Danfoss

Balancing of differential pressure in heating systems

We believe in balanced solutions

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Preface

When a media, in this case water, flows through a pipe system, a resistance arises. If the flow is to continue, a pressure increase has to be created. This is accomplished in a radiator system by using a circulation pump. The increase in pressure across the pump, Δp_{pump}, should be equal to the resistance in the pipe system at the flow in question.

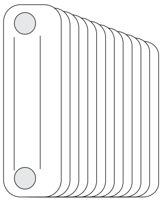
If we look at the system as a whole, we notice that the available pressure decreases the further from the pump we get. The available pressure Δp_{avail}, is measured as the difference between dynamic pressure in the flow- and return pipe respectively. The dynamic pressure arises because of the resistance in the pipe system when the water flows through the pipes.

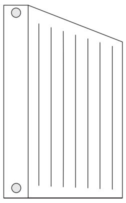
Consequently, the Δp_{avail} is highest closest to the pump and then decreases. There are several methods used in order to equal out these differences, this inbalance, of which pre-adjustment is the oldest. This method implies that a resistance is provided, at the branches carrying a too high available pressure, equal to the unnecessary pressure.

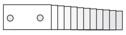
A more modern, automatic, solution is the pressure controller. It does the same thing, i.e removes the unnecessary pressure, but it does it by keeping the differential pressure over the riser in question constant. The benefit of using this method is that it also is able to manage a varying flow, which a fixed pre-adjustment can not.

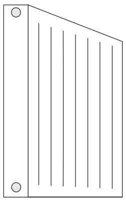
By controlling the pressure increase across the circulation pump, a reduction of the differences in available differential pressure is also possible. However, pressure controllers are necessary in order to reach a satisfactory result at varying flow.

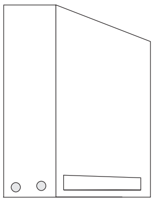
The size of the flow is determined by the heat emission from the radiator and of how great the temperature drop, Δt, becomes over it. These functions are controlled by the size of the radiator and by the flow temperature going to the radiator. The thermostatic valve utilizes the incidental heat gains from other heat sources than the radiator. This reduces the heat supply/flow to the radiator correspondingly. These variations in flow affect the resistance in the pipe system and consequently the Δp_{avail}.


Radiator made up of sections.


Panel radiator.


Convector.


Convection radiator.


Fan coil unit.

For the sake of simplicity, only radiators are mentioned in the text, but the described conditions and measures taken also apply to convection radiators, convectors and fan coil units which are used for heating or cooling systems.

Flow in radiator systems

Heat requirements

Several factors affect the flow in a radiator system. The starting point is the calculated heat requirement. Required flow is obtained by dividing the heat requirement by the temperature drop (and a conversion factor 1,16). The temperature drop, Δt, has an immediate influence on the size of the flow. If the Δt is halved, the flow has to be increased to be double if the same amount of heat is to be delivered. It is important to keep the ideas of flow, the amount of water circulating through the system and delivered amount of heat, apart. A waterflow through a radiator emits no heat unless the return temperature is lower than the flow temperature. Temperature drop multiplied by flow gives the delivered heat amount.

Unfortunately, it is common that the calculated heat amount is considerably greater than the actual heat amount and this causes some problems because even the flow and the temperature drop gets wrong i.e differs from the calculated values.

$$Q = \frac{P}{\Delta t \times 1{,}16};$$

$$Q_{20} = \frac{2000}{20 \times 1{,}16}; Q_{20} = 86 \text{ lit/h};$$

$$Q_{10} = \frac{2000}{10 \times 1{,}16}; Q_{10} = 172 \text{ lit/h};$$

Fig. Ap. 1:1

The flow, Q, is calculated by dividing the heat requirement by the temperature drop and a conversion factor.

Heat emission from radiators

The heat transmission from the radiators to the room is determined by the difference in temperature between the surface of the radiator (the mean temperature) and the room air. The greater difference in temperature the greater heat emission.

Flow temperature = 70 °C. Δt=25 °C. Room temperature=20 °C.

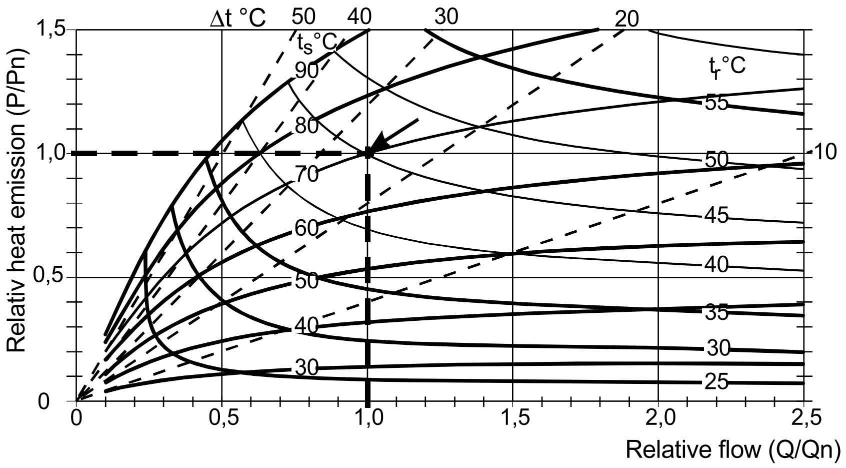


Fig. Ap. 1:2

The chart shows the relative heat emission and the flow for one radiator at varying flow temperatures. The radiators are selected according to the flow temperature of 70 °C and the return temperature 45 °C at flow 1,0. All points along the horizontal line 1,0 gives the same heat amount.

Flow temperature

The radiators are selected with the theoretical heat requirement as starting point and are therefore too large. A required heat emission can be obtained at a lower flow temperature than the calculated one. The flow temperature determines, for a certain radiator, how high the flow should be in order to supply the desired amount of heat. A high flow temperature gives a low flow and a large temperature drop. A low flow temperature, on the other hand, gives a high flow and a small temperature drop.

It is difficult to define ”correct” flow temperature. It could be the theoretical but that results in a large temperature drop and a low flow. It could also be the flow temperature that provides the theoretical temperature drop. Or the one providing the theoretical flow. All are correct in their own way.

Authorities or heating plants could for instance issue regulations or recommendations stating a highest permitted temperature. Demands on a highest return temperature at maximum load is generally the case.

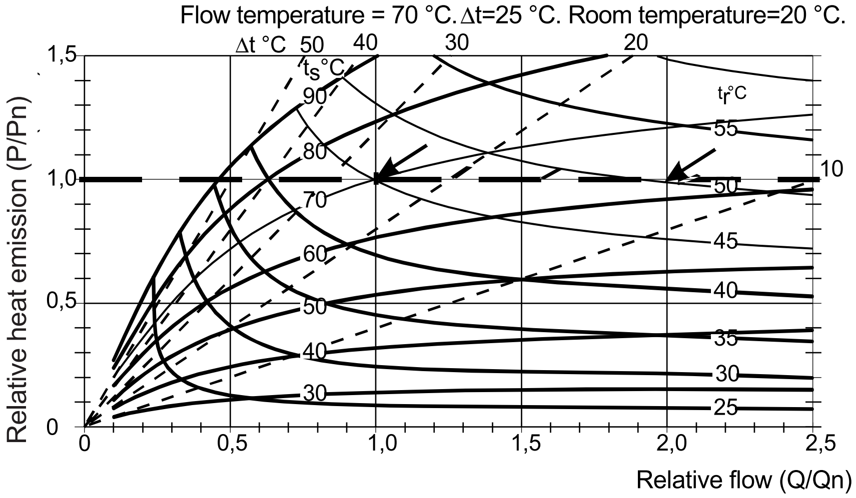


Fig. Ap. 1:3

All points along the line 1,0 gives the same heat amount. If the flow temperature is reduced from 70 to approx. 63 °C, the flow has to be increased by the double. The temperature drop becomes 12,5 °C and the return temperature approx. 50 instead of 45 °C. Consequently, a lower flow temperature gives a higher return temperature.

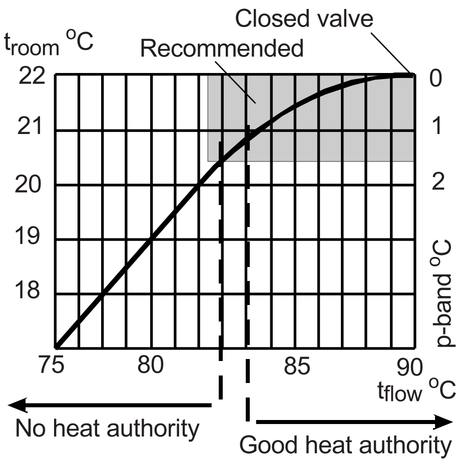


Fig. Ap.1:4

Good heat authority gives small p-band and better use of external heat sources.

