_{v1} = 6\ m^3/hr$) and valve C ($k_{v1} = 3\ m^3/hr$) to control the flow rate in a circuit with design flow rate equal to 1500 l/hr. The corresponding pressure loss in the circuit, excluding the valve, is 6 kPa.



Regulation valves

Three-way valves

Typical use

Supply temperature control via mixing/ diverting in hydraulic circuits with constant flow

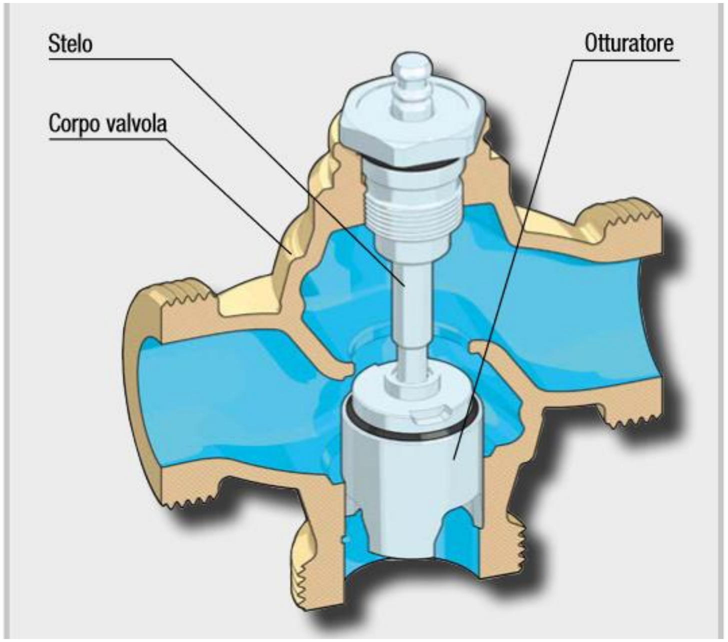
Examples

- Mixing valves on the supply line downstream heat generation systems (heat pumps, gas boilers etc)
- Diverting valves on the return line downstream heat loads (heat exchangers)

