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BALANCING OF DISTRIBUTION SYSTEM

The most efficient methods for balancing waterflows in distribution systems for heating and cooling systems.

Franz Josef Spital, Austria

"Balancing of Distribution Systems" is Manual No. 2 in the TA Hydronics series of publications for HVAC practitioners. Manual No. 1 deals with balancing control loops. Manual No. 3 deals with balancing radiator systems. Manual No. 4 deals with stabilising of differential pressure.

Please note that this publication has been prepared for an international audience. Since the use of language differs somewhat from country to country, you may find that some of the terms and symbols are not the same as those you are used to. We hope this does not cause too much inconvenience.

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Content

This manual deals with the hydronic balancing methods.
For balancing of control loops, please see TA manual N° 1.
For balancing of radiators systems, please see TA manual N° 3
For stabilising the differential pressure across the circuits, please see TA manual N° 4.

1. Why balance?

(More about in appendix F)

Many property managers spend fortunes dealing with complaints about the indoor climate. This may be the case even in new buildings using the most recent control technology. These problems are widespread:

- Some rooms never reach the desired temperatures, particularly after load changes.
- Room temperatures keep swinging, particularly at low and medium loads even though the terminals have sophisticated controllers.
- Although the rated capacity of the production units may be sufficient, design capacity can't be transmitted, particularly during start-up after weekend or night set back.

These problems frequently occur because incorrect flows keep controllers from doing their job. Controllers can control efficiently only if design flows prevail in the plant when operating under design conditions. The only way to get design flows is to balance the plant. Balancing means adjusting the flow by means of balancing valves. This has to be done in five respects:

1. The production units must be balanced to obtain design flow in each boiler or chiller. Furthermore in most cases, the flow in each unit has to be kept constant. Fluctuations reduce the production efficiency, shorten the life of the production units and make effective control difficult.

2. The distribution system must be balanced to make sure all terminals can receive at least design flow, regardless of the total load on the plant.

3. The control loops must be balanced to bring about the proper working conditions for the control valves and to make primary and secondary flows compatible.

4. Balancing with manual balancing valves gives the possibility to detect most of the hydronic abnormalities and to determine the pump oversizing. The pump head can be adjusted at the correct value, optimising the pumping cost.

5. When the plant is balanced a central controller or optimiser can be used as all rooms react the same way. Moreover, when the average room temperature deviates from the design value, due to absence of balancing, a costly uncomfort may be the result as explained hereafter.

(More about in appendix F)

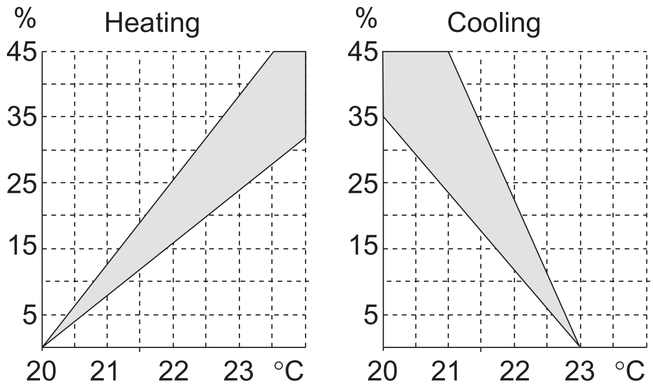


Fig 1.1: Percentage increase in energy costs for every degree too high or too low, relative to design comfort room temperature.

Why is the average temperature higher in a plant that is not balanced? During cold weather it would be too hot close to the boiler and too cold on the top floors. People would increase the supply temperature in the building. People on the top floors would stop complaining and people close to the boiler would open the windows. During hot weather the same applies. It is just that it would be too cold close to the chiller, and too hot on the top floors.

One degree more or less in a single room rarely makes any difference to human comfort or to energy costs. But when the average temperature in the building is wrong, it becomes costly. One degree above 20°C increases heating costs by at least 8 percent in mid Europe (12% in the south of Europe). One degree below 23°C increases cooling costs by 15 percent in Europe (Fig 1.1).

A HVAC system is designed for a specific maximum load. If the plant cannot deliver full capacity in all circuits because it is not balanced for design condition, the investments for the entire plant are not realised. Control valves are fully open when maximum capacity is required and thus cannot manage this situation. Furthermore, control valves are generally oversized and they cannot contribute to balancing. Hydronic balancing is thus essential and represents typically less than two percents of the total HVAC system.

Each morning, after a night set back, full capacity is required to recover the comfort as soon as possible. A well-balanced plant does this quickly. If a plant starts up 30 minutes quicker, this saves 6 percent of the energy consumption per day. This is often more than all distribution pumping costs.

But an important consideration is to compensate for pump oversizing. Balancing valves adjusted with the Compensated Method or the TA Balance Method reveal the degree of pump oversizing. All the overpressure is shown on the balancing valve closest to the pump. Corrective action (e.g. reduce the pump speed or trim the impeller) can then be taken.

Hydronic balancing requires the correct tools, up to date procedures and efficient measuring units. A manual balancing valve is the most reliable and simple product to obtain the correct flows in design conditions. It also allows the flows to be measured for diagnostic.

Three things are necessary:

Flow measuring and regulating devices,
measurement instrument
and a balancing procedure.

Flow measuring and regulating devices

These are:
Balancing valves which are both variable orifice and regulating valves or
Orifice devices with an independent regulating valve.