The p-band is the temperature increase by the sensor, requred to move the thermostatic valve from open to closed position.

Heat authority

Heat authority is a concept which is relevant when it comes to radiators with thermostatic valves. The heat authority shows the relationship between available and required heat amount and it should be more than 1,0.

Ha = Heat authority

$$Ha = \frac{\text{Available heat}}{\text{Required heat}} \geq 1$$

If a thermostatic valve should be able to control the temperature in a room, it has to have access to at least the amount of heat required to keep the room temperature set on the thermostat, preferably a bit more.

A too low flow temperature, heat authority less than 1,0, results in that the room temperature becomes lower than the temperature set on the thermostat. The thermostatic valve senses the lower temperature and opens up for a higher flow. At best, it manages to keep the lower room temperature, but it has changed the flow throughout the system. Maybe it takes flow from another radiator and influences the differential pressure.

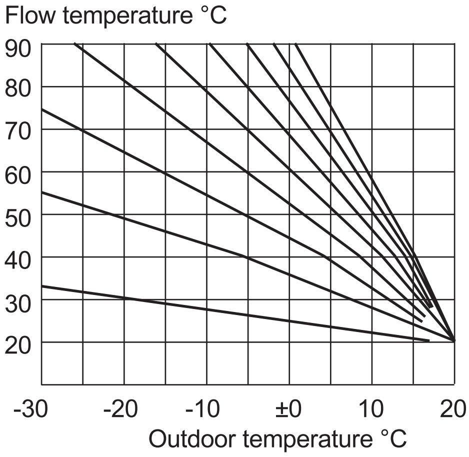


Fig. Ap.1:5

Setting of the flow temperature with a weather compensator is made by choosing the curve that gives desired flow temperature at sizing outdoor temperature. It is possible to parallelly shift the curve up- or downwards.

Controlling the flow temperature

An adjustment of the flow temperature according to the outdoor temperature, so called weather compensation, is generally used today. Theoretically, no more heat than necessary should be emitted. The flow should be held constant and only the flow temperature varies. In reality, this is not the case. The room temperature in an appartment building is not influenced by a short term drop of the outdoor temperature by a few degrees. The flow temperature, on the other hand, does. It consistently follows the outdoor temperature. The building keeps to a mean temperature during one or several days. If the radiators are equipped with thermostatic valves, they adjust the heat supply from the radiators according to the requirement in the rooms. In that way, unnecessary over temperatures are avoided and heat consumption is reduced. Considering one-pipe systems, it is important that the coil is properly insulated. If not, it will emit a lot of heat even when the thermostat has closed the flow through the radiator.

Controlling the room temperature

Weather compensation can not keep track of the heat supplied to the separate rooms from other heat sources than the radiator. The better insulated the buildings are, the greater influence these secondary heat sources have.

They are equally great in a bad as well as in a well insulated house. Other heat sources like solar irradiation, free heat from electrical equipment etc. will raise the room temperature if radiators are not equipped with thermostatic radiator valves. The constant room temperature will be achieved by reducing the flow through radiators.

If the radiator is not equipped with a thermostatic valve, the room temperature will increase.

Most weather compensators pay no attention to the increased air change in the building arising due to increased wind forces. In these situations, it takes a higher flow temperature in order to keep the room temperature. The building's ability to accumulate heat is of slight or no significance. In these situations, it is about cold outdoor air entering through the walls and it has to be heated up to room temperature quickly. An increased flow temperature and thermostatic valves supplying heat where it is needed is a good solution.

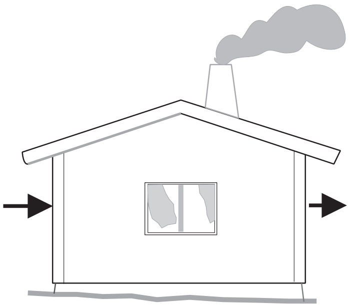


Fig. Ap. 1:6

The wind has a great influence on the air change in buildings. It takes an increase in flow temperature if the room temperature is to be maintained.

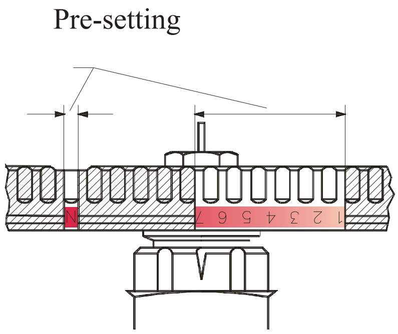


Fig. Ap. 1:7

Thermostatic valve with pre-setting.

Radiators with thermostatic valves and periodic set back of the flow temperature

Periodic set back of the flow temperature, night set back, implies that the heat authority becomes less than 1,0. The thermostatic valves have no longer access to required heat amount to keep set room temperature. They will as the room temperature drops, open up more and more and the balance in the system disappears.

It is enough to make a rough pre-setting of flow at a radiator valve to be able to handle the distribution during a set back period.The pre-setting will prevent overflow at radiators located close to the heating source, and underflow at others.

The flows musn't be set too low. This means that the thermostatic valves will not have enough heat authority. Consequently they do not function well.

The pre-setting can be made according to radiator size/heat requirement if each riser have access to the same differential pressure. The easiest way to secure the constant differential pressure over the thermostat radiator valve is by using the differential pressure controllers at each riser or branch.

If not, the available and required differential pressure has to be calculated for each thermostatic valve.

Fig. Ap. 1:8

A periodic set back of the flow temperature requires a rough adjustment for the heat distribution to be accurate. The preset values above apply to Danfoss RA valves and shows the precision required.

Radiator size	**Setting**
1 The largest in the radiator circuit	N
2 Half of previous	6
3 Half of previous	4
4 Half of previous	2

Flow type

The type of flow used in a radiator system is significant because it influences the resistance. The flow can either be constant or varying.

In systems with a constant flow, fixed resistances can be used in order to remove unnecessary differential pressure. If the flow varies, the resistance is changed in a fixed resistance by the square of the flow change. A halved flow, Q=0,5, reduces the resistance to $0,5^2$=0,25. The total available differential pressure should be handled by the thermostatic valves.

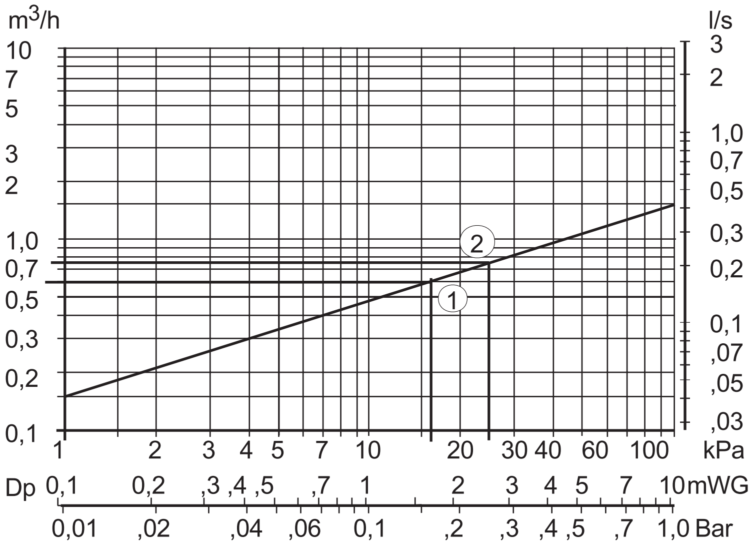


Fig. Ap. 1:9
Constant flow = constant Δp.
Varying flow = varying Δp
The flow through a fixed adjustment will vary when the available differential pressure fluctuates.

1: Δp 16 kPa, Q 600 l/h

2: Δp 25,6 kPa, Q 740 l/h

Constant flow

Constant flow occurs in one-pipe systems where the flow which does not pass through the radiator passes through a by-pass. Even if all radiator valves are shut, the flow through the coil is equally high. This goes for manually controlled as well as thermostatic radiator valves.

Two-pipe systems with manually controlled radiator valves generate constant flow as well.

Varying flow

In two-pipe systems with thermostatic valves that has a heat authority larger than 1,0, the flow will vary. The thermostatic valve senses if the temperature in a room increase and then reduces the heat supply/flow.

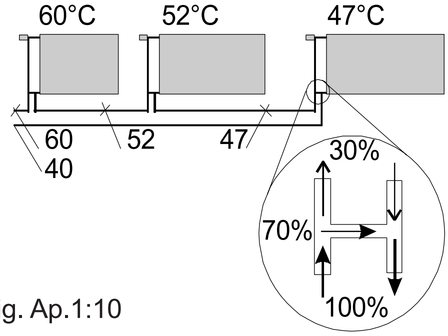


Fig. Ap.1:10

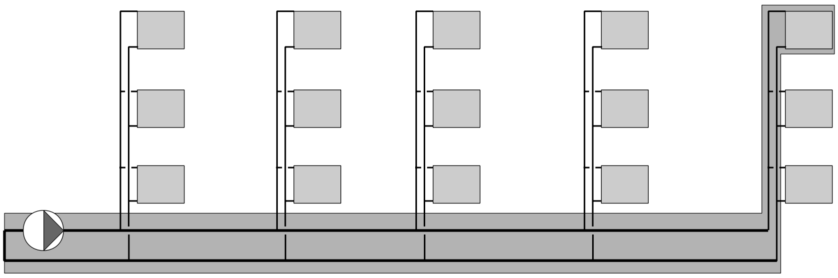
One-pipe systems always have a constant flow through the coil. Possible thermostatic valves only affect the flow to each radiator.

