KNOWLEDGE

Hydronics in building systems

siemens.com/buildingtechnologies

SIEMENS

Contents

Introduction

Heating, ventilation and air conditioning (HVAC) plants are used to create comfortable environmental conditions for human beings.

To satisfy this requirement in our climatic zone, heat – but also cooling energy – must be generated, adequately regulated and delivered to the right place at the right time.

Hydronic systems are designed to integrate the required plant components in the circuit between the heating / cooling source and the consumer in a way that optimum operating conditions can be reached for the:

- heating / cooling source (temperature, flow of water)
- transportation of the heating / cooling energy carrier such as water or steam
- integrated control equipment

Training program "Hydronics in building technology"

The training program "Hydronics in building technology" offers fundamental training in hydronics and is aimed at conveying the knowledge required for more advanced hydronics courses and other training courses in the field of control engineering. The program is designed primarily for experts in the heating and air conditioning sector who deal with hydronic plants and who want to enhance their knowledge.

The training program "Hydronics in building technology" and this documentation especially focus on hydronics on the consumer side.

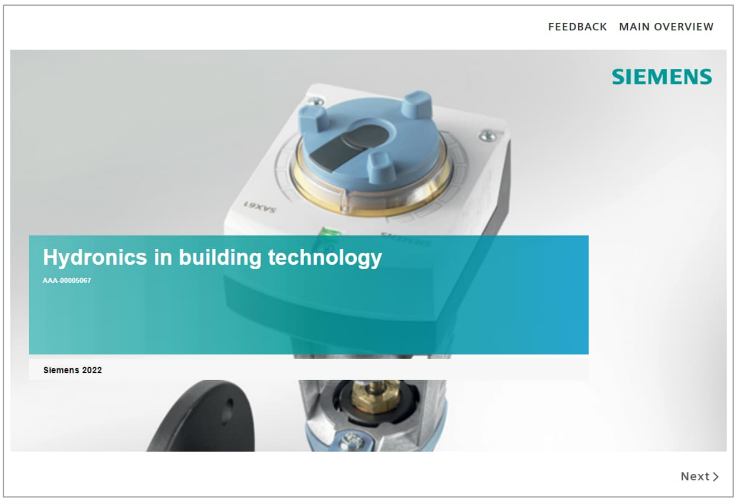
This does not mean, however, that the knowledge of heating / cooling sources is less important – the contrary is the case. As a result of the continued technical development of the heating / cooling sources, hydronic considerations on that side are becoming more and more important as well. However, it is not the purpose of the present training program to cover those aspects in detail. But much of the knowledge gained about the hydronics behavior of the consumer can also be applied to the heating / cooling source.

This documentation contains key information out of the training modules from the training program “Hydronics in building technology”. It is designed as a supporting documentation for and a reference to the training program. In addition, this document contains examples on dimensioning control valves. These examples are not part of the training program but are content of a separate class room training.

The majority of the graphs and illustrations are taken from the training program. Many of them are animated in the training program and interactive, so you can try for yourself how hydronic circuits and components behave under different operating conditions.

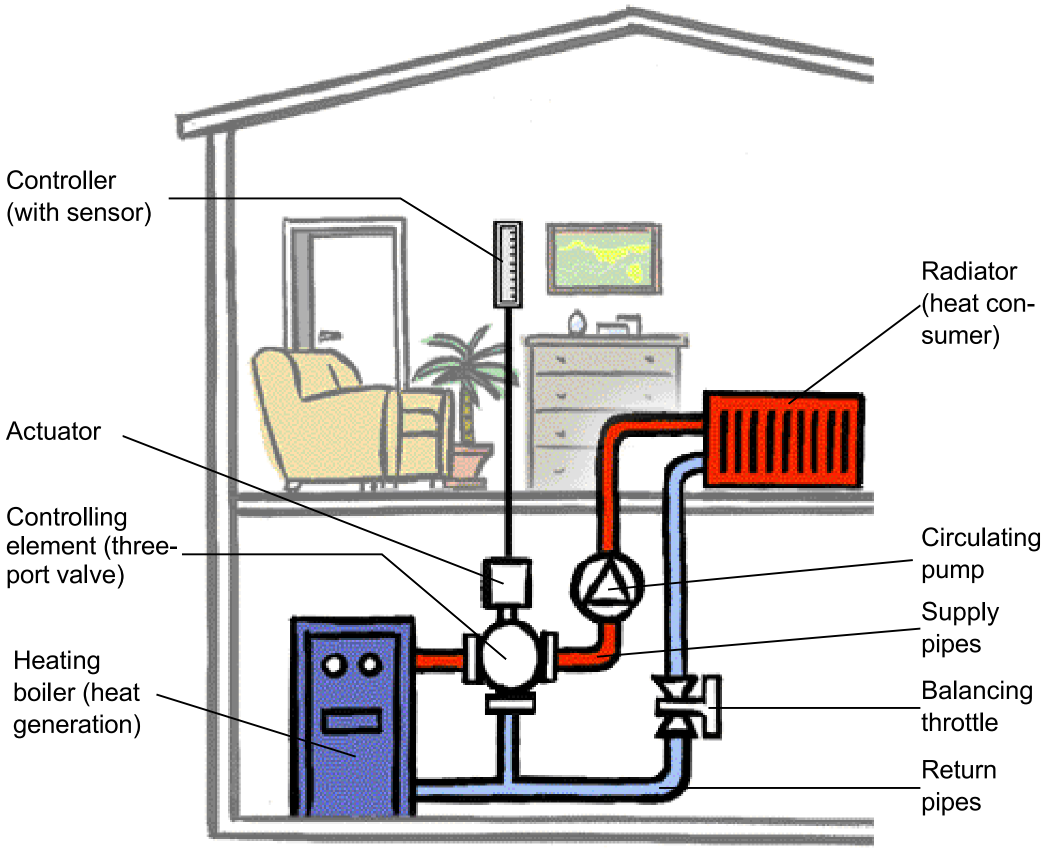
e-learning

If you are interested in the e-learning “Hydronics in building technology”, please contact your Siemens sales office.

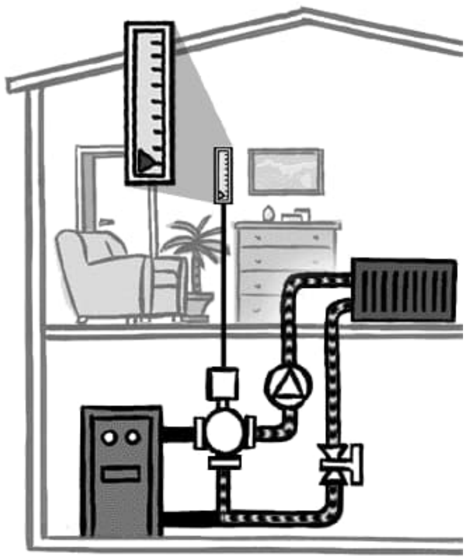


1 Hydronic circuits

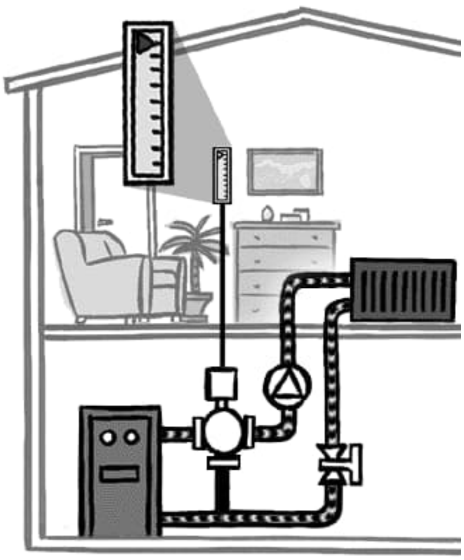
1.1. Key components of a hydronic plant



Key components of a hydronic plant



Circulation in a hydronic plant (valve fully closed)

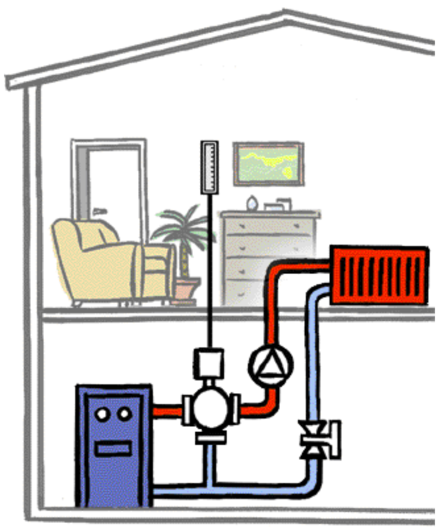


Circulation in a hydronic plant (valve fully open)

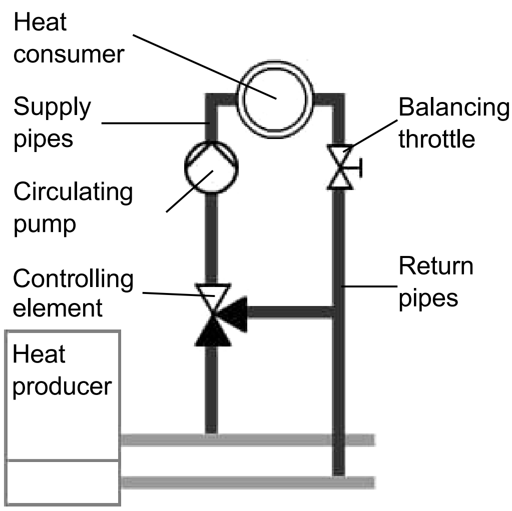
1.2. Different hydronic circuits

The hydronic circuits shown so far are easy to understand. For the expert, however, they are not common practice because they are not suited to explain plant-related interrelationships.

For this reason, schematic diagrams are used in the HVAC field. All the essential elements of an HVAC plant can be shown there and technical processes and interrelationships are easier to understand.



Pictorial diagram of a plant

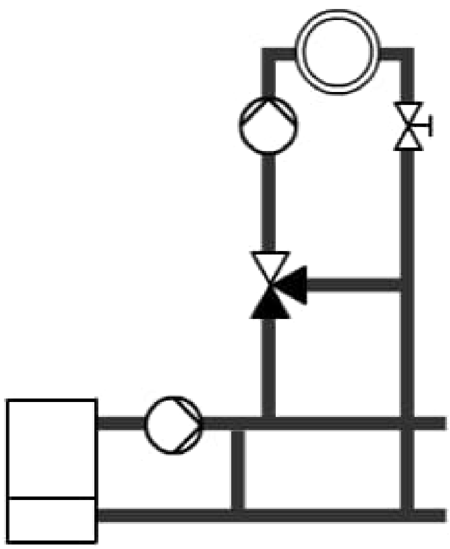


Schematic diagram of a plant

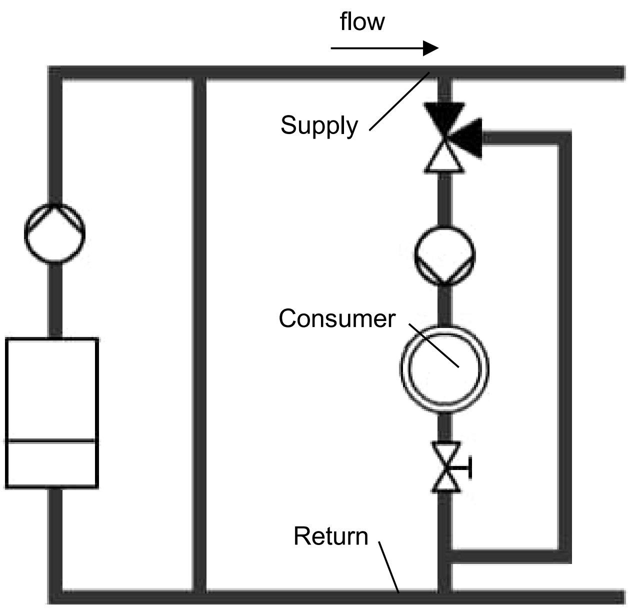
From the pictorial to the schematic plant diagram

There are two different kinds of schematic plant diagrams:

- geographic diagram
- synoptic diagram



Geographic diagram

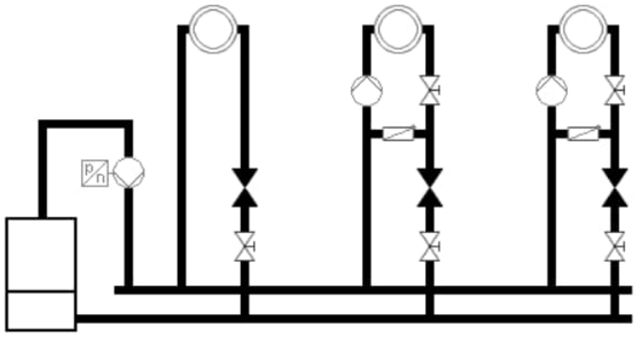


Synoptic diagram

Geographic and synoptic diagram of a basic plant

Geographic diagram

Often, the schematic diagram shown above is used for basic plants. It is called a geographic diagram and is closely related to the actual design of the plant.



Example of a geographic diagram showing a heating plant with several consumers

The geographic diagram is less suited for larger plants, because it becomes more and more difficult to understand, especially when interrelationships between consumers and heating / cooling sources are getting complex. For example in the case of a ground water heat pump with storage tank and additional heating boiler that delivers heat to several distributed consumers.

For this reason and due to the extensive use of CAD systems, the kind of diagram frequently used today is a more structured one.

Synoptic diagram

The synoptic diagram shows the schematic representation of complex and extensive hydraulic plants in a clearly structured and easy-to-understand manner.

With the synoptic diagram, a number of important rules are typically considered:

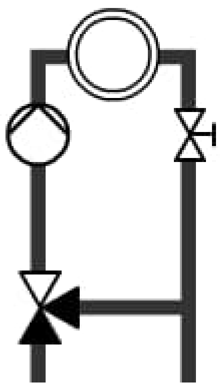
- The supply is shown at the top, the return at the bottom. It is often referred to as supply lines.
- Heating / cooling source and consumers are shown parallel in the direction of flow between supply and return

Note on the representation of controlling elements

In the schematic diagrams of hydronic circuits, it is also important that the correct symbols of the plant components are used.

Especially important is the correct use of the symbol for the three-port controlling element (stroke or slipper valve).

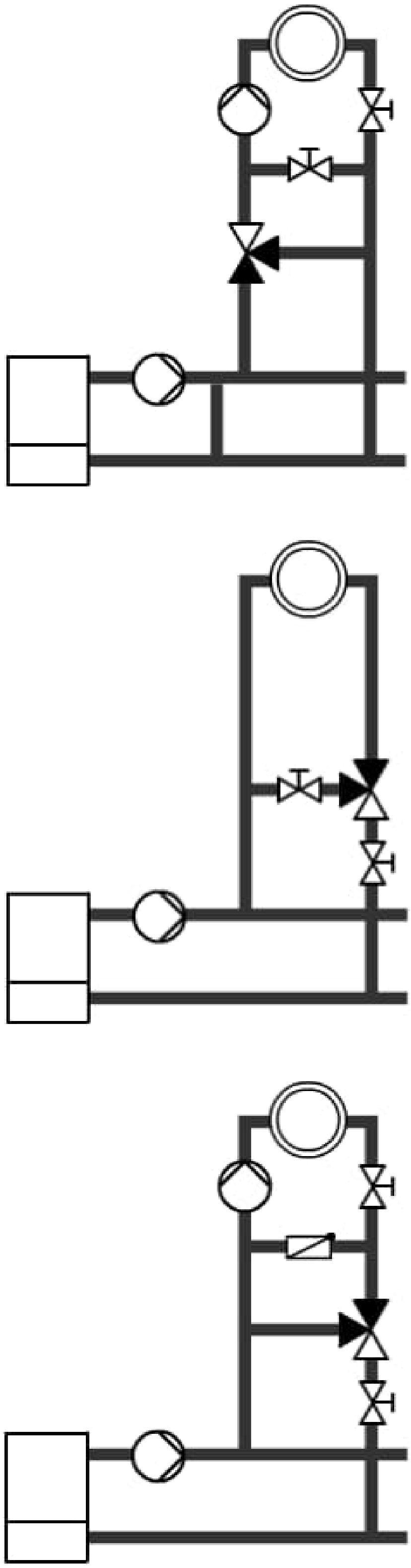
The two triangles representing the ports with variable flow are shown filled while the triangle representing the port with constant flow is shown empty.



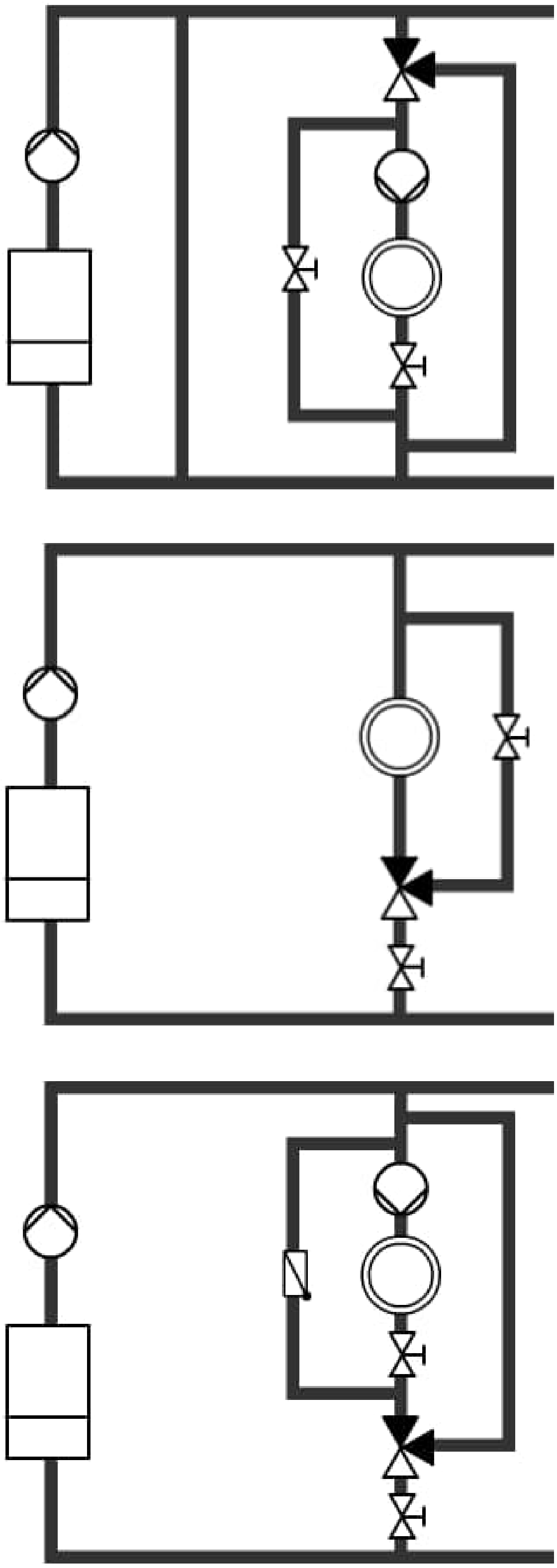
Schematic representation of the valve ports
triangle filled = variable flow
triangle empty = constant flow

In a large number of the schematic diagrams used in the training program “Hydronics in building technology” and in this documentation, controlling elements are shown without their actuators. Thus the diagrams are easier to understand. In addition, the assumption is made that the controlling element is always a valve.

Examples of geographic and synoptic diagrams:



Geographic diagrams



Synoptic diagrams

1.3. Consumers with their basic hydronic circuits

1.3.1. Hydronic circuits with variable and constant flow

The output of a heating / cooling source or consumer (amount of heating or cooling power) is proportional to the product of mass flow and temperature differential across the heating / cooling source or consumer.

$$\dot{Q} = \dot{V} \cdot \rho \cdot c \cdot \Delta T$$

For our considerations and for the standard applications in building technology plants, we consider the density “ρ” and the specific heat capacity “c” to be constant. This means that the output of a heating / cooling source or consumer is proportional to the product of volumetric flow and temperature differential.

$$\dot{Q} \sim \dot{V} \cdot \Delta T$$

Hence, in hydronic circuits, the following variables can be used for adjusting the output:

- Volumetric flow — is changed while the temperature is maintained at a constant level.
  - ⇒ Operation with variable volumetric flow
  - ⇒ Control of the flow
- Temperature — is changed while the volumetric flow is maintained at a constant level.
  - ⇒ Operation with constant volumetric flow
  - ⇒ Control of mixing temperature

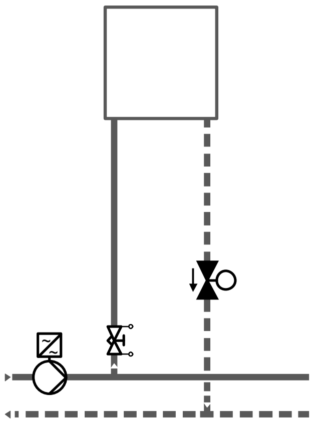
1.3.2. Control of flow and control of mixing

Both control of flow (variable volumetric flow) and control of mixing (constant volumetric flow) use two different basic hydronic circuits.

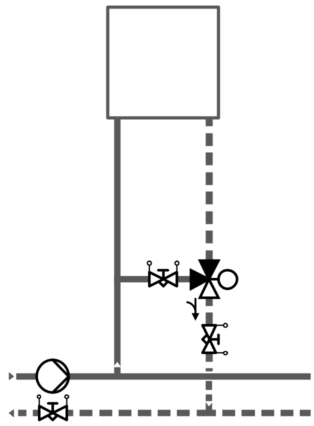
Control of flow

With control of flow (variable volumetric flow, the following hydronic circuits are used:

- Throttling circuit
- Diverting circuit



Throttling circuit



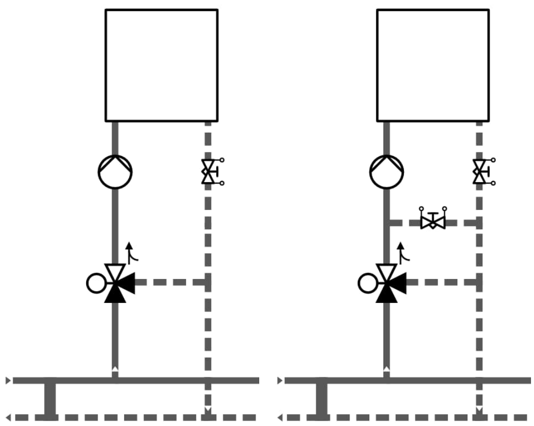
Diverting circuit

Both hydronic circuits adjust their outputs by varying the volumetric flow passing through the consumer.

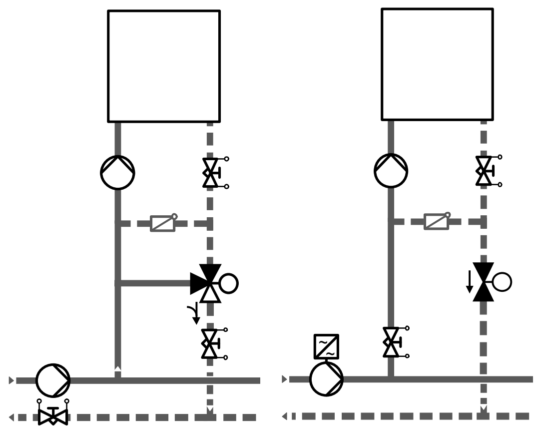
Control of mixing

With the control of mixing (constant volumetric flow) the following hydronic circuits are used:

- Mixing circuit (and mixing circuit with fixed pre-mixture)
- Injection circuit (with a two- or three-port valve)



Mixing circuit (without / with fixed pre-mixture)



Injection circuit (with three-port valve or two-port valve)

Both hydronic circuits adjust their outputs by delivering different fluid temperatures to the consumer. Each hydronic circuit possesses its own pump to push the fluid through the consumer.

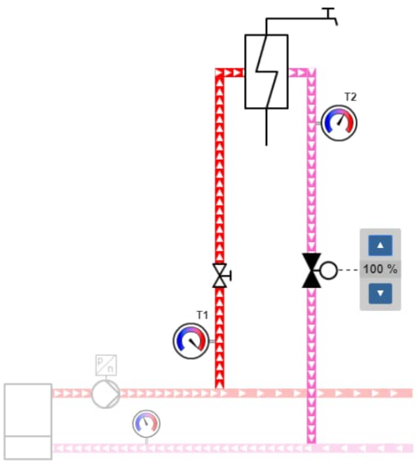
1.4. Basic hydronic circuits

1.4.1. Throttling circuit

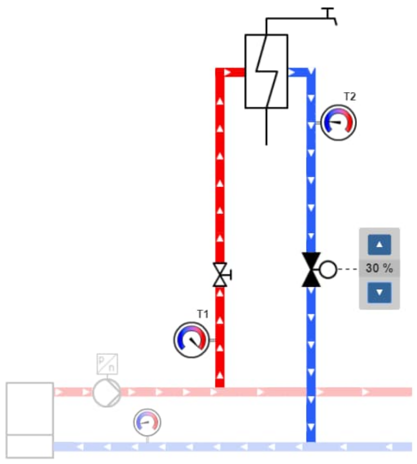
Mode of operation

When the valve is adjusted, the volumetric flow will change both in the heating / cooling source section and in the consumer section of the hydronic circuit. As a result, pressure conditions will vary considerably throughout the system.

Example: Hot water storage tank charge



Valve fully open
Throttling circuit



Valve 30 % open
(smaller velocity in the variable water flow section)

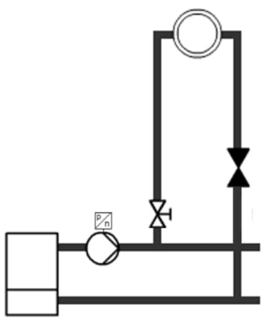
Characteristics

- Low return temperature T2 in part load operation (for heating)
- Variable volumetric flow throughout the entire plant
- On startup, the correct fluid temperature will reach the consumer with a certain delay (dead time, depending on the length of the pipe and the cooling down effect)
- When the valve is fully closed, the pump can reach excessive temperatures (⇒ use of speed-controlled pumps)

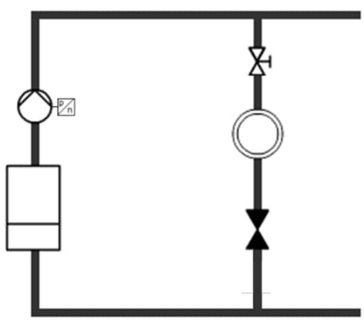
Field of use

- Air heating coils without risk of freezing
- Air cooling coils with dehumidification
- Hot water storage tank charging
- District heat connections (with heat exchanger or direct)
- Storage tank charging and discharging
- Plants using condensing boilers

Types of diagrams



Geographic diagram



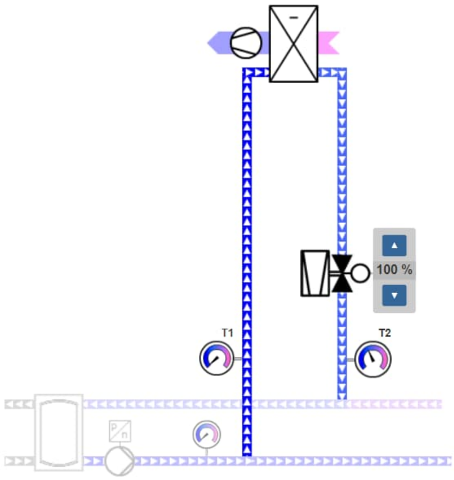
Synoptic diagram

1.4.2. **Throttling circuit with PICV** (pressure independent control valve)

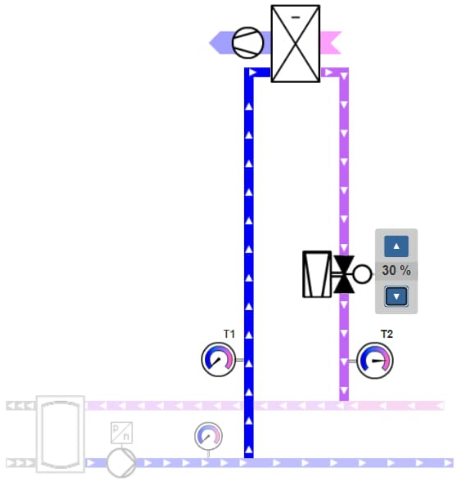
Mode of operation

When the PICV is adjusted, the volumetric flow will change both in the consumer and the source section (or boiler respectively). As a result, pressure conditions will change considerably throughout the system. The differential pressure controller in the PICV needs a minimal pressure Δp_{min} provided by the pump to establish stable pressure conditions across the control valve section.