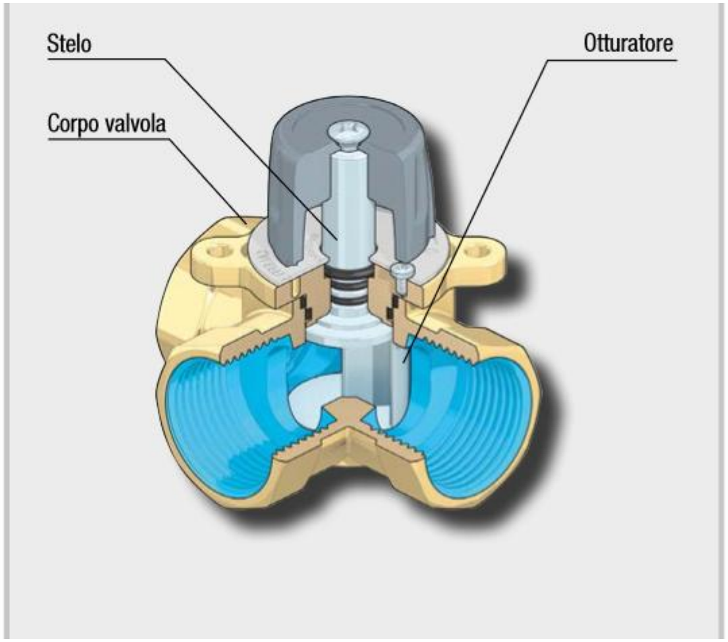
Regulation valves

Three-way valves

GLOBE VALVES

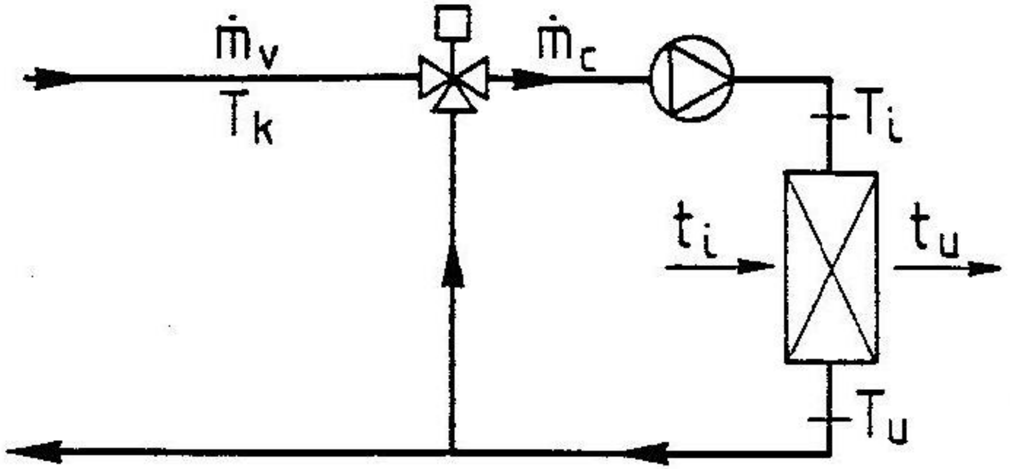


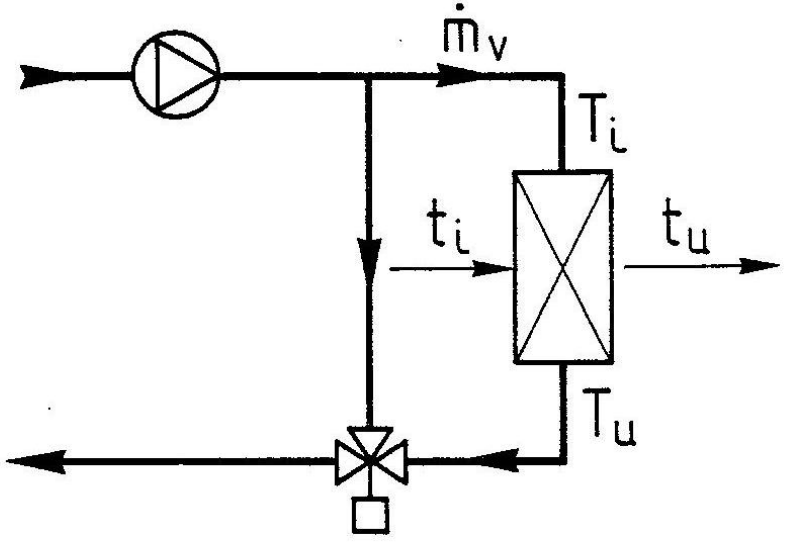
SECTOR VALVES



Regulation valves

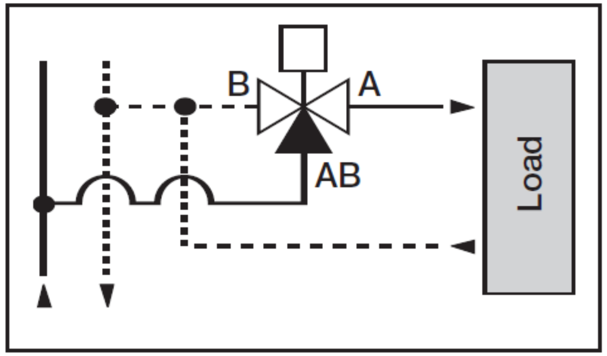
Three-way mixing valves



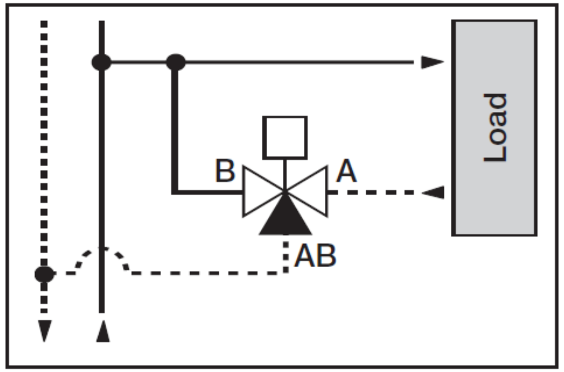


Regulation valves

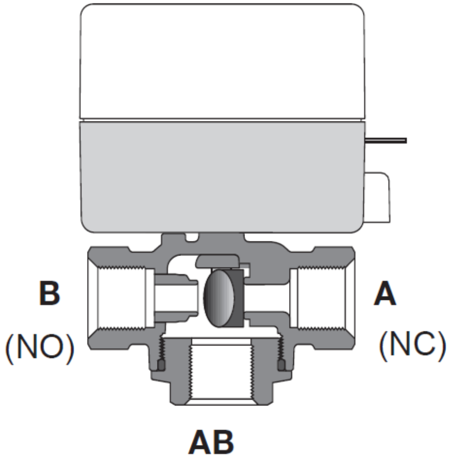
Three-way diverting valves



3-way installed on the supply in diverting configuration



3-way installed on the return



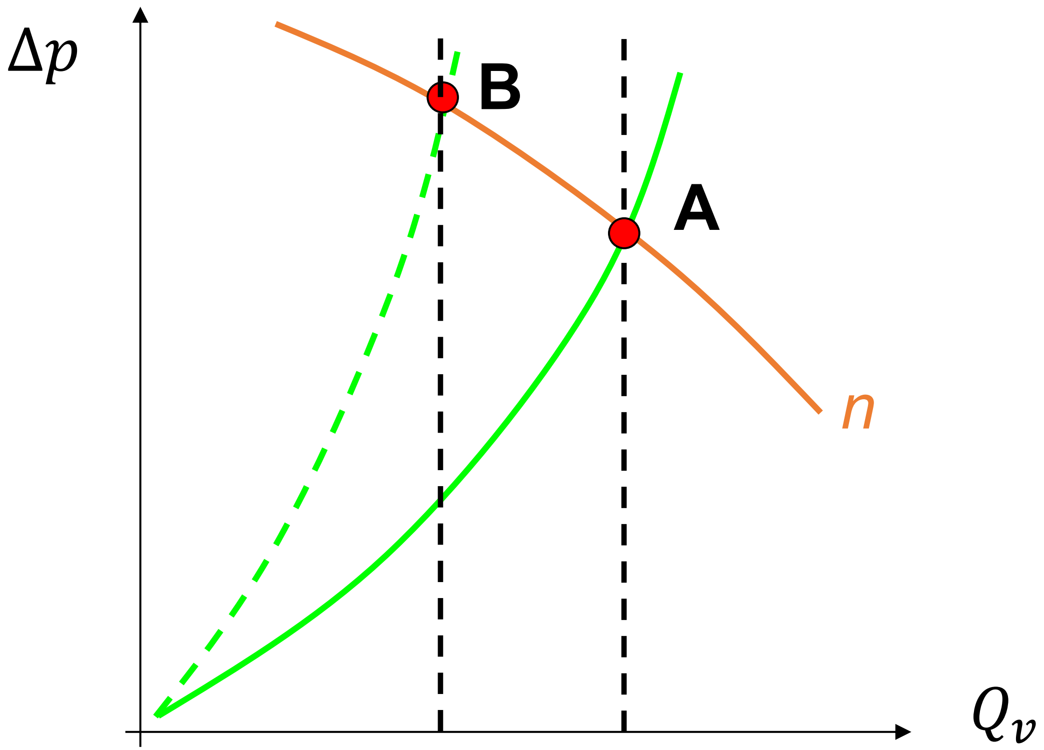
3-way valve normally closed actuator

3-way Zone valves can be fitted with NC actuators only.