Pressure conditions in radiator systems

The piping which determines required pressure increase across the pump is called the sizing circuit. It consists of the horizontal distribution pipe coming from the pump, out to the riser located farthest away and the radiator back to the pump.

Fig. Ap. 1:11

The sizing circuit is the pipes from the heat exchanger to the farthest away radiator. The resistance in this circuit is equal to the pump head.



The resistance in the sizing circuit, Δp_{sizing} is equal to the pressure increase across the pump, Δp_{pump}.

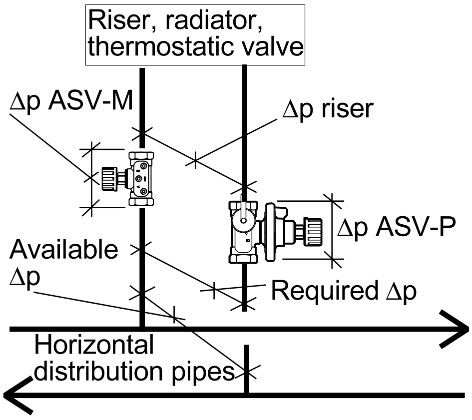
Available differential pressure at a riser, Δp_{avail}, is equal to the pressure increase across the pump minus the resistance in the distribution line between the pump and the riser in question. Δp_{avail} is measured as the difference in pressure between flow and return.

The resistance across a riser Δp_{riser} is equal to the differential pressure needed to circulate water up to and through the worst located radiator and back again. The resistance in balancing valves is not included in $\Delta p_{required}$ at the bottom of the riser.

Fig. Ap. 1:12

Definitions for Δp at a branch to a riser.

ASV-M and ASV-P are balancing valves.



$$\Delta p_{required} = \Delta p_{riser} + \Delta p_{ASV-M} + \Delta p_{ASV-P}$$

The resistance in the branch pipe involves that the available differential pressure always is largest for the risers located closest to the pump. The further away the risers are located, the more Δp_{pump} has been consumed. Only the required differential pressure should be left at the last riser.

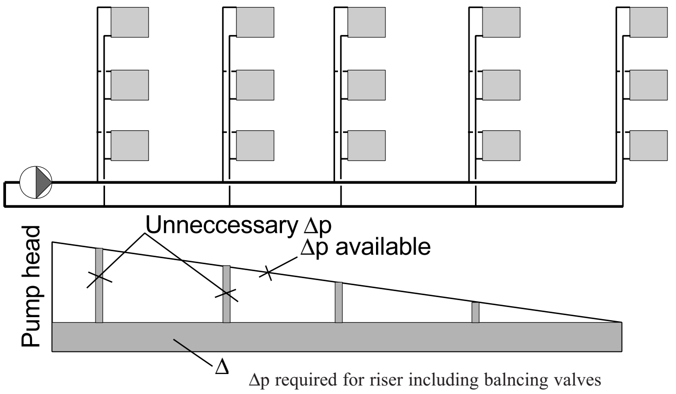


Fig. Ap. 1:13

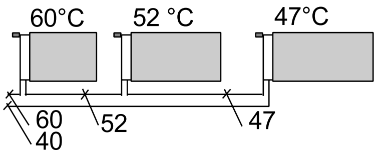
Pressure distribution in the distribution pipes in a two-pipe system at maximum flow. The same conditions apply in the distribution to a one-pipe system.

The things mentioned above applies regardless of whether the flow is constant or varying.

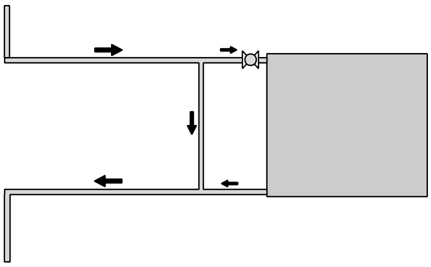
Constant flow

One-pipe system

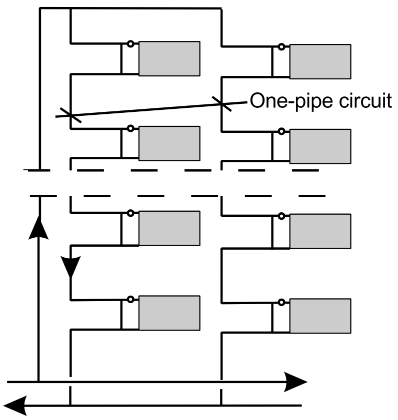
In a one-pipe coil, the available pressure is the same for each radiator. No measures in order to distribute the flow between the radiators therefore has to be taken. There could, on the other hand, be big differences in available differential pressure for the different one-pipe coils in a system.



Horizontal one-pipe system.



Vertical one-pipe system.



Vertical one-pipe system. Two circuits.

Fig. Ap. 1:14

A one-pipe coil always has constant flow. But the available pressure for each coil is depending on the distance from the pump in the same way as for two-pipe systems.

Distribution pipes and risers in a one-pipe system forms a two-pipe system. The coils located close to the pump have access to a higher differential pressure than the ones located further away. The unnecessary pressure has to be removed so that the accurate flow is obtained for each coil. If this is not done, the flow will not be sufficient for the furthest away connected coils and the closest connected receives too high flow.

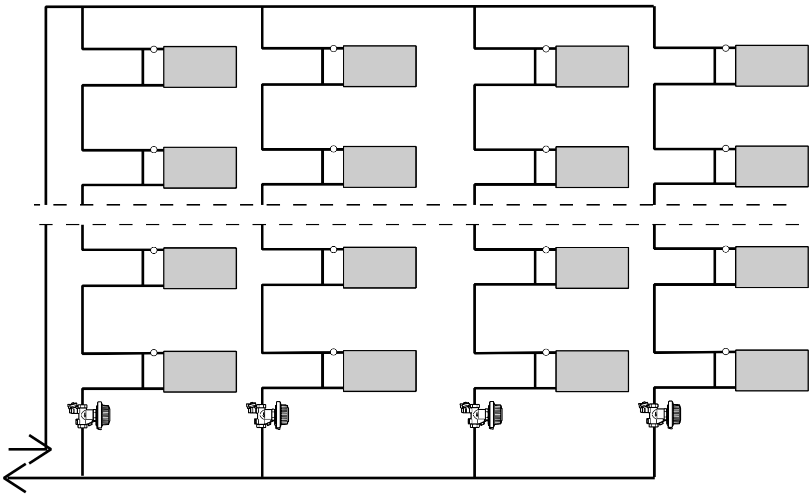


Fig. Ap. 1:15

The unnecesary differential pressure for each one-pipe coil has to be removed. If not, the first coils will steal flow from the coils located further out in the system. The easiest and thereby the most secure way is to install a flow limiter, ASV-Q, in each coil.

The unnecessary differential pressure can be removed by using a manual balancing valve. It will take a lot of calculating, screwing and measuring before it is put in place, but it works.

An easier way is to install automatic flow limiters on each one-pipe coil. They are simply set at required flow and then the system works. The automatic flow limiter also takes care of the increase in flow which could occur due to gravity.

Recommendations

Set the flow for each one-pipe coil. Use automatic flow limiters in buildings with more than 6 floors (3 m/floor). They will compensate for the increases in flow which could occur due to gravity.

Two-pipe systems with manually controlled radiator valves

Each radiator in this type of system has its own available differential pressure. Unnecessary pressure should be removed by adjustment so that the flow and heat distribution will be accurate.

In large systems, it is not sufficient to make an adjustment on each radiator but an adjustment also has to be made on each riser.