Example: Dehumidifying air cooling coil



Valve fully open
Throttling circuit with PICV



Valve 30 % open
(smaller velocity in the variable water flow section)

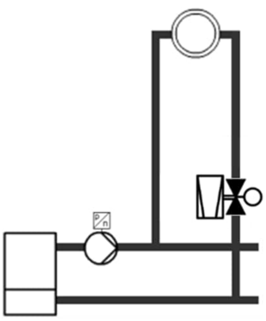
Properties

- High return temperature T2 in part load operation (for cooling)
- Variable volumetric flow throughout the entire plant
- On startup, the correct fluid temperature will reach the consumer with a certain delay (dead time, depending on the length of the pipe and the warming up effect)
- When the valve is fully closed, the pump can reach excessive temperatures (⇒ use of speed-controlled pumps)

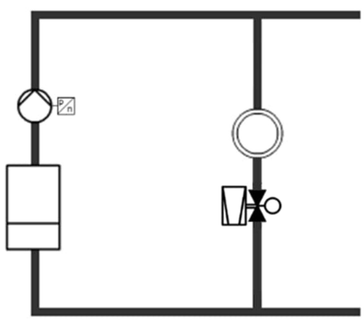
Field of use

- Air cooling coils with dehumidification
- Air heating coils without risk of freezing
- Hot water storage tank charging
- District heat connections (with heat exchanger or direct)
- Storage tank charging and discharging
- Plants using condensing boilers

Types of diagrams



Geographic diagram



Synoptic diagram

1.4.3. Injection circuit with two-port valve

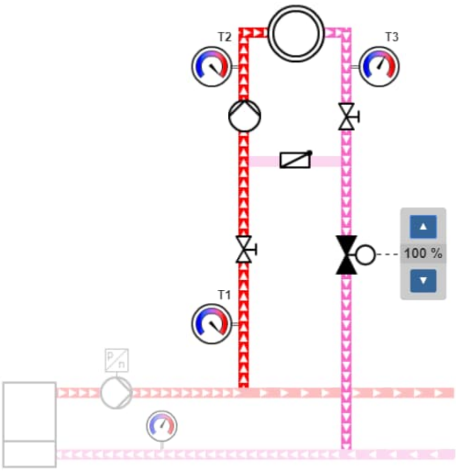
Mode of operation

The pump in the heating source circuit injects more or less hot supply water into the consumer circuit, depending on the position of the two-port valve.

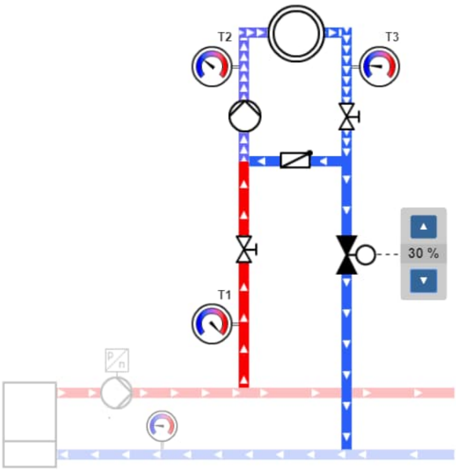
As a result, there is a constant volumetric flow with varying temperatures in the consumer circuit.

In the heating source circuit, by contrast, the volumetric flow and pressure vary significantly, a fact to be taken into consideration in the case of plants with several consumer circuits.

Example: Room heating group



Valve fully open
Injection circuit with two-port valve



Valve 30 % open
(smaller velocity in the variable water flow section)

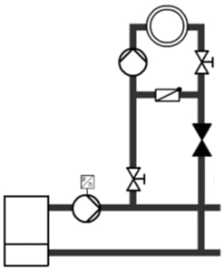
Characteristics

- Relatively low return temperature T3 (for heating)
  (cold … consumer return temperature at 100 % load)
- Even temperature distribution across the heat consumer
- Constant volumetric flow in the consumer circuit
- Variable volumetric flow in the source circuit
- Small risk of freezing with air heating coils
- With a fully closed valve, the pump in the heating source circuit can reach excessive temperatures (⇒ use of speed-controlled pumps)

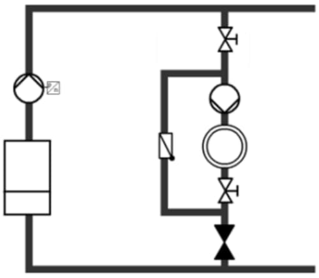
Field of use

- Heat storage tanks and heat pumps
- Low temperature boiler plants (condensing boilers)
- Direct district heat connections
- Radiators and floor heating
- Air cooling coils with/without dehumidification

Types of diagrams



Geographic diagram



Synoptic diagram

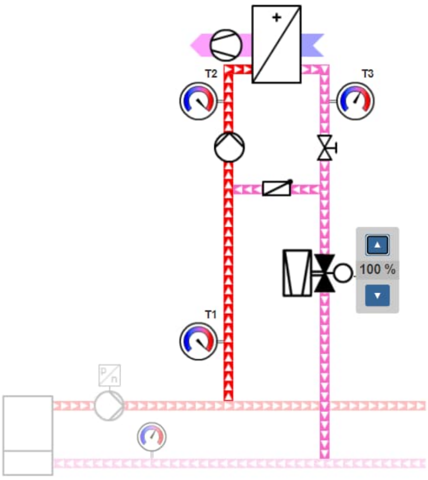
1.4.4. **Injection circuit with PICV** (pressure independent control valve)

Mode of operation

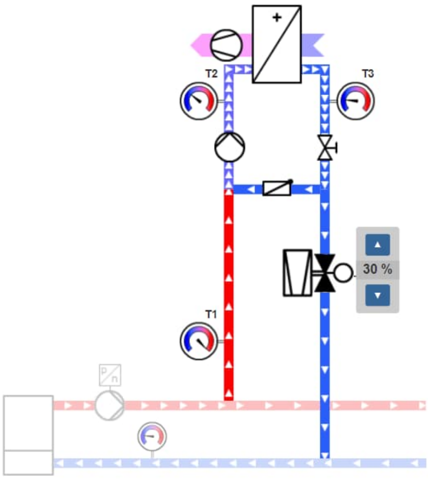
The pump in the heating source circuit injects more or less hot supply water into the consumer circuit, depending on the position of the PICV. As a result, there is a constant volumetric flow with varying temperatures in the consumer circuit.

In the heating source circuit, by contrast, the volumetric flow and pressure vary significantly, a fact to be taken into consideration in the case of plants with several consumer circuits.

Example: Air heating coil



Valve fully open
Injection circuit with PICV



Valve 30 % open
(smaller velocity in the variable water flow section)

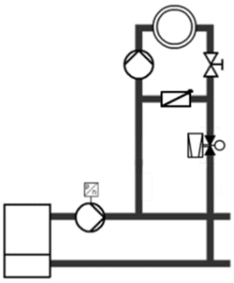
Characteristics

- Relatively low return temperature T3 (for heating)
  (cold … consumer return temperature at 100 % load)
- Even temperature distribution across the heat consumer
- Constant volumetric flow in the consumer circuit
- Variable volumetric flow in the source circuit
- Small risk of freezing with air heating coils
- With a fully closed valve, the pump in the heating source circuit can reach excessive temperatures (⇒ use of speed-controlled pumps)

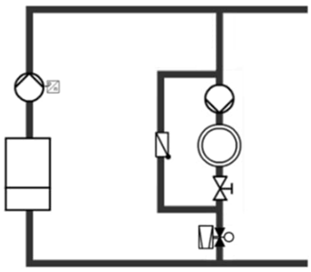
Field of use

- Heat storage tanks and heat pumps
- Low temperature boiler plants (condensing boilers)
- Direct district heat connections
- Radiators and floor heating
- Air cooling coils with/without dehumidification

Types of diagrams



Geographic diagram



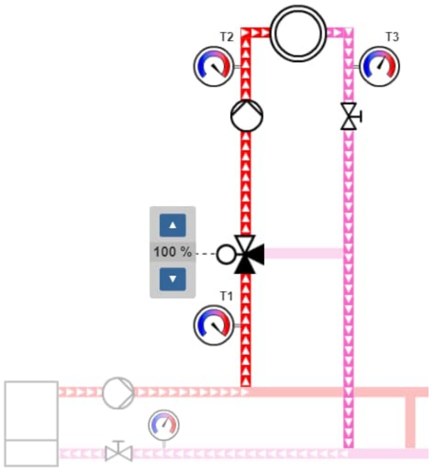
Synoptic diagram

1.4.5. Mixing circuit

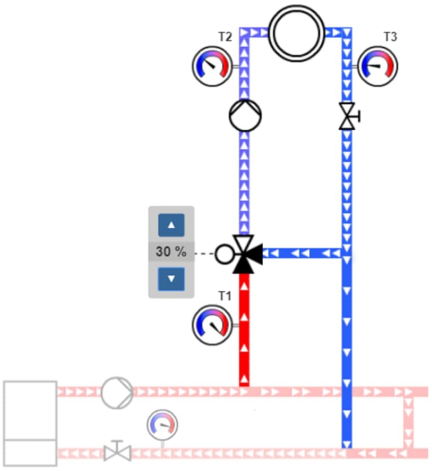
Mode of operation

A three-port valve subdivides the hydronic circuit into a primary circuit (heating source circuit) and a secondary circuit (consumer circuit). The hot water delivered by the heat source and the cooler return water are mixed to attain the supply temperature required for the consumer, thereby adjusting the output to meet the demand for heat.

Example: Room heating group



Valve fully open
Mixing circuit (with three-port valve)



Valve 30 % open
(smaller velocity in the variable water flow section)

Characteristics

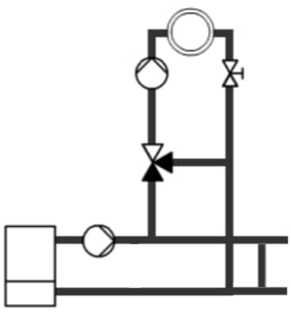
- Heating: low return temperature T3 with small loads
  Cooling: high return temperature T3 with small loads
- Variable volumetric flow through the heat source circuit
- Constant volumetric flow with variable temperatures through the consumer circuit
- Even temperature distribution across the heat consumer
- Low risk of freezing with air heating coils

The mixing circuit is not suited for plants with a distance of more than 20 m between the mixing bypass and control sensor (T2). The long transportation time (dead time) makes the control task way too difficult.

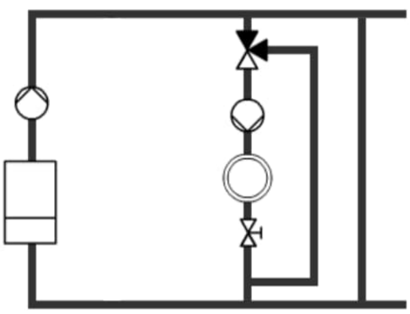
Field of use

- Heating systems with radiators, …
- Air heating coils with risk of freezing

Types of diagrams



Geographic diagram

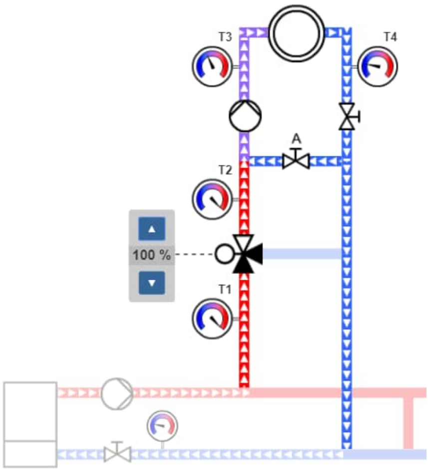


Synoptic diagram

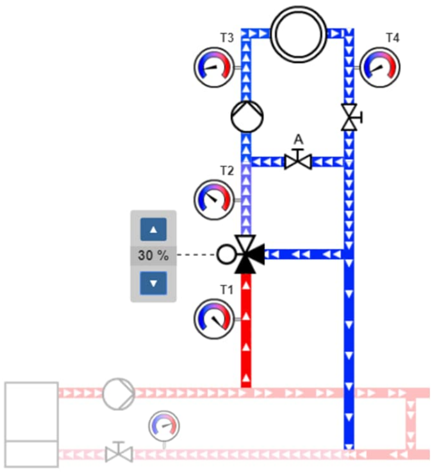
Mixing circuit with fixed premixing

Here too, a three-port valve subdivides the hydronic circuit into a primary circuit (heat source circuit) and a secondary circuit (consumer circuit). Fixed premixing ensures that a certain portion of cooler return water will always be added to the supply flow. This is applicable when, under design conditions, the required supply temperature to the consumer is considerably lower than the supply temperature delivered by the heating producer. Thus, it is made certain that the three-port valve will operate across its entire valve stroke (from the fully closed to the fully open position).

Example: Room heating group with floor heating



Valve fully open
Mixing circuit with fixed premixing



Valve 30 % open
(smaller velocity in the variable water flow section)

Characteristics

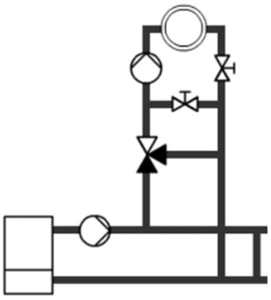
- Generally low return temperature T4
- Variable volumetric flow through the heat source circuit
- Constant volumetric flow with variable temperature T3 through the consumer circuit
- Control across full valve stroke

The mixing circuit with fixed premixing is not suited for plants with a distance of more than 20 m between bypass and control sensor (T3). The long transportation time (dead time) makes the control task much more difficult.

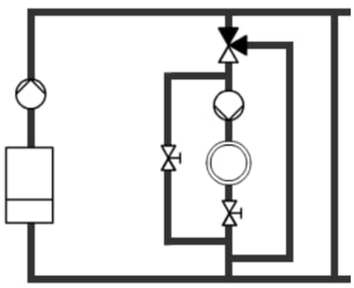
Field of use

- Consumer circuits where the flow temperature is lower than that of the heat source circuit
- Heating systems with floor heating and radiators with high temperature heat sources (e.g. wood burning boilers)

Types of diagrams



Geographic diagram



Synoptic diagram

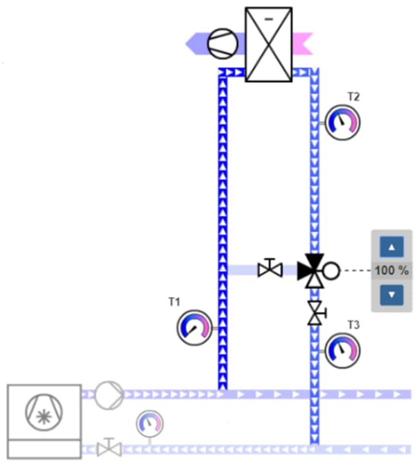
1.4.6. Diverting circuit

Mode of operation

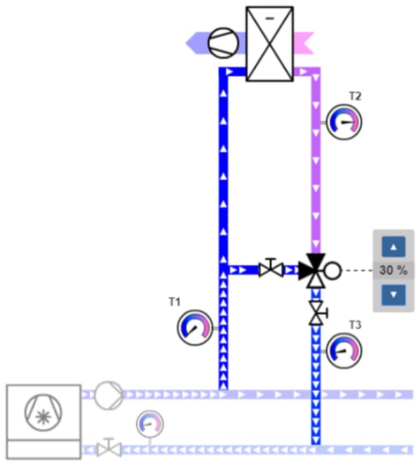
The valve distributes the supply flow over the consumer and the bypass. Depending on the position of the valve, more or less water flows through the consumer. The output of the consumer is controlled by adjusting the volumetric flow.

When the valve is fully closed, the temperatures of supply and return are approximately equal.

Example: Air cooling coil with dehumidification



Valve fully open
Diverting circuit



Valve 30 % open
(smaller velocity in the variable water flow section)

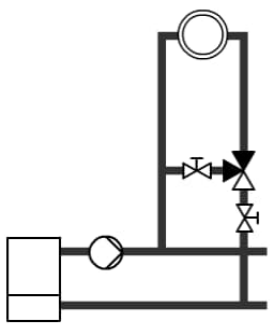
Characteristics

- Changes to the volumetric flow varies thermal output at the consumer
- Variable volumetric flow through the consumer circuit
- Constant volumetric flow and pressure in the source circuit
- Cooling: medium to high temperature T3 in return to the source
  (Heating: medium to high temperature T3 in return to the source)
- On startup, the boiler supply temperature reaches the heat consumer with only little delay (provided that the controlling element is rather close to the consumer)

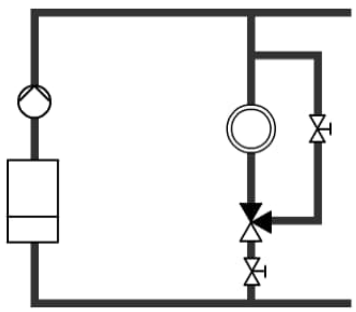
Field of use

- Air cooling coils with dehumidification
- Air heating coils where there is no risk of freezing
- Heat recovery systems
- Hot water heating
- Not suited for plants with a district heat connection (high return temperature)

Types of diagrams



Geographic diagram



Synoptic diagram

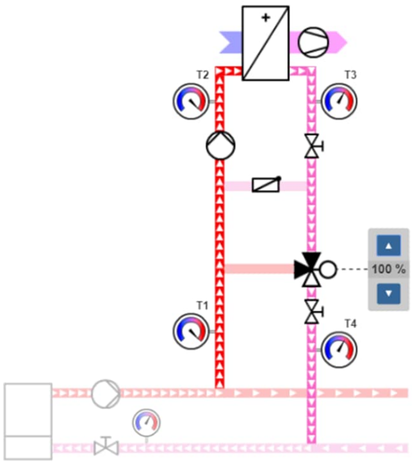
1.4.7. Injection circuit with three-port valve

Mode of operation

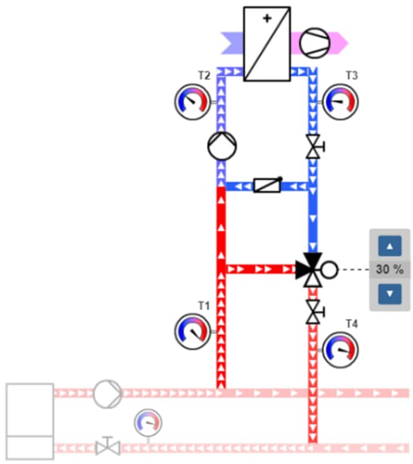
The pump on the lower left produces the pressure required in the heating source circuit, including the pressure drop across the valve. The pump above produces the pressure in the consumer circuit.

The pump in the heat source circuit injects more or less hot supply water into the consumer circuit, depending on the position of the three-port valve. The hot water mixes with cooler return water from the consumer which the consumer's pump sucks in via the bypass. As a result, there is a constant volumetric flow with varying temperatures in the consumer circuit.

Example: Air heating coil with risk of freezing



Valve fully open
Injection circuit with three-port valve



Valve 30 % open
(smaller velocity in the variable water flow section)

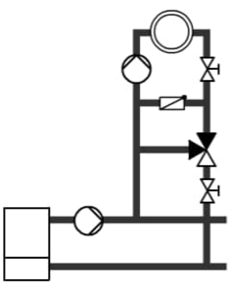
Characteristics

- Constant volumetric flow in both the heat source and the consumer circuit
- Variable volumetric flow through the bypass
- Relatively high return temperature T4 (corresponding to the heating source supply temperature when load = 0 %, and the consumer return temperature when load = 100 %)
- Even temperature distribution across the heat consumer
- Small risk of freezing with air heating coils

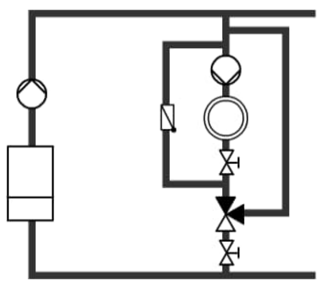
Field of use

- Radiator and floor heating systems
- Air heating coils with a risk of freezing
- Air cooling coils without controlled dehumidification
- Hot water storage tank charging
- Not suited for plants with district heat connection (high return temperatures)

Types of diagrams



Geographic diagram



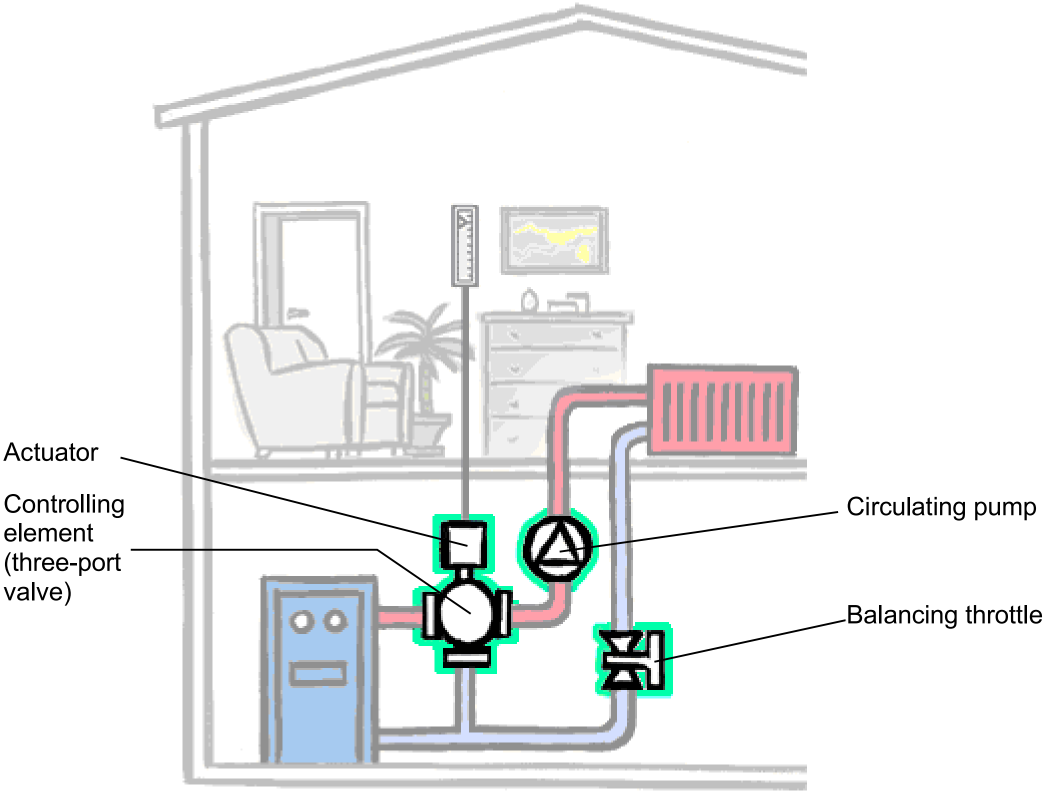
Synoptic diagram

1.5. Components in the consumer circuit

In practical applications, the hydronic circuits discussed above operate only accurately if a number of components are used and installed in the right locations.

The following plant components are discussed here:

- Controlling element (valve)
- Circulating pump
- Balancing throttle



Major components in the consumer circuit

1.5.1. Controlling element

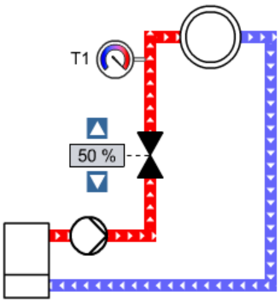
The task of the controlling element is to control the volumetric flow from the heat source to the consumer in such a way that the supply of heat can be varied between 0 and 100 %. Every controlling element has a controlled port that can be more or less open, or fully open or fully closed.

The controlling elements used in hydronic circuits are slipper valves (rotary movement) or seat valves (linear movement). The seat valves are divided into:

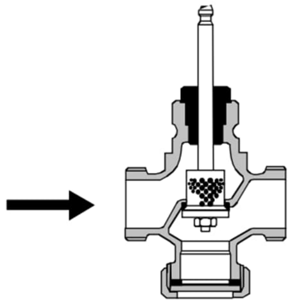
- Two-port valve and PICV
- Three-port valve

Two-port valve

With the two-port valve, the cross-sectional area for the flow is increased or decreased by a change of stroke so that the volumetric flow can be varied to satisfy the demand for heating / cooling.



Flow control



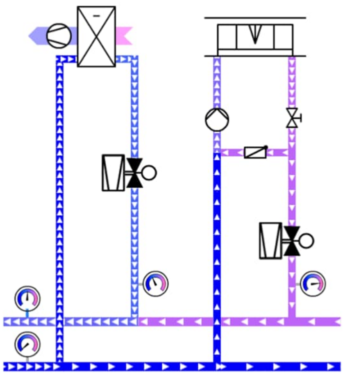
Two-port valve (cross-section)

Two-port valve

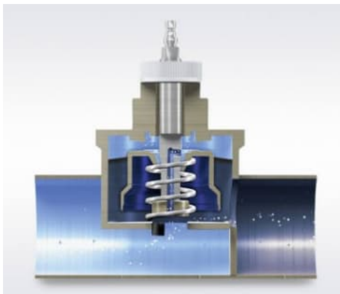
PICV (Pressure Independent Control Valve)

In hydronic circuits where a two-port valve could be used, today PICVs (pressure independent control valve) are often utilized.

The PICV combines a control valve with a differential pressure controller which provides for stable conditions across the control valve even when there are pressure variations in the piping network. By that a hydronic cross-influence of consumers is eliminated. In addition, the nominal flow can be set at the PICV, thus eliminating the need for a separate balancing valve – and the hydronic balancing is already done. For the differential pressure controller of the PICV to work properly, a minimal pressure (Δp_{min}) must always be provided by the pump.



Hydronic circuits with PICVs

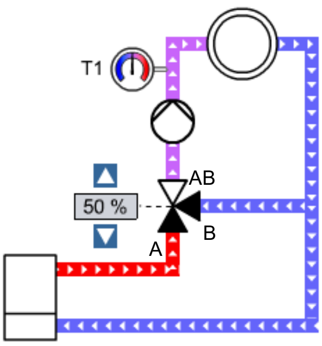


PICV (cross-section, simplified)

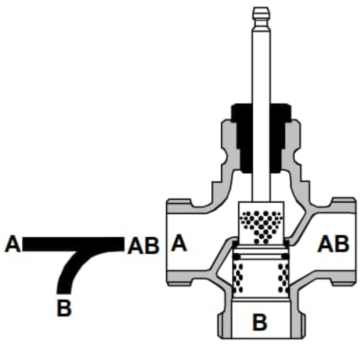
Threaded PICV

Three-port valve

The three-port valve has a port with a constant volumetric flow. Depending on the use of the valve - mixing or diverting – the change of stroke is different.



Mixing control



Three-port valve with designation of ports (cross-section)

Three-port valve

Designation of ports

Valve ports can be designated differently, e.g. AB, A, B (see illustration above) or I, II, III.

Mixing:
The delivered volumetric flow remains constant. It is the result of two variable volumetric flows.

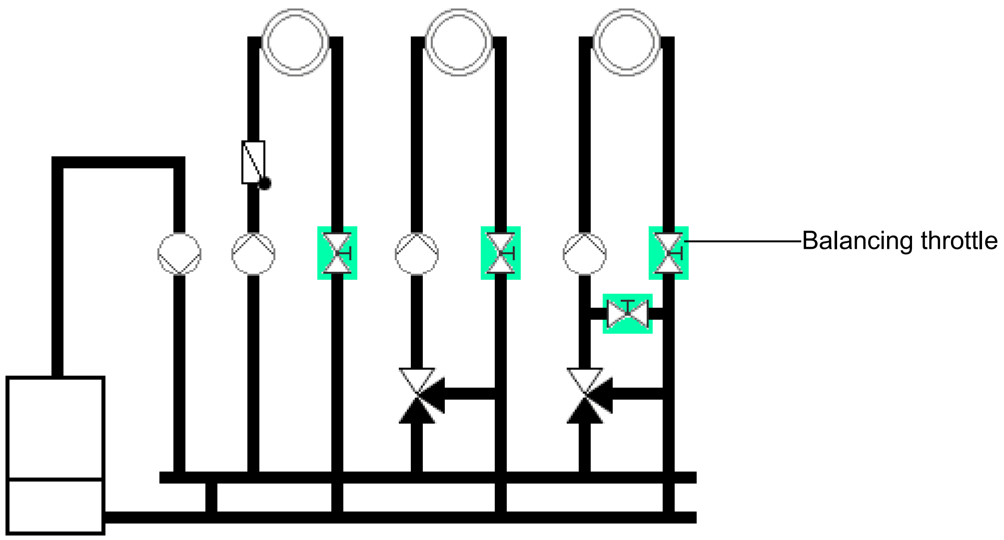
Diverting:
The incoming constant volumetric flow is divided into two variable outlet flows.
(Note: not all types of three-port valves are suitable for use as diverting valves).