There is a great difference between balancing valves of different makes. This translates into an equally great difference in the accuracy of indoor climate control, in energy savings—and in the time, cost and effort required to do an adequate balancing job.

TA, whose products are used worldwide, cater for all the different market requirements and offer both fixed and variable flow measuring devices and regulating valves.

These are some of the distinguishing features of TA products:

STAD
STAD balancing valve
15 to 50 mm

STAF
STAF balancing valve
20 to 300 mm

STAP
STAP Differential pressure controller
15 to 100 mm

Balancing valves and orifice devices

- Flow precision for valves better than +/- 10% and for fixed orifices better than +/- 5%.
- Sizes up to 50 mm have four full turns from open to closed position. Larger sizes have eight, twelve or sixteen full turns.
- The valves are available with internal threads, with flanges, with welded or soldered valve ends, with grooved ends and with compression fittings.
- Sizes up to 50 mm are made of Ametal®, probably the only pressure die casting alloy that meets the world’s toughest demands for resistance to dezincification.

Differential pressure controller

- Adjustable set point.
- To stabilize the differential pressure across the control valves and/or circuits.

Measurement instrument

Measuring is required in order to really know that design flows are achieved and also to find what differential pressures that are applied in different parts of the plant. It is also a good tool for trouble-shooting and system analyses.

The balancing instrument CBI from TA has all necessary features to fulfil these demands, eg:

- Measures and documents differential pressure, flow and temperature of STAD, STAF, STAP/STAM and other valves from TA.
- Programmed to calculate presetting values for balancing and also the TA Method and TA Balance.
- Two-way communication with PC.
- Corrects the calculations for antifreeze agents.
- Large storage capacity - can handle 1000 valves and 24 000 values when logging.
- Graphic display making it possible to assign plain-language names for plants and valves.

Proportional relief valve

In variable flow system, a TA BPV valve can be used to perform three distinct functions:

- ensure a minimum flow to protect the pump.
- reduce the temperature drop in pipes.
- limit the differential pressure on the terminal circuits.

The BPV has a shut-off function and preset point of 10–60 kPa. 15 to 32 mm (1/2” to 1 1/4”)

Balancing of the water flows shall be carried out prior to the finetuning of control equipment.
Prepare the balancing carefully. This gives a better final result at less time input.

Acquire drawings and study them for a sound understanding of the principles of the plant's function. Make an on-site inspection to avoid losing time over practical problems such as searching for a key to a locked room or trying to find a non-existent balancing valve.

For detailed instructions, see Appendix E.

3.1 Plan the balancing at your desk

Study the plant drawing carefully

Make an initial study of the plant drawings in order to understand design and operation principles. Identify control loops, distribution system and balancing valves. Divide the plant in modules as explained in section 3.2.

In a four-pipe distribution system, you should prepare separate drawings for the heating circuit and the cooling circuit. Sometimes it may be a good idea to draw up a circuit scheme of principle with all details eliminated that do not concern the balancing work.

Select a suitable balancing method

When you adjust the flow with a balancing valve, the pressure loss changes in the valve and pipe line. Then the differential pressure across other balancing valves also changes. Hence, each flow adjustment disturbs the flow in already adjusted valves. In other words, the circuits are interactive. The main difference between different balancing methods is how they compensate for interaction between circuits. Some methods do not compensate at all. This means the balancer will have to set the same balancing valve several times until the flow finally converges towards the desired flow. Other methods compensate directly or indirectly. Three such methods are the Proportional Method, the TA Compensated Method and the TA Balance Method, which are described in this manual.

The Compensated Method is a further development of the Proportional Method, giving better results with less time input. The TA Balance is the easiest method requiring only one setter and one measuring unit to balance a complete installation.

However, none of these methods can be used to balance distribution systems designed according to the reverse return principle. In that case, you must use an iterative method. That is: go through the entire plant several times and adjust the flows ”by ear” until they correspond reasonably well with design flows, or calculate, manually or by computer, the correct preset values for the balancing valves.

TA manual No. 1 ”Balancing of Control Loops” provides efficient step-by-step methods for the balancing of 23 control loops for two-way and three-way control valves.

3.2 Divide the plant into modules

Theory and practice

In theory, it is sufficient with one balancing valve per terminal unit to create the correct repartition of flows in the distribution system. But this requires that the preset value for all the balancing valves are calculated, that these calculations are made correctly, and that the plant is realised according to the drawings.

If you change one or several flows, all other flows are more or less affected, as previously mentioned. It may require a long and tedious series of corrections to get back to the correct flows.

In practice, it is necessary to divide larger systems into modules and install balancing valves in such a way that readjusting only one or a few balancing valves can compensate a flow adjustment anywhere in the system.

The law of proportionality

The terminals in the figure 3.1 form a module. A disturbance external to the module causes a variation in the differential pressure across A and B. Since the flow depends on the differential pressure, the flows in all terminals change in the same proportion.

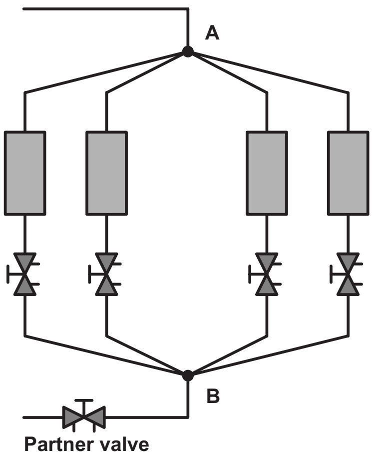


Fig 3.1: An external disturbance has the same effect on each terminal in the module.