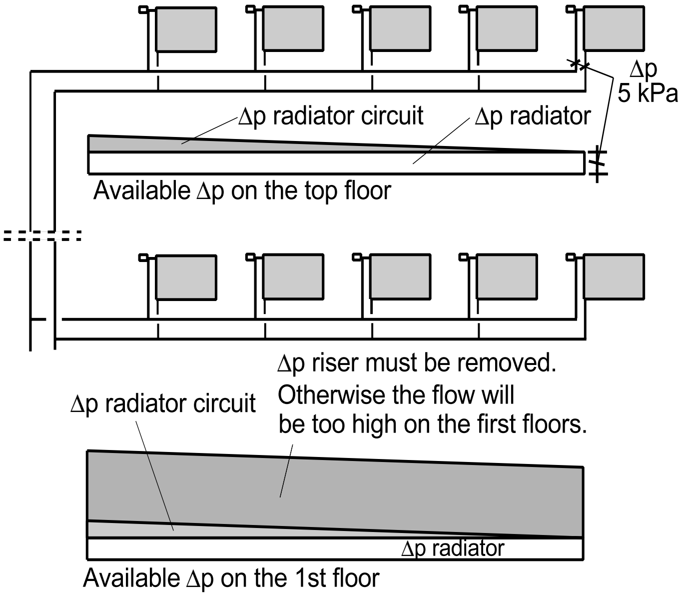


Fig. Ap. 1:16

Systems with manually controlled radiator valves have constant flow. Then, fixed adjustments of the flow can be used. Firstly a setting is made on each radiator. If this is not enough, an adjustment on a manual balancing valve at the bottom of each riser or for each radiator circuit has to be made.

Recommendations

Set the flow at each radiator and at each riser. Use automatic flow limiters in buildings with more than 6 floors

(3 m/floor). They will compensate for the increases in flow which could occur due to gravity forces.

Recommendations

Make a rough pre-adjustment of the flow to all the radiators. Supply each radiator circuit, in buildings with more than 6 floors, with a differential pressure controller.

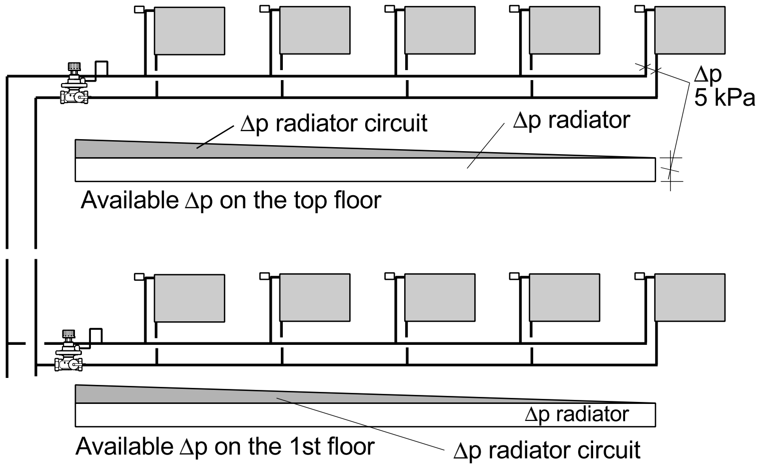
Varying flow

Two-pipe systems with thermostatic valves

The pressure distribution in this system is at maximum load the same as when using manually controlled radiator valves, but the flow will decrease as soon as the thermostatic valves begin to use the incidental heat gain. The manual balancing valves with fixed settings which can be used on manually controlled radiator valves does not work at varying flow, and that is what we have got here. The only solution that works is using differential pressure controllers which keep a constant differential pressure across a riser or a circuit.

Fig. Ap. 1:17

Thermostatic valves give a varying flow and a fixed adjustment will not work at all. With differential pressure controllers on each riser or radiator circuit, the same available differential pressure is obtained for all circuits regardless of flow. Thermostatic valves can handle the small differences in available differential pressure that arises without any problem.



Circulation pumps

The pumps in our heating systems maintain the circulation by creating a sufficient pressure increase. It has always been difficult to calculate required flow and differential pressure for a heating system. Pumps with adjustable pressure increase that are available and commonly used today have therefore been favourably received. Many people think that these solve all problems concerning too high or varying differential pressure. It is, however, not that simple.

As regards two-pipe systems with manual balancing valves, it still takes extensive adjustments. The same thing applies to one-pipe systems if you don't choose to install an automatic flow limiter on each one-pipe coil. An adjustable pump can, for these systems with a constant flow, only be used to set required differential pressure.

Dealing with two-pipe system with thermostatic valves providing a varying flow is a more complicated matter. We shall take a close look at this below.

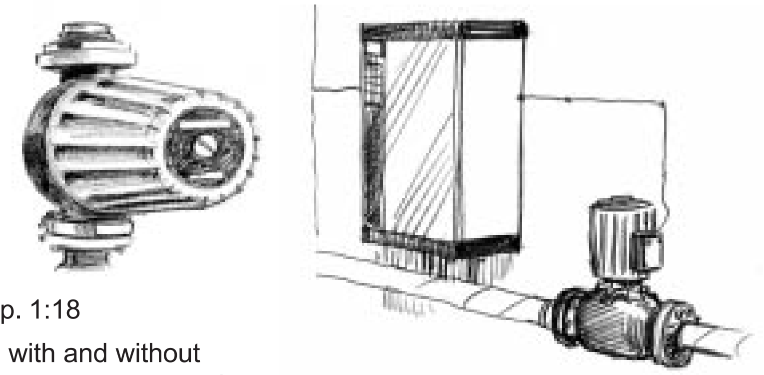


Fig. Ap. 1:18

Pump with and without pressure control respectively.

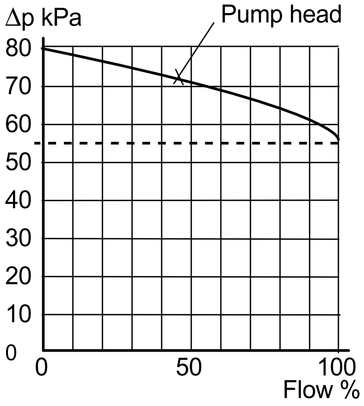


Fig. Ap. 1:19a

Pump chart for pump without controlling. Required pressure increase across the pump at 100 % flow is 55 kPa, dotted line. At reduced flow, the pressure increases according to the pump head. 0 % flow gives approx. 80 kPa.

Pump without pressure controlling

We begin by looking at a pump without pressure controlling. What is a pump head, what does it look like and what can it be used for?

The pump head shows, in a chart, flow and pressure increase for a certain pump. The inclination on the pump head varies between different pumps. When you know the flow and the pressure increase required in a system you choose a pump that provide these values.

The values you start out from applies to maximum requirement. Any check of what happens at lower flow is rarely done.

It is quite simple to enter a curve for the resistance in the sizing circuit into the pump chart. (The resistance changes by the square of the flow change) Then you can clearly follow what happens with the for the thermostatic valve available differential pressure. Note that this applies for the sizing circuit.

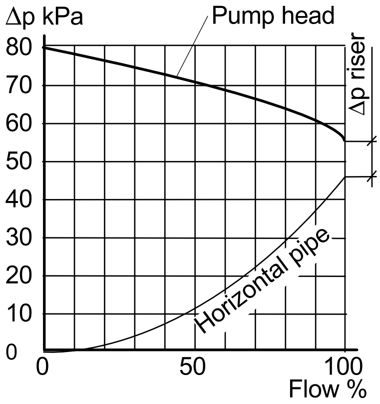


Fig. Ap. 1:19b

A curve showing the resistance in the horizontal distribution line can be entered into the chart. The distance between the two curves is equal to the available differential pressure for the last riser.

In order to find out how it looks like in the other risers, we can supplement the pump chart with a diagram showing the pressure distribution in a pipe system at different flows. The sloping line represents the resistance in the horizontal distribution line. The shaded box at the bottom represents the differential pressure required to overcome the resistance in each riser including the radiator located highest up. The additional 10 kPa is reserved for a balancing valve.

Fig. Ap. 1:20

Two pipe system with thermostat radiator valves.

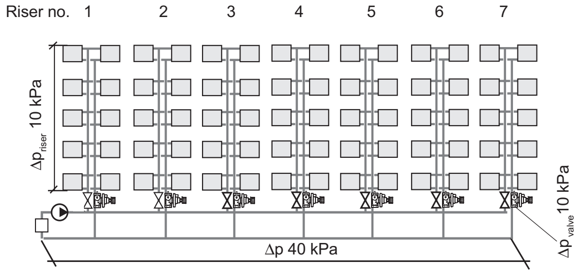
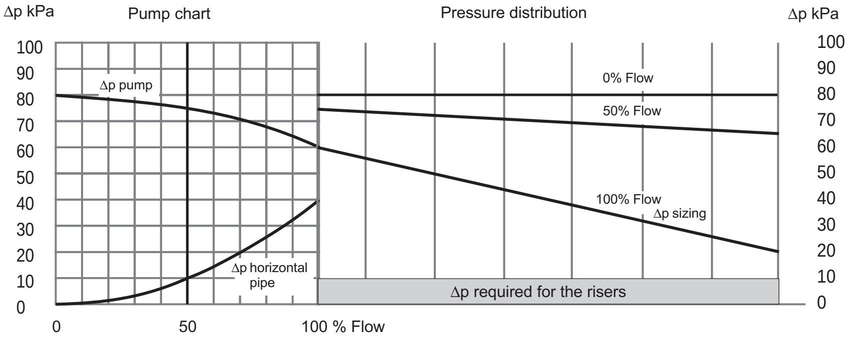


Fig. Ap. 1:21

The chart shows the available pressure along a distribution line at 0%, 50% and 100 % flow. At a flow of 0, the same available pressure prevails throughout the whole system. In the example, 80 kPa.