Note! Rotate 180° the valve body for NO applications

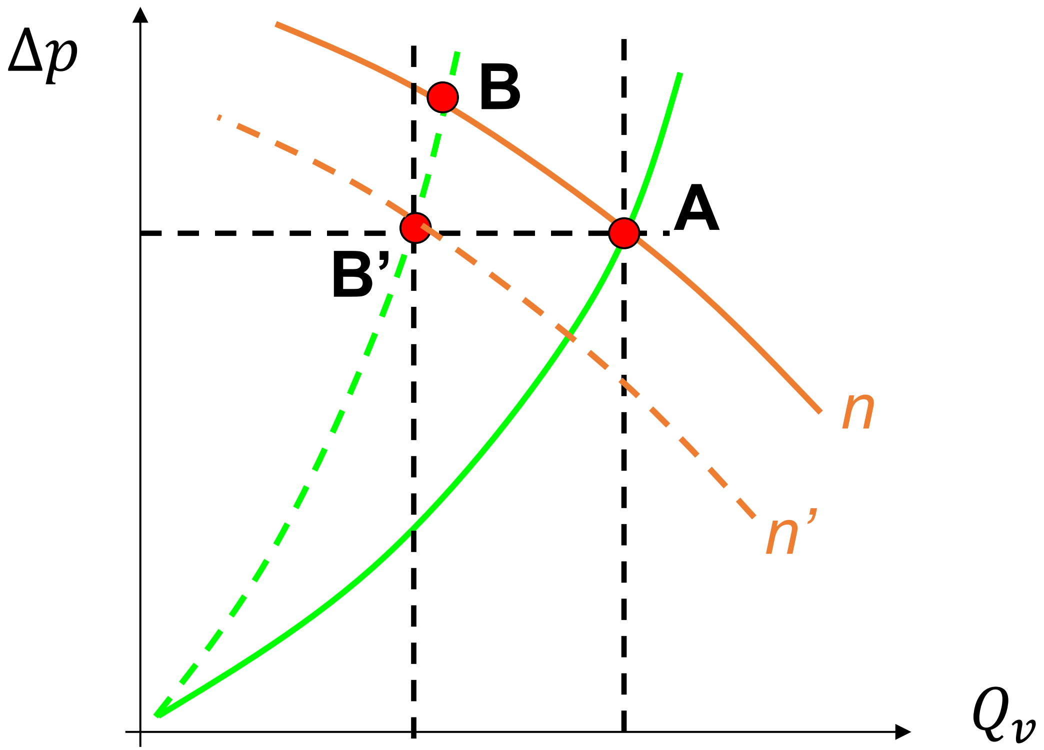
Constant speed pumps

Control at constant speed



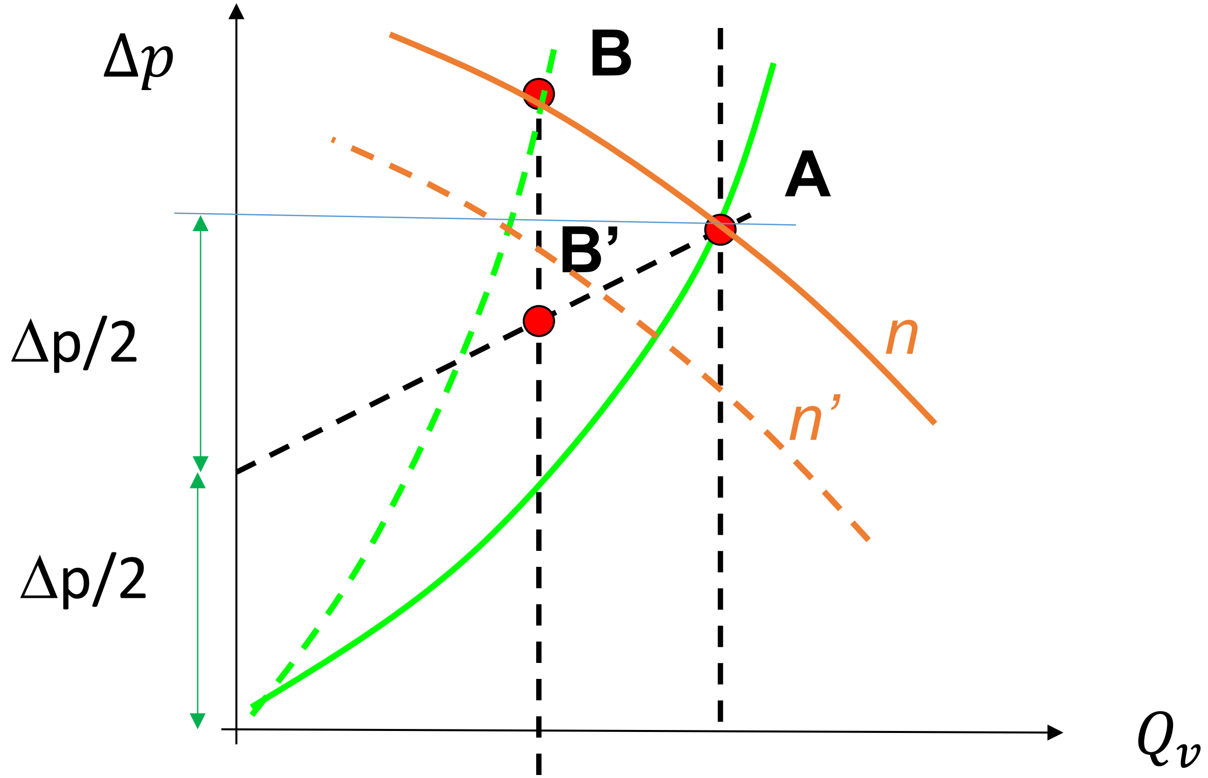
Variable speed pumps

Control at constant Δp



Variable speed pumps

Control at proportional Δp



$$P = \dot{m} \cdot g \cdot \Delta z$$

P = 55/3.6 x 11.5 x 9.81

= 1723 W

η = 75%

P = 1723/0.75 = 2300 W

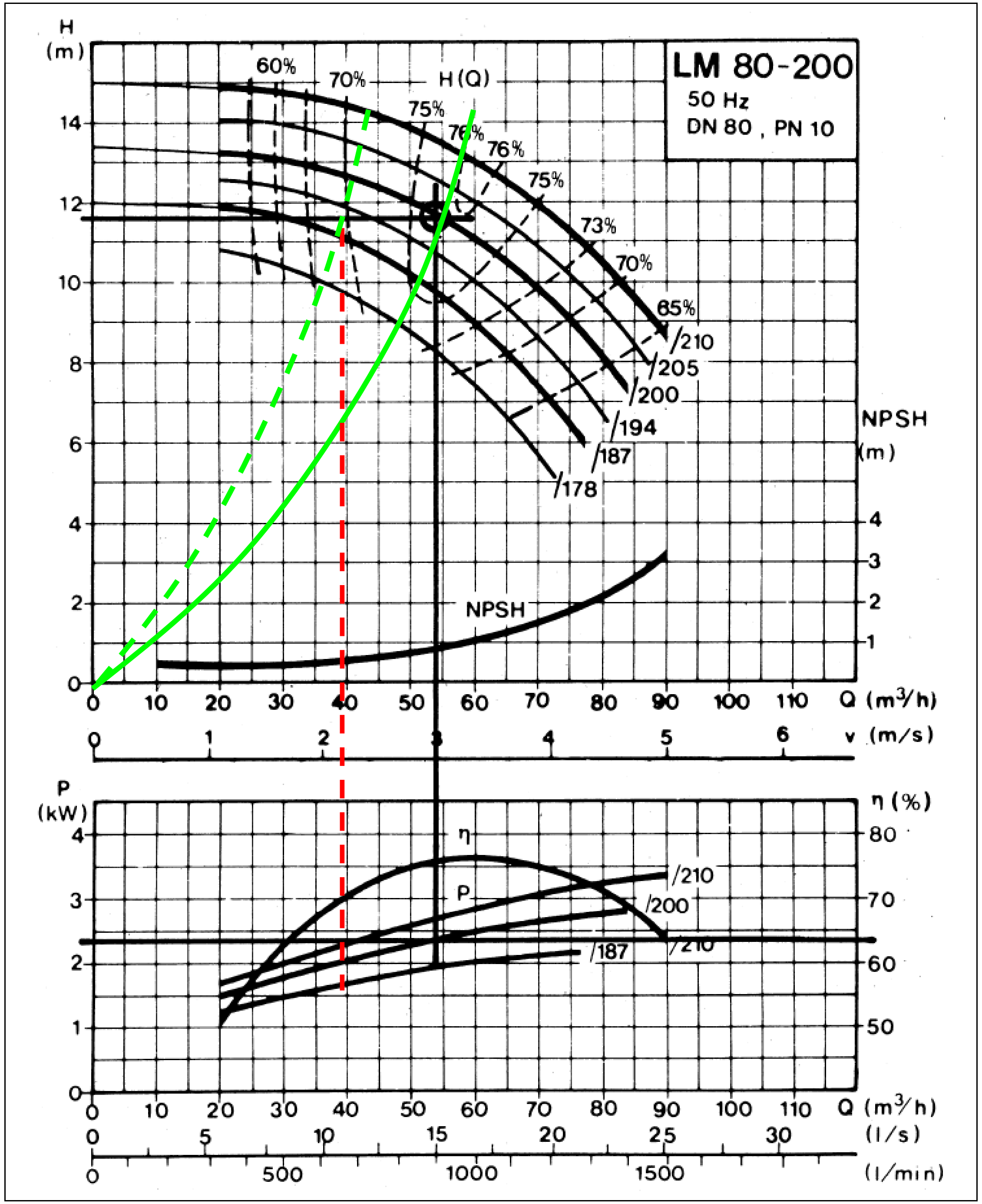
P = 40/3.6 x 11.5 x 9.81

= 1253 W

η = 70%

P = 1253/0.7 = 1790 W

ΔP = -22%



$$P = \dot{m} \cdot g \cdot \Delta z$$

P = 55/3.6 x 11.5 x 9.81