The flow through these terminals can therefore be monitored through measurement of the flow in just one of them, which can serve as a reference. A balancing valve common to all terminals can compensate for the effect of the external disturbance on the terminal flows in the module. We call this common valve the Partner valve.

However, terminals are normally connected as in figure 3.2. The water flow through each terminal depends on the differential pressure between A and L. Any modification of this pressure affects the flow in each terminal in the same proportion.

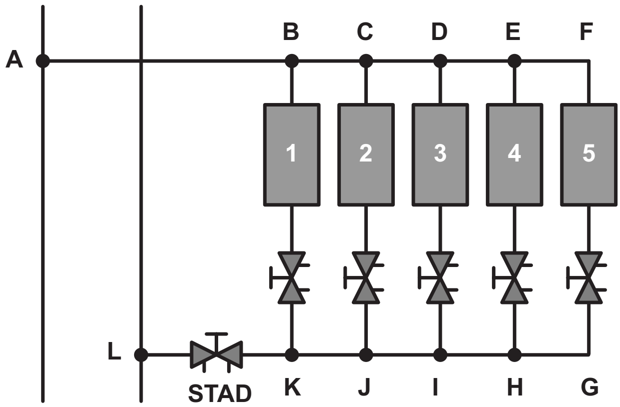


Fig 3.2: A branch with several terminals forms a balancing module. STAD is the Partner valve, which can compensate for external disturbances on the circuits already balanced.

But what happens if we create a disturbance that is internal to the module, for instance by closing the balancing valve of terminal 3?

This will strongly influence the flows in pipes lines CD and IJ, and thus the pressure loss in these pipe lines. The differential pressure between E and H will change noticeably, which will affect the flows in terminals 4 and 5 in the same proportion.

The fact that terminal 3 is closed has little effect on the total flow in the pipe lines AB and KL. The pressure losses in these pipe lines change very little. The differential pressure between B and K is changed only somewhat and terminal 1 will not react to the disturbance in the same proportion as terminals 4 and 5. Thus, the law of proportional flow change does not apply for internal disturbances (as shown in figure 3.3).

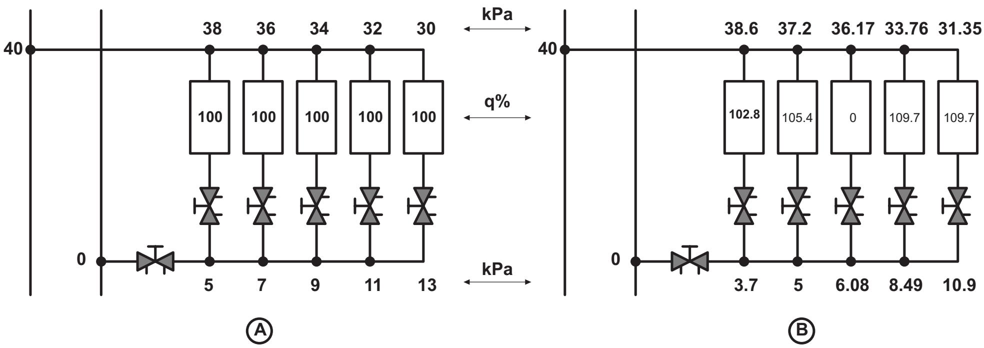


Fig 3.3: At an internal disturbance, the flows do not change in proportion to each other.

However, the water flows change in proportion in a module only if all the pressure drops depend on the flow q according to the same relation everywhere in the module. This is not true in reality because for the pipes the pressure drop depends on $q^{1.87}$, while it depends on q^2 in valves. For low flows, the circulation can become laminar and the pressure drop becomes linearly proportional to the flow. The law of proportionality can be used only to detect deviations around design values. This is one of the reasons why the most accurate balancing method is the Compensated Method described in chapter 5 as the design flows are maintained during the balancing process of each module.

A module can be a part of a larger module

When the terminals on a branch are balanced against themselves, you may see the branch as a ”black box”, i.e. a module. Its components react proportionally to flow adjustment external to the module. The Partner valve can easily compensate such disturbances.

In the next step, the branch modules are balanced against each other with the riser balancing valve as the Partner valve. After this, all modules on the riser form a larger module, whose flow can be adjusted with the riser's balancing valve. Finally, the risers are balanced against each other with each riser as a module and the balancing valve on the main pipe line as the Partner valve.