It is not possible to predict in which riser or risers the flow will reduce when the thermostatic valves reduces the heat supply. The reduction can be distributed evenly between the risers, or some risers answers for the whole reduction. This uncertainty factor implies that the smallest differential pressure possible has to be chosen equally to the differential pressure at maximum flow. A 100% flow in any riser must always be possible.

When using a pump without pressure controlling, the available differential pressure for risers will increase as the flow decreases. The same differential pressure prevails throughout the system as the flow reaches zero. The decreased flow reduces the resistance in the pipe system by the square of the flow change.

The differential pressure applied at the radiator thermostat valve is equal to the difference between pump had and resistance in pipe system. At 100% flow, this difference is just right for the last riser, and rapidly increase when the flow is reduced. In order to keep constant differential pressure over the thermostat radiator valve, and reduce the noise, differential pressure controllers on each riser are recommended.

Pressure controlled pumps

Pumps on which you can set a pressure increase and flow are generally used. A pressure increase can then electronically be adjusted according to the requirements in question.

There are in principle three different types of control

- Constant differential pressure (2)
- Proportional differential pressure (3)
- Differential pressure parallel to the system curve (4)

Proportional differential pressure is most frequently used.

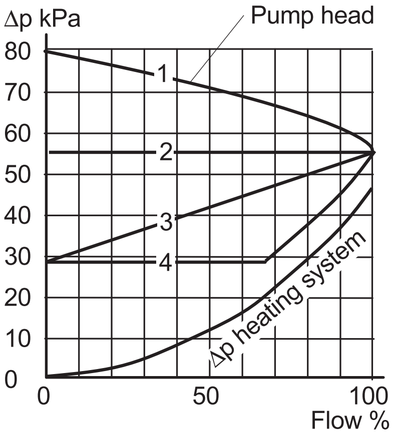


Fig. Ap. 1:22 Pump controllers

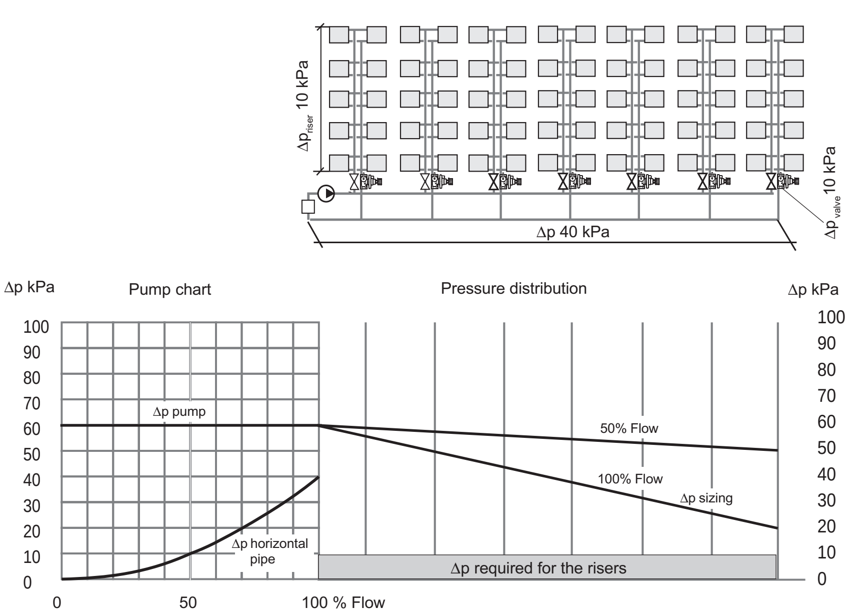
Pump with constant differential pressure

This type of control implies that the pump always deliver the pressure increase set, regardless of flow changes.

What separates it from a non controlled pump is that it does not increase the pressure further when the flow decreases. Otherwise it gives the same result as a pump without pressure control.

The risers located closest to the pump receives fairly the same available differential pressure at different flows in the system. One could think that they could be handled with manual balancing valves and fixed pre-adjustments. They could exept if the flow in these risers is not reduced. The pre-adjustments won't work and the thermostatic valves will receive a higher/too high differential pressure.

The measures that has to be taken to obtain good functioning in the radiator system are the same, differential pressure controllers at the bottom of each riser.



Note:

Balancing valves are sized for available differential pressure at 100 % flow.

Fig. Ap 1:23

Pump with constant Δp control

Δp_{pump}= 60 kPa, at 100% flow

Δp_{avail} = 20 kPa, at the last riser

Δp_{pump}= 60 kPa, at 50% flow

Δp_{avail} = 50 kPa, at the last riser

Recommendations

In two-pipe systems with thermostatic valves should risers or radiator circuits be equipped with differential pressure controllers if Δp-pump in any operation surpasses 25 kPa.

Pump with proportional or parallel differential pressure

Here you set sizing pressure and flow. At proportional pump the pump curve is straight line going down proportionally to half of the differential pressure at the maximum flow. At the pump controlled parallel to the resistance in the pipe system, the pump curve will run parallel to the system curve, but only down to half of the differential pressure at the maximum flow.

The values for available differential pressure at 100% and 50% flow are shown in the charts.

Required differential pressure for the risers and balancing valves is 20 kPa. The distribution line requires 40 kPa. Pressure increase across the pump at 100% flow is 60 kPa.

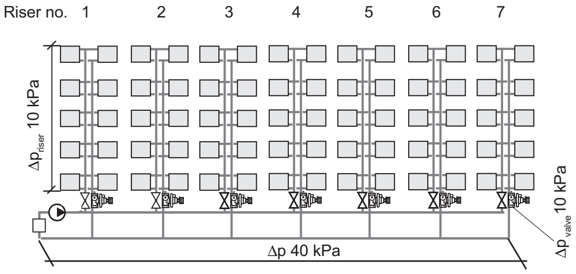


Fig. Ap 1:24a

Pump with proportional Δp control

Δp_{pump} = 60 kPa, at 100% flow

Δp_{avail} = 20 kPa, at the last riser

Δp_{pump} = 45 kPa, at 50% flow

Δp_{avail} = 35 kPa, at the last riser

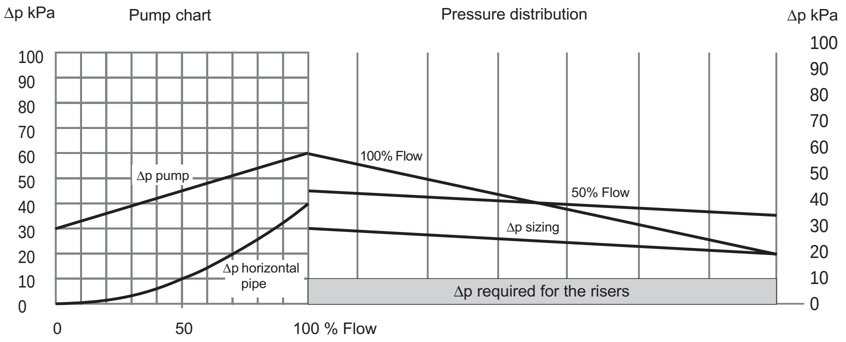


Fig. Ap 1:24b

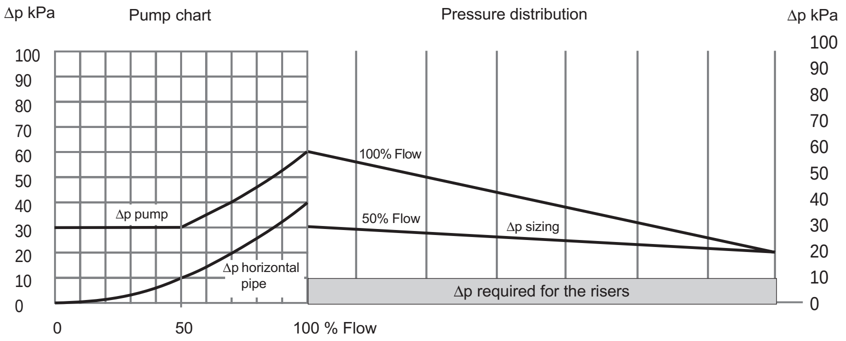
Pump with parallel Δp control

Δp_{pump} = 60 kPa, at 100% flow

Δp_{avail} = 20 kPa, at the last riser

Δp_{pump} = 30 kPa, at 50% flow

Δp_{avail} = 20 kPa, at the last riser



The last risers receive fairly the same available differential pressure at different flows in the system. Would now the manual balancing valves with fixed pre-setting be enough? For the last riser maybe, but not for the risers close to the pump.