1.5.2. Balancing throttle

Balancing throttles in the sections of hydronic circuits with a constant volumetric flow are used during commissioning to adjust the calculated nominal volumetric flow.

Hydronic balancing

The procedure is called hydronic balancing. It is an important prerequisite for ensuring the correct functioning of the plant.



Heating groups with balancing throttles (in the piping sections with constant volumetric flow)

1.5.3. Circulating pump

A hydronic circuit only operates correctly if the circulating pump:

- is correctly sized
- is correctly installed and connected
- operates at the right speed

Also, in certain types of hydronic circuits, there is a risk of excessive pump temperatures, especially when the pump works against a fully closed valve (also refer to throttling circuits).

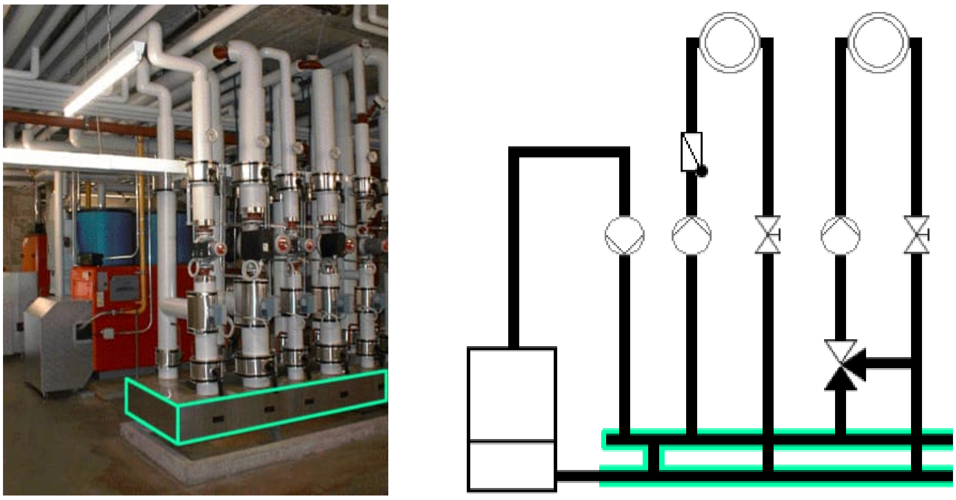
In such situations, it is recommended to use speed-controlled pumps or to install a small, adjustable bypass which ensures minimum circulation when the valve is fully closed.

Also, a pump can be deactivated when the valve closes or when a minimum opening position is reached (e.g. < 2 %).

1.6. Distribution circuits

In typical plants, one generation generally supplies multiple consumers.

A distribution is the link between the heating / cooling generation and multiple consumers. Medium from the generation supply is distributed to various consumer circuits; the return medium from all consumer circuits is collected and returned to the generation.



Distributor as the connecting element between heating generation and consumer side

Requirements

Consumers and generation place certain requirements on distributions e.g. pressure conditions, constant or variable flow, required flow and return temperatures, etc.

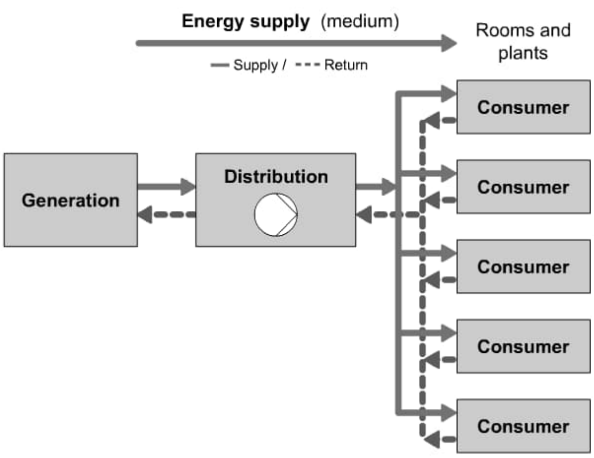
⇒ various types of distribution circuits are needed to meet all these requirements.

Suitable combinations

A distribution cannot be considered on its own. It is important to use the generation and consumer circuits suitable for the distribution type.

From the distribution's point of view, all the properties listed above must be the same (or similar) for all connected consumers.

Therefore we will consider the distribution as part of the overall hydronic setup.

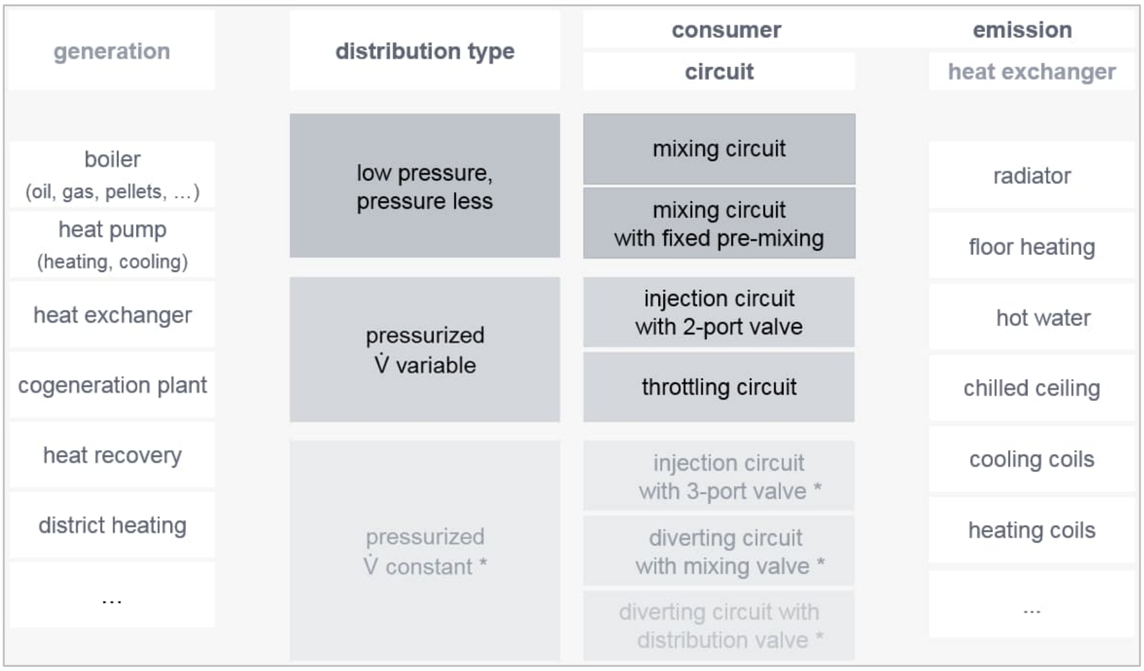


Hydronic circuit model

1.6.1. Combinations of distribution and consumer circuits

The overview includes a number of possible generators and consumers (list not conclusive). Not all generators can be combined with every type of consumer though.

We will focus on three types of distribution and suitable consumer circuits that can be combined with selected generators and consumers to provide appropriate solutions. The solutions vary in regard to energy efficiency.

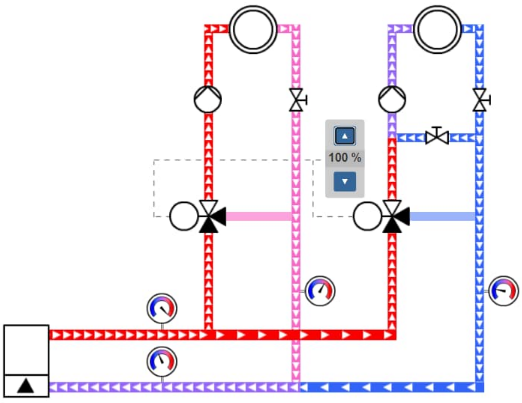


Overview generation, distribution and consumer

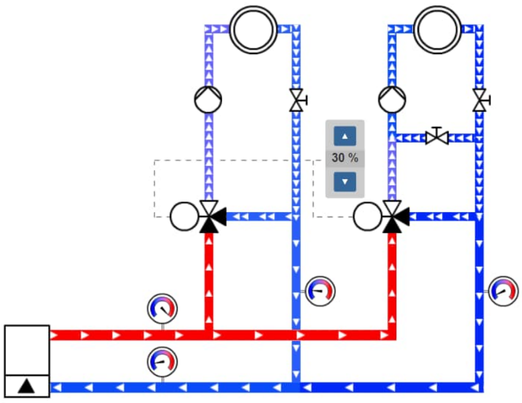
* should be avoided; not energy-efficient from the view-point of the main pump

1.6.2. Low-pressure distribution

Example: Room heating groups with gas boiler



Valves fully open



Valves 30 % open
(smaller velocity in the variable water flow section)

Distribution between gas boiler and room heating groups

Characteristics

- Low return temperature to generation
- Variable volume flow in generation

Important for trouble-free use

- Generously size distribution main pipes
- Connected consumer groups with constant or year-round heat demand at the start of distribution (prevent unnecessary flow through distribution)
- Obey required min. flow across generation

Field of use

Generation that requires a low return water temperature and that has a small internal resistance

Energy efficiency

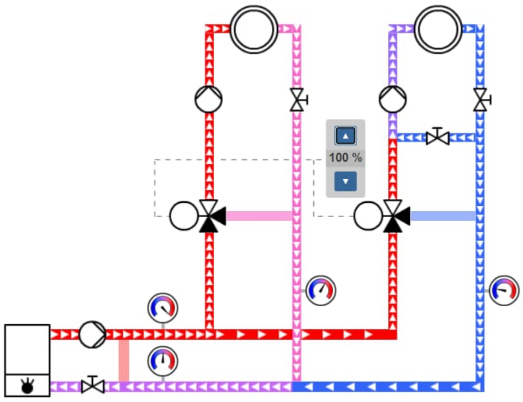
This combination of distribution and consumer circuits has a high energy efficiency.

Reasons:

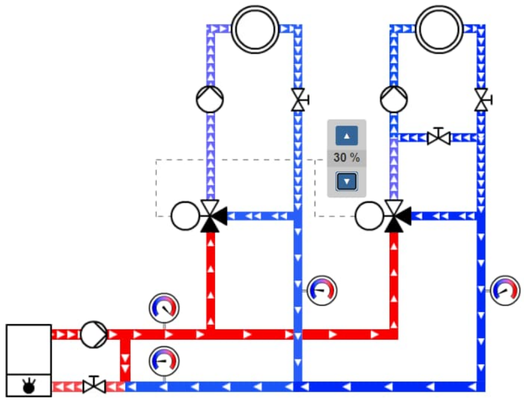
- The volumetric flow across the generator and the distribution is variable.
- The return temperature from the distribution back to the generation is always at or below the design return temperature.
- The heat losses in the distribution network can be kept low.

1.6.3. Pressure-less distribution

Example: Room heating groups



Valves fully open



Valves 30 % open
(smaller velocity in the variable water flow section)

Characteristics

- High return temperature to generation
- Constant volume flow in generation
- Clear hydronic separation between generation and consumer

Important for trouble-free use

- Generously size distribution and above all the bypass (short circuit)
- Connected consumer groups with constant or year-round heat demand at the start of distribution (prevent unneeded flow through distribution)
- Consumers with a demand for high supply temperatures (e.g. heating coils in air handling units or domestic hot water heat exchangers) should be connected before the bypass, i.e. on the generation side of the distribution

Field of use

- Generation requiring a high return temperature
(e.g. oil boilers, wood burning boilers)

Energy efficiency

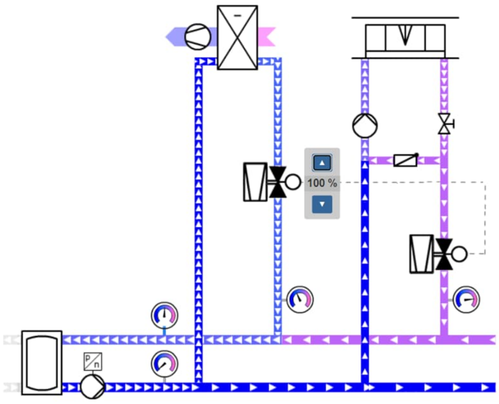
There is only limited energy efficiency in this combination of distribution and consumer circuits.

Reasons:

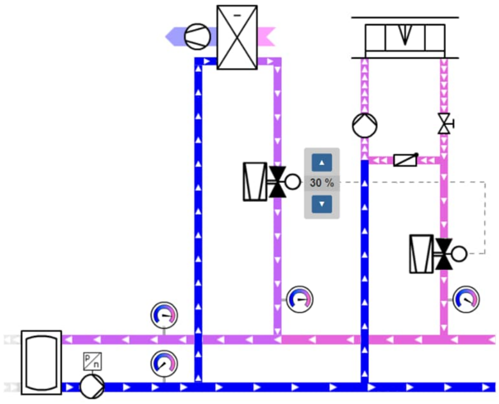
- Volumetric flow drawn by the distribution from the generation is variable and runs with high temperature. This results in significant losses of thermal energy in the generation and distribution.
- The volumetric flow provided continuously by the distribution pump is only needed at full load. The loss of pump energy is also significant.

1.6.4. Pressurized distribution at variable flow

Example: Chilled water distribution for cooling coil and chilled ceilings



Valves (PICVs) fully open



Valves (PICVs) 30 % open
(smaller velocity in the variable water flow section)

Characteristics

- Cooling: High return temperature to generation
  Heating: Low return temperature to generation
- Variable volumetric flow in distribution

Important for trouble-free operation

- Controlling elements (valves) for the consumer circuits must be properly sized
- Variable speed control pump or adjustable bypass for minimum circulation

(The variable speed control reduces the use of energy or shuts down at zero low to prevent damage to the pump. The bypass is mounted at the beginning of the distribution.)

Field of use

- Chilled water supply for cooling coils and chilled ceilings (example).
  (consider different working temperatures)
- Supply in district heating network (e.g. community heating supply)

High energy efficiency

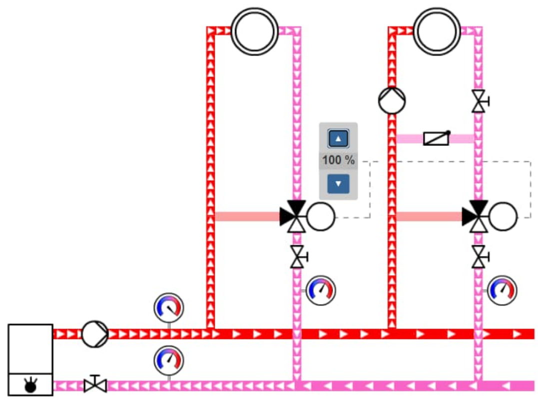
This combination of distribution and consumer circuits is highly energy efficient.
It represents a future-oriented approach!

Reasons:

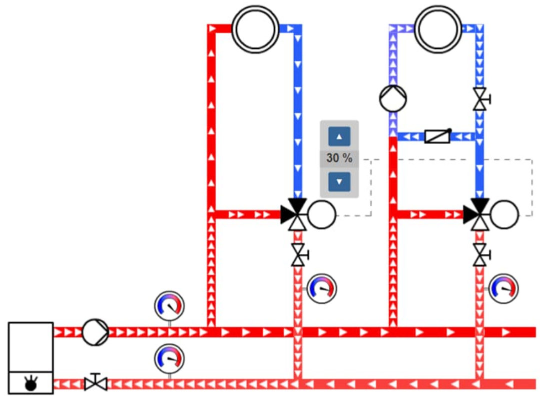
- The volumetric flow in the distribution is variable. It corresponds to the sum of all variable volume flows from all connected consumer circuits. As a result, the distribution only draws as much medium from the storage tank as is actually needed by the consumers.
- The temperature differential between distribution supply and return is sufficiently high at nominal load and increases with decreasing load (corresponding to return temperatures from variable volume consumer circuits). The temperature differential built up by generation (thermal energy) in the storage tank remains quite high and is used by this hydronic circuit in an energy-efficient manner.

1.6.5. Pressurized distribution at constant flow

Example: Heating consumers (left variable flow, right variable temperature across consumer)



Valves fully open



Valves 30 % open
(smaller velocity in the variable water flow section)

Characteristics

- High return temperature to generation
- Constant volumetric flow in generation
- Primary pump must cover pressure loss across consumers when using diverting circuits
- Hydronic balancing is a challenge

Important for trouble-free use

- Correctly sized controlling elements (valves) for the consumer groups
- Only recommended, if with regard to pump output, key consumers can be operated without a group pump
- Generation must be suitable for high return temperatures

Field of use

- Should not be utilized in new plants anymore (see Energy efficiency)
- Generation requiring return minimum limitation

Energy efficiency

The level of energy efficiency is unsatisfactory in this combination of distribution and consumer circuits.

Reasons:

- Nominal flow runs continuously throughout distribution as well as inlet and outlet of all consumer circuits. The temperature differential between distribution supply and return is very low at zero load and small at partial load. This results in considerable losses in thermal energy in the generation, distribution and connecting lines to consumer circuits.
- Distribution pump must be operated continuously at nominal flow. The required additional expense in pump transport energy is also considerable.

2 Hydronic characteristics

Parts of the hydronic circuit also constitute part of the controlled system.

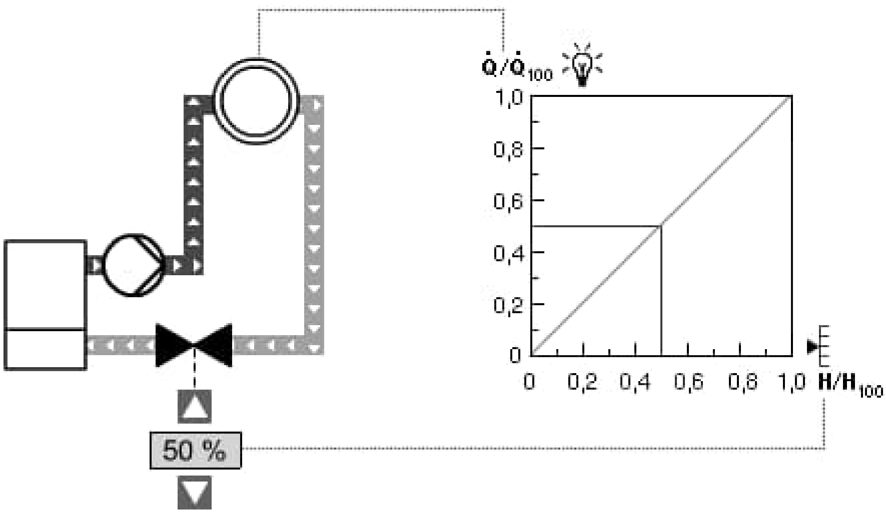
To provide comfortable conditions for the occupants of the building while ensuring low wear and tear during the operation of the plant, the hydronic circuits must also satisfy the requirements of control technology.

The combination of characteristics and properties of valves, heat exchangers and pumps in the hydronic circuit determines whether or not the actuating device (controlling element and actuator) is capable of adequately controlling the plant's heating / cooling output.

The actuator converts the positioning signal from the controller to a linear or rotary movement of the controlling element so that the volumetric flow passing through it can be adjusted between 0 and 100 %.

Goal is optimal controllability

The aim is to achieve a linear relationship between valve travel and heating (cooling) output. In other words, when the valve position reaches 50 % of the stroke range, the heat output should be 50 % of the nominal output.



Desired characteristic: 50 % heat output at 50 % valve opening

In practice, however, this characteristic cannot be fully achieved. It is affected by a number of factors that are described in the following chapters.

2.1. Heat exchanger characteristic and a-value

2.1.1. Heat exchanger characteristic

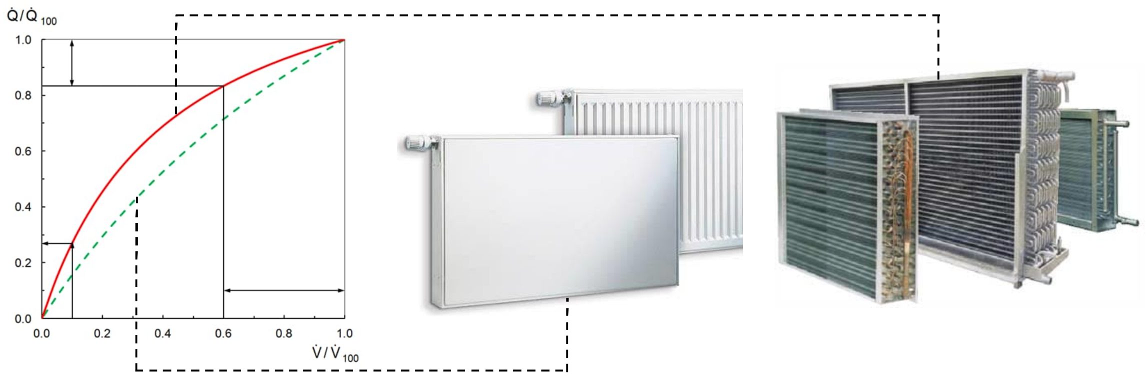
The ratio of volumetric flow of the heat exchanger and heat output is dependent on the following factors:

- Design of the heat exchanger
- Temperature differential of water inlet and outlet
- Temperature differential between the heat-absorbing and heat-delivering medium which, as a rule, is not linear

In the case of a small volumetric flow, the majority of heat exchanger characteristics are extremely steep. One consequence, for example, is the significant increase of the temperature of a heating coil for an air handling unit, even if the amount of hot water passing through it is relatively small.

Examples:

- 10 % volumetric flow ⇒ 27 % heat output
- Change from 60 % to 100 % volumetric flow
  ⇒ 18 % more heat output



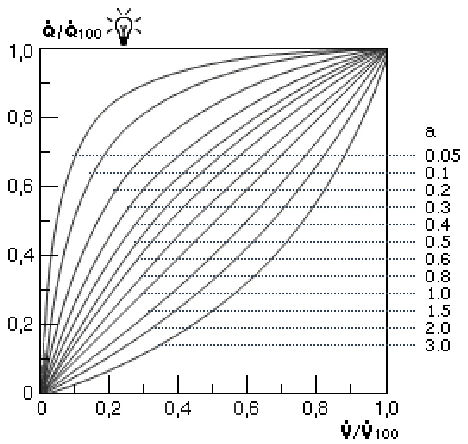
Typical heat exchanger characteristic (examples: radiators or cooling/heating coils for air handling units)

2.1.2. a-value

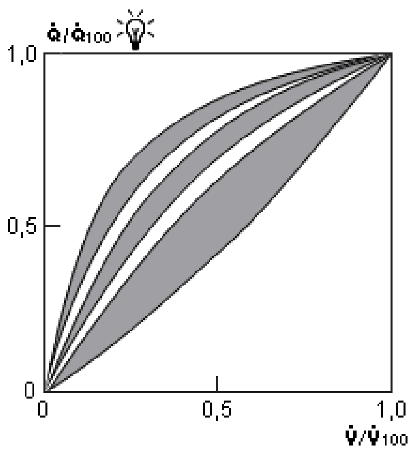
The a-value is the measure for the nonlinearity of a heat exchanger characteristic. The calculation is based on the temperature conditions at the heat exchanger and is dependent on the type of hydronic circuit (see “calculating the a-value” in the Appendix).

Conclusion:

To attain the desired controllability of the plant the flexion (nonlinearity) of the heat exchanger characteristic must be offset by an appropriate valve characteristic.



Heat exchanger characteristic with different a-values



Ranges of typical heat exchanger characteristics:
top: air cooling coil, variable flow
middle: radiator heating
bottom: heat exchanger water / water

The following applies:

- a-value = 1 ⇒ linear characteristic
- a-value < 1 ⇒ upward inflection
- a-value > 1 ⇒ downward inflection

2.2. Valve characteristic

The following parameters are important to determine the valve size:

- Required flow rate
- Pressure drop across the path with variable flow

2.2.1. k_V values and k_{VS} value

k_V value: flow value at a certain valve position (stroke

The k_V value corresponds with the flow rate of water through a valve at a constant differential pressure of 1 bar across the controlled port. The unit is m^3/h or l/min.

The k_V value of a valve is dependent on the valve's position (stroke).

k_{VS} value: flow value when the valve is fully open

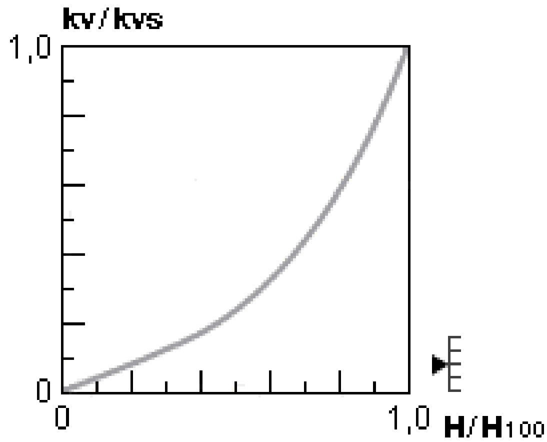
The k_V value of the fully open valve (nominal stroke H_{100}) is called the k_{VS} value.

The manufacturers of seat valves and throttling valves specify this design-dependent variable k_{VS} for every type of valve.

To be able to compare different makes and types, all valves are specified in a uniform manner:

- k_V values in relation to the k_{VS} value: k_V / k_{VS} = 0...1
- Stroke H in relation to the nominal stroke H_{100}: H / H_{100} = 0...1

If k_V / k_{VS} is shown as a function of the stroke range 0 ... 1, then this is called valve characteristic (or basic valve characteristic).



Typical valve characteristic

2.2.2. Rangeability S_V and smallest controllable flow value k_{Vr}

The rangeability S_V of a valve is the ratio of the nominal flow value k_{VS} to the smallest controllable flow value k_{Vr}.

Rangeability $S_V = k_{VS} / k_{Vr}$

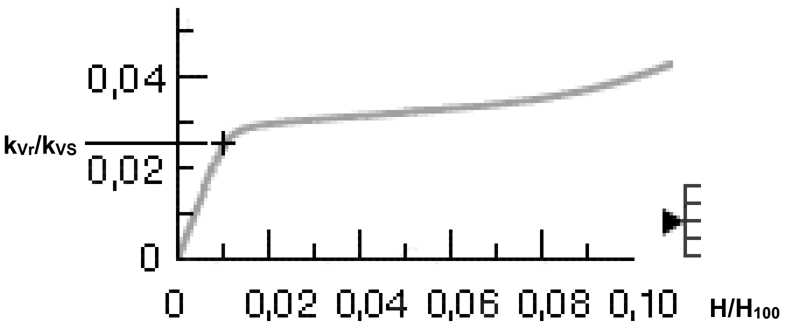
Typical values of the S_V reach from 50 to >150

The rangeability is an important characteristic that is used to assess the controllable range of a valve and is mainly dependent on the design of the valve plug and valve body.

Smallest controllable flow value k_{Vr}

The smallest controllable flow value k_{Vr} is the volumetric flow at the point where the valve suddenly opens, that is, where the valve's characteristic suddenly drops.

The k_{Vr} is either described in ratio to the k_{VS} (k_{Vr}/k_{VS}) or in m^3/h.



Smallest controllable flow value k_{Vr} of a valve

Modulating control below k_{Vr} is not possible because the valve only permits volume surges to pass (on / off operation).

2.2.3. Different valve characteristics

A distinction is made between:

- the basic form of the characteristic
  which is determined mathematically (that is, theoretically)
- the basic characteristic
  which represents the flow rate under standard conditions (1 bar, 25 °C), ascertained at each valve position

The most common basic forms of characteristics are briefly described next:

Linear characteristic

The same change of stroke produces the same change of k_V value.