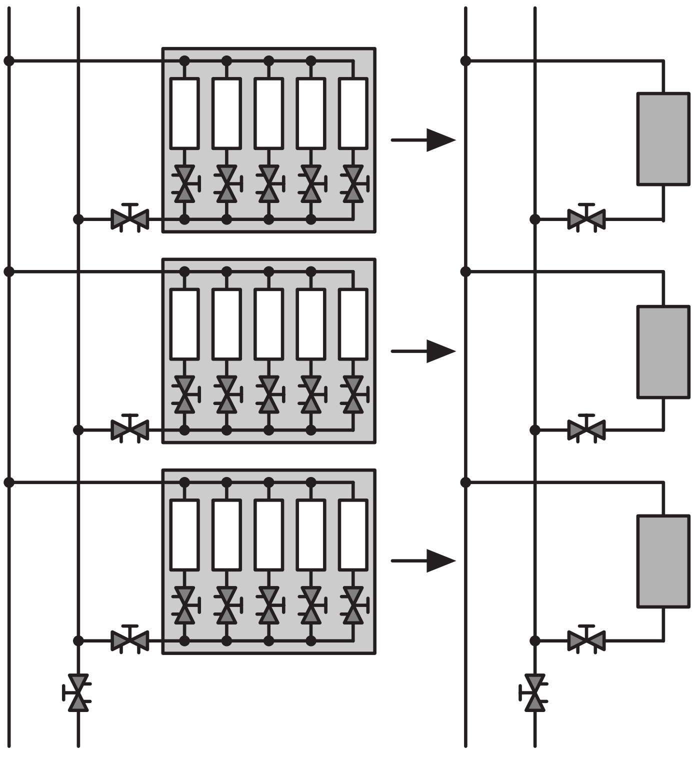


Fig 3.4: Each branch on a riser forms a new module.

What is optimum balancing?

Figure 3.5 shows two modules. The numbers indicate the design pressure loss in each terminal and the pressure loss in each balancing valve. Both modules are balanced. In both cases the differential pressure on each terminal is the required one to obtain design flow. The pressure losses are differently distributed between the balancing valves of the terminals and the Partner valve.

Which balancing is the better of the two?

Optimum balancing means two things: (1) that the authority of the control valves is maximised for exact control, and that (2) pump oversizing is revealed so that pump head and thereby pumping costs can be minimised. Optimum balancing is obtained when the smallest possible pressure loss is taken in the balancing valves of the terminals (at least 3 kPa to allow precise flow measurement). Any remaining excess pressure is taken in the Partner valve.

Balancing to obtain pressure losses as in (b) in the figure is thus the best, since the pressure loss is then the lowest admissible in all balancing valves on the terminals to obtain the design flows. Note that optimum balancing is only possible when the required Partner valves are installed.

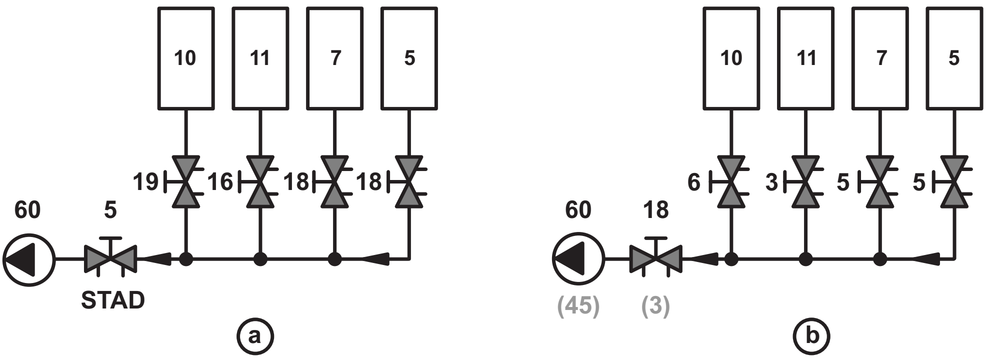


Fig 3.5: A set of terminals can be balanced in many ways, but only one is the optimum.

The Partner valve reveals the excess of differential pressure. The pump speed for instance can be decreased correspondingly and the partner valve reopened. In example ”b”, the pressure drop in the Partner valve and the pump head can be reduced both by 15 kPa, decreasing the pumping costs by 25%.

Where balancing valves are needed

The conclusion is that balancing valves should be installed to split the system in modules that can be balanced independently of the rest of the plant. Thus, each terminal, each branch, each riser, each main and each production unit should be equipped with a balancing valve.

It is then simple to compensate for changes relative to the drawings, for any construction errors, and for oversizing. This saves time and allows optimum balancing. Furthermore, the plant can be balanced and commissioned in stages, without having to rebalance when the plant is completed.

The balancing valves are also used for troubleshooting and shut-off during service and maintenance.

Accuracy to be obtained on flows

We have considered the advantages of hydronic balancing. Before studying balancing procedures, the precision with which flows have to be adjusted has to be defined.

In practice, the flow adjustment precision to be achieved depends on the precision to be obtained on the room temperature. This precision depends also on other factors such as the control of the supply water temperature and the ratio between the required and installed coil capacity. Some specifications stipulate a required water flow accuracy of between +0 and +5%. There is no technical justification for this severity. This requirement is even more surprising that little care appears to be taken about the actual temperature of the supply water to remote units. Particularly, in the case of variable flow distributions, the supply water temperature is certainly not the same at the beginning and at the end of the circuit, and the influence of this water temperature is not negligible. Furthermore, water flows are frequently calculated based on required capacity and they are rarely corrected as a function of the really installed capacity. Oversizing of the terminal unit by 25% should normally be compensated by a water flow reduction in the order of 40%. If this is not done, there is no point in adjusting the water flow to within 5% of accuracy while the required water flow is defined with an initial error of 40%.

An underflow cannot be compensated by the control loop, and has a direct effect on the environment under maximum load conditions; it must therefore be limited. An overflow has no direct consequence on the environment since in theory, the control loop can compensate for it. We may be tempted to accept overflows, especially when they have little effect on the room temperature. This would neglect the pernicious effect of overflows. When the control valves are fully open, for example when starting up the plant, the overflows produce underflows elsewhere and it is impossible to obtain the required water temperature at high loads, due to incompatibility between production and distribution flows. Overflows must therefore also be limited. This is why it is logical to penalise underflows and overflows with the same factor and to adopt a general precision rule in the form ±x%.