= 1723 W

η = 75%

P = 1723/0.75 = 2300 W

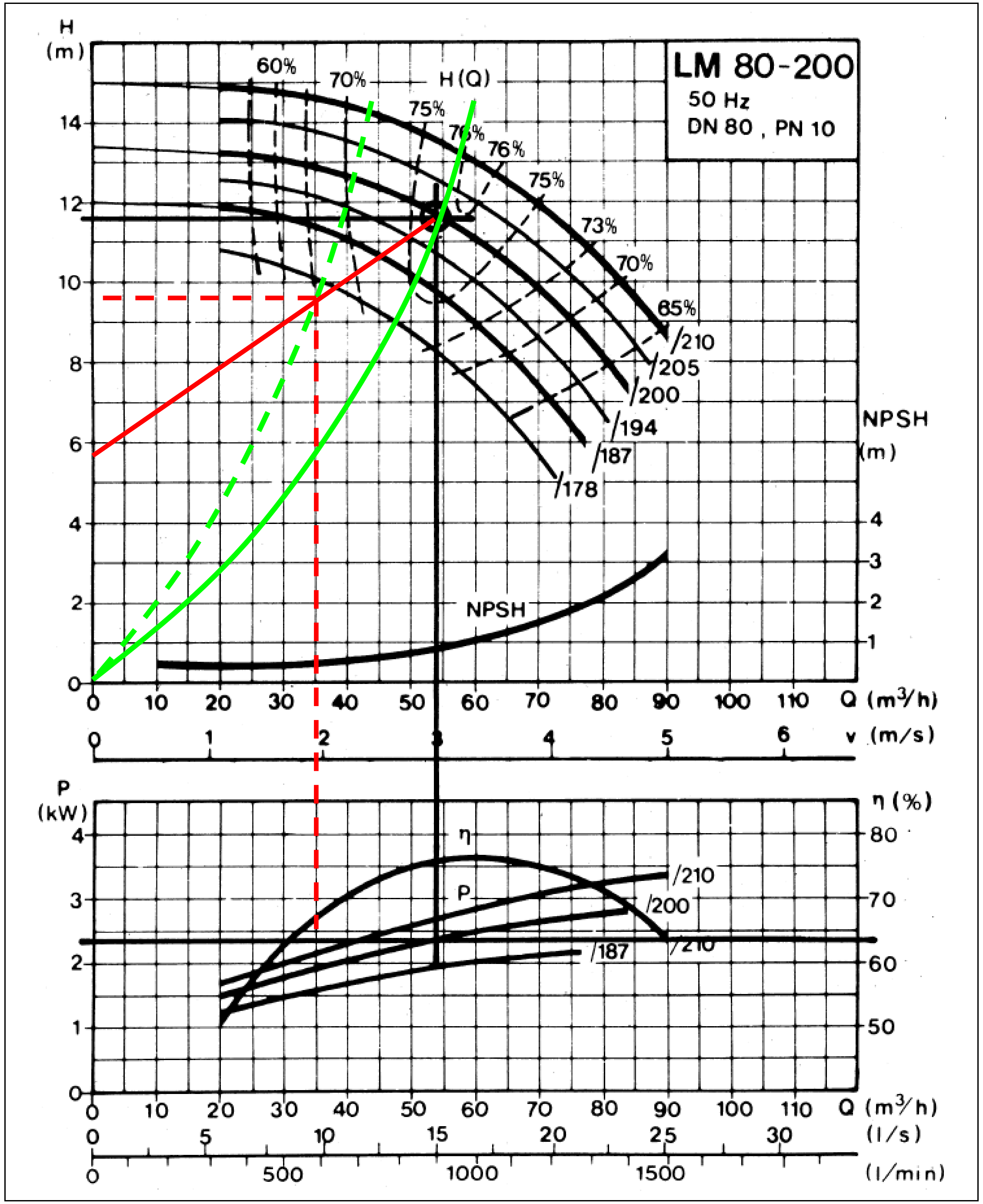
P = 35/3.6 x 9.5 x 9.81

= 906 W

η = 67%

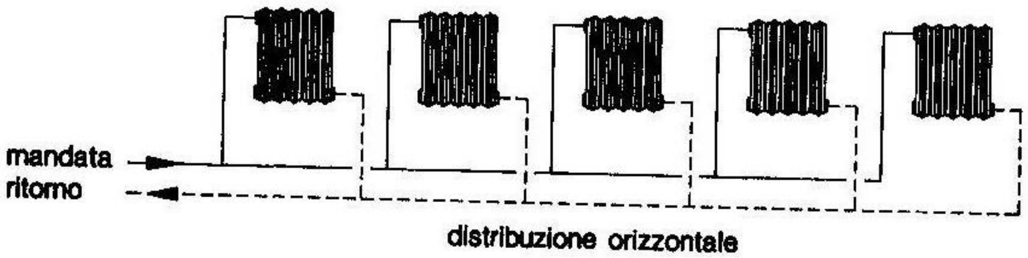
P = 906/0.67 = 1352 W

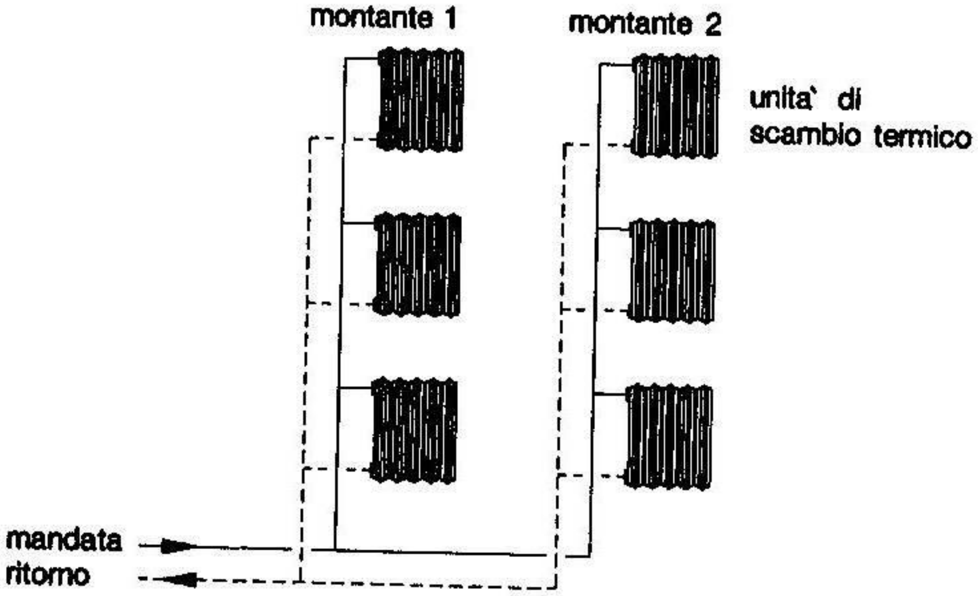
ΔP = -41%



Balancing valves

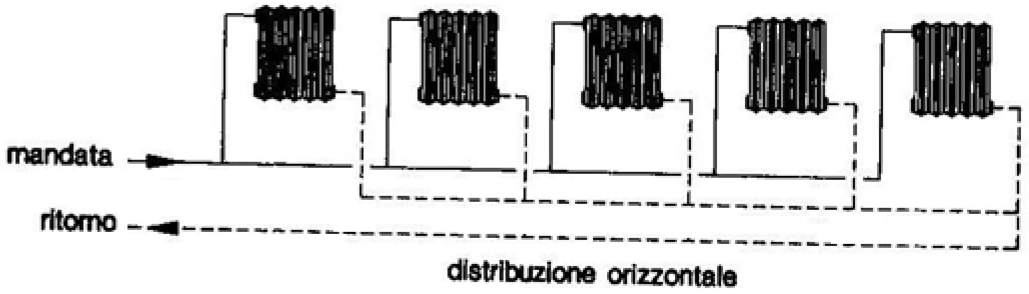
Direct return distribution

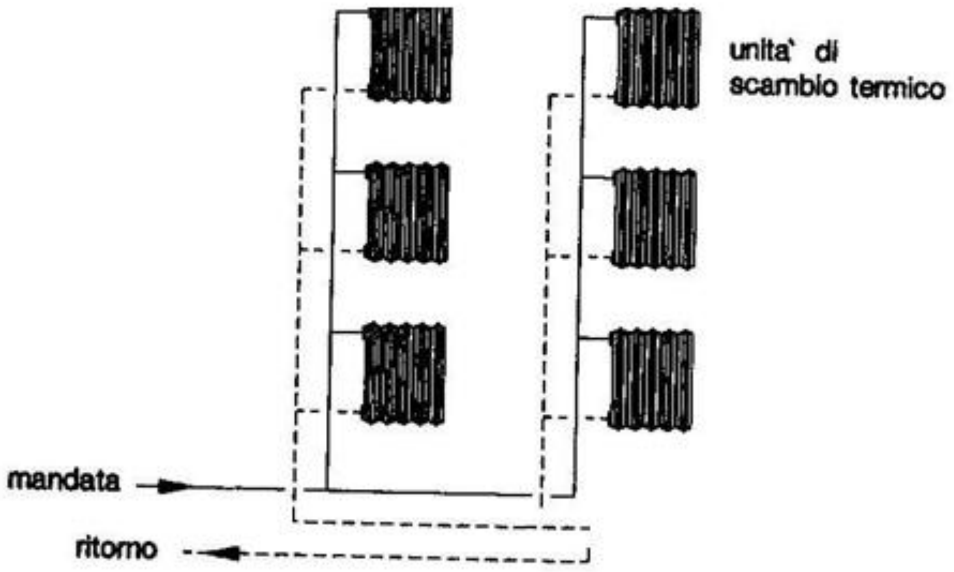




Balancing valves

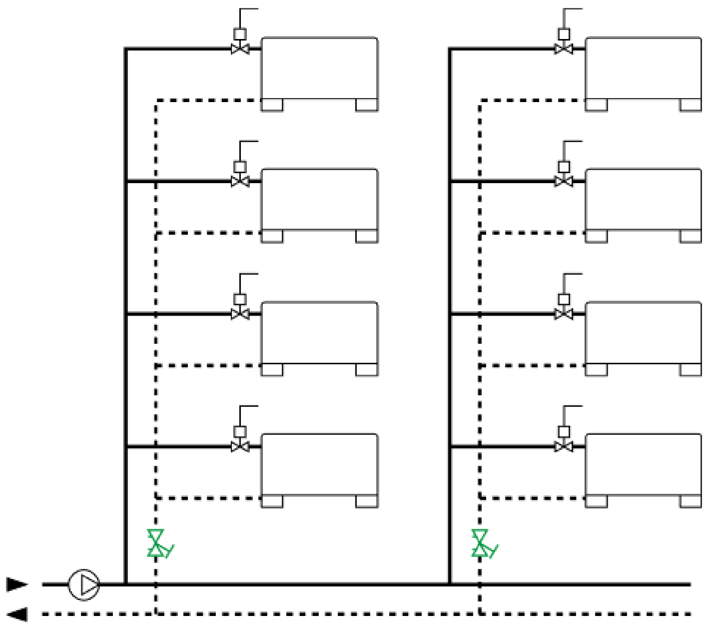
Reverse return distribution (Tichelman loop)



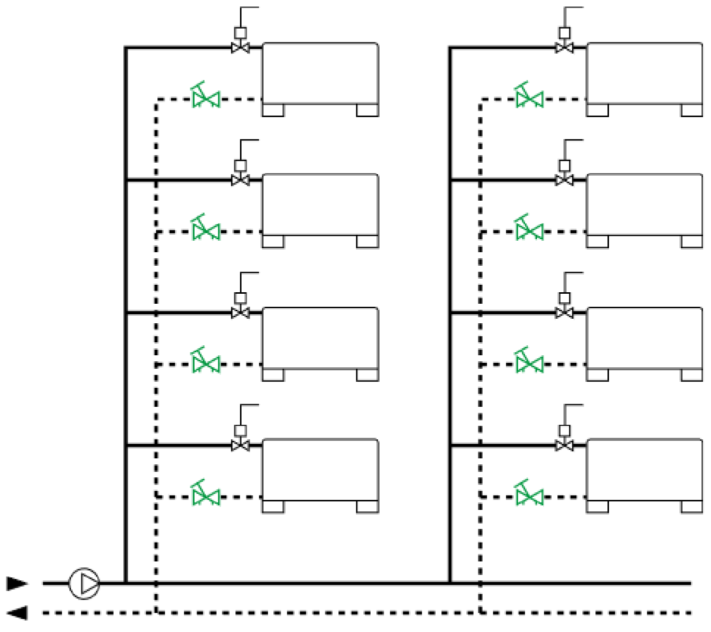


Balancing valves

Application examples