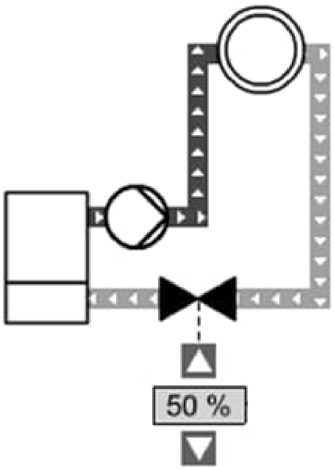
Equal-percentage characteristic

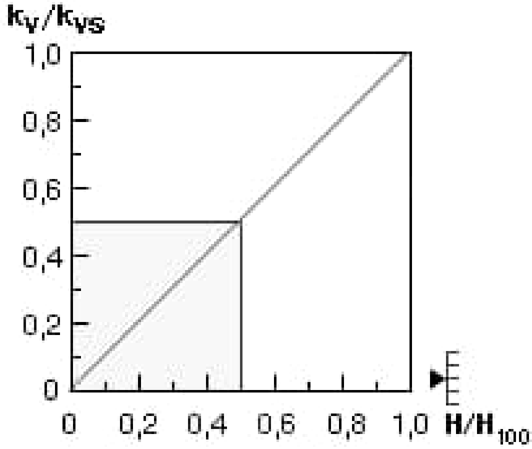
The same change of stroke produces the same percentage change of the relevant k_V value, that is, the greater the stroke (the more open the valve), the greater the impact of the stroke change on the volumetric flow. In the lower stroke range, the characteristic is flat. In the upper stroke range, it becomes steeper and steeper.

Equal-percentage / linear characteristic

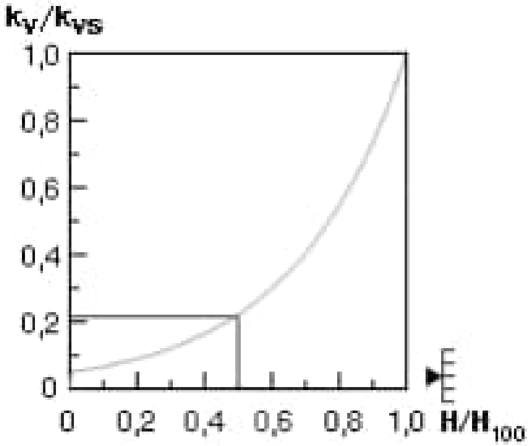
Basic form of the characteristic that is linear in the lower stroke range and that adopts an equal-percentage characteristic from about 30 % of stroke.

The basic form of the characteristic represents the basis for designing the valve plug which then determines the valve’s basic characteristic.

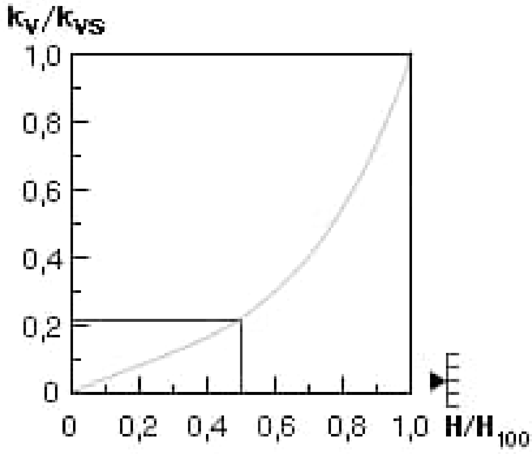




Linear characteristic



Equal-percentage characteristic

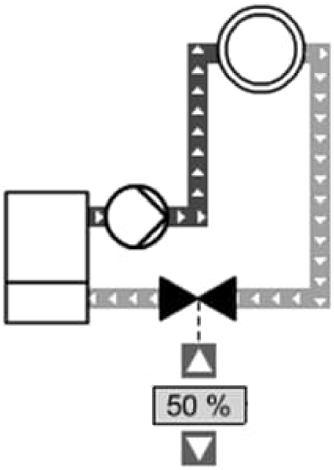


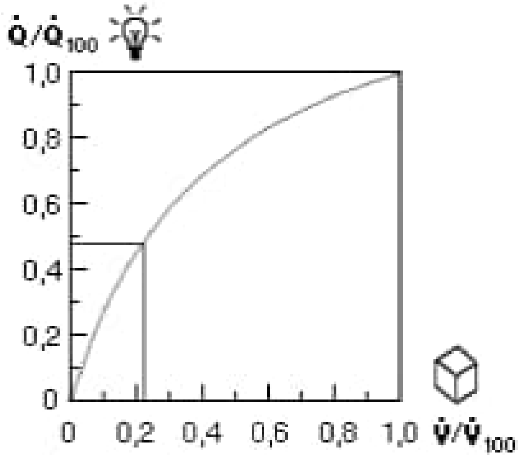
Equal-percentage / linear characteristic

Comparison of valve characteristics

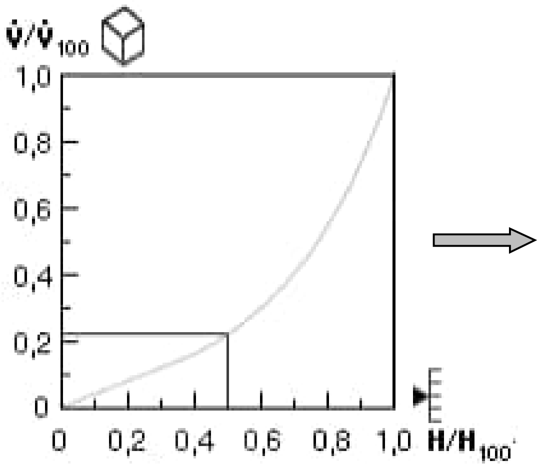
2.3. Characteristic of the controlled system

When a valve is installed in a plant, the valve characteristic should offset the heat exchanger characteristic. The resulting output of the heat exchanger can also be shown in the form of a graph, the so-called characteristic of the controlled system or control characteristic.

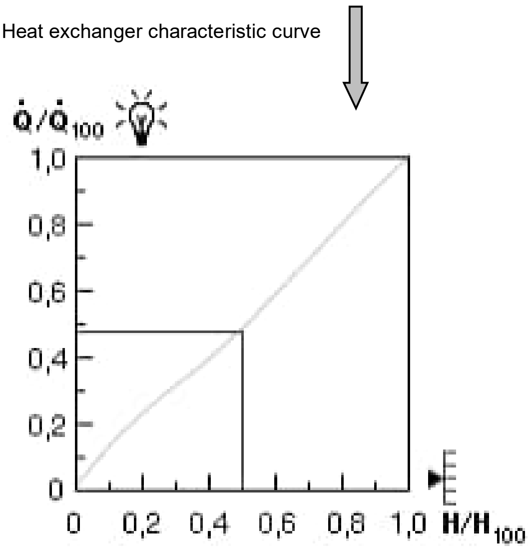




Heat exchanger characteristic curve

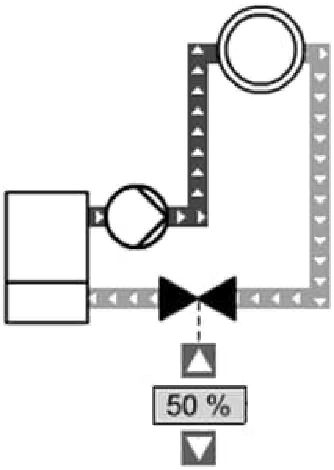


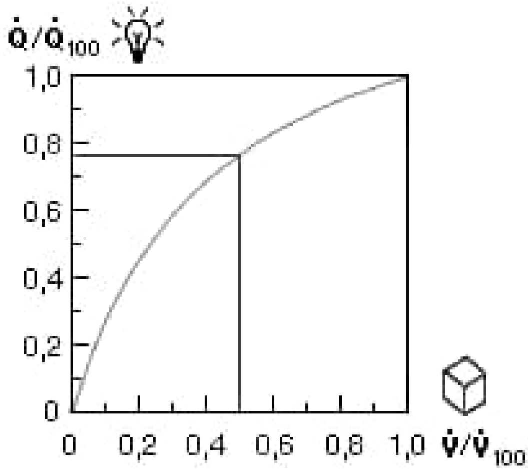
Valve basic characteristic curve, equal-percentage



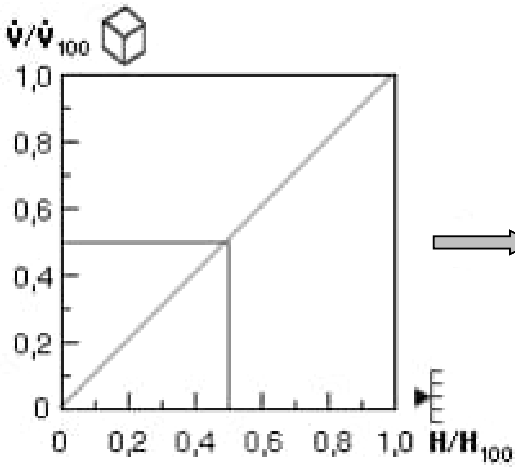
Controlled system characteristic as the result of heat exchanger characteristic and valve with an equal-percentage basic characteristic

A suitable valve characteristic was chosen here. The resulting control characteristic is almost linear. The controlled system can be controlled in a stable manner.

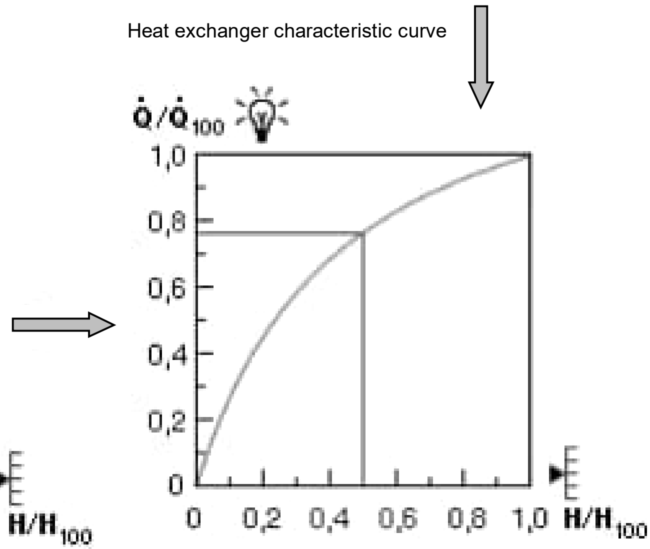




Heat exchanger characteristic curve



Valve basic characteristic curve, linear



Controlled system characteristic as the result of heat exchanger characteristic and valve with a linear basic characteristic

With the selection of a linear valve characteristic it is not possible to compensate the a-value of the heat exchanger characteristic. The controlled system cannot be controlled in a stable manner.

The graphs above reveal that through adequate selection of the valve characteristic the overall performance will be improved, but this is not yet enough to achieve a fully linear characteristic.

2.3.1. Valve operating characteristic and Valve authority P_V

The characteristic of the controlled system is determined not only by the basic valve characteristic and the heat exchanger characteristic but also by the pressure drop across the valve.

The valve's operating characteristic shows the correlation between stroke and volumetric flow of a valve installed in a hydronic circuit.

The operating characteristic is different from the valve's basic characteristic since the pressure differential across the valve's entire stroke range is not constant.

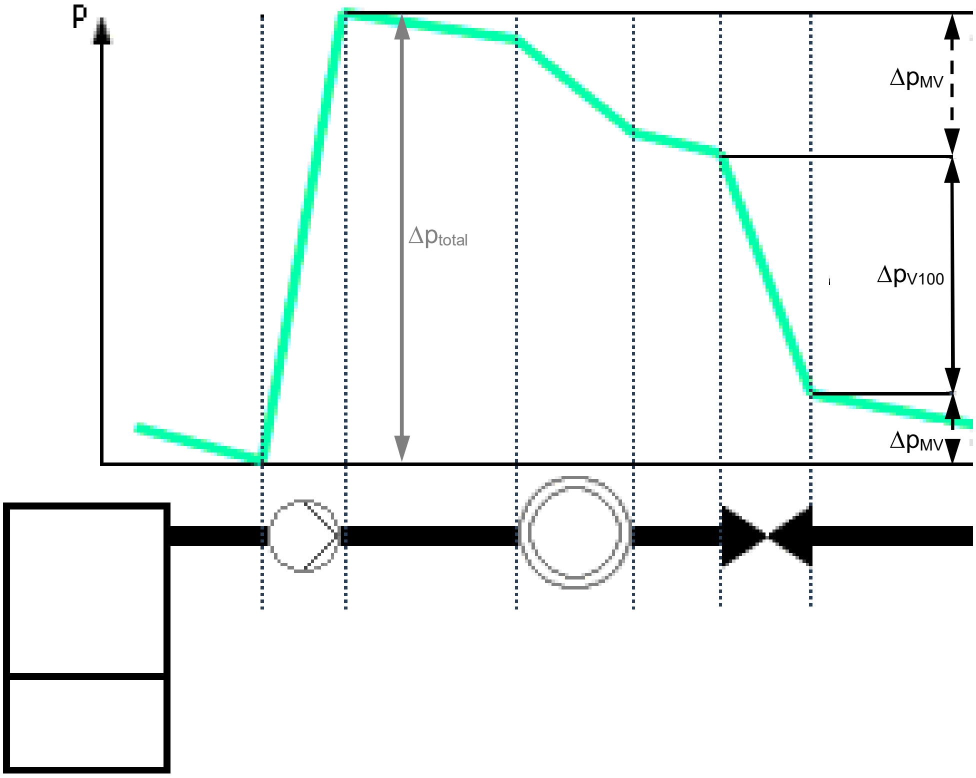
The extent of deviation is called the valve authority P_V:

$$\text{Valve authority } P_V = \frac{\Delta p_{V100}}{\Delta p_{total}} \text{ or } \frac{\Delta p_{V100}}{\Delta p_{V100} + \Delta p_{MV}}$$

Δp_{MV} the resistance of the piping network sections that experience variable flow (MV) due to the control valve at nominal (design) flow

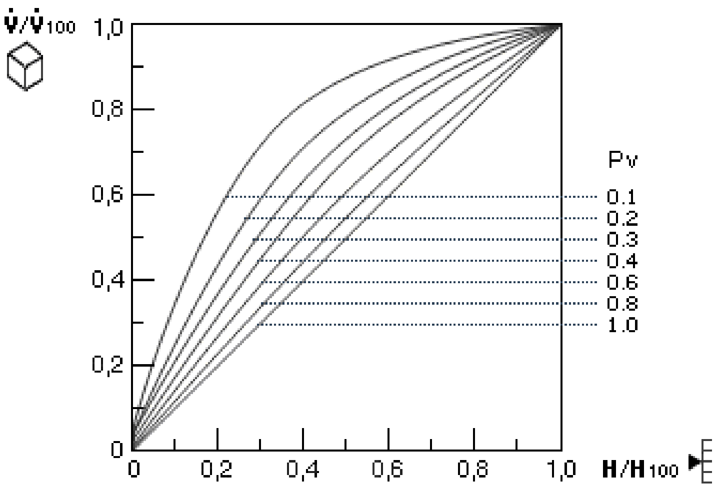
Δp_{V100} resistance of the fully open valve at nominal (design) flow

Δp_{total} resistance of the total piping network (incl. control valve) at nominal (design) flow



The valve authority P_V is determined by Δp_{V100} and Δp_{MV}

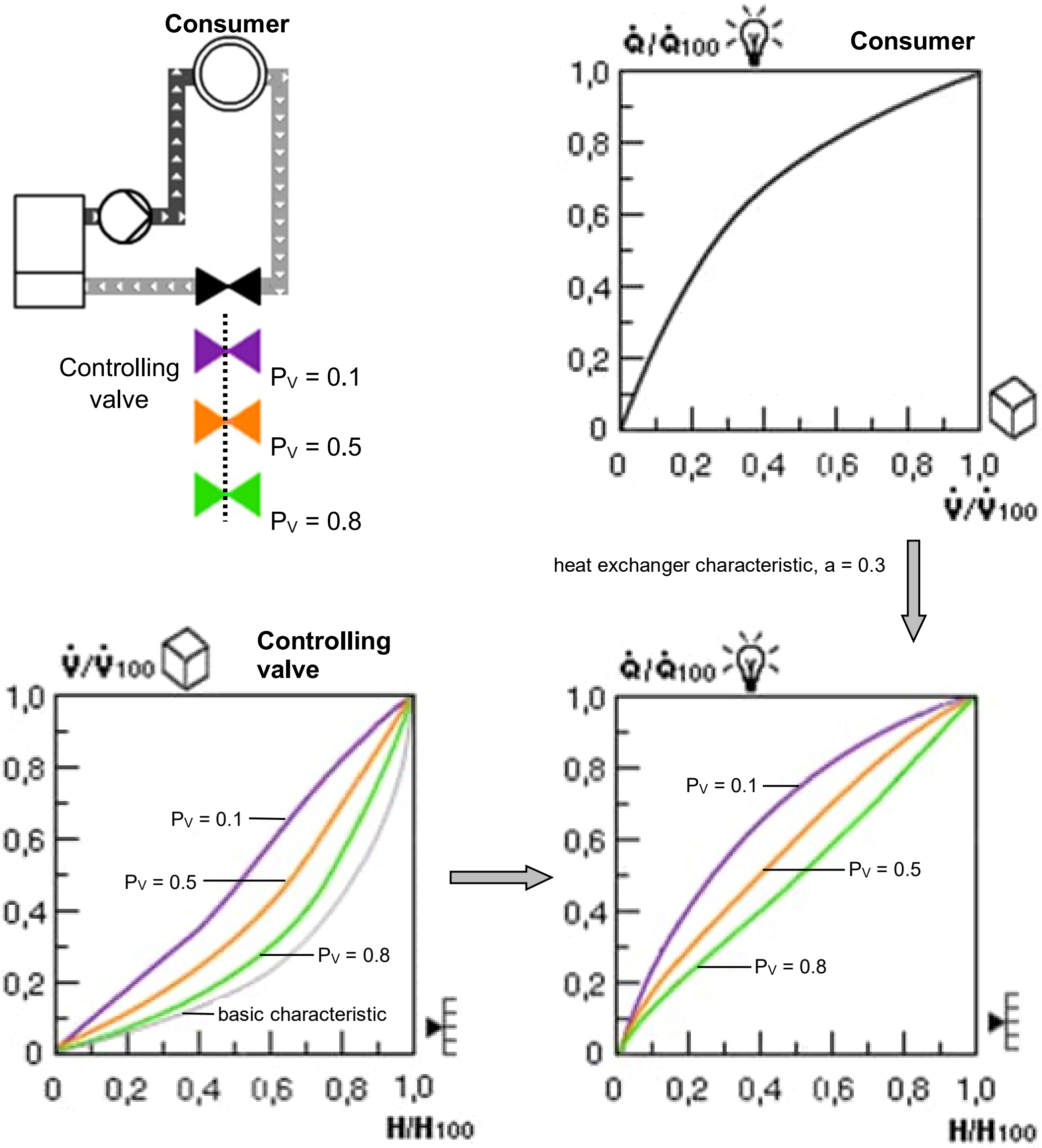
Impact of valve authority on the valve's basic characteristic



Valve operating characteristics as a function of P_V (example with a linear basic characteristic, that is, P_V = 1.0)

The operating characteristics shown above (example with a linear basic characteristic) show the impact of the valve authority $P_V < 1$ on the basic characteristic:

- The smaller the pressure drop Δp_{V100} across the valve in comparison with the affected piping with variable flow, the smaller the valve authority P_V
- The smaller the valve authority P_V, the greater the deformation of the basic characteristic
- If the valve authority $P_V = 1$, the operating characteristic corresponds to the valve's basic characteristic



valve operating characteristics

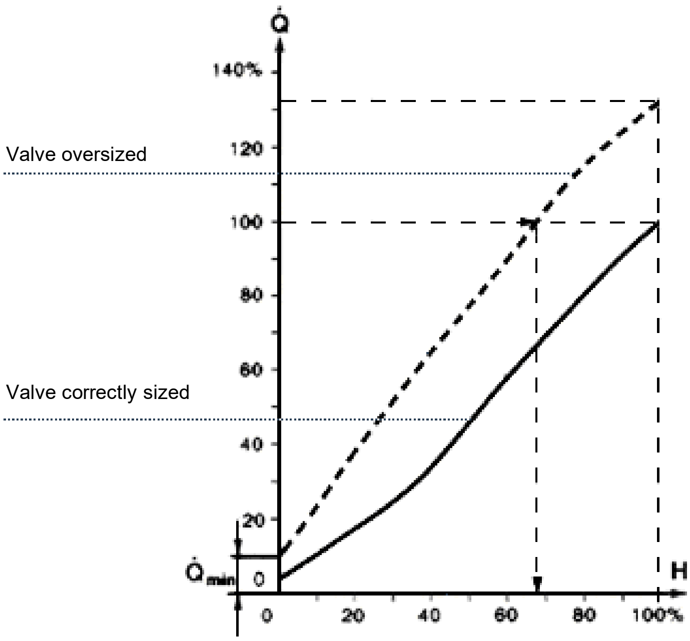
resulting characteristic of the controlled system

Heat exchanger characteristic, valve operating characteristics and the resulting characteristic(s) of the controlled system

The graph shows which system characteristic results from a heat exchanger characteristic (a-value = 0.3) in combination with different valve operating characteristics.

In the example above, a valve authority of $P_V = 0.8$ produces a nearly linear system characteristic.

2.3.2. Oversized valves



System characteristic with correctly and oversized valve

Consequences of incorrect dimensioning

Oversizing:

- The minimum controllable output $\dot{Q}_{min}$ increases.
- Since the control limits the stroke according to the required nominal output, the usable stroke span of the valve will be restricted.

Due to these effects the plant will become more difficult to control.

Under sizing:

- The required volumetric flow cannot pass through the valve
- In the system an unnecessarily high pressure drop occurs and a more powerful pump is needed.

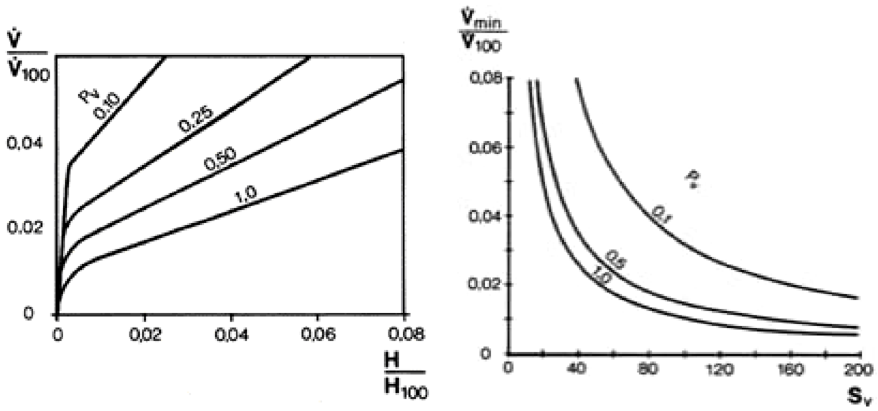
Benefits resulting from a correctly sized valve:

- Smaller initial flow surge $\dot{V}_{min}$, therefore the minimum controllable output $\dot{Q}_{min}$ will be smaller
- Higher valve authority P_V
- Valve stroke of 0...100 % can be fully used
- The controllability will be considerably improved

2.3.3. Controlling in the low load range

Initial flow surge $\dot{V}_{min}$

= smallest volumetric flow through a valve that can be controlled in modulating mode



Initial flow surge as a function of valve authority P_V and rangeability S_V

Initial output surge $\dot{Q}_{min}$

= smallest possible output of a consumer (e.g. of a radiator) that can be controlled in modulating mode

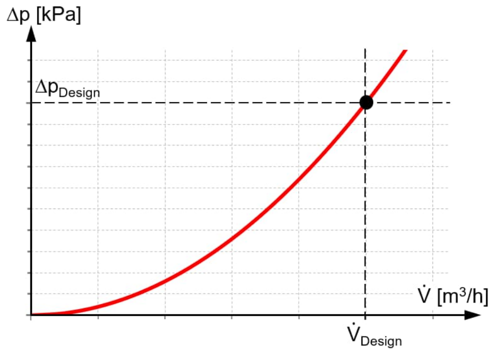
The initial output surge becomes the smaller,

- the larger the rangeability S_V of the valve
- the higher the valve authority P_V
- the greater the a-value of the heat exchanger
  (that is, smaller temperature differentials of heat source and consumer circuit)

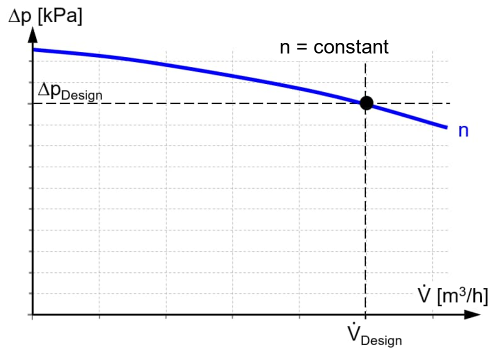
2.4. Plant characteristics, pump characteristics and operating point

The plant characteristics and the pump characteristics are needed to determine the operating point of the pump.

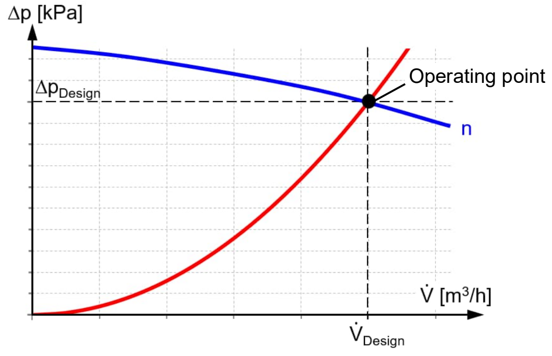
The correct operating point is essential to reach a stable and energy efficient system.



Plant characteristic (piping network characteristic)

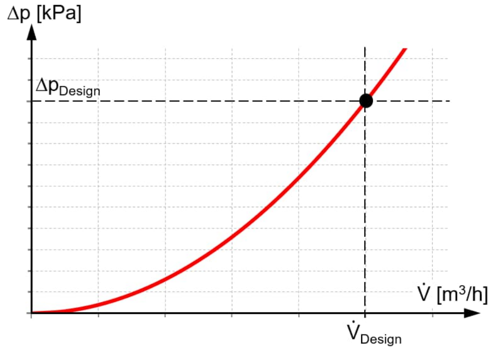


Pump characteristic with constant speed „n“



Operating point

2.4.1. Plant characteristic (piping network characteristic)



Plant characteristic

The plant characteristic shows the pressure drop Δp of the whole piping network.

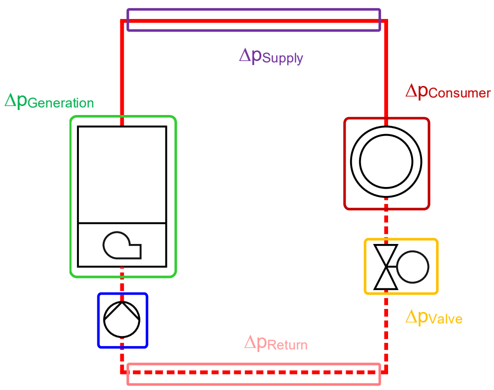
The pressure drop depends, among others, on the following parameters:

- temperature
- speed of water
- volumetric flow
- friction
- local situation (piping characteristics such as quality, number of bends, nominal size, lengths, etc.)
- plant elements (heat meters, balancing throttles, etc.)
- medium (glycol, viscosity, heat transfer oil, steam, etc.)

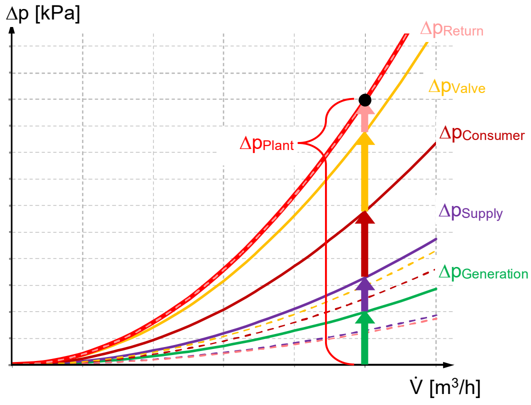
Hydronic resistances in HVAC plants

Each part in an HVAC plant contributes to the differential pressure and thus to the hydronic resistance to the water flowing in a piping network.