Fortunately, when the flow is situated close to the design value, it has no dramatic effect on the room temperature. By accepting a deviation of ± 0.5°C on the room temperature at full load due to water flow inaccuracy, the value of x, with a certain safety factor, is in the order of:

$$x = \frac{\pm 100\,(t_{sc} - t_{ic})}{(t_{sc} - t_{rc})(t_{ic} - t_{ec} - a_{ic})} \quad \text{with}$$

t_{sc} : Design supply water temperature.
t_{ic} : Design room temperature.
t_{rc} : Design return water temperature.
t_{ec} : Design outdoor temperature.
a_{ic} : Effect of internal heat on the room temperature.

Examples:

Heating- t_{sc} = 80°C; t_{rc} = 60°C; t_{ic} = 20°C; t_{ec} = -10°C; a_{ic} = 2°C; x = ±10%.
Cooling- t_{sc} = 6°C; t_{rc} = 12°C; t_{ic} = 22°C; t_{ec} = 35°C; a_{ic} = 5°C; x = ±15%.

Variations in the differential pressure across a circuit change the flow in the circuit terminals in the same proportion. This fundamental principle is the basis for the Proportional Method.

The Proportional Method is shortly described hereafter as the Compensated Method 'chapter 5' or the TA Balance Method 'chapter 6' progressively replace it. For more information, please see the TA Handbook "Total Hydronic Balancing"- second edition 1997- section 5.4.

We will just examine step by step the balancing of one branch of one riser.

1. Measure the flow in all terminals on the selected branch, with the branch balancing valve (STAD-1.2.0) fully open.

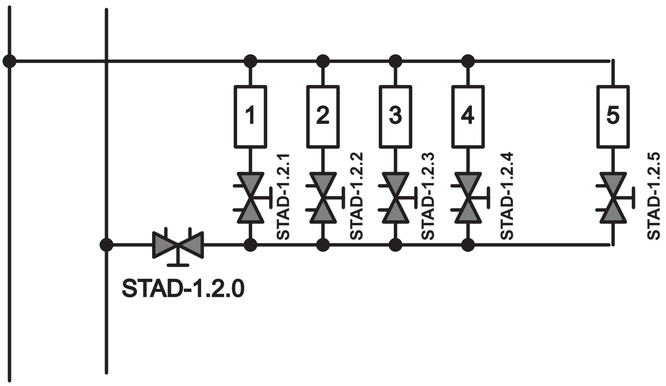


Fig 4.1: Balancing of terminals on a branch.

2. For each one of the terminals, calculate the flow ratio λ: measured flow/design flow. Identify the terminal with the lowest flow ratio λmin. Call it "index unit". If the terminals have the same pressure loss for design flow, terminal 5 normally has the lowest flow ratio since it receives the smallest differential pressure. If the terminals do not have the same pressure loss, any of them may have the lowest flow ratio.

3. Use the balancing valve of the last terminal on the branch as the Reference valve (STAD.1.2.5 in the figure 4.1).

4. Adjust the Reference valve STAD-1.2.5 so that λ5=λmin. Lock STAD-1.2.5 to this setting (screw the inner spindle to stop). Connect a CBI for continuous flow measurement.

5. Set STAD-1.2.4 so that λ4=λ5. This will change the flow ratio λ5 somewhat. If the setting of STAD-1.2.4 changes the flow in the Reference valve by more than 5%, then STAD-1.2.4 must be readjusted so that λ4 becomes equal to the new value of λ5. Lock STAD-1.2.4 to this setting.

6. Adjust the flow in all terminals on the branch. Work your way against the pump according to step 5 above. When STAD-1.2.2 is adjusted, the flow ratio λ5 changes, but λ3 and λ4 remain equal to λ5. Terminal 3, 4 and 5 therefore remain balanced relative to each other. This is the reason why the last terminal is used as the reference. When all terminals are balanced relatively to each other, it is possible to adjust the Partner valve STAD-1.2.0 so that λ5=1. All the other flow ratios λ4, λ3, λ2 and λ1 would then become equal to 1. However, do not carry out this operation since it will be done automatically as you perform the very last balancing operation for the plant.

7. Repeat the same procedure for all branches of the same riser.

Note: Instead of controlling the flow ratio to the Reference valve (circuit 5), it can be done on the last balancing valve adjusted. For instance, after setting the balancing valve of circuit 2, the new flow ratio for all balancing valves of circuits 3-4 and 5 is the same and can be measured on the balancing valve of circuit 3 instead of going to the reference (circuit 5). This can save time for the balancer who has to use two CBI (CBIa and CBIb).

When the circuit 3 is set, the CBIa remains on it. The balancer goes to circuit 2 and adjusts it, with CBIb, for the correct flow ratio. He goes back to circuit 3, he measures the new flow ratio, and removes the CBIa. He readjusts now the flow of circuit 2 and, without removing the CBIb put on this circuit, he goes to circuit 1 with CBIa and so on...

Remember that proportional balancing is only valid when the flow ratios remain close to one (see remark at the end of section 3.2), this condition is fulfilled only with the Compensated Method.