To adjust the flow rate to each riser



To adjust the flow rate to each terminal

Balancing valves

Operating principle

- The balancing valve is a hydraulic device that **regulates the flow rate** of the medium passing through it.
- Regulation is performed **using a knob** that governs the movement of an obturator, to regulate the flow of the medium.
- The desired flow rate is obtained by adjusting the ***Δp* value**, which is **measured through two piezometric connections** suitably positioned on the valve.

Balancing valves

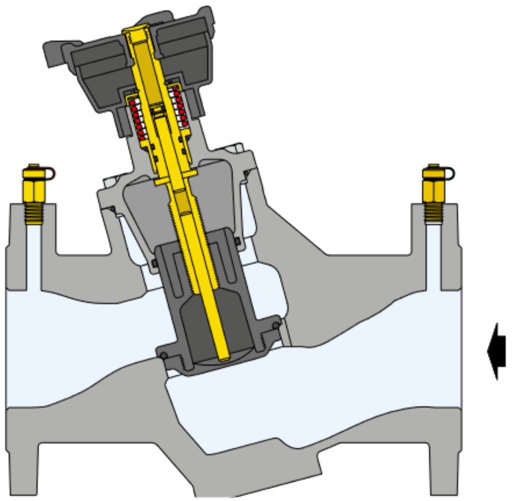
Static vs dynamic balancing

- Variable flow rate systems are the most difficult to balance because the differential pressures, and therefore the network flow rates, vary continuously in relation to the opening or closing position of the 2-way valves.
- These variations can only be controlled with balancing devices that work in dynamic conditions, i.e. in variable positions.
- In variable flow rate systems, static devices can only limit the maximum flow rates, but they are not able to cope with the continuous pressure and flow rate change that characterizes the operation of these systems.