Therefore, it is mandatory to know the parts with high differential pressures in the piping network.



Heating plant with outlined hydronic resistances in all parts of the plant



Added resistances Δp of the individual components

In the example shown above these resistances are:

- Generation
- Consumer
- Valve
- Pipes (supply, return)

Possible values of the different elements of the plant

• Generator:	$\Delta p_{Generation}$	= 10...50 kPa
• Pipes (50...200 l/h):	Δp_{Pipes}	= 40...130 Pa/m
• Consumer:	$\Delta p_{Consumer}$	= 2...200 kPa
• Valve	Δp_{Valve}	= 3…30 kPa or more depending on the hydronic circuit

All elements of the plant in this example are connected in series.

Law of proportionality

In hydronic systems in HVAC plants the 2nd proportional law applies:

$$\frac{\Delta p_1}{\Delta p_2} = \left(\frac{\dot{V}_1}{\dot{V}_2}\right)^2$$

The resistance changes with the square to the volumetric flow in the piping network.

The elements of a given plant can be considered as a constant “C” (simplification). Hence the plant characteristic can be determined with the formula:

Pressure drop $\Delta p = C \cdot \dot{V}^2$

Calculation of a plant characteristic (piping network characteristic)

Plant design data:

volumetric flow: 10 m^3/h

differential pressure: 3 mWC ≙ 30 kPa = 0.3 bar (mWC: meter water column)

With this data, the constant C for this plant characteristic can be determined.

Differential pressure: $\Delta p = C \cdot \dot{V}^2$

converted with respect to C:

$$C = \frac{\Delta p}{\dot{V}^2}$$

Many pump suppliers specify the pressure head of the pump as pump head in meters.
The unit is mWC, meter water column.

This corresponds with the hydrostatic pressure.

Thus, it is easier to calculate with H instead of Δp.

$H \triangleq \Delta p$

$$C = \frac{H}{\dot{V}^2} \qquad Þ\ C = \frac{3\ \text{mWC}}{(10\ \text{m}^3/\text{h})^2} = \frac{3\ \text{mWC}}{100\ (\text{m}^3/\text{h})^2} = 0.03\ \frac{\text{mWC}}{(\text{m}^3/\text{h})^2}$$

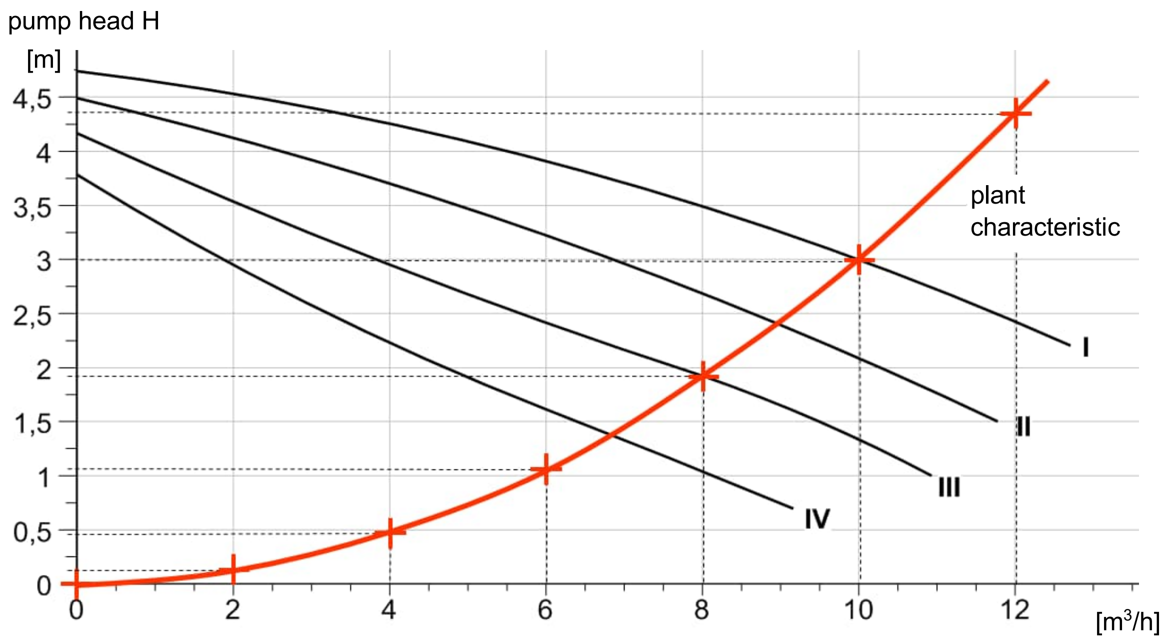
Determination of the pump head, using C (e.g. volumetric flow: 4 m^3/h):

$$H = C \cdot \dot{V}^2 \qquad Þ\ H = 0.03\ \frac{\text{mWC}}{(\text{m}^3/\text{h})^2} \cdot 4\ \text{m}^3/\text{h} = 0.48\ \text{mWC}$$

Further data of this plant characteristic are determined the same way.

volumetric flow	$\dot{V}$	[m^3/h]	0	2	4	6	8	10	12	14
pump head (differential pressure)	H	[mWC]	0	0.12	0.48	1.08	1.92	3	4.32	5.88

With this data, the plant characteristics can be outlined.



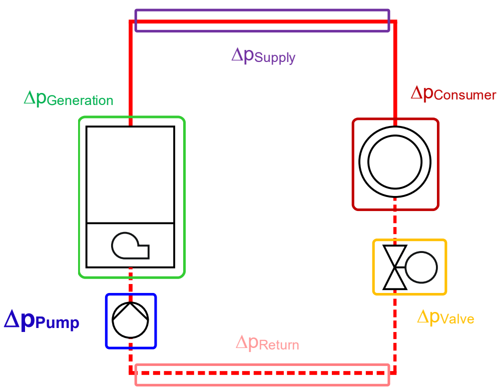
Resulting plant characteristic outlined in a pump diagram

2.4.2. Pump characteristic

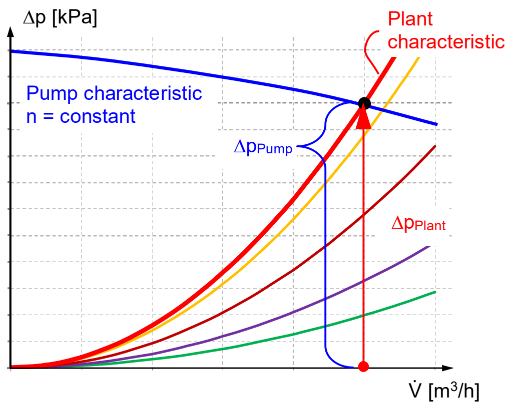
Determination of the pump pressure

The differential pressure across the pump is supposed to be equal to the sum of all other partial resistances in the plant:

$$\Delta p_{Pump} = \Delta p_{Generation} + \Delta p_{Supply} + \Delta p_{Valve} + \Delta p_{Consumer} + \Delta p_{Return}$$



Heating plant with outlined hydronic resistances in all parts of the plant



$\Delta p_{Pump} = \Delta p_{Plant}$

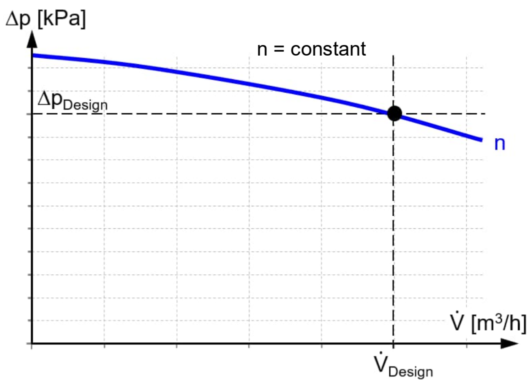
- The total resistance corresponds to the sum of all partial resistances in the plant (without pump).
- The pump needs to build up the same pressure to overcome this total resistance.
- The pressure provided by the pump corresponds to the pump head of the pump.

$\Rightarrow \Delta p_{Plant} = \Delta p_{Pump} \triangleq$ pump head in mWC

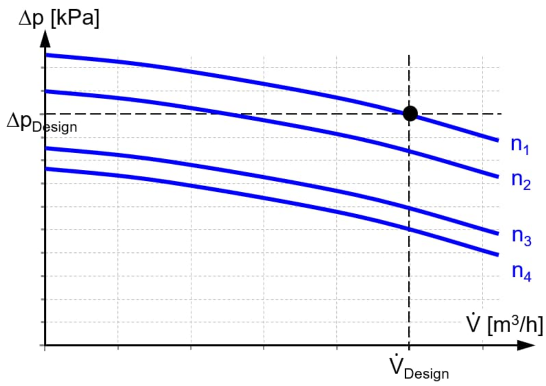
Dependency of the pressure difference across the pump and the volumetric flow

The increase of the pressure in the pump and the volumetric flow through the pump depend on each other. The pump characteristic shows this fact.

There is a different pump characteristic for each speed of the pump.



Pump characteristic at constant speed n



Pump characteristics at different speeds ($n_1 \ldots n_4$)

2.4.3. Operating point

The operating point is characterized by:

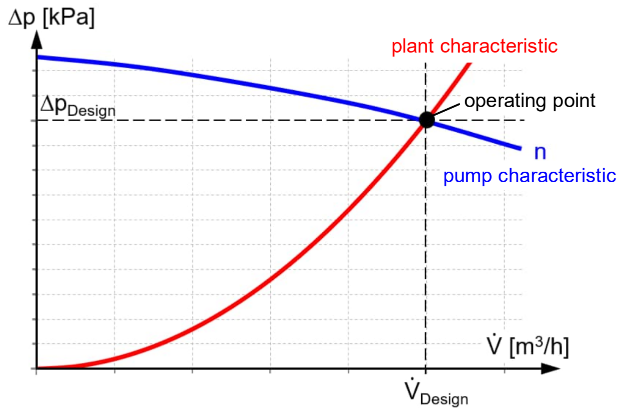
$$\frac{\dot{V}_{Plant}}{\Delta p_{Plant}} = \frac{\dot{V}_{Pump}}{\Delta p_{Pump}}$$

Thus, the operating point is at the intersection of the pump characteristic and the plant characteristic (e.g. at the state of design)

Requirement:

$\dot{V}_{Plant} = \dot{V}_{Pump}$ and hence as well $\Delta p_{Plant} = \Delta p_{Pump}$

In the operating point the pump head of the pump is equal to the total resistance of the plant at the pumped volumetric flow.



Operating point

If the volumetric flow changes, the operating point changes as well ($\Delta p = C \cdot \dot{V}^2$).

To design the optimal operating point, it is important to understand the interaction of pump characteristic and plant characteristic.

Undesired consequences may result, if the following condition is not met:

$$\frac{\dot{V}_{Plant}}{\Delta p_{Plant}} = \frac{\dot{V}_{Pump}}{\Delta p_{Pump}}$$

Consequences of an operating point that is not properly designed

Volumetric flow too high:

- pump delivers more than needed
- output too high
- room temperature too high

Volumetric flow too low:

- pump head is smaller than the differential pressure required from the system
- output too low
- room temperature too low

Pump head

As mentioned above the differential pressure of the pump corresponds to the pump head in the state of design:

$\Delta p_{Pump} \triangleq$ pump head in mWC (meter of water column)

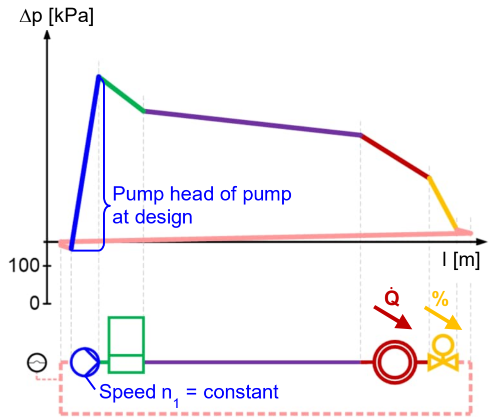
If the pump head is higher than the required differential pressure to overcome the resistance of the piping network a throttling (balancing) valve will be mounted (see 1.5.2 page 22, hydronic balancing).

2.5. The operation of pumps

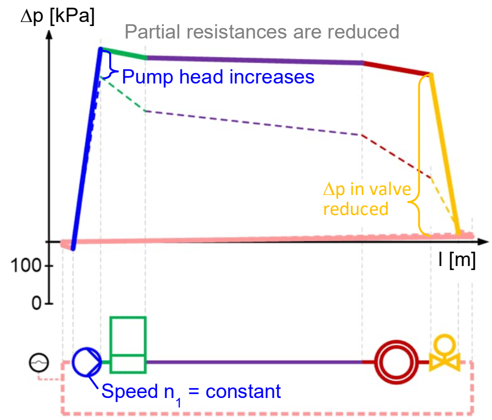
The behavior of uncontrolled and controlled pumps will be shown in the following chapters.

2.5.1. The operation of uncontrolled pumps

To reduce the power $\dot{Q}$ at the consumer, the valve needs to close, reducing the volumetric flow $\dot{V}$ through the consumer. The uncontrolled pump works at constant speed “n1” and reacts to this reduced volumetric flow. The operating point shifts to the left along the pump characteristic and the pump increases the pressure (pump head). At the same time, however, the resistance in the piping network decreases sharply with a reduced volumetric flow (see 2.4.1; 2nd proportional law). As a result, the difference between the increased pressure of the pump and the reduced system resistance must be reduced by the control valve.

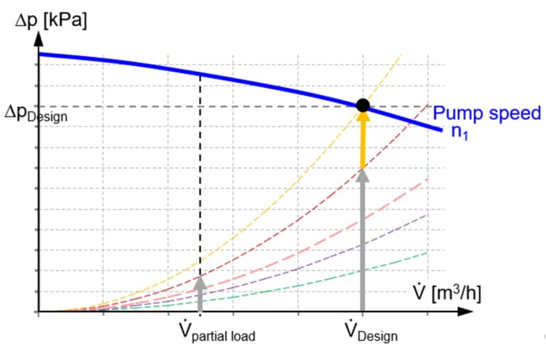


Plant situation at design

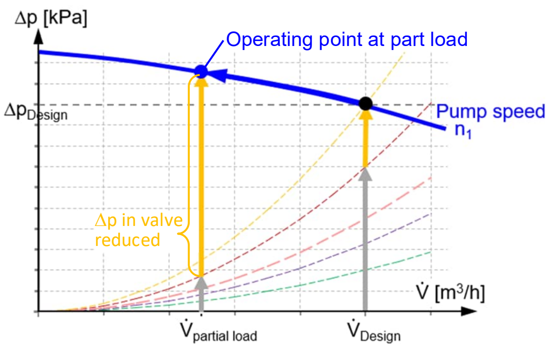


Plant situation at part load 50 %

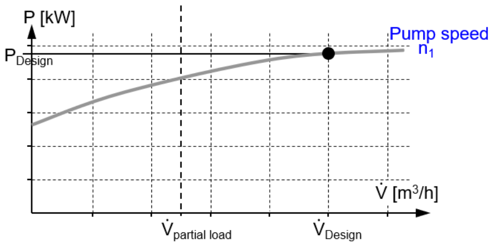
The example below illustrate the change in the operating point at partial load 50 % and the associated change in the power consumption of the pump.



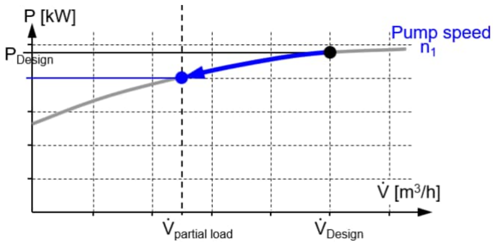
Operating point at design



Operating point at part load 50 %



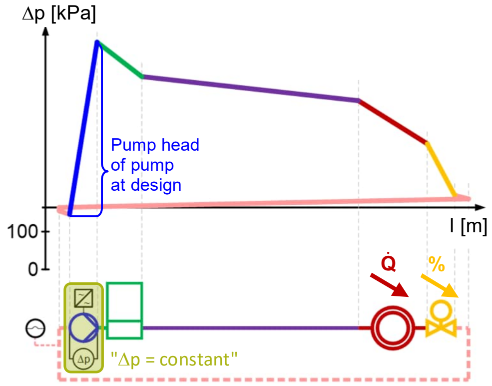
Power consumption at design



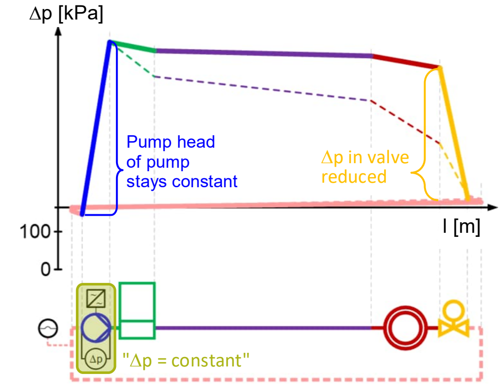
Power consumption at part load 50 %

2.5.2. The operation of controlled pumps

Constant pressure across the pump



Plant situation at design

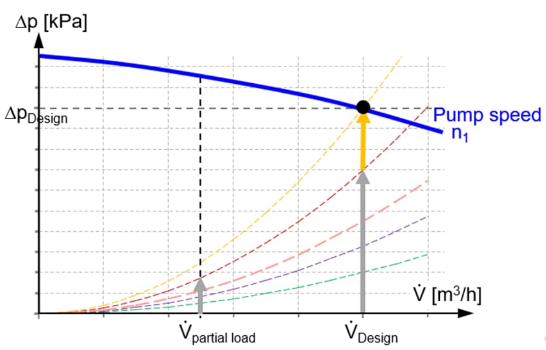


Plant situation at part load 50 %

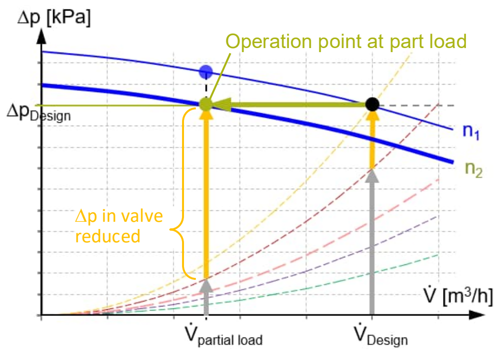
At part load the pressure across the pump (pump head) is kept constant. This can be controlled either electronically in the pump itself or with a differential pressure control and a variable speed drive at the pump.

⇒ the operating point follows the line of constant pressure horizontally to the left.

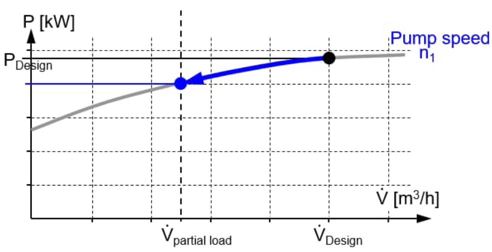
The example shown below demonstrates the shifting of the operating point at part load 50 % and as a result, the altered power consumption of the pump.



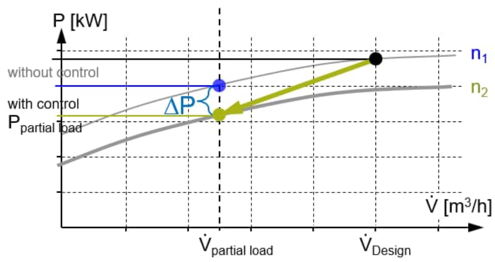
Operating point at design



Operating point at part load 50 %

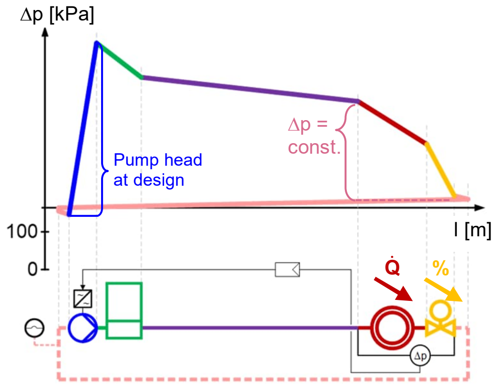


Power consumption at part load „constant speed“

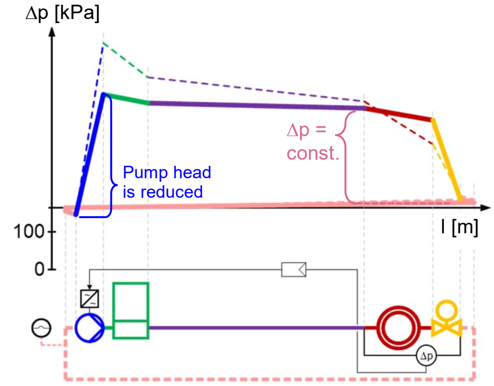


Power consumption at part load 50 %

Constant differential pressure across the end point of the plant



Plant situation at design



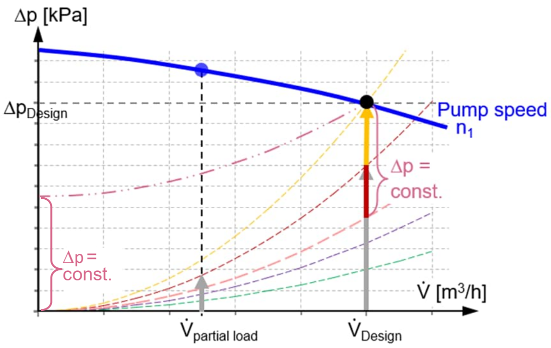
Plant situation at part load 50 %

The differential pressure is held constant across the end point of the plant. There are two possibilities to achieve this constant pressure at the end point:

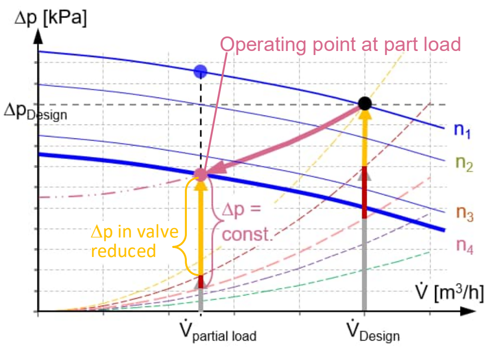
- a measuring point at the end of the plant, connected to a pressure controller and a variable speed drive (VSD) at the pump
- an electronic control in the pump itself ("Δp proportional" control), e.g. to half the pump head at design.

⇒ the operating point follows the control slope that runs towards Δp = constant near $\dot{V}$ = 0 m³/h.

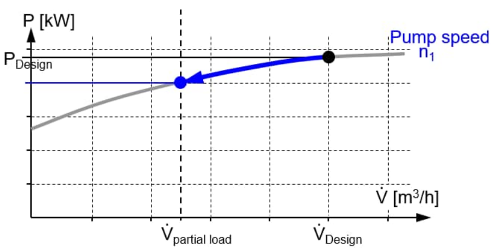
The example shown below demonstrates the shifting of the operating point at part load 50 % and as a result, the related changes in the energy consumption of the pump.



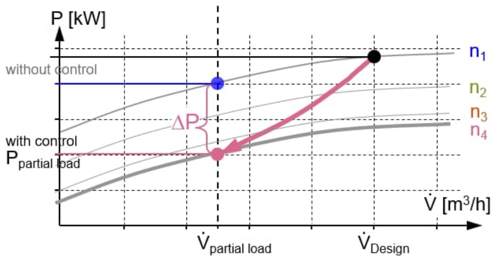
Operating point at design



Operating point at part load 50 %



Power consumption at part load „constant speed“



Power consumption at part load 50 %

Due to the reduced volumetric flow the resistance in the plant is reduced as well. The controlling across the end of a plant ensures that the necessary differential pressure there is always maintained.

With a controlled pump with the measuring point at the end point of the plant, the power consumption of the pump is even further reduced, compared to a pump controlled to constant pressure across itself.

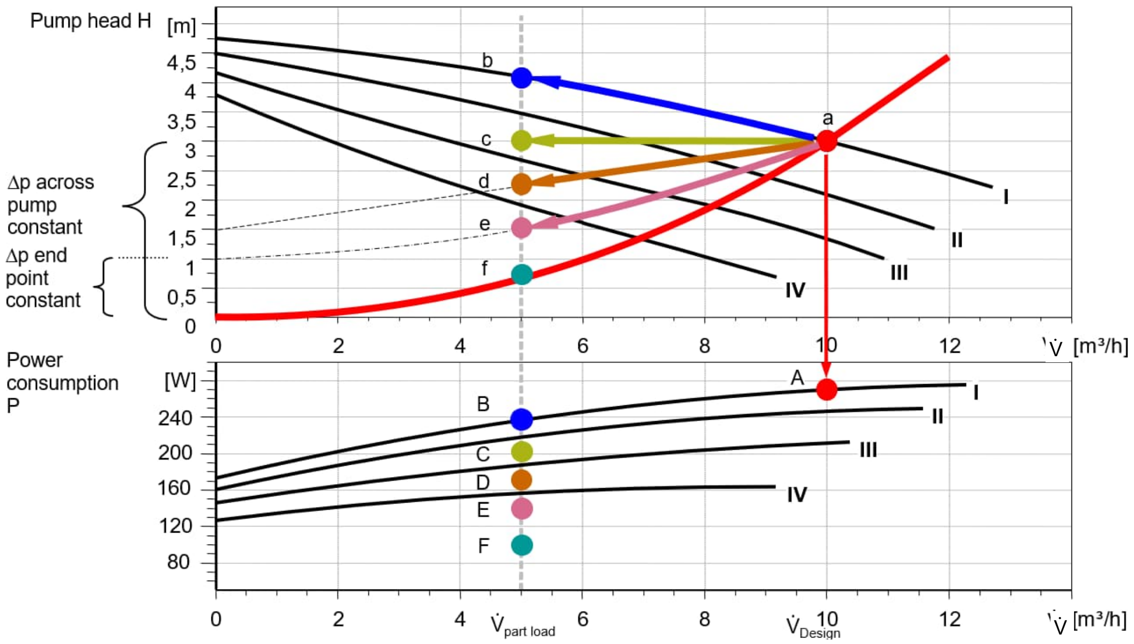
Energy savings with controlled pumps

For plants with variable volumetric flows, controlled pumps save energy very efficiently.

The selection of the control system depends on the situation on site (distances, investments, etc.)

As shown in the chart below, controlled pumps consume less power. Thus, energy and costs can be saved. A pump with constant differential pressure across the end of the plant is more efficient than a controlled pump with a constant pump pressure.

The chart below shows the saving capacity on the basis of a data sheet of a pump.



Operating points and power consumption in comparison

a: operating point, design

b: operating point, part load, uncontrolled

c: operating point, part load, Δp = constant controlled across pump

d: operating point, part load, Δp = proportional in electronically controlled pump

e: operating point, part load, Δp = constant controlled across end point of plant

f: operating point, part load, Δp = control based on demand from consumers, e.g., valve positions

A: power consumption, design

B: power consumption, part load, uncontrolled

C: power consumption, part load, Δp = constant controlled across pump

D: power consumption, part load, Δp = proportional in electronically controlled pump

E: power consumption, part load, Δp = constant controlled across end point of plant

F: power consumption, part load, Δp = control based on demand from consumers, e.g., valve positions

Speed control based on demand from consumers

Another possibility to adjust the pump speed to the conditions of the plant is the speed control based on the consumers demand (f).

This type of speed control is suitable when the current positions of the various consumer valves can be detected and analyzed in a building automation (BA) system. The BA system can then provide the required setpoint for the speed control. With that it can be ensured that the valve with the highest demand is always opened as much as possible (e.g. 90 %).

With this approach even smaller pump heads are possible than with the control across the endpoint of the plant (E above). The power consumption of the pump is further reduced to point F which is often substantially below point E.