5. The Compensated method

(TA Method)

The Compensated Method is a further development of the Proportional Method, with three main advantages:

Staged commissioning: *You can balance the plant in stages as construction goes on, without having to rebalance the entire building when it is completed.*

Quicker commissioning: *It reduces time consumption significantly since it is not necessary to measure the flows in all balancing valves and calculate all flow ratios. It also requires just one flow adjustment at each balancing valve.*

Pumping costs may be minimised: *When balancing is finished, you can read off the pump oversizing directly on the main balancing valve. The pump head may be reduced correspondingly. Frequently, large energy savings can be made, particularly in cooling plants.*

5.1 A development of the Proportional Method

The Compensated Method is based on the Proportional Method, but is further developed in one essential aspect: Using the Compensated Method, *the flow ratios are automatically kept equal* to 1 throughout the balancing process of a module (see remark at the end of section 3.2).

a) Staged commissioning

- The plant may be divided in modules. This means that the plant can be commissioned in stages, as construction goes on, and no rebalancing of the entire building is required after completion.

b) Quicker commissioning

- No first scan to measure the flows in all branches and risers. No calculation of flow ratios to determine the starting point of balancing.
- Balancing can start at any riser (although you should close the risers you are not balancing).
- No worrying about causing a too high flow for the main pump. No worrying about the differential pressure being too small to produce measurable flows.
- Only one flow adjustment at each balancing valve is required.

c) Pumping costs may be minimised

- The Compensated Method automatically minimises pressure losses in the balancing valves. The main balancing valve reveals any oversizing of the main pump. The pump may often be exchanged for a smaller one.
- The set point of a variable speed pump can be optimised.

5.2 Reference valve and Partner valve

When the flow is adjusted by a balancing valve, pressure losses change in the valve and pipe line, thereby changing the differential pressure across other balancing valves. Flow adjustment in one balancing valve thus changes the flow in valves that have already been adjusted. This often makes it necessary to adjust the same balancing valve several times over.

The Compensated Method eliminates this difficulty. The flow in each balancing valve is only adjusted once. The method assumes that it is possible to measure the flow disturbance occurring when a balancing valve is adjusted, and that the disturbance can be compensated in some way.

The disturbance is detected on the balancing valve furthest away from the pump, in this module. This balancing valve is called the Reference valve.

A balancing valve acting on the total branch flow, called the Partner valve, compensates for the disturbance. With this valve, the differential pressure across the Reference valve can be reset to its initial value each time a disturbance occurs.

The method begins by adjusting the flow to design value in the Reference valve, according to a particular procedure presented below. The result is a certain differential pressure ΔpR (Fig 5.1), which is to be monitored continuously. The Reference valve is then locked to this setting.

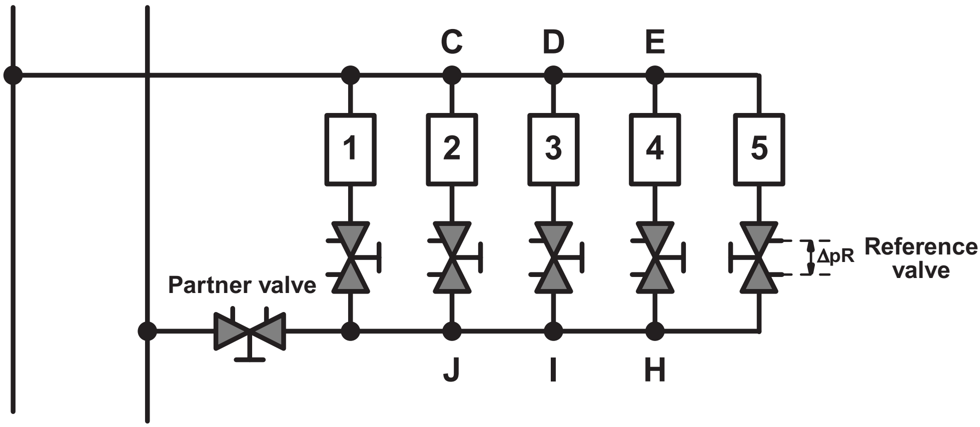


Fig 5.1: The Reference valve is always located in the module and on the terminal furthest away from the pump. The Partner valve determines the total flow in the branch.

Since the flow is now correct, the pressure losses are also correct in terminal 5, its balancing valve and accessories. The differential pressure ΔpEH is therefore correct and we may proceed to adjust the flow in terminal 4.

When the flow in terminal 4 is being adjusted, ΔpR changes slightly in the Reference valve, whose setting is locked. This is an indication of the disturbance from the flow adjustment in terminal 4.

ΔpR must be readjusted to its initial value with the Partner valve. In other words, design flow must be readjusted in the Reference valve by compensating on the Partner valve.

Since the flows in terminal 4 and 5 are now at their design values, the differential pressure ΔpDI across terminal 3 is also equal to the design value. The flow in this terminal may therefore be adjusted.

Adjustment of the flow in terminal 3 creates a disturbance, which is detected at the Reference valve and compensated on the Partner valve. The readjustment of design flow in terminal 5 automatically brings the differential pressure ΔpEH and the flow in terminal 4 to design value.

This procedure works well regardless of the number of terminals on a branch. Adjustments must be carried out by working towards the pump, beginning at the Reference valve. The same procedure is then applied for balancing of risers. The last branch on the riser furthest away from the pump is used as the reference, and the riser's balancing valve becomes Partner valve.

5.3 Setting the Reference valve

Select ΔpR as small as possible but big enough to meet the following two conditions:

• Minimum of 3 kPa to obtain sufficient measurement accuracy.

The CBI balancing instrument indicates flow for differential pressures down to 0,5 kPa. However, to decrease the relative influence of the pressure pulsation in the plant on the flow measurement, we recommend ΔpR > 3 kPa.