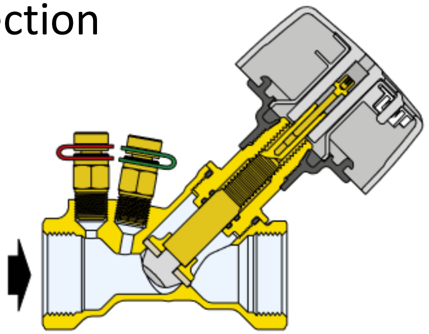
Balancing valves

Static balancing

Flanged connection

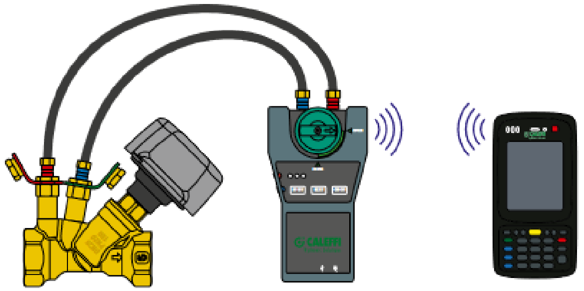


Threaded connection

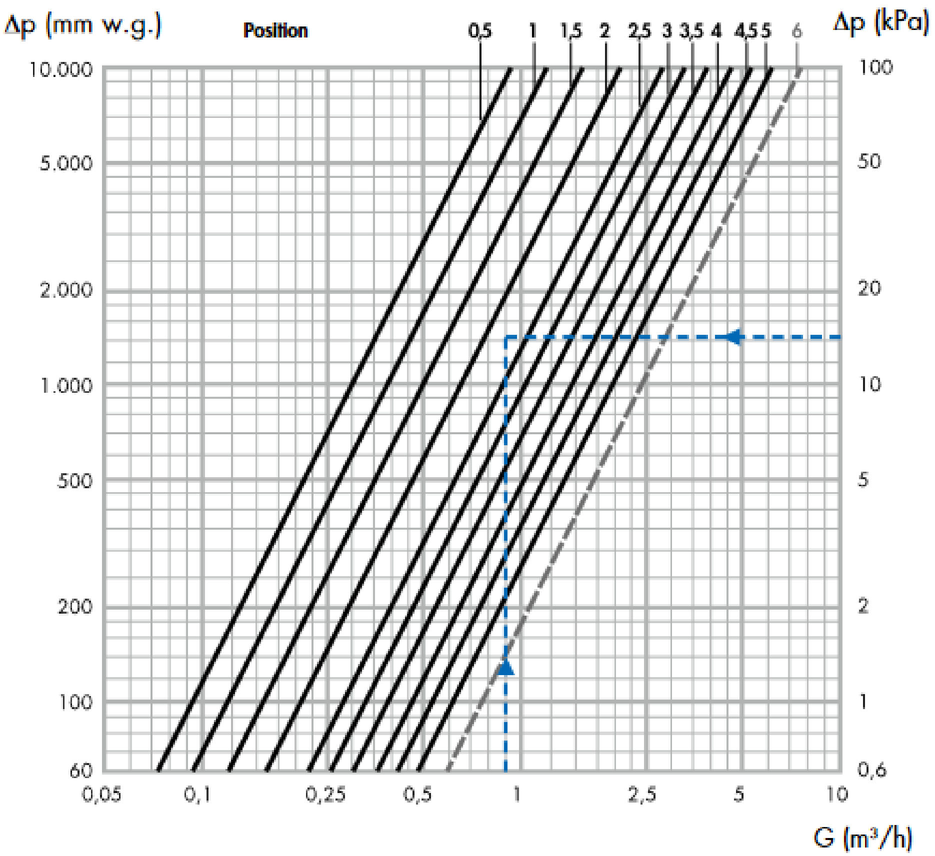


Balancing valves

Static balancing



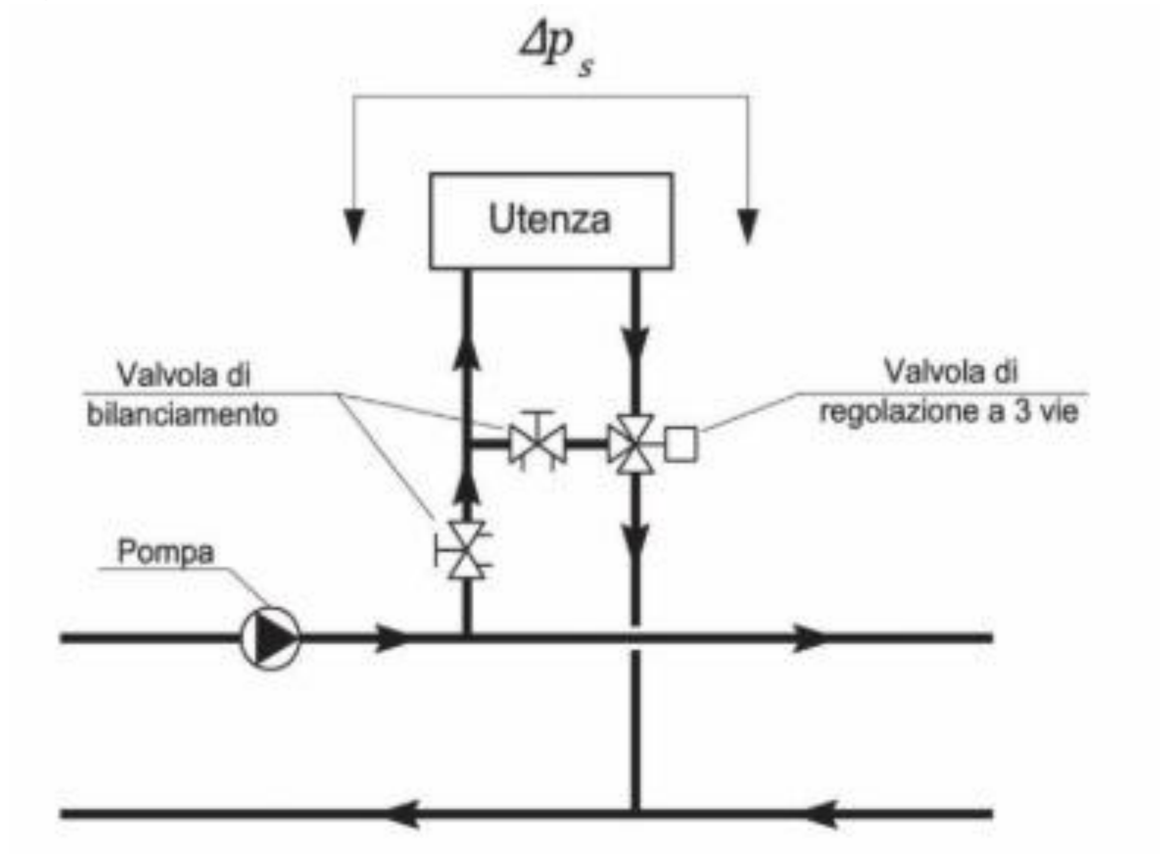
$$kv = \frac{Q}{\sqrt{\Delta P}}$$



DN 25	Position										Kvs
Size 1"	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	6
Kv (m³/h)	0,93	1,19	1,52	2,07	2,60	3,30	3,88	4,61	5,29	6,10	7,63