Sizing available differential pressure Δp sizing should be chosen in a way, that any riser at the lowest possible flow in the system is able to receive 100% flow. Than manual balancing valves with fixed pre-setting can not take care of the unnecessary differential pressure at the first risers at 50% flow. The overflow and noise will occur at these risers, and the hydraulic balance of the system will disappear. It is therefore essential to maintain the constant differential pressure with differential pressure controllers on the risers or radiator circuits.

Another example that shows the problem of using proportional or parallel variable speed pumps is building with two branches.

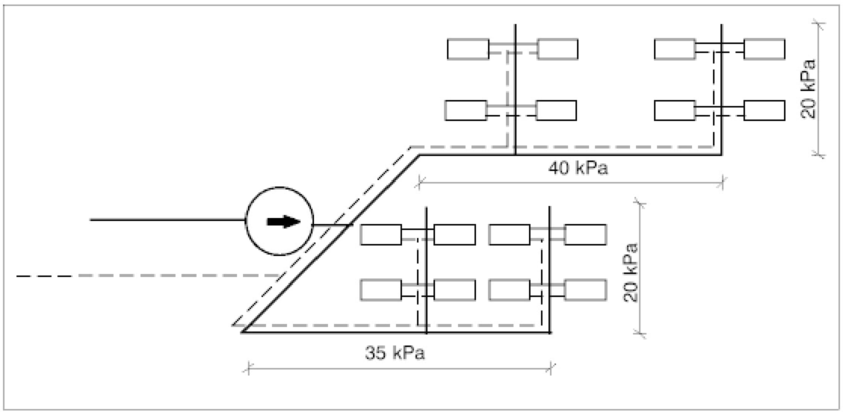


Fig. Ap 1:24c

Sizing circuit, Δp_{pump} = 60 kPa

Second circuit, Δp_{pump}= 55 kPa

The pump is sized for 60 kPa at 100% flow. Building is equipped with thermostatic radiator valves, which will decrease the flow at sunny weather. If the first part of the building (sizing circuit) is on the sunny side, the flow in this circuit will decrease. Simultaneously the pump head will decrease as well. But the second part of the installation still requires high pressure. In this example Δp_{pump}= 55 kPa.

Using pumps with parallel or proportional characteristic can cause too low available pressure especially for big buildings at varying flow: in our example Δp_{pump} = 30 kPa, at Q50 instead of 55 kPa!

Pump comparison and conclusions

Variations of the available differential pressure at the last and at the first risers are shown in the table below for each of the pump type used. In the first column the sizing differential pressure is shown, and in the next two the available differential pressure at 100% and 50% flow.

Whenever the available differential pressure is higher than sizing differential pressure the overflow will occur, and the system balance will disappear. If the difference is high enough, the noise in the radiator thermostats will appear.

Table 1: Last riser

Pump type		Δp_{sizing}	100 % flow	50 % flow
			$\Delta p_{available}$	$\Delta p_{available}$
①	No control	20 kPa	20 kPa	65 kPa
②	Constant Δp	20 kPa	20 kPa	50 kPa
③	Proportional Δp	20 kPa	20 kPa	35 kPa
④	Parallel Δp	20 kPa	20 kPa	20 kPa

At the last riser (table no 1) the highest difference in sizing and available differential pressure occurs at 50% flow. The difference is the biggest when pumps with no control are used (65-20=45 kPa) and becomes smaller with variable speed pumps. What happens at the first riser is shown in the table 2. The highest difference in the differential pressure occurs at 100% flow when variable speed pumps are used (56-29=27 kPa)!

Table 2: First riser

Pump type		Δp_{sizing}	100 % flow	50 % flow
			$\Delta p_{available}$	$\Delta p_{available}$
①	No control	56 kPa	56 kPa	74 kPa
②	Constant Δp	56 kPa	56 kPa	59 kPa
③	Proportional Δp	29 kPa	56 kPa	44 kPa
④	Parallel Δp	29 kPa	56 kPa	29 kPa

Recommendations

Variable speed pumps should be used in larger systems together with the differential pressure controllers on the risers or branches. A constant differential pressure at the last branch or riser provides the best possibility for the largest cut in the operation cost for the pump. The Δp sensor of a variable speed pump should be installed in the last (critical) riser, and set to the required Δp for that riser. In all other risers, differential pressure controllers should be used.

It is clear that manual balancing valves with the fixed pre-setting are not able to handle the changes in the differential pressure occurred at varying flows, no matter of the pump type used. The variable speed pump will make this difference in the differential pressure smaller, but only the pump itself is not enough to balance the system with more risers or branches. The differential pressure controllers at each riser or a branch are the only solution that gives satisfactory result at varying flow. They keep the same available differential pressure regardless of the size of the flow. Besides, you do not have to make hard decisions about the minimum available differential pressure. Calculations on pre-set values as well as measurements of pressure drops are unnecessary. Above all the system will function problem free. This is not the case with manual balancing valves with fixed pre-setting. From a technical, economical and functional point of view, there exists only one rational solution: differential pressure controllers on the risers or radiator circuits.

Sizing of automatic differential pressure controllers

Sizing of differential pressure controllers is much easier then sizing manual balancing valves with fixed pre-setting. It does not matter how flow and pressure varies at the bottom of each riser or at the beginning of a radiator circuit. The available differential pressure for radiator thermostats can maximally be the one set on the differential pressure controller. The sizing is further simplified because the heating system can be divided into smaller units, a riser or radiator circuit for instance.

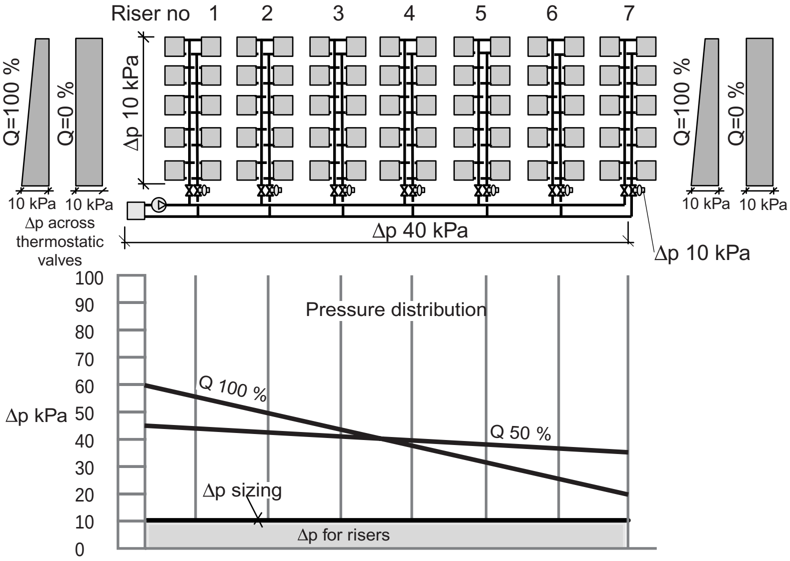


Fig. Ap. 1:25

It does not matter how flow and pressure varies when using differential pressure controllers at the bottom of each riser. The available differential pressure can maximally be the one set on the differential pressure controller.

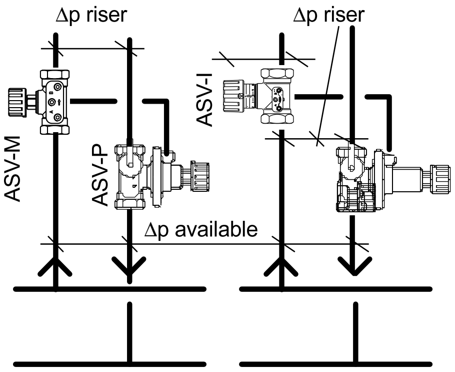
Differential pressure over riser

The differential pressure for a riser is usually not higher than the one the radiator thermostat valve can handle and this is max 25 kPa.

For reasonably tall buildings a differential pressure of 10 kPa is sufficient for riser including radiators. Calculate with 5 kPa for the last radiator and its thermostatic valve. That leaves 5 kPa to resistance in the pipes. 0,1 kPa per meter pipe is an aiming point that allows space for 50 meters of pipe in the riser. This gives with a floor height of three meters sufficient differential pressure for nine floors, 50/6=8,3. Six meters of pipe per floor. But the pipes do not pass the last floor, they just reach it. So the differential pressure 10 kPa is enough for nine floors.

If the circulation pump is equipped with pressure control, its lowest pressure increase has to be higher than the for riser and differential pressure control required differential pressure.

The differential pressure controller should be installed in the return pipe and from there an impulse tube is drawn to the flow pipe to ASV-M or ASV-I.



Δp_{riser} does not include $\Delta p_{ASV\text{-}M}$

Δp_{riser} includes $\Delta p_{ASV\text{-}I}$

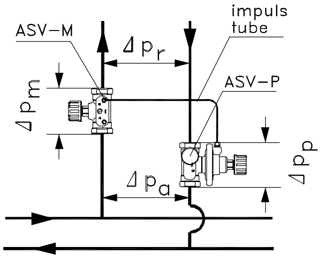
Fig. Ap. 1:26

Definition of differential pressure when using ASV-M and ASV-I respectively.