3 Sizing the controlling elements

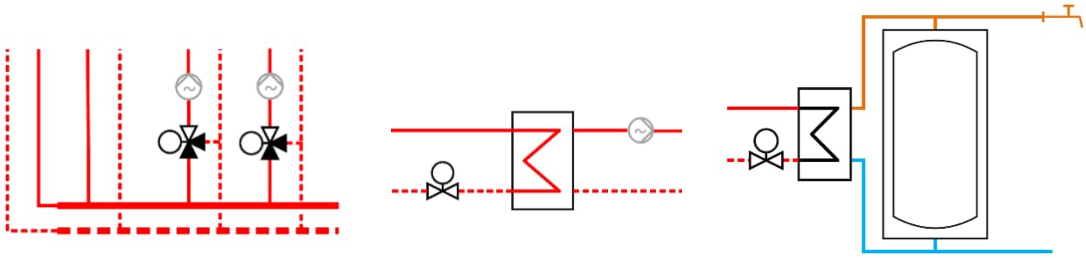
The previous chapters covered hydronic circuits, controlling elements and the physical fundamentals of a plant. In this chapter you will find a detailed description of how to size a controlling element i.e. control valves.

Before the sizing of actuating devices (controlling elements and actuators) can be started and before they can be selected, all important data about the plant must be available:

- The basic schematics of the hydronic circuits of both the generation and consumer side (either as geographic or synoptic schematics)
- The thermal power provided by the generator and required by the consumer side with the associated temperature differentials
- The designations of the generator(s) and consumers
  e.g. “Heating group West”, “Floor heating new building”, “Air heating coil”, etc.
  ⇒ these sometimes provide information on crucial plant issues.

It is also important to know whether the subject hydronic circuits or control loops (e.g. floor heating systems) are standard or whether special hydronic circuits are used, making it necessary to gather special detailed information about the plant, such as:

- start-up control of a heat pump
- hot water charging with controlled charging temperature
- district heating substations
- plant sections with high network pressures
- etc.



When sizing controlling elements, the different hydronic circuits and their properties must be taken into account.

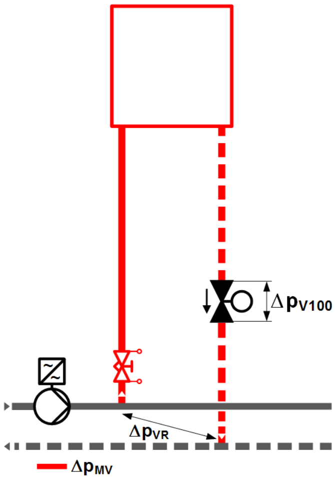
It is also of utmost importance to know the pressure drops in the part of the piping with variable volumetric flow and across the individual plant components in the hydronic circuits, such as air heating coils, heat meters, etc. (also refer to section 3.1.1).

Once all this information is available, the controlling element can be sized straightforwardly and accurately to satisfy the plant conditions.

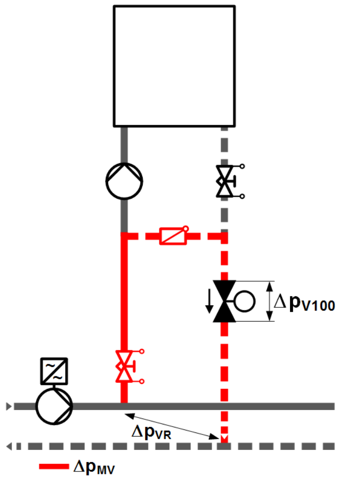
3.1.1. Piping sections with variable volumetric flow in different hydronic circuits

When sizing controlling elements, it is very important to identify network sections with variable flow of water (in operation) correctly, because the pressure drop in these sections (with the installed plant components) is an important factor.

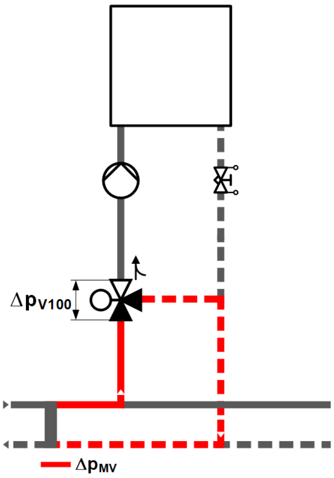
In addition to section 1.3 “Consumers with their basic hydronic circuits“ the following graphics show the sections of individual hydronic circuits with variable volumetric flow that are decisive for determining the pressure drop. The piping sections with variable flows of water are marked in red.



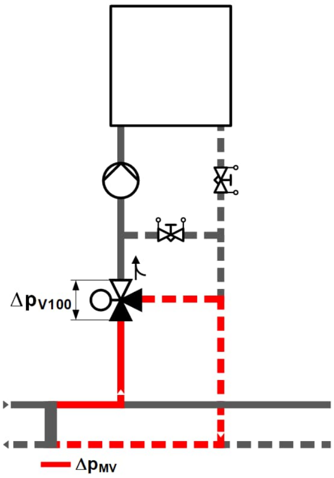
Throttling circuit
from header across consumer and back



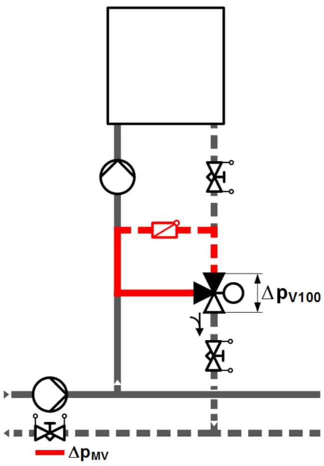
Injection circuit with two-port-valve
from header to injection-bypass and back



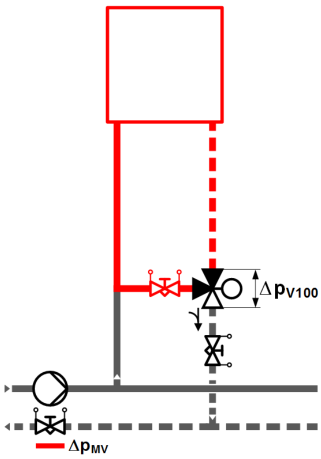
Mixing circuit:
piping from / to the header



Mixing circuit with fixed premixing:
piping from / to the header



Injection circuit with three-port valve: *outdated*
between injection bypass to valve bypass



Diverting circuit: *outdated*
from injection-bypass across consumer and back

3.2. Valve sizing example

In a discussion with the planning engineer the following information has been collected:

Example of a plant with two heating groups

Boiler

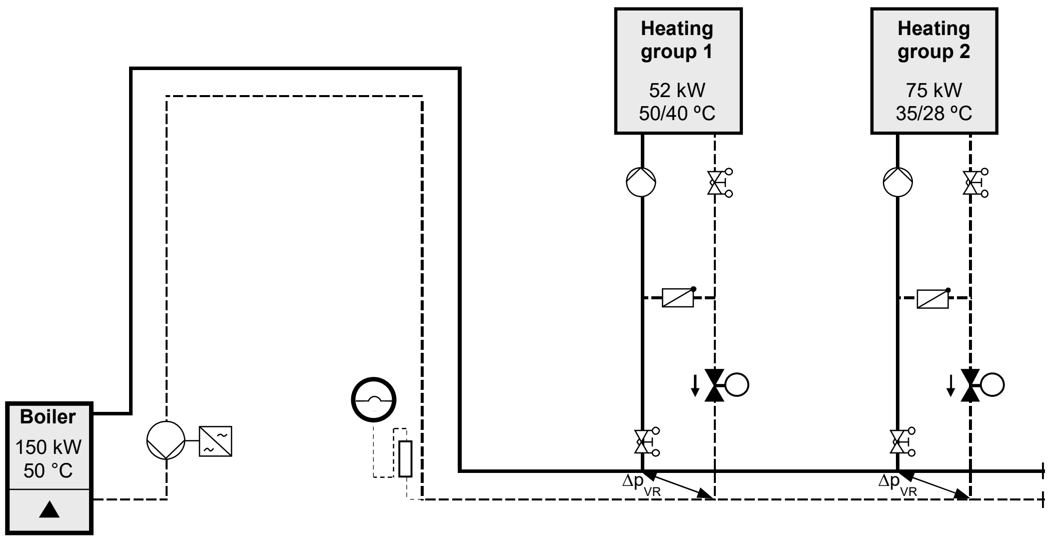
- Output: 150 kW
- Supply temperature: 50 °C

Heating group 1 (old building)
with radiators

- Output: 52 kW
- Supply temperature: 50 °C
  Return temperature: 40 °C
  ⇒ ΔT across consumer 10 K
- Injection circuit with 2-port valve directly mounted onto the distributor
- Pressure drop between supply/return Δp_{VR} ca. 6 kPa

Heating group 2 (new building)
with floor heating system

- Output: 75 kW
- Supply temperature: 35 °C
  Return temperature: 28 °C
  ⇒ ΔT across consumer 7 K
- Injection circuit with 2-port valve directly mounted onto the distributor
- Pressure drop between supply/return Δp_{VR} ca. 6 kPa



Plant example with heating groups 1 and 2, directly mounted onto distribution

3.2.1. Sizing the valve (controlling element)

A controlling element is sized by proceeding as follows:

- Derive the volumetric flow $\dot{V}$ (often also called $\dot{V}_{100}$) based on the power $\dot{Q}$ and the temperature difference ΔT
- Determine the decisive pressure drop Δp_{MV} (resp. Δp_{VR}) in the piping section with variable flow
- Determine the required valve authority P_V
  and by that the required pressure drop Δp_{V100} across the valve
- Determine the k_V value
- Select the valve with an appropriate k_{VS} value
  and a suitable actuator

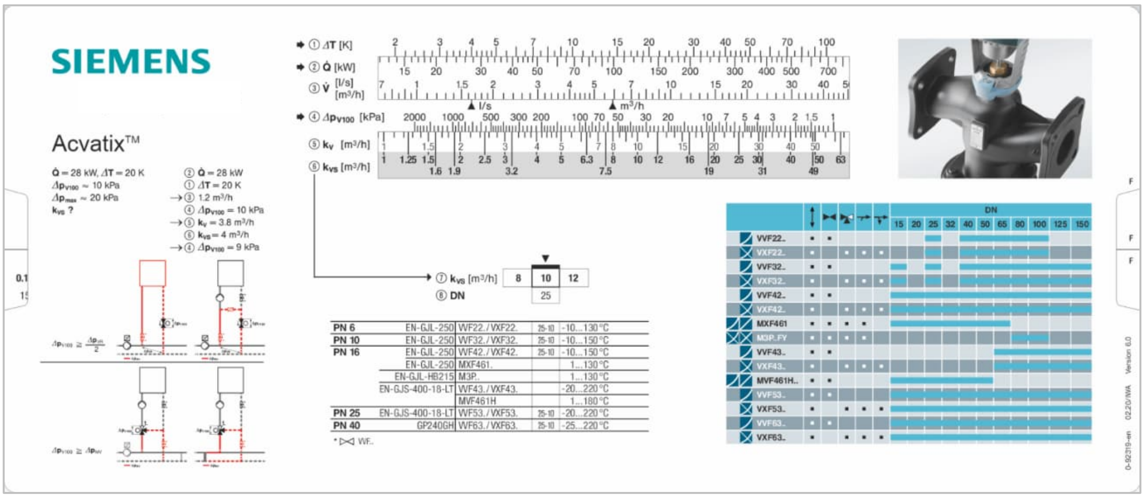
Heating group 1 (old building with radiators)

Determining the volumetric flow

The volumetric flow at nominal load (control valve fully open), can be derived from the following formula:

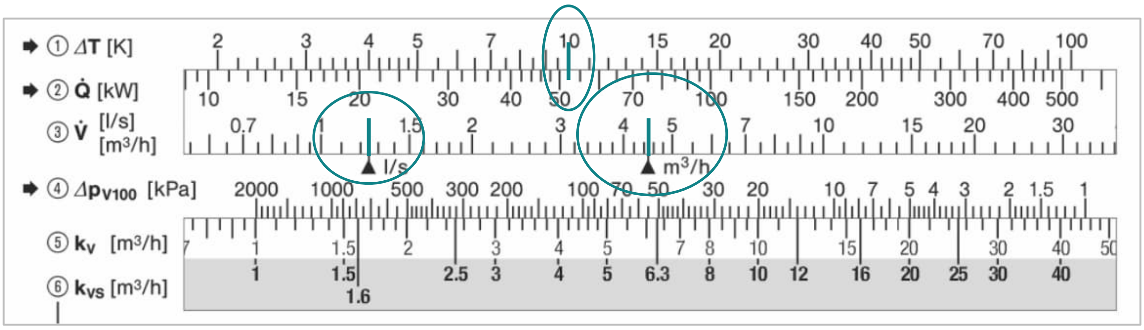
$\dot{Q} = \dot{m} \cdot c \cdot \Delta T$ or $\dot{Q} = \dot{V} \cdot \rho \cdot c \cdot \Delta T$

The volumetric flow can also be determined with the help of a valve slide rule.
In this example, the Siemens valve slide rule is used.



Siemens valve slide rule (use either side, with flanged or threaded valves)

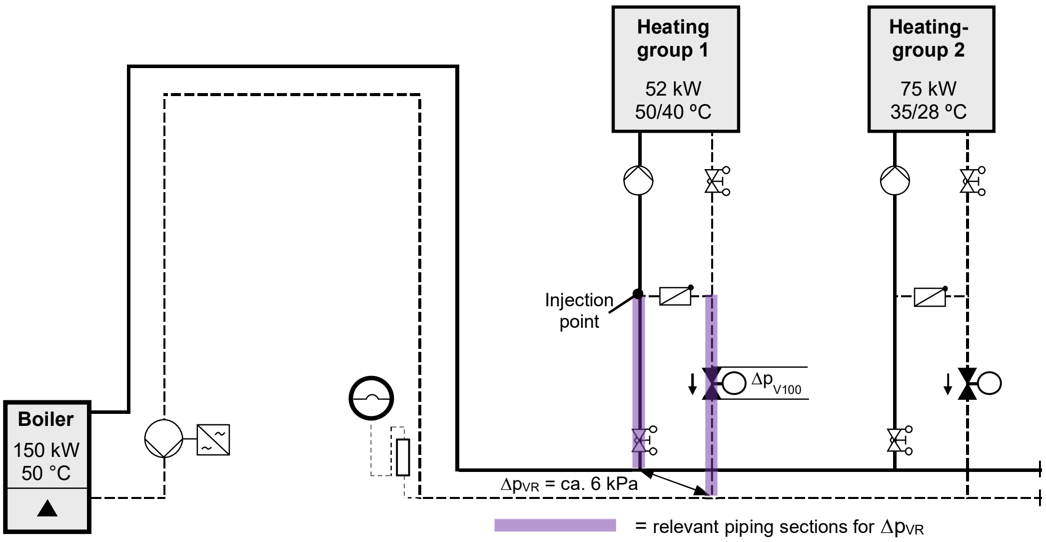
1. Slide line ② with the value of $\dot{Q}$ = 52 kW below the value of ΔT = 10 K in line ①
2. Now, in line ③, the volumetric flow $\dot{V}$ can be read off:
   $\dot{V}$ = 4.5 m³/h or 1.24 l/min



Determination of the volumetric flow at nominal load (controlling element 100 % open) with the help of the valve slide ruler

Hence, this part of the valve slide rule is based on the formula: $\dot{Q} = \dot{V} \cdot \rho \cdot c \cdot \Delta T$

Decisive pressure drop in the piping section with variable flow



Piping sections with variable water flow in heating group 1

1. In the hydronic circuit, determine the piping sections with variable water flow in normal operation. In the injection circuit with 2-port valve, these are the lines from the distributor to the bypass (→ injection point) and back.
2. The planning engineer has foreseen a Δp_{VR} of 6 kPa for this. This is the planned total pressure drop from the distributor for these pipe sections (incl. control valve with Δp_{V100}).

Note:

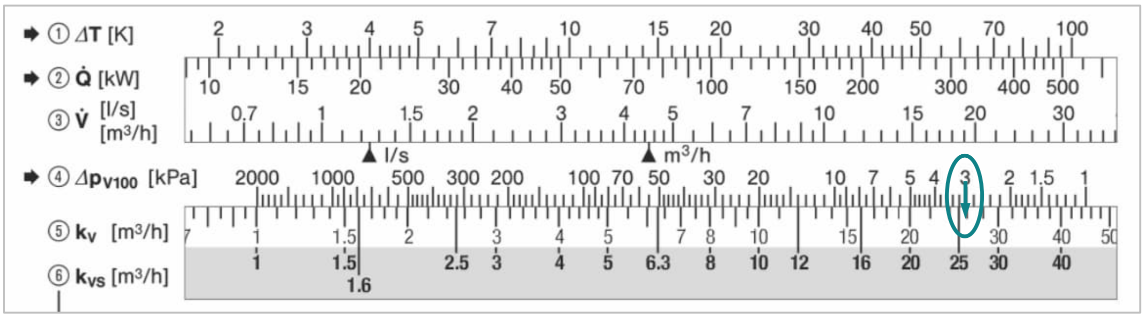
If the injection circuit is not installed directly on the distributor, but far away (e.g. for a heating coil on an air handling unit), then Δp_{VR} will be correspondingly larger (e.g. 20 kPa or more) due to the long pipes. Therefore, Δp_{VR} must always be considered for the valve selection according to the system situation.

Determining the required valve authority P_V

It is now necessary to determine the required valve authority P_V for the heating group. For a heating group with an injection circuit with a 2-port valve, the resistance across the valve Δp_{V100} should be at least half of the total pressure loss between supply and return Δp_{VR} to ensure good control behavior. This corresponds to a valve authority of $P_V \geq 0.5$. In this example, this results in the desired resistance of the valve: $\Delta p_{V100} \geq 0.5 \cdot \Delta p_{VR} \geq 0.5 \cdot 6\ \text{kPa} \geq 3\ \text{kPa}$.

Determining the k_{VS} value

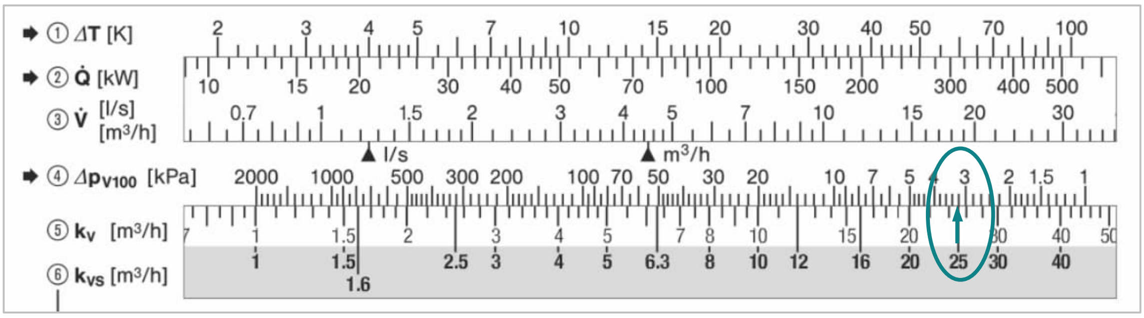
Read off the k_V value (desired k_{VS} value) on line ⑤ at Δp_{V100} (line ④) = 3 kPa.



Determination of the k_{VS} value based on Δp_{V100}, using the valve slide rule (excerpt)

Based on a volumetric flow of 4.5 m³/h (line ③) and Δp_{V100} = 3 kPa (line ④), the valve slide rule shows a k_V value of about 26 m³/h (line ⑤). The k_V value corresponds to the desired k_{VS} value for this particular plant situation. The closest k_{VS} values are 25 and 30 (line ⑥).
Here, a k_{VS} value of 25 is chosen because a somewhat larger P_{Veff} valve authority results from it.

Based on the selected k_{VS} value of 25 m³/h, $\Delta p_{V100eff}$ = 3.2 kPa results.



Determination of $\Delta p_{V100eff}$ based on the k_{VS}- value 25 using the valve slide rule (excerpt)

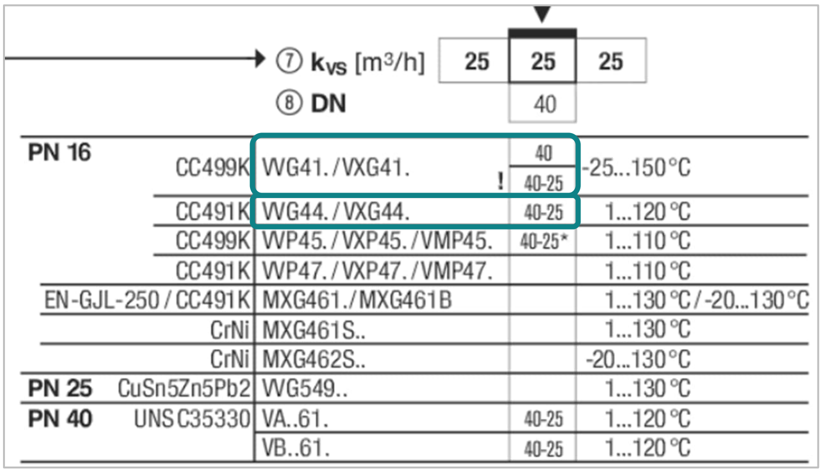
Check briefly the resulting effective valve authority P_{Veff}:

$$P_{Veff} = \frac{\Delta p_{V100eff}}{\Delta p_{total}} = \frac{\Delta p_{V100eff}}{\Delta p_{V100eff} + \Delta p_{MV}} \qquad \Rightarrow P_{Veff} = \frac{3.2\ \text{kPa}}{(3.2 + 3)\ \text{kPa}} = 0.52$$

Resulting effective valve authority P_{Veff} = 0.52 (with $\Delta p_{VR\ eff}$ = 6,2 kPa), which is very close to the envisioned target.

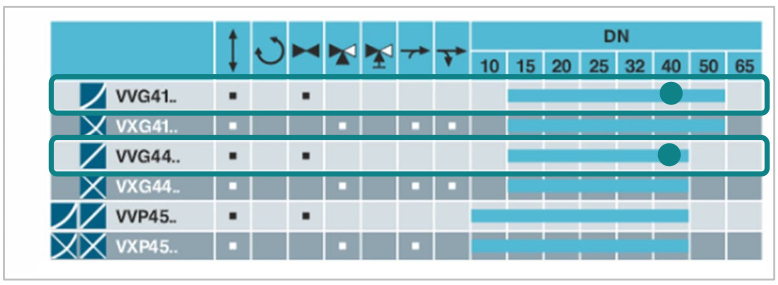
Selecting the suitable valve and the actuator

Select suitable valves with a k_{VS} value of 25.
For that purpose, slide line ⑦ (k_{VS} value) until the value of “25” appears in the outlined field.
Now, possible valve types can be selected from the list below.

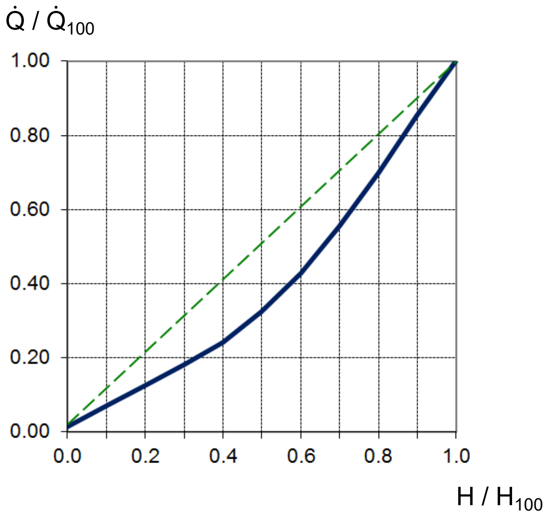


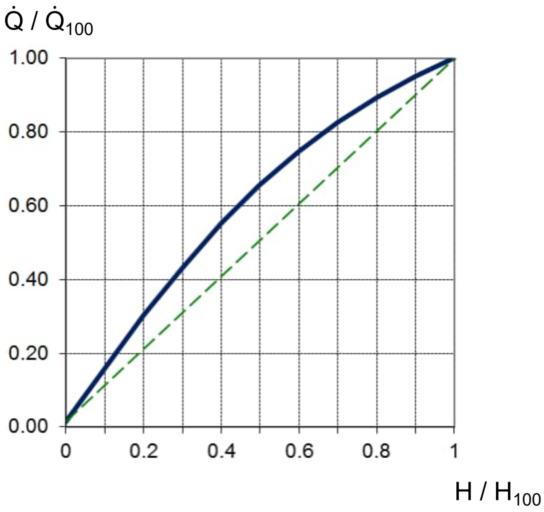
			⑦ k_{VS} [m³/h] 25	25	25
			⑧ DN	40	
PN 16	CC499K	WG41./VXG41. !		40 / 40-25	-25...150 °C
	CC491K	WG44./VXG44.		40-25	1...120 °C
	CC499K	WP45./VXP45./VMP45.		40-25*	1...110 °C
	CC491K	WP47./VXP47./VMP47.			1...110 °C
	EN-GJL-250/CC491K	MXG461./MXG461B			1...130 °C/-20...130 °C
	CrNi	MXG461S..			1...130 °C
	CrNi	MXG462S..			-20...130 °C
PN 25	CuSn5Zn5Pb2	WG549..			1...130 °C
PN 40	UNS C35330	VA..61.		40-25	1...120 °C
		VB..61.		40-25	1...120 °C

Choice of valves with a k_{VS} value of 25 m³/h (excerpt of valve slide rule)



In our example, either a 2-port valve VVG41.40-25 with equal-percentage characteristic (cf. left) or a three-port valve VVG44.40-25 with linear characteristics (cf. left) can be selected as both result in a similarly well linearized characteristic in combination with a heat exchanger characteristic with an a-value of 1 (see 2.3 and Appendix with a-value calculation guidelines; applies to supply temperature control with injection circuit with 2-port valve or with mixing circuit).





Characteristic of the controlled system with equal-percentage valve ($P_V = 0.5$, a = 1)

Characteristic of the controlled system with linear valve ($P_V = 0.5$, a = 1)

Product types have different stroke

For the valve selection it should also be considered that these valve types have different stroke values (VVG41… 20 mm, VVG44… 5.5 mm), i.e. the VVG41… products provide a much higher mechanical resolution than the VVG44… products.

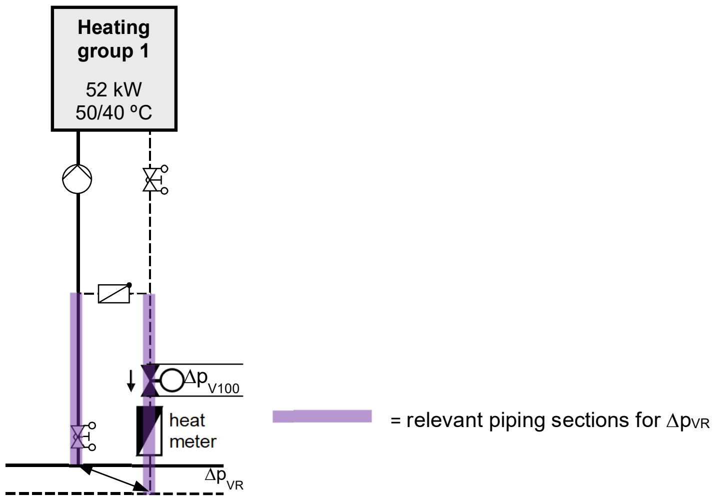
Actuator selection

A three-position actuator can be selected (e.g. SAX31 or SQS35) since there are no special requirements and these types of actuators offer a good price / performance ratio. Suitable combinations of valves and actuators can also be found on the additional data sheet provided with the Siemens valve slide rule or in the technical documentation.