The Kv value may be calculated for a pressure loss of at least 3 kPa using the formula:

Kv = 5,8 x q (m3/h) or Kv = 21 x q (l/s)

Another and simpler way, is to let the CBI calculate the correct setting of the Reference valve.

• The pressure drop in the valve fully open and at design flow.

If the pressure loss is greater than 3 kPa for design flow and the balancing valve fully open, it is obviously not possible to set the Reference valve to create 3 kPa. This represents the second condition on the ΔpR: at least as high as the pressure loss across the fully open balancing valve at design flow. In this case, the balancing valve on the reference is just fully open.

When a suitable ΔpR is selected, preset the Reference valve to create ΔpR for design flow. Use the CBI or a nomogram to find the correct handwheel setting. Then lock the handwheel.

To obtain the selected ΔpR, and thus design flow, adjust the Partner Valve. This is always possible since the other risers are closed and the pressure loss in the main pipe line is small. The available differential pressure is thus higher than normal. The surplus will be taken in the Partner valve.

If the pressure losses differ substantially between the terminals, please refer to section 5.8.

5.4 Equipment needed

Two CBI balancing instruments are needed to measure differential pressures and flows in the balancing valves.

5.5 Balancing terminals on a branch

Select any riser, for instance the one closest from the pump. This ensures a sufficient differential pressure for the selected riser. Select any branch in the riser you have selected. Normally, you do not have to shut any of the other branches of this riser. However, if some branches are provided with a bypass line, which can create short circuits, the flow in these branches has to be limited or these branches isolated.

1. Determine which is the handwheel position of the Reference valve that will give design flow at the selected ΔpR (normally 3 kPa). Use the CBI or a nomogram to find the correct handwheel position.
2. Adjust the Reference valve to this position and lock the valve (turn the inner spindle down to stop).
3. Connect one CBI to the Reference valve.
4. Balancer (1) adjusts the Partner valve to obtain the selected ΔpR in the Reference valve. Information about current value of ΔpR is transmitted to Balancer (1) from Balancer (3) by means of a walkie-talkie for instance. This operation gives design flow in terminal 5. If the selected ΔpR cannot be reached, the cause may be that non balanced terminals on the branch are passing a too high flow. Shut as many of them as required to obtain the selected ΔpR.

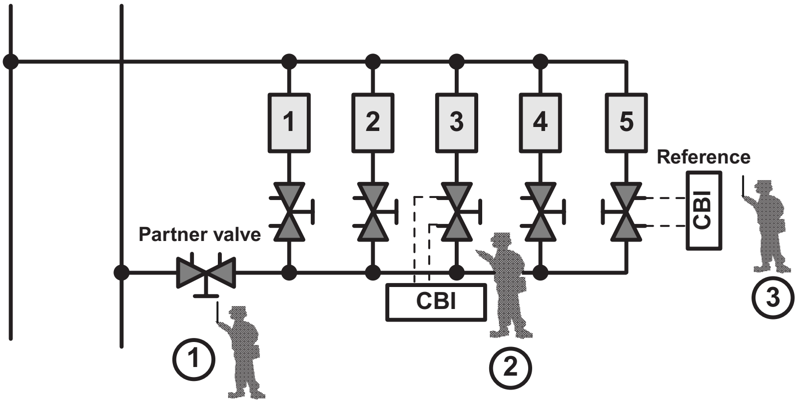


Fig 5.2: Balancing of terminals on a branch.

5. Balancer (2) now adjusts the flow to design in terminal 4 by using the CBI computer function. It calculates which handwheel position that will give design flow. During the whole procedure, balancer 1 continuously readjusts the partner valve to maintain ΔpR to its initial value.

6. Balancer (2) adjusts the flows in each terminal by working successively towards terminal 1, according to step 5 above. All terminals on the branch are now balanced relative to each other, independently of the current differential pressure applied on the module.

Note: Let us suppose working with two balancers (1 and 2) and two CBI (CBIa and CBIb). When adjusting terminal 3 for instance, with CBIa, the balancer can check the change of the flow in terminal 4 (CBIb) instead of going to the reference (terminal 5). He communicates with balancer 1 to readjust the flow at terminal 4, takes back the CBIb put on this terminal and eventually he readjusts the flow at terminal 3. He leaves the CBIa put on terminal 3 and goes with CBIb to terminal 2, following the same procedure and checking the flow evolution at terminal 3. Repeat proceedure for all valves.