Examples of sizing

Example 1: Differential pressure control in the riser or branch (P control).

Combination of ASV-M and ASV-P or ASV-M and ASV-PV is used to control the diffirential pressure in rises or branches where the radiatore valves have flow pre-setting function. ASV-M is a shut of valve with the connection for impulse tube. The ASV-P is a pressure controller factory set to 10 kPa. If higher or lower differential pressure than 10 kPa is needed, than ASV-PV is used. It can be set to maintain constant differential pressure in riser or branch from 5 kPa to 25 kPa. Both ASV-P and PV have shut off and draining function as well.



$$\Delta p_a = \Delta p_m + \Delta p_r + \Delta p_p$$

Fig. Ap. 1:27, example 1:

Δp_p	Pressure drop across ASV-P, PV valve
Δp_m	Pressure drop across ASV-M valve
Δp_r	Necessary pressure for the riser
Δp_a	Available pressure for the riser

Given

Pipe flow (Q)	200 l/h
Differential pressure across riser Δp_r:	0,1 bar (10 kPa)
Pump pressure available ahead of riser Δp_a: ..	0,3 bar (30 kPa)

Required

a) Pressure drop across balancing valve ASV-M
b) Pressure drop across balancing valve ASV-P, PV
c) Correct valve size

Solution

a) Pressure drop across ASV-M

Pressure drop for ASV-M valves can be found from the diagram fig. 1:28. From point Q = 200 l/h horizontal line is drawn to the line that represents the valve size. With the vertical line the pressure drop of Δp_m = 0,015 bar (1,5kPa) can be read.

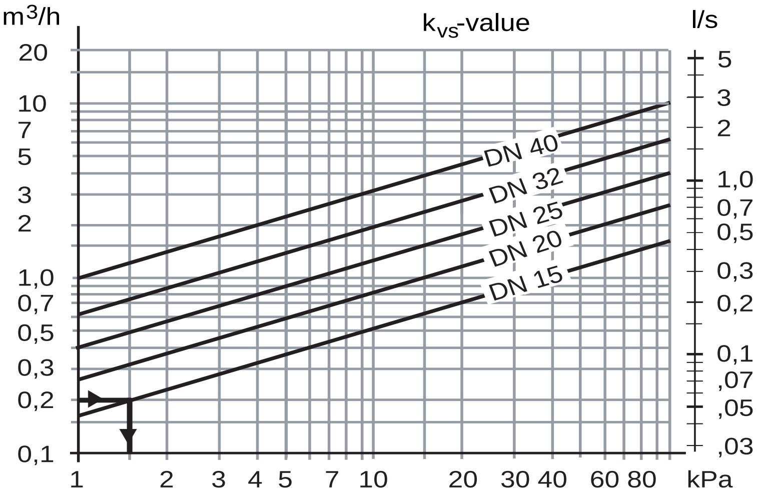


Fig. Ap. 1:28

Graph represents pressure drop over ASV-M valves

Note

ASV-P, PV is used together with ASV-M to control the differential pressure in risers where the radiator valves have pre-setting facilities.

b) Pressure drop across ASV-P, PV

$\Delta p_a = \Delta p_m + \Delta p_r + \Delta p_p$
$\Delta p_p = \Delta p_a - \Delta p_m - \Delta p_r$
$\Delta p_p = 0.3 - 0.015 - 0.1 = 0.185$ bar

The difference between available differential pressure and resistance across the shut-off valve ASV-M and riser gives the differential pressure on the differential pressure control valve ASV-P, PV.

If ASV-P (fixed pre-setting on 10 kPa) is used, the resistance in the shut-off valve in the flow has to be carefully checked so that there is enough differential pressure. The impulse tube is installed behind the shut-off valve, therefore the resistance of ASV-M is not part of the resistance in the riser. ASV-M provides that function, not ASV-I.

c) Correct valve size

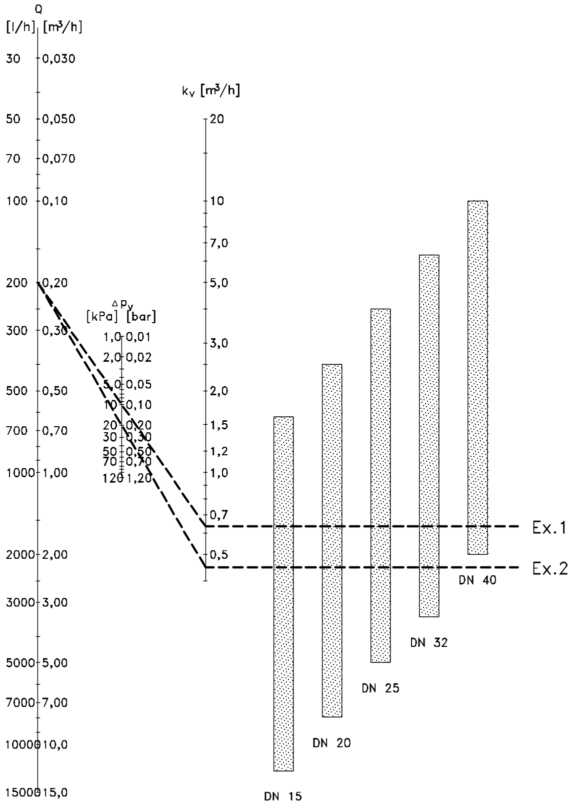
The correct valve size can be found from the diagram for valve sizes, fig. 1:29. From point Q= 200 l/h the line is drawn through 0,185 bar for Δp_p to the k_v scale. With horizontal line the right valve size is specified. In this example it is DN 15.

Recommendations

Always calculate with min. 10 kPa pressure drop over the differential pressure controller ASV-P or ASV-PV

Fig. Ap. 1:29

Graph for sizing ASV-P, PV



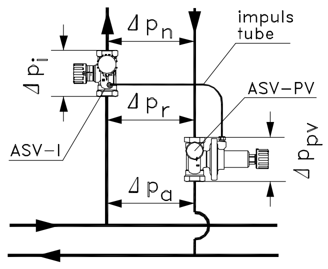
Note

Maximum admissible differential pressure across the valve 1.2 bar (120 kPa) should not be exceeded at partial load.

Example 2: Differential pressure and flow control in the riser or branch (P and Q control).

Combination of ASV-I and ASV-PV is used whenever the flow limitation at the riser or branch is required together with differential pressure control. One example of using this combination is when the radiator thermostats do not have pre-setting function, and the flow can only be set at the riser.

Δp_{pv}	Pressure drop across ASV-PV valve
Δp_i	Pressure drop across ASV-I valve
Δp_r	Pressure drop in the riser including ASV-I
Δp_a	Available pressure for the riser
Δp_n	Necessary pressure for the riser



$$\Delta p_r = \Delta p_i + \Delta p_n$$

$$\Delta p_a = \Delta p_r + \Delta p_{pv}$$

Fig. Ap. 1:30

Given

Required max. pipe flow (Q) .... 200 l/h

Differential pressure across riser Δp_n at Q = 200 l/h .... 0,09 bar (9 kPa)

Required

a) Pressure drop across ASV-I
b) Pressure drop across ASV-PV
c) Correct valve size
d) Setting of differential pressure at ASV-PV
e) Available pressure for the riser

Solution

a) Correct setting of ASV-I

Since the Δp_a is not known, we have to calculate with minimum Δp_i = 3kPa. This is the min. pressure drop for reliable measurements.

The ASV-I setting can be read from the pressure drop graph, fig. 1:31. With a pressure drop Δp_i of 0,03 bar (3 kPa) and a flow Q of 200 l/h, an ASV-I DN 15 valve must be set on 1,7 to give max. flow in the riser of 200 l/h.

b) Pressure drop across ASV-PV (Δp_v)

We should always calculate with 10 kPa of available differential pressure for the differential pressure controller even if the resistance at the flow in question is lower. Δp_{pv} = 0,1 bar (10 kPa)

c) Correct valve size

The correct valve size can be found from the diagram for valve sizes, fig. 1:29. From point Q = 200 l/h the line is drawn through 0,1 bar for Δp_{pv} to the k_v scale. With horizontal line the right valve size is specified. In this example it is DN 15.

d) Setting the differential pressure for the riser

$\Delta p_r = \Delta p_i + \Delta p_n = 3 + 9 = 12$ kPa,

ASV-PV should be set to maintain 12 kPa over the riser.

e) Available pressure for the riser

$\Delta p_a = \Delta p_r + \Delta p_{pv} = 12 + 10 = 22$ kPa

The pump should be chosen to give at least 22 kPa ahead of the riser.