Devices fitted in piping sections with variable volumetric flow

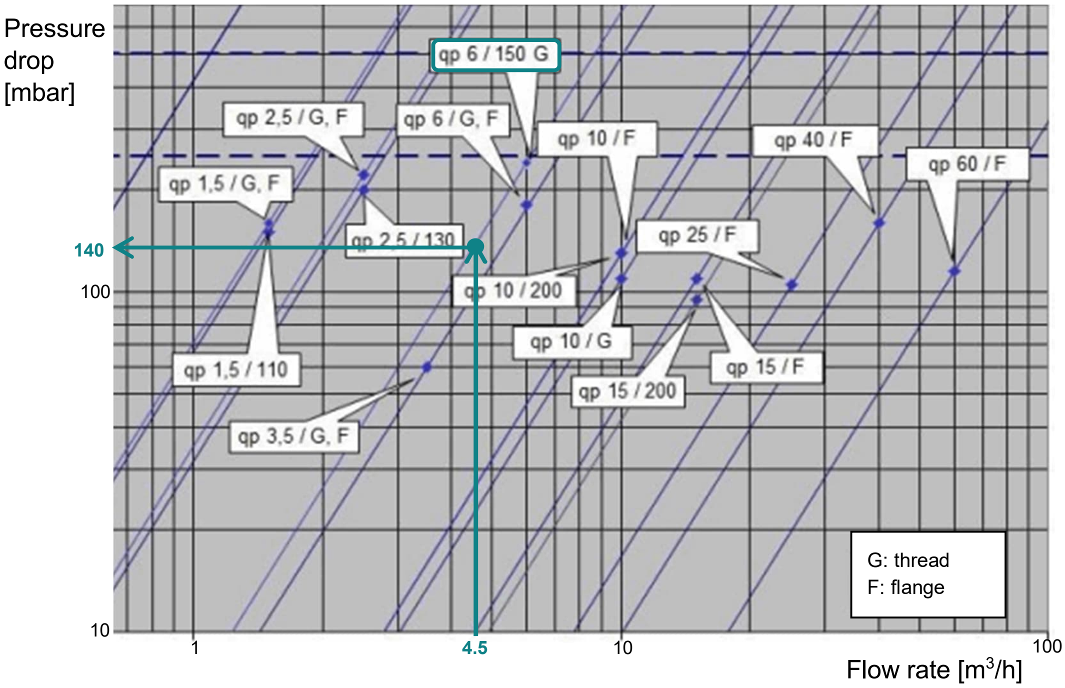
If there are any additional devices fitted into the piping sections with variable volumetric flow, the resulting pressure drop must be taken into consideration as well.

In this example a heat meter (4.5 m^3/h) has additionally been placed into heating group 1.



Heat meter in Heating group 1

This results in $\Delta p_{VR} = \Delta p_{pipes} + \Delta p_{V100} + \Delta p_{heat\ meter}$

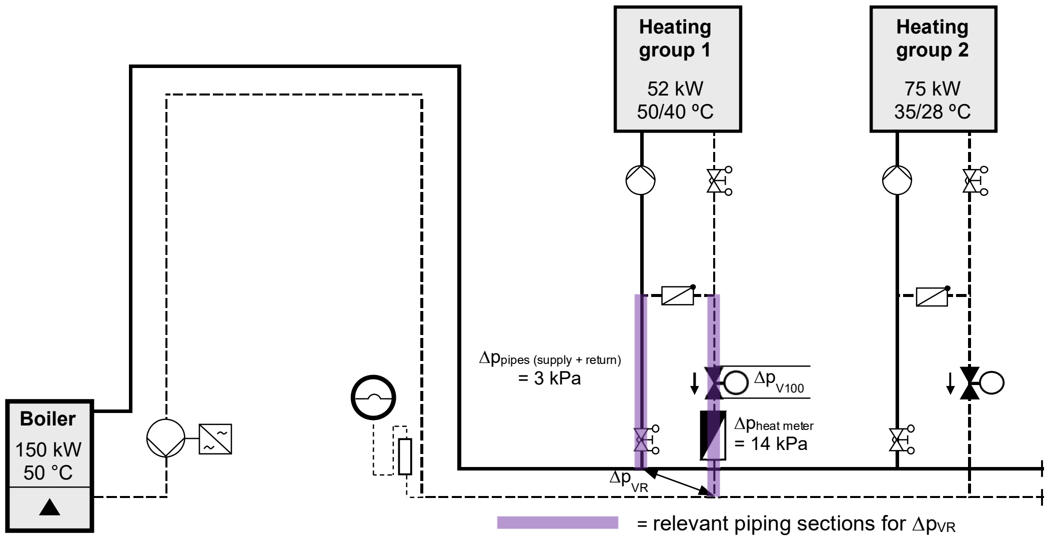


Pressure drop diagram of heat meters

The pressure drop of the heat meter can be obtained from the manufacturer's documentation: $\Delta p_{heat\ meter}$ = 140 mbar = 14 kPa.

The total pressure loss Δp_{VR}, which is decisive for the valve selection, is therefore correspondingly larger. Here too Δp_{V100} should be ≥ 0,5 · Δp_{VR}:

⇒ $\mathbf{\Delta p_{V100} \geq}$ ($\Delta p_{heat\ meter}$ + Δp_{pipes}) ≥ 14 kPa + 3 kPa ≥ **17 kPa**

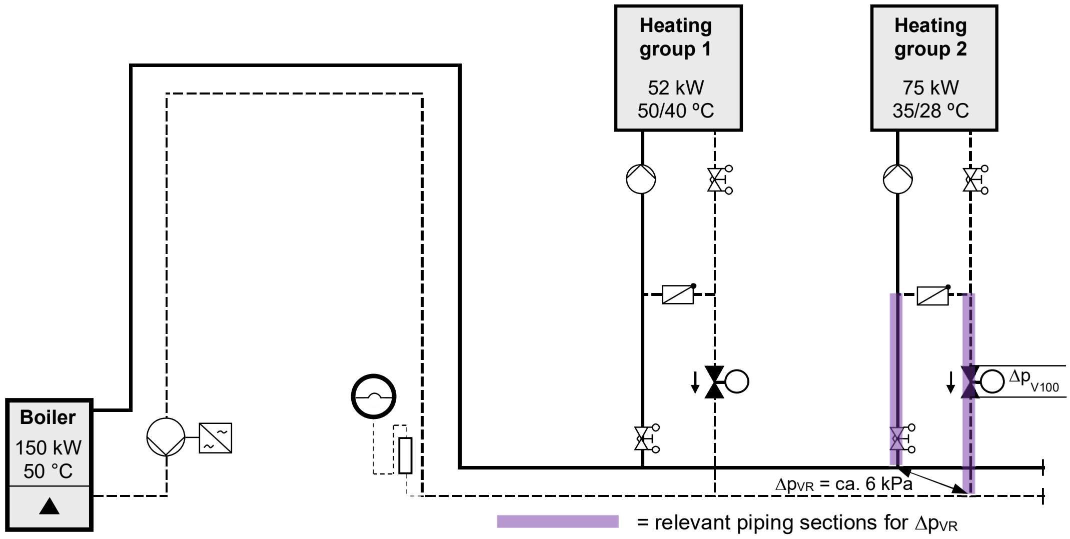


Heating group 1 with built in heat meter

This results in a smaller valve (e.g. VVG41.25-10 or VVG44.25-10) with a nominal size of DN 25, k_{VS} = 10 m^3/h and a higher $\Delta p_{V100eff}$ value of 20 kPa (→ P_{Veff} = 0.54).

Heating group 2 (new building with floor heating system)

An injection circuit with 2-port valve is also foreseen for the new building part.



Piping sections with variable water flow during operation for heating group 2

Heating group 2 is designed for a supply temperature of 35 °C. This is somewhat lower than the temperature of 50 °C supplied by the boiler. Cooled return water at 28 °C must therefore be added via the bypass of the injection circuit in order to achieve this lower temperature of 35 °C in the design state. The necessary mixing ratio is achieved by correctly adjusting the volume flows with the aid of the two balancing valves at the distributor outlet and across the consumer (→ "hydronic balancing").

Due to this fixed admixture setting, the volume flow rate that flows from the boiler ($\dot{V}_{boiler}$) is reduced and the valve can be dimensioned proportionally smaller than for heating group 1.

Determining the volumetric flow

Due to the fixed premixing the volumetric flow drawn from the boiler $\dot{V}_{Boiler}$ is reduced. Thus, a comparably smaller valve than in heating group 1 can be chosen here.

The volumetric flow that will be obtained from the producer side at design conditions can be determined by using the following mixing formula:

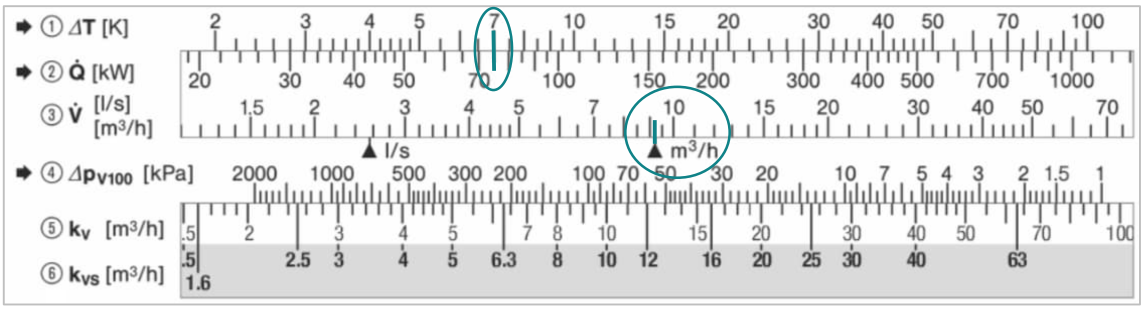
$$\dot{V}_{Boiler} = \dot{V}_{Heating\ group} \cdot \frac{\theta_{supply} - \theta_{return}}{\theta_{boiler\ supply} - \theta_{return}}$$

$\dot{V}_{Heating\ group}$ can be determined as in Heating group 1 using e.g. the Siemens valve slide rule.

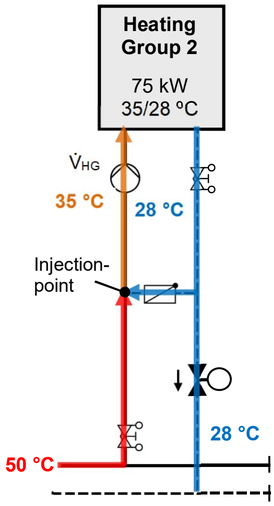
Slide line ② with the value of $\dot{Q}$ = 75 kW below the value of ΔT = 7 K (35 °C - 28 °C) on line ①

Now, on line ③, the volumetric flow $\dot{V}_{Heating\ group}$ can be read off:

$\dot{V}_{Heating\ group}$ = 9.2 m^3/h or 2.59 l/s



Determination of the volume flow circulating in heating group 2 with valve slide ruler (excerpt)



Heating group 2 with fixed admixture setting for cooled down return water at the injection point

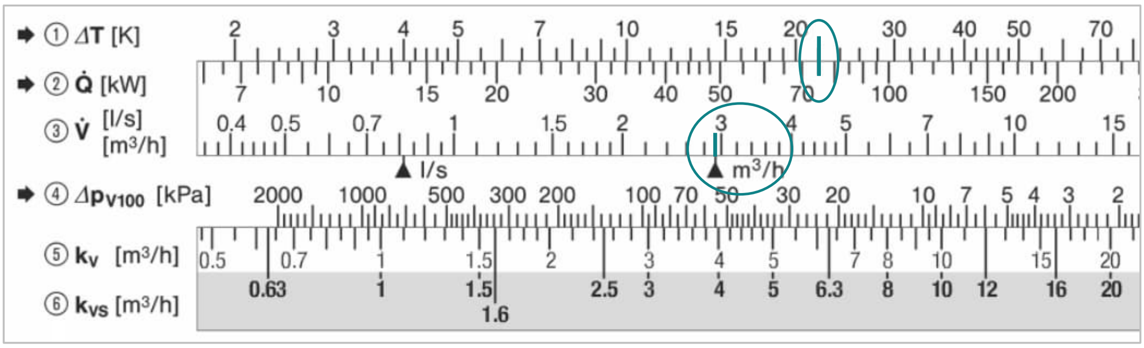
Determine the volumetric flow $\dot{V}_{boiler}$ that will be obtained from the boiler at design conditions using the calculation formula shown below:

$$\dot{V}_{Boiler} = \dot{V}_{Heating\ group} \cdot \frac{\theta_{supply} - \theta_{return}}{\theta_{boiler\ supply} - \theta_{return}} = 9.2\ m^3/h \cdot \frac{35\ °C - 28\ °C}{50\ °C - 28\ °C} = 2.93\ m^3/h$$

To determine $\dot{V}_{Boiler}$ in practice, it is more common to use the temperature difference ΔT that applies at the valve.

Determine $\dot{V}_{Boiler}$ in that way:

1. Slide line ② with the value of $\dot{Q}$ = 75 kW below the value of ΔT = 22 K (50 °C – 35 °C) in line ①
2. Now, you can read off the volumetric flow $\dot{V}$ on line ③. As calculated above, it is ≈ 2.93 m³/h as well.



Determination of the volumetric flow that is decisive for the controlling valve with the valve slide ruler (excerpt)

Decisive pressure drop in the piping section with variable flow

1. In the hydronic circuit, determine the piping sections with variable water flow in normal operation. In the injection circuit with 2-port valve, these are the lines from the distributor to the bypass (→ injection point) and back.
2. The planning engineer has foreseen a Δp_{VR} of 6 kPa for this. This is the planned total pressure drop from the distributor for these pipe sections (incl. control valve with Δp_{V100}).

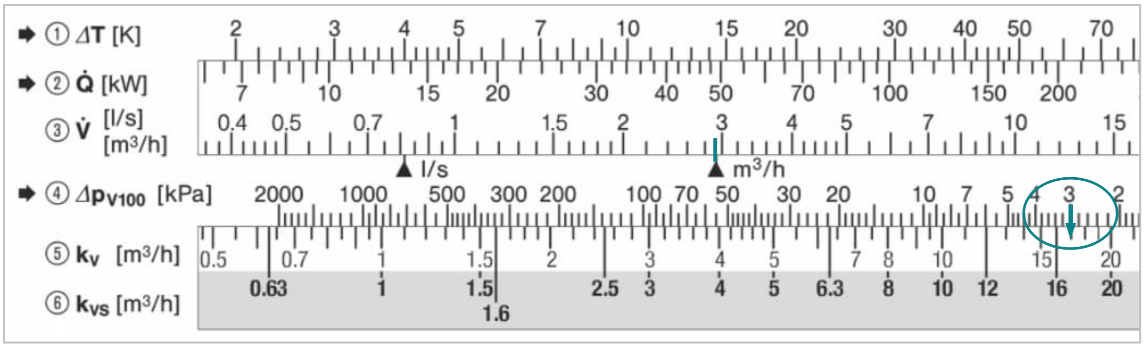
Note:

If the injection circuit is not installed directly on the distributor, but far away (e.g. for a heating coil on an air handling unit), then Δp_{VR} will be correspondingly larger (e.g. 20 kPa or more) due to the long pipes. Therefore, Δp_{VR} must always be considered for the valve selection according to the system situation.

Valve authority P_V

We also select a valve authority $P_V \geq 0.5$ (or $\Delta p_{V100} \geq 0.5 \cdot \Delta p_{VR}$).

This results in: $\Delta p_{V100} \geq 3$ kPa.

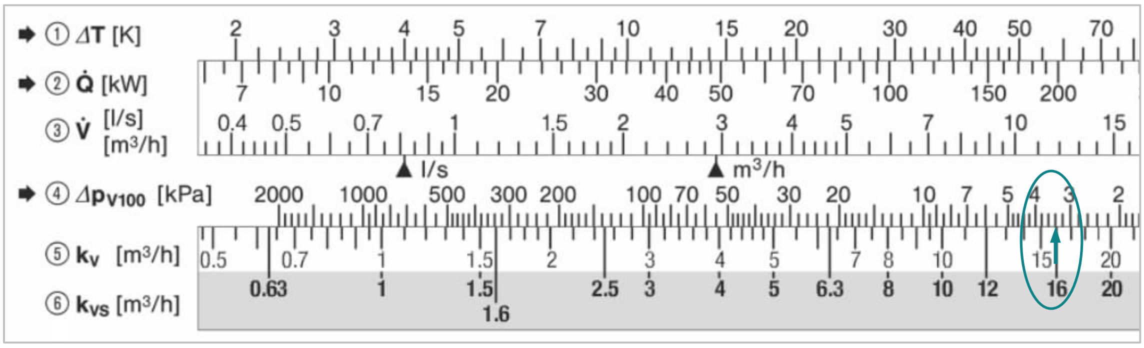


Determination of the k_V value based on ΔpV100 with valve slide ruler (excerpt of side with threaded valves)

Based on the information from the valve slide ruler, with a volume flow of 2.93 m^3/h (line ③) and Δp_{V100} of 3 kPa (line ④), this results in a k_V value of 17 m^3/h (line ⑤).

It makes sense to select the slightly smaller valve with a k_{VS} value of 16 m^3/h (line ⑥).

That leads to $\Delta p_{V100eff} \approx 3.4$ kPa (line ④).



Determination of $\Delta p_{V100eff}$ based on the k_{VS} value of 16 using the valve slide rule (excerpt)

Check briefly the resulting effective valve authority P_{Veff}:

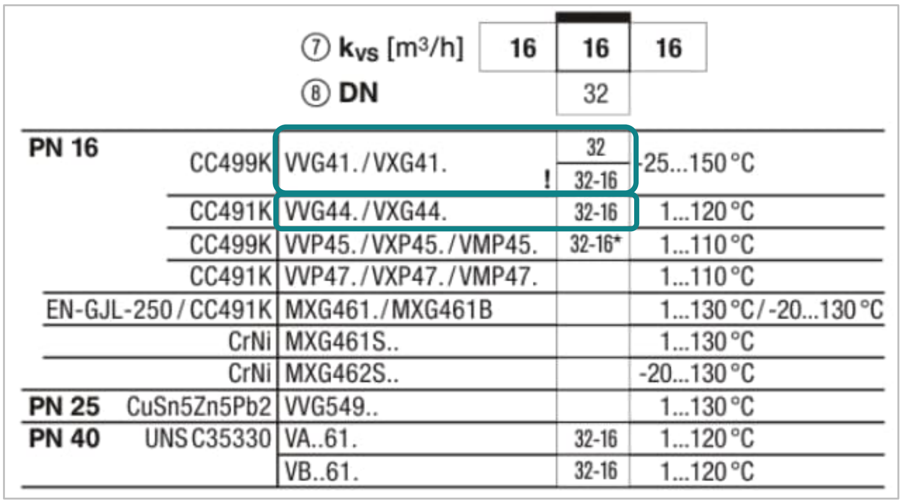
$$P_{Veff} = \frac{\Delta p_{V100eff}}{\Delta p_{total}} = \frac{\Delta p_{V100eff}}{\Delta p_{V100eff} + \Delta p_{MV}} \qquad \Rightarrow P_{Veff} = \frac{3.4 \text{ kPa}}{(3.4 + 3) \text{ kPa}} = 0.53$$

Resulting valve authority: $P_{Veff} = 0.53$ (and $\Delta p_{V100eff} = 3.4$ kPa), which is close to the specification.

Selecting the valve and the actuator

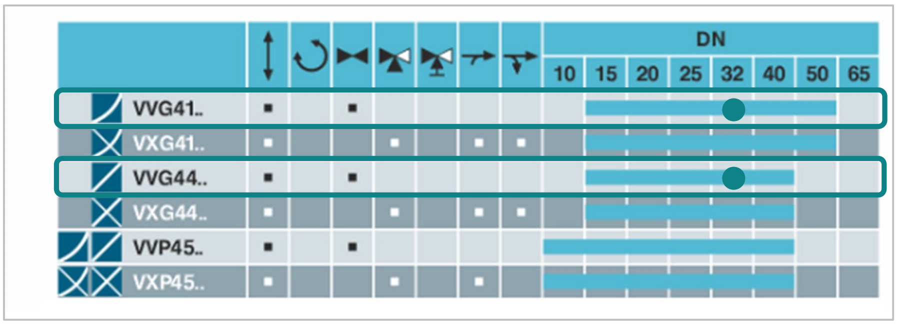
Select suitable valves with a k_{VS} value of 16.

For that purpose, slide line ⑦ (k_{VS} value) until the value of “16” appears in the outlined field. Now, a suitable valve can be selected. A range of suitable actuators can be found on the additional data sheet or in the technical documentation.

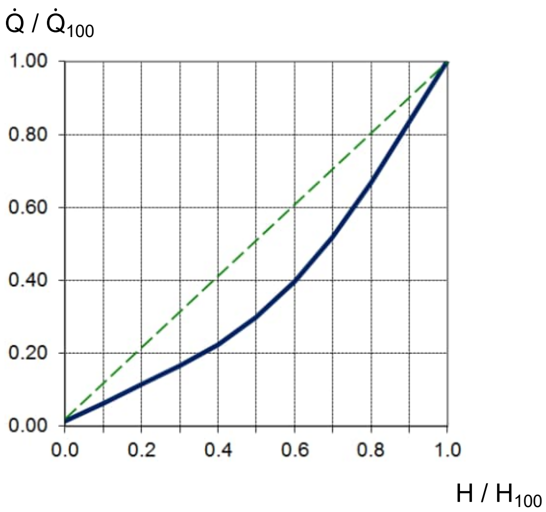


			⑦ k_{VS} [m³/h]	16	16	16
			⑧ DN		32	
PN 16	CC499K	VVG41./VXG41.			32 ! 32-16	-25...150 °C
	CC491K	VVG44./VXG44.			32-16	1...120 °C
	CC499K	VVP45./VXP45./VMP45.			32-16*	1...110 °C
	CC491K	VVP47./VXP47./VMP47.				1...110 °C
	EN-GJL-250 / CC491K	MXG461./MXG461B				1...130 °C / -20...130 °C
	CrNi	MXG461S..				1...130 °C
	CrNi	MXG462S..				-20...130 °C
PN 25	CuSn5Zn5Pb2	VVG549..				1...130 °C
PN 40	UNS C35330	VA..61.			32-16	1...120 °C
		VB..61.			32-16	1...120 °C

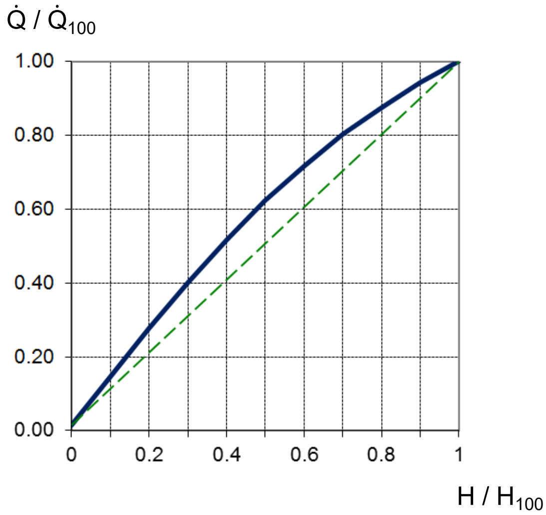
Choice of valves at a k_{VS} value of 16 m³/h (excerpt of valve slide rule)



In our example, either a 2-port valve VVG41.32-16 with equal-percentage characteristic (cf. ◪ left) or a 2-port valve VVG44.32-16 with linear characteristic (cf. ◪ left) can be selected as both result in a similarly well linearized characteristic in combination with a heat exchanger characteristic with an a-value of 1 (see 2.3 and Appendix with a-value calculation guidelines; applies to supply temperature control with injection circuit with 2-port valve or with mixing circuit).



Characteristic of the controlled system
with equal-percentage valve (P_V = 0.5; a = 1)



Characteristic of the controlled system
with linear valve (P_V = 0.5; a = 1)

For the valve selection it should also be considered that these valve types have different stroke values (VVG41… 20 mm, VVG44… 5.5 mm), i.e. the VVG41… products provide a much higher mechanical resolution than the VVG44… products.

The actuator can be a three-position actuator (e.g. SAX31 or SQS35), since there are no special requirements, and these types of actuators offer a good price / performance ratio.

3.2.2. Impact of valve authority P_V on total volumetric flow with three-port valves

Combination of characteristic for three-port valves

The total volumetric flow (AB) shown in the graphic below is made up of the volumetric flow through the controlled port (characteristic A) and that through the bypass port (characteristic B).

In practice, two combinations of characteristics are used (controlled port / bypass port):

- equal-percentage / linear
- linear / linear

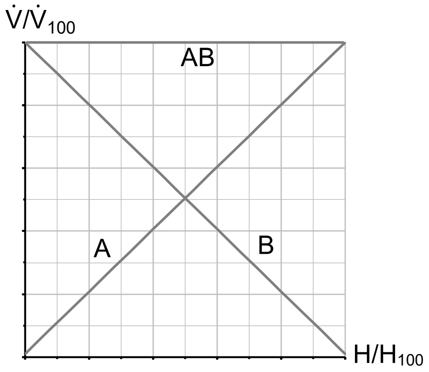
Objective of valve sizing

The objective of sizing a valve is to obtain a control characteristic that is as linear as possible. This necessitates a total volumetric flow AB across the entire stroke as constant as possible.

The total volumetric flow can change considerably, depending on the combination of characteristics and valve authorities P_V. For this reason, when sizing a valve, the total volumetric flow and the valve authority P_V (see section 2.3.1) are of utmost importance.

Linear/linear combination

The valve authority to be strived for here should be reasonably high ($P_V \geq 0.5$). As a result, the total volumetric flow across the entire stroke range is nearly constant. However, a too high valve authority means also a large Δp_{V100} and therefore increased resistance to be overcome by the pump.



Linear / linear characteristics

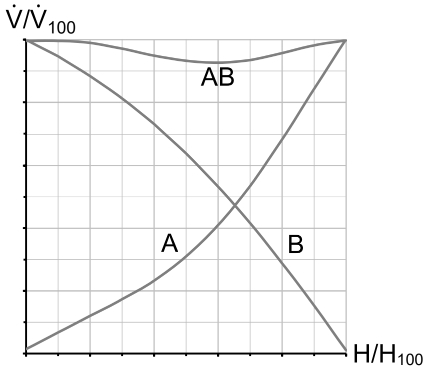
Total volumetric flow (AB) with three-port valves with controlled port (A) and bypass port (B)

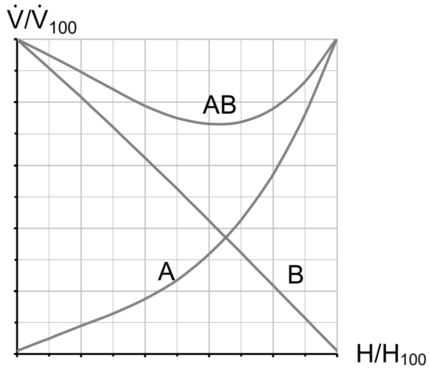
Equal-percentage/linear combination

The valve authority selected on the graph at bottom left is about P_V = 0.5. As a result, the total volumetric flow across the entire stroke range is nearly constant, thus giving rise to a relatively linear characteristic of the controlled system at medium a-values of 0.4 ... 0.5.

The graph at bottom right shows an example with a high valve authority P_V = 0.9. In that case, the total volumetric flow in the medium stroke range drops sharply.

At P_V < 0.4, the total volumetric flow increases sharply.



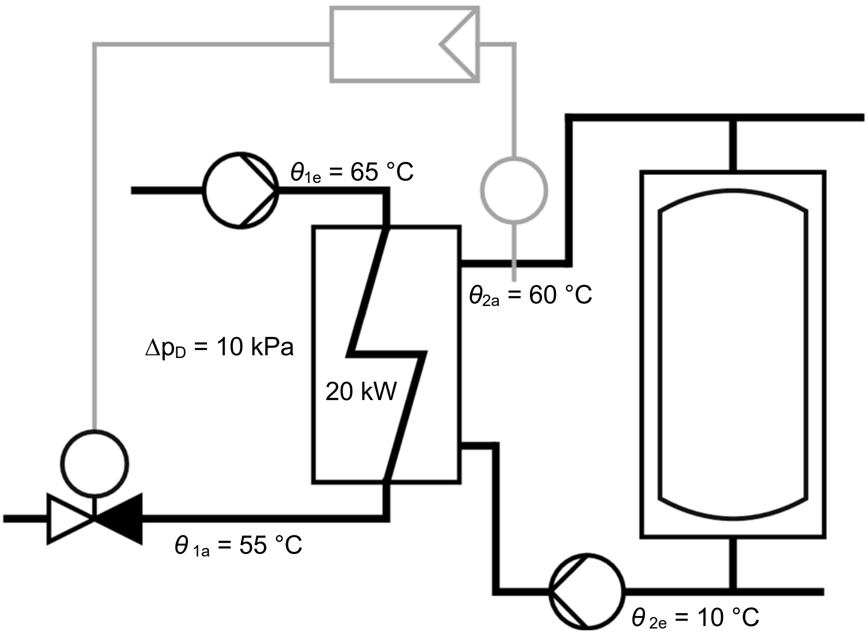


Dependency of the total volumetric flow on the valve authority with equal-percentage / linear characteristics.