Balancing valves

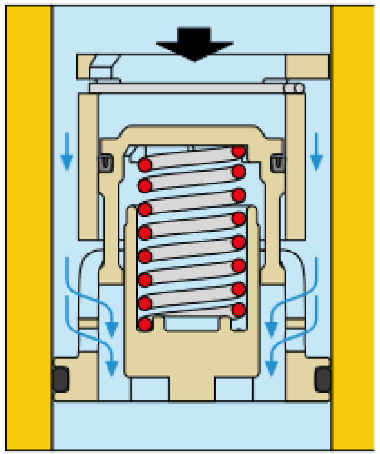
Application examples

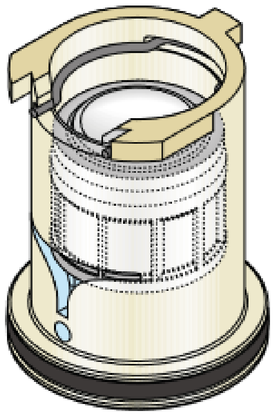


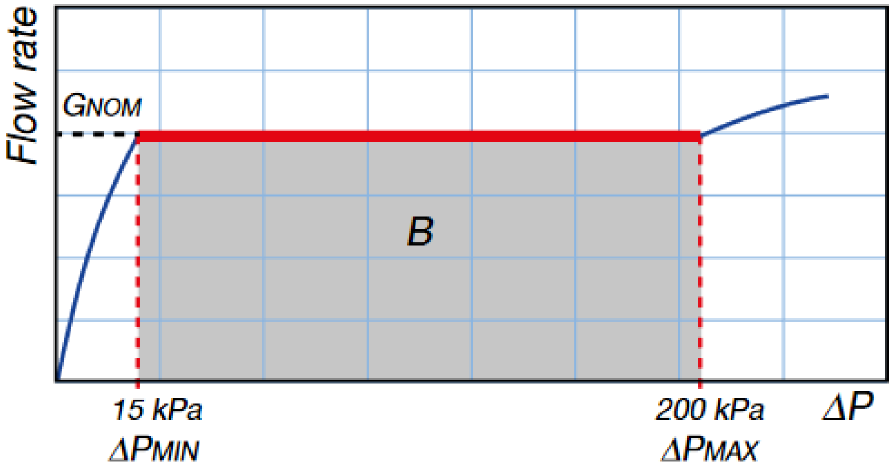
Balancing valves

Dynamic balancing

$$G_{(constant)} = Kv_{(variable)} \cdot \sqrt{\Delta P_{(variable)}}$$





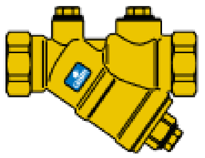


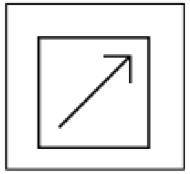
Balancing valves

Dynamic balancing

FLOW RATE DYNAMIC BALANCING

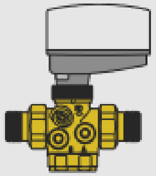
Automatic flow rate regulator

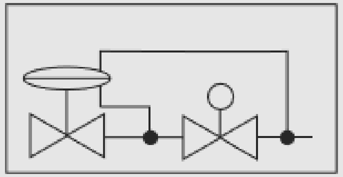




The automatic flow rate regulators are able to keep a constant flow rate of the medium that passes through the circuit in which they are installed.

Independent regulator from pressure





They are pressure independent flow regulators (they are indicated by the abbreviation PICV: Pressure Independent Control Valve). They keep the flow constant to the pre-set value when the operating conditions change. By means of a suitable actuator they can change the nominal flow rate.

Balancing valves

Balancing flow rate

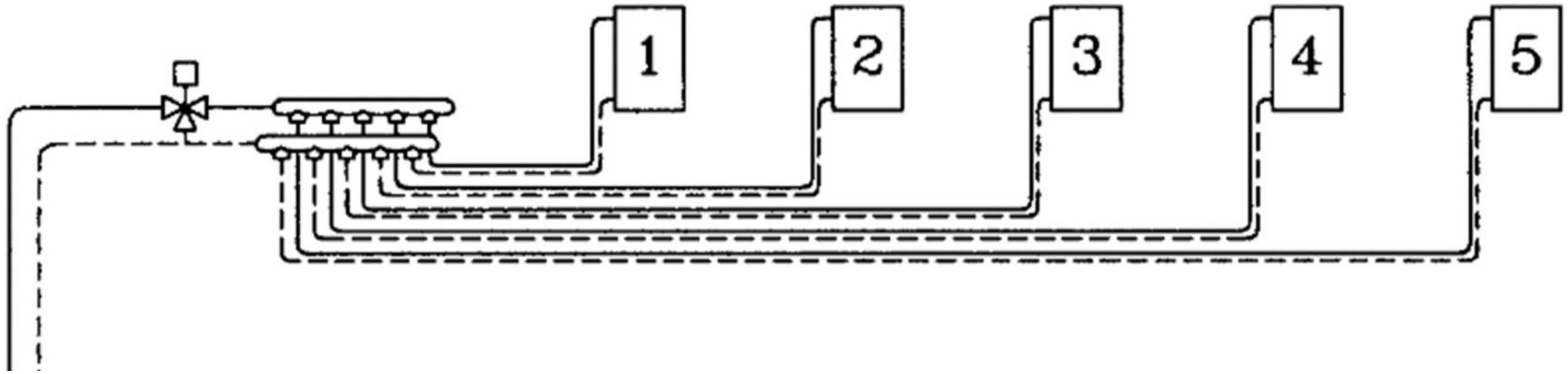
The balancing flow rate is the new flow rate obtained by varying the head applied to a circuit. It can be calculated, with good approximation, using the following formula:

$$G = G_o \left(\frac{H}{H_o}\right)^{0.5}$$

Regulation valves

Example: selection of a three-way valve

Choose the mixing valve to control the supply temperature for a house with 6 radiant system circuits.



References

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- ASHRAE Handbook – 2020 HVAC Systems and Equipment (SI Edition)
- Caleffi Handbooks (available online both Italian and English)