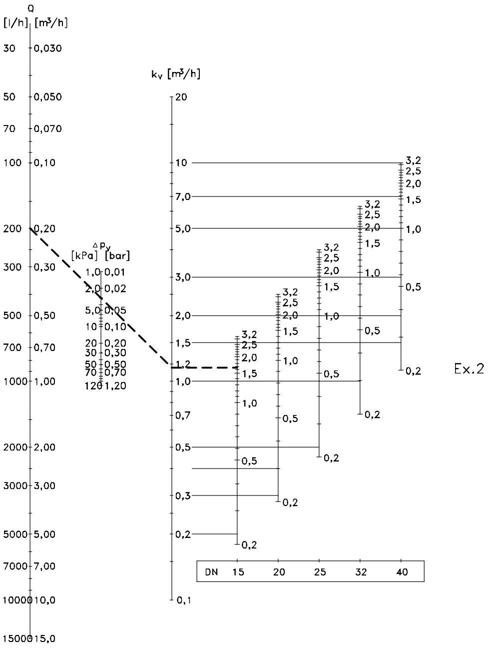


Fig. Ap. 1:31 Graph for sizing ASV-I.

Flow limitation and balancing of differential pressure at control valves

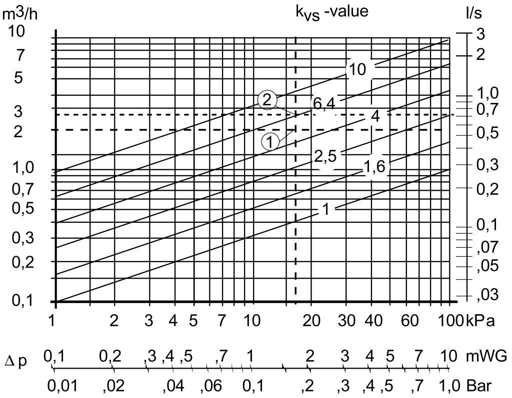


Fig. Ap. 1:32

At a flow of 2 m^3/h and an available differential pressure of 16 kPa, point 1, a valve with k_{VS} 6,4 has to be chosen. This valve is too large and will at a fully open position give 2,8 m^3/h point 2.

Control valves are manufactured with a certain capacity for all separate dimensions. Seldom the sizes of the valves corresponds to the requirement. To make sure the larger of the two valves is chosen, between which the required flow lies. Consequently there is an emotional requirement of limiting – adjusting the capacity of the valve according to the maximum requirement.

Here is a difference between two- and three-way valves. The former provides a varying flow while the latter provides a constant flow for one slot. The constant flow should be set in one way or another. As regards the two-way valve, it should, even if it is too large, provide the accurate flow as long as it has access to required amount of heat. If the heat amount, however, decreases below the required, the valve will open up and let through a higher flow. Accordingly, it should have heat authority to manage the situation. If you want to secure a maximum flow through the valve during such an operational disturbance, you should choose a method that does not influence the control qualities of the valve.

There are three methods used in these circumstances.

- Pre-adjustment
- Automatic flow limitation
- Control of the differential pressure

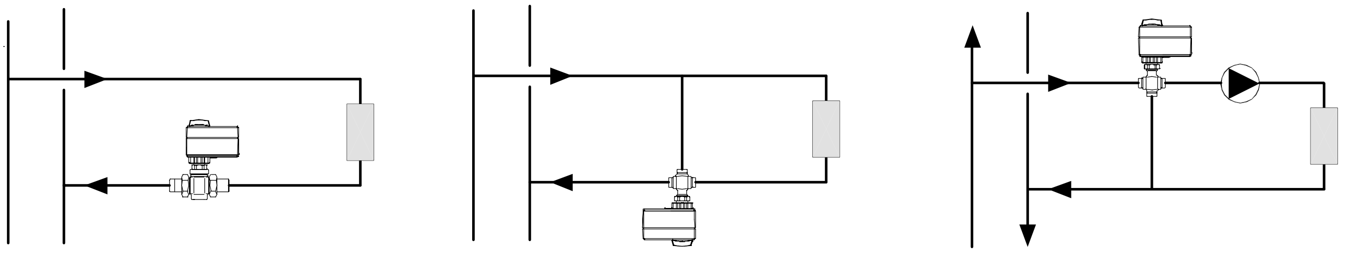


Fig. Ap. 1:33

The two-way valve gives a varying flow in the circuit where it is and in the shunt line in this coupling

The three-way valve gives a constant flow in the primary circuit. The flow in the shunt lines varies.

Here, the three-way valve gives a varying flow in the primary circuit and in the shunt line.

Constant flow – 3-way valves

A 3-way valve affects the flow both in the primary and the secondary circuit. Constant flow can occur in the primary- or the secondary circuit depending on how the system is constructed.

Pre adjustment works well in a circuit with a constant flow. Setting of desired flow can be made if the the size of the flow and the available pressure is known. The cost for the valve is low while the cost for the setting is high. Lowest differential pressure to provide a steady flow, 5 kPa.

An automatic flow limiter is easy to install and set for the flow in question. The cost for the valve is higher and requires a higher available pressure, 25 kPa.

A differential pressure controller can be used to keep a constant differential pressure across the three-way valve. It should be set on the differential pressure required across the three-way valve to provide desired flow. Lowest differential pressure across the differential pressure controller in order to provide steady pressure, 10 kPa.

Recommendations

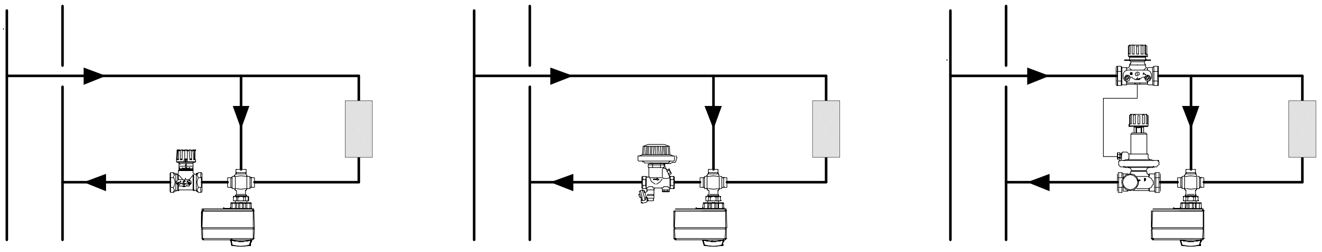


Fig. Ap. 1.34

A fixed adjustment works well at constant flow but requires a solid basis for a pre-set.

An automatic flow limiter, ASV-Q for instance, makes the pre-setting considerably easier.

Differential pressure control with ASV-PV. The ASV-PV is set on the pressure that the control valve at a fully open position requires to give desired flow.

Varying flow – two way valves

All attempts to influence the flow outside the two-way valve worsen its functionality, the characteristics of the valve are changed.

Pre adjustment or automatic flow limitation only works at sizing flow. At lower flows, the control valve gets to operate with a higher differential pressure. This results in less lift hight for the cone and worse functionality.

Control of the differential pressure across the control valve on the other hand provides the opportunity to take full advantage of the control valve. The maximum flow can be limited in a way that it does not affect the function of the valve negatively.

The procedure is simple. Find out what differential pressure is required across the fully opened valve to provide desired flow. Set this differential pressure with the differential pressure controller.

The control valve will work with the whole stroke length, i.e. the characteristics of the valve stays intact. Besides, the available differential pressure will remain the same from 100 to 0 % flow. Technically the function will be optimal.

Recommendations

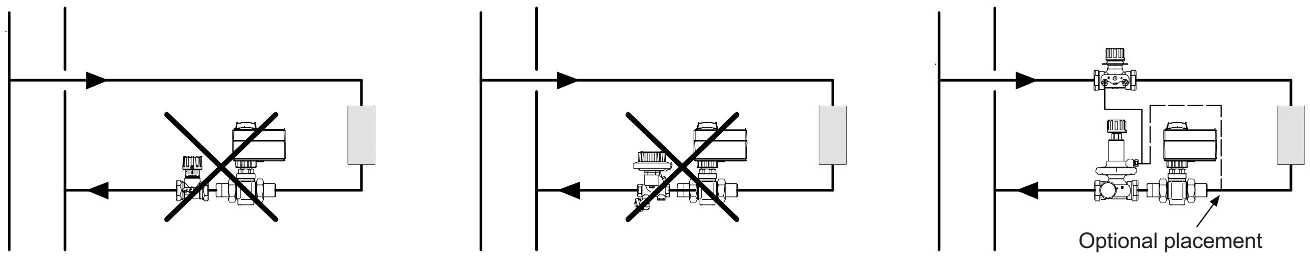


Fig. Ap. 1:35

An adjustment at varying flow only works at maximum flow. Adjustment should therefore not be made.

Flow limiters only work at maximum flow and should therefore not be used.

A differential pressure controller, set on the differential pressure the control valve requires in a fully open position, is the optimal solution.

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