5.6 Balancing branches on a riser

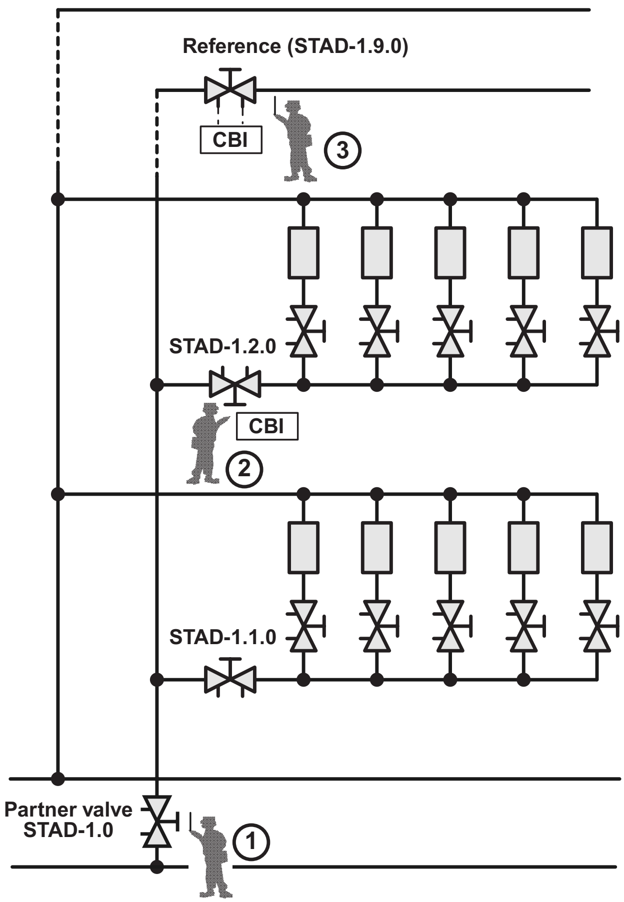


Fig 5.3: Balancing branches on a riser.

1. Find out the handwheel position for the Reference valve STAD-1.9.0 that will give design flow for the selected ΔpR, normally 3 kPa. Use the CBI or a nomogram to find the correct position.
2. Adjust the Reference valve to this handwheel position and lock the valve (turn the inner spindle down to stop).
3. Connect one CBI to the Reference valve.
4. Balancer (1) adjusts the Partner valve to create the selected ΔpR in the Reference valve. This then gives the design flow in the reference branch. If the selected ΔpR cannot be obtained, the cause may be that some branches on the riser are passing a too high flow. Then close as many branches as required to obtain the selected ΔpR.

5. Balancer (2) now adjusts to design flow in branch 1.2.0 by using the CBI computer function. It calculates the handwheel position that will give design flow. During the whole procedure, balancer 1 continuously readjusts the partner valve to maintain the flow in the reference to its initial value.
6. Balancer (2) adjusts the flows in each branch by working successively towards branch 1.1.0 according to the procedure in step 5 above. All branches on the riser are now balanced relative to each other independently of the current differential pressure available on the riser.

5.7 Balancing risers on a main pipe line

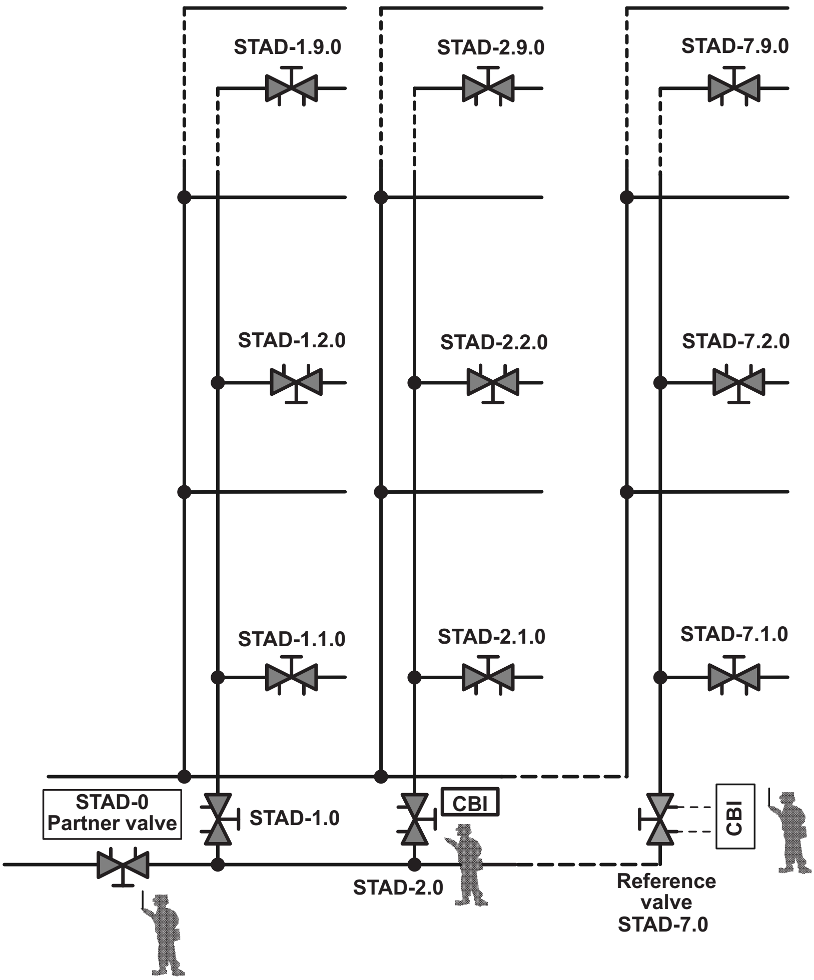


Fig 5.4: Balancing of risers.

The balancing procedure is exactly the same as for balancing of branches on a riser. The Reference valve is now STAD-7.0 and the Partner valve is STAD-0.

When balancing of risers 7.0, 6.0, 5.0 etc., is completed, the entire plant is balanced for design flows and the remaining pressure loss in STAD-0 reveals the pump oversizing. If the excess pressure is large, it may be profitable to change the pump for a smaller one.

When using a variable speed pump, the STAD-0 is not necessary. The maximum speed is adjusted to obtain the correct design flow in the Partner valve of one riser. All the other flows will be automatically at design value.

5.8 Setting the Reference valve