3.3. Example of hot water charging control

The control valve used for this hot water charging control system shall be selected in such a way that the resulting control characteristic becomes as linear as possible.

The required data such as output power, the temperature differentials on the primary and secondary side, and the decisive pressure drop are given in the plant diagram below.



Basic plant diagram of hot water charging control

To be able to select a basic valve characteristic and to determine the required valve authority P_V, the a-value of the heat exchanger must first be determined.

Calculating the a-value

The a-value is dependent on the temperatures at both sides of the heat exchanger and its design and operating mode which is considered by the factor "f" (also refer to “Calculating the a-value” in the Appendix).

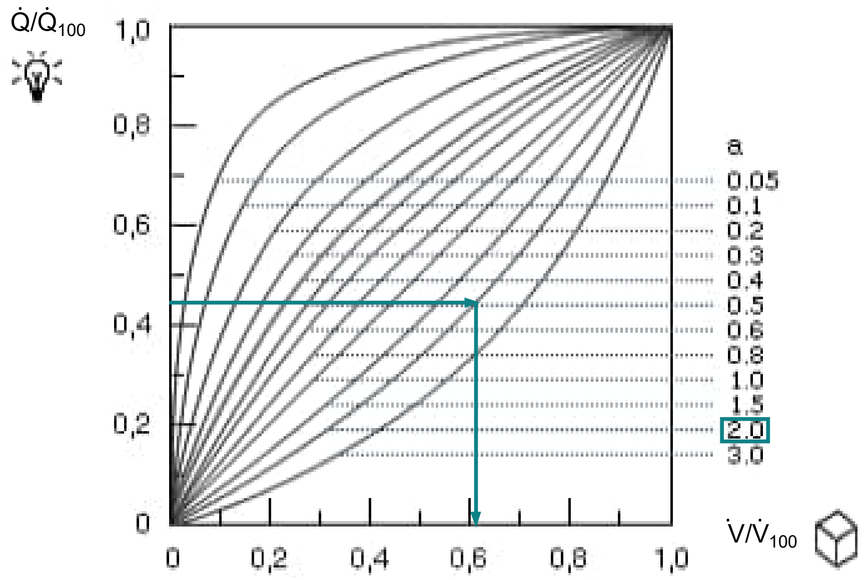
Calculation of the a-value:

$$a = f \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2a}}$$

The heat exchanger used in the above example operates in counter flow mode, f = 1.

$$\Rightarrow \quad a = 1 \cdot \frac{(65 - 55)\ K}{(65 - 60)\ K} = 2$$

The calculated a-value of 2 is now used to graphically determine the basic valve characteristic and the required valve authority with the help of graphs. First, on the graph with the heat exchanger characteristics (for different a-values), the corresponding values for $\dot{Q} / \dot{Q}_{100}$ and $\dot{V} / \dot{V}_{100}$ will be determined.



Graph with heat exchanger characteristics (for the different a-values)

For example, at an output ratio $\dot{Q}/\dot{Q}_{100} = 0.45$ and an a-value of 2 a volumetric flow ratio $\dot{V}/\dot{V}_{100} = 0.62$ results.

Valve with linear characteristic

To offset the heat exchanger characteristic and to obtain a control characteristic as linear as possible, a valve with a linear basic characteristic is selected.

Required valve authority P_V

Next the required valve authority P_V, that best offsets the a-value, must be determined. In order to read it off, you need the chart with the operating characteristics of the valves and use the value $\dot{V}/\dot{V}_{100} = 0.62$ that was previously ascertained to determine the point of intersection with the stroke ratio $H/H_{100} = 0.45$. This represents the required valve authority P_V to achieve a linear control characteristic of the heat exchanger / controlling element combination.

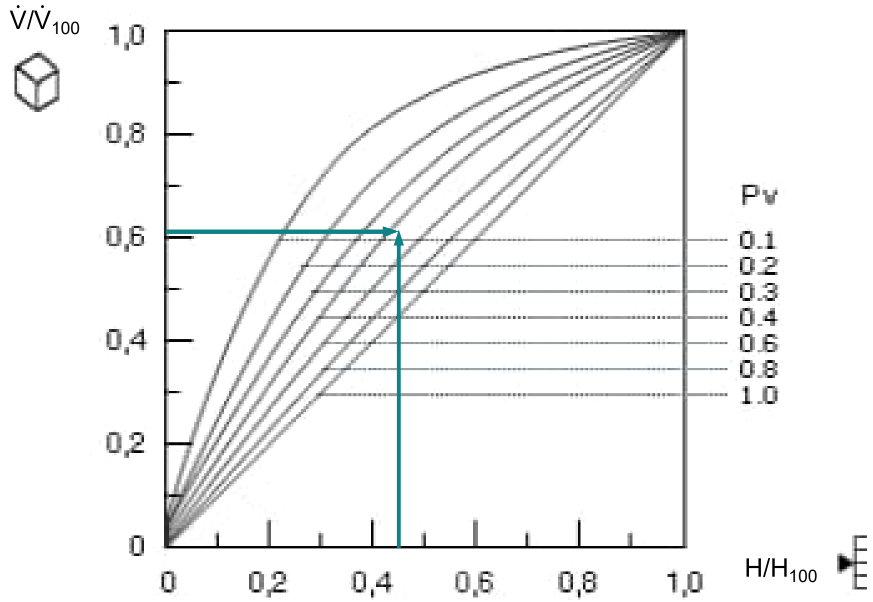


Chart with valve authorities P_V (linear basic characteristic of valve)

For this hot water control system, the desired valve authority P_V is ≈ 0.45.

Calculating of the k_V value and finding the suitable k_{VS} value

This means that all basic data is now available to calculate the key characteristics Δp_{V100}, $\dot{V}_{100}$ and the k_V value that are required for sizing the valve (k_{VS} value):

Definition of the k_{VS} value according to VDI 2173 is:

k_{VS} value = nominal flow in m^3/h across fully opened valve (nominal stroke H_{100}) and Δp_0 = 1 bar (respectively 100 kPa) across the valve

The k_V value shows the desired k_{VS} value for the valve to be selected.

The determination of the k_V value is based on the 2nd proportional law:
(see chapter: 2.4.1, Plant characteristic (piping network characteristic))

$$\frac{\Delta p_1}{\Delta p_2} = \left(\frac{\dot{V}_1}{\dot{V}_2}\right)^2$$

In this context:

$$\frac{\Delta p_{V100}}{\Delta p_0} = \left(\frac{\dot{V}_{100}}{k_V}\right)^2$$

Solve the equation for k_V:

$$k_V = \dot{V}_{100} \cdot \sqrt{\frac{\Delta p_0}{\Delta p_{V100}}} \quad \text{or} \quad \dot{V}_{100} \cdot \sqrt{\frac{100\ \text{kPa}}{\Delta p_{V100}}}$$

Determination of the other terms:

$$P_V = \frac{\Delta p_{V100}}{\Delta p_{V100} + \Delta p_D}$$

Solve the equation for Δp_{V100}:

$$\Delta p_{V100} = \frac{P_V \cdot \Delta p_D}{1 - P_V} \quad \Rightarrow \Delta p_{V100} = \frac{0.45 \cdot 10\ \text{kPa}}{1 - 0.45} = 8.2\ \text{kPa}$$

$$\dot{V}_{100} = \frac{\dot{Q}_{100}}{1.163 \cdot (\theta_{1e} - \theta_{1a})} \quad \Rightarrow \dot{V}_{100} = \frac{20\text{kW}}{1.163 \cdot (60 - 40)} = 0.86\ \text{m}^3/\text{h}$$

$$k_V \text{ value } (k_{VS\ desired}) = 0.86\ \text{m}^3/\text{h} \cdot \sqrt{\frac{100\ \text{kPa}}{8.2\ \text{kPa}}} = 3.0\ \text{m}^3/\text{h}$$

Note:

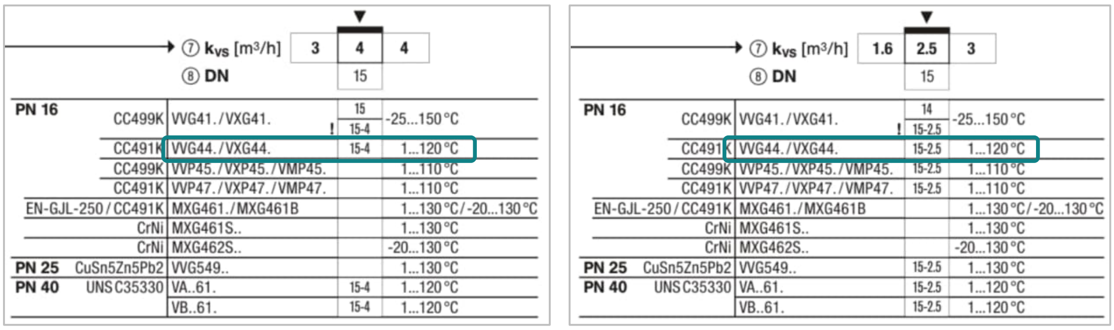
The value of 1.163 in this calculation is the specific heat capacity of water in kWh/(m^3·K) and also includes the density ρ = 1000 kg/m^3 and the conversion from s to h.

Available valves

According to the valve slide ruler there is no threaded valve in this range with the calculated k_{VS} value.

The types of available valves (with a linear characteristic) have a k_{VS} value of 2.5 or 4:

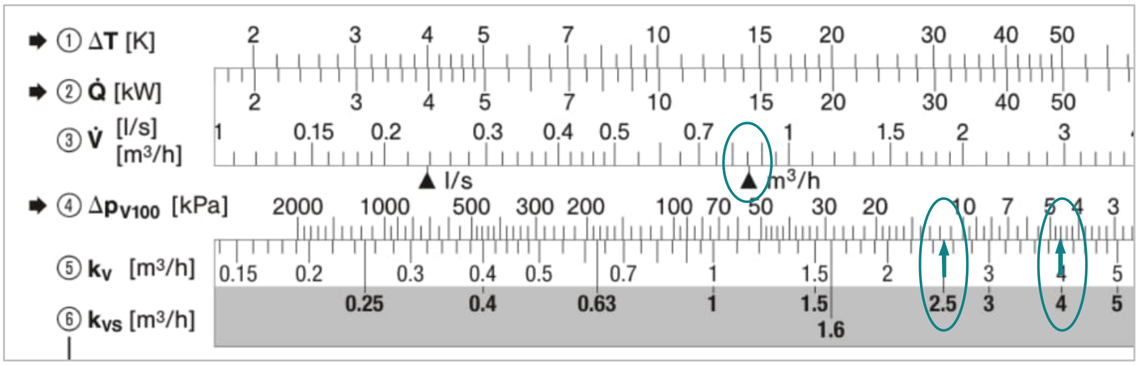
- Variant 1: example: valve VVG44.15-4 with a k_{VS} value = 4
- Variant 2: example: valve VVG44.15-2.5 with a k_{VS} value = 2.5



Available valves with a k_{VS} value = 2.5 or k_{VS} value = 4 (excerpt of a valve slide rule)

Check the effective valve authority

When the valve slide rule is set to the nominal volumetric flow $\dot{V}_{100}$ = 0.86 m³/h the resulting pressure drop Δp_{V100} can be read off for both variants. Thus, the effective valve authority P_{Veff} can be calculated.



Determine the pressure drop Δp_{V100} at k_{VS} = 2.5 or k_{VS} = 4 with the help of the valve slide rule (excerpt)

Variant 1: k_{VS} value = 4

$\Rightarrow \Delta p_{V100}$ = 4.6 kPa

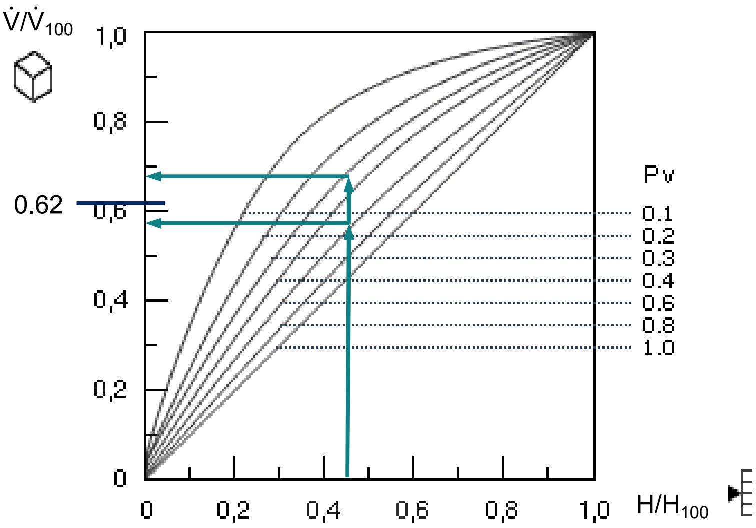
$$P_{Veff} = \frac{\Delta p_{V100eff}}{\Delta p_{V100eff} + \Delta p_D} \qquad \Rightarrow P_{Veff} = \frac{4.6 \text{ kPa}}{(4.6 + 10) \text{ kPa}} = 0.32$$

Variant 2: k_{VS} value = 2.5

$\Rightarrow \Delta p_{V100}$ = 11.8 kPa

$$P_{Veff} = \frac{\Delta p_{V100eff}}{\Delta p_{V100eff} + \Delta p_D} \qquad \Rightarrow P_{Veff} = \frac{11.8 \text{ kPa}}{(11.8 + 10) \text{ kPa}} = 0.54$$

Using these valve authorities P_{Veff}, the resulting volumetric flow ratios $\dot{V}/\dot{V}_{100}$ can be ascertained from the graph below and compared with the requirements.



Graph with valve operating characteristics and the resulting valve authorities P_V for k_{VS} = 2.5 and 4

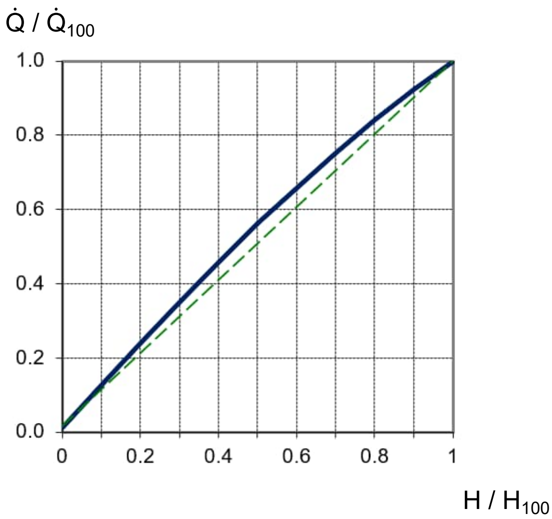
The deviation from the previously ascertained ratio of $\dot{V}/\dot{V}_{100}$ = 0.62 is approximately 5 % with both variants.

Final selection of valve

Select Variant 1. It provides

- a smaller pressure drop
- a nearly linear characteristic

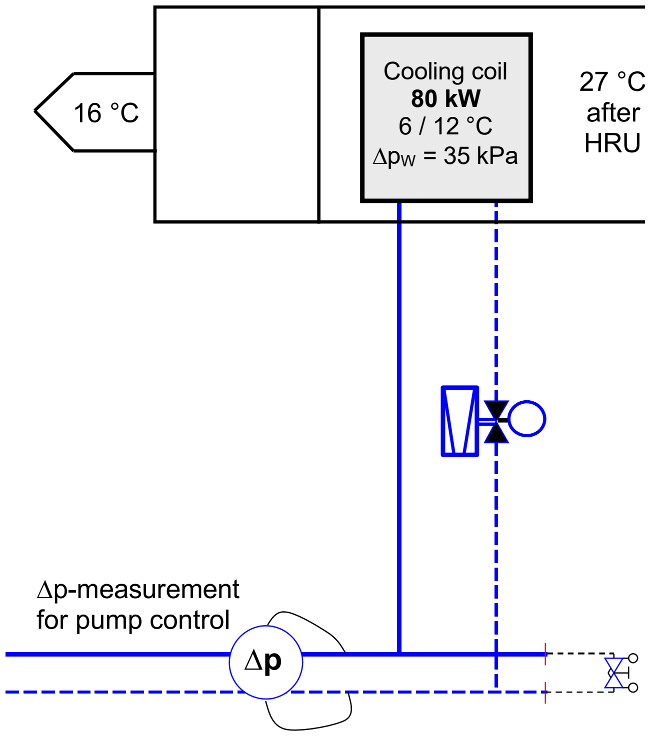
⇒ use VVG44.15-4 with a k_{VS} value of 4



Characteristic of the controlled system
with linear valve with k_{VS} value of 4

3.4. Example of air-cooling coil with PICV valve

With an optimally selected valve for an air-side controlled air-cooling coil, the resulting control characteristic should become as linear as possible.



Schematic diagram of air-cooling coil

Determining the volumetric flow

From power formula, the volumetric flow is calculated:

$$\dot{V}_{100} = \frac{\dot{Q}_{100}}{c_w \cdot \rho \cdot (\theta_{supply} - \theta_{return})} \quad \Rightarrow \quad \dot{V}_{100} = \frac{80\ \text{kW} \cdot 3600\ \text{s/h}}{4.190\ \text{kJ/(kg·K)} \cdot 1000\ \text{kg/m}^3 \cdot (12 - 6)\ \text{K}} = 11.46\ \text{m}^3\text{/h}$$

Simplified formula:

$$\Rightarrow \dot{V}_{100} = \frac{80\ \text{kW}}{1.163 \cdot (12 - 6)\ \text{K}} = 11.46\ \text{m}^3\text{/h}$$

Note:

The value of 1.163 in this calculation is the specific heat capacity of water in kWh/(m^3·K) and also includes the density ρ = 1000 kg/m^3 and the conversion from s to h.

Determining valve size

From the volume flow of 11.46 m^3/h and with the data sheet for valves (see table below) a maximum volumetric flow of “15 m^3/h” (14.3 m^3/h) is determined (Rule of thumb: Volumetric flow < 80 % max. volumetric flow). Note that this is a valve with a linear characteristic.

From the standard flow rate table of the valve VPF44.50F15, it can be read out that a pressure difference Δp_{min} of about 21 kPa is needed for the determined volumetric flow and to guarantee optimal operation. This pressure difference is relevant for the subsequent dimensioning of the pump.

The presetting (Dial) for this valve is about 2.7 (→ “hydronic balancing” is done).

PN 16 Data sheet	1...120 °C A6V11466366	DN	$\dot{V}_{min}$ [m³/h]	$\dot{V}_{100}$ [m³/h]	Δp_{min} [kPa]
	VPF44.50F15 [3)]	50	3.7	14.3	25
	VPF44.50F25 [3)]	50	5.7	24.6	55
	VPF44.65F25 [3)]	65	4.5	24.4	32
	VPF44.65F35 [3)]	65	6.4	37.7	50
	VPF44.80F35 [3)]	80	6.8	35.7	22
	VPF44.80F45 [3)]	80	8.5	49	40
	VPF44.100F70	100	12.2	69.6	33
	VPF44.100F90	100	14.8	90.9	75

Low flow rate

VPF44.50F15; VPF54.50F15																					15 m³/h nominal
$\dot{V}$ [m³/h]				3.7	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	11.9	12.6	13.2	13.5	13.8	14.1	14.3
Dial	Min.	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	Max.
Δp_{min} [kPa]				13	14	15	16	16	17	18	18	19	20	21	21	22	23	23	24	25	25

Choosing the right valve size according to the standard flow rate (Rule: Volumetric flow < 80 % max. volumetric flow)

Calculating the a-value

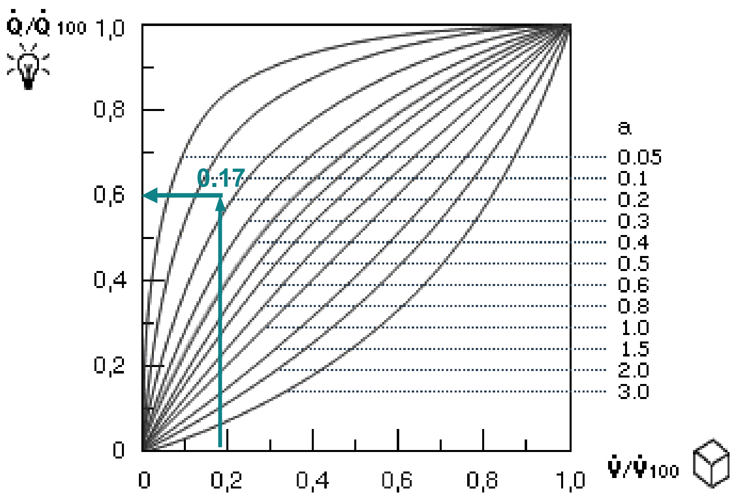
To be able to calculate the a-value, the hydronic circuit used by the air-cooling coil must be known, because the f-factor depends on the type of hydronic circuit.

In our example, the hydronic circuit is a throttling circuit which enables the air-cooling coil to operate always on the same low cooling water supply temperature.

When calculating the a-value for an air-cooling coil connected to a throttling circuit (volumetric flow control), factor f = 0.6 has to be used (refer to Appendix “Calculating the a-value”).

Calculation of the a-value:

$$a = f \cdot \frac{\theta_{\text{return flow}} - \theta_{\text{supply flow}}}{\theta_{\text{return flow}} - \theta_{\text{air prior to HRU}}} \qquad \Rightarrow a = 0.6 \cdot \frac{(6 - 12)\ K}{(6 - 27)\ K} = 0.17$$



Graph with heat exchanger characteristics (for different a-values)

Actuator with equal-percentage characteristic

To offset this extremely nonlinear cooling coil characteristic (a = 0.17) and to obtain a control characteristic as linear as possible, a valve with an equal-percentage basic characteristic should be selected (see Chapter 2). But PICVs have a linear characteristic (see above). That makes either an equal-percentage actuator necessary, or the linearization needs to be carried out with a special software component in the building automation system.

From the actuator data sheet, the characteristics can be read out. For the SAX61P03 actuator, the characteristic can be switched with an internal switch between linear and equal-percentage. The equal-percentage characteristic is chosen.

Flanged PICVs

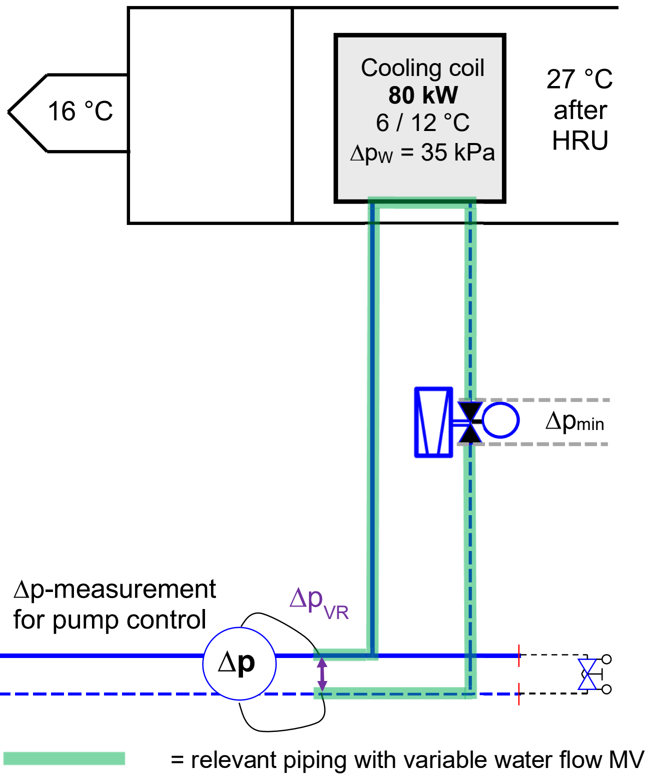
Typical applications	Actuators	Data sheet					20 mm 500 N
– District heating – Heating groups – Air handling units	SAX..P.. SQV91P.. SAV..P..	N4509 N4833 N4510					
	Operating voltage	Positioning signal	Positioning time [s] SAX	SQV	SAV	Spring return function [s]	
	AC 230 V	3-position	30	–	120	–	SAX31P03
		3-position	–	40/80	–	30	–
		3-position	–	40/80	–	30	–
	AC/DC 24 V	3-position	30	–	120	–	SAX81P03
		3-position	–	40/80	–	30	–
		3-position	–	40/80	–	30	–
Switchable actuator characteristic (DIL); set here to equal-percentage		0...10 V, 4...20 mA	30	–	120	–	SAX61P03
		0...10 V, 4...20 mA	–	40/80	–	30	–
		0...10 V, 4...20 mA	–	40/80	–	30	–
		Modbus	30	–	120	–	SAX61P03/MO

Actuator for PICVs overview table

Determining the pump output

The required pump pressure (pump head) is determined from the given pressure difference between supply and return flow (Δp_{VR}).

Δp_{VR} is composed of the pressure drop across the relevant piping with variable water flow Δp_{MV} ($\Delta p_{pipes} + \Delta p_{heating\ coil}$) and the minimal required pressure difference across the PICV Δp_{min} and results in: $\Delta p_{VR} = \Delta p_{MV} + \Delta p_{min}$ = 37 kPa + 21 kPa = **58 kPa** resp. 5.8 mWC (meter Water Column).



= relevant piping with variable water flow MV

Appendix: Calculating the a-value

Definition of the a-value:

In general:

$$a = f \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{1a0}}$$

For practical applications under near zero load conditions: $(\dot{V}_0 = \dot{V}_{min} > 0)$

$$a = f \cdot \frac{\Delta T_{\text{primary design load}}}{\Delta T_{\text{primary zero load}}}$$

Formulas used for calculating the a-value:

Radiators

Range approx. 0.5 … 0.65 (supplier's specification, room control affecting mixture)

Floor heating systems

Range approx. ca. 0.8 … 0.9 (supplier's specification, room control affecting mixture)

Supply temperature control

For example, mixing circuit (or injection circuit with 2-port valve): a = 1

Mixing circuits, water → water, f = 1

θ_{2a} controlled:

$$a = \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2a}}$$

θ_{2e} constant, θ_{2a} not controlled:

$$a = \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2e}}$$

Mixing circuits, water → air, f = 1

Preheating coil θ_{2a} controlled:

$$a = \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2a}}$$

Reheating coil θ_{2a} or room temperature controlled:

$$a = \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2e}}$$

For flow control, water → water, $f_{\text{parallel flow}} = 2$; $f_{\text{counter flow}} = 1$

θ_{2a} controlled:

$$a = f \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2a}}$$

θ_{2e} constant, θ_{2a} not controlled:

$$a = f \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2e}}$$

For flow control, water → air, f = 0.6

Preheating coil θ_{2a} controlled:

$$a = 0.6 \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2a}}$$

Air heating / cooling coil, θ_{2a} or room temperature controlled:

$$a = 0.6 \cdot \frac{\theta_{1e} - \theta_{1a100}}{\theta_{1e} - \theta_{2e}}$$

Legend of formula symbols used:

$\dot{V}_0$	Minimum volumetric flow that can be adjusted on the primary side $\dot{V}_{min} > 0$
θ_{1e}	Primary inlet temperature upstream of the controlling element
θ_{1a100}	Primary outlet temperature at $\dot{V}_{100}$
θ_{1a0}	Primary outlet temperature at $\dot{V}_0$
θ_{2e}	Secondary inlet temperature
θ_{2a}	Secondary outlet temperature
f	Design-dependent correction factor of the heat exchanger

Smart Infrastructure intelligently connects energy systems, buildings and industries, enhancing the way we live and work to significantly improve efficiency and sustainability.

We work together with customers and partners to create an ecosystem that both intuitively responds to the needs of people and helps customers achieve their business goals.

It helps our customers to thrive, communities to progress and supports sustainable development to protect our planet for the next generation.

Creating environments that care.
siemens.com/smart-infrastructure

Published by
Siemens Switzerland Ltd

Smart Infrastructure
Global Headquarters
Theilerstrasse 1a
6300 Zug
Switzerland
Tel +41 58 724 24 24

For the U.S. published by
Siemens Industry Inc.

800 North Point Parkway
Suite 450
Alpharetta, GA 30005
United States

Nominal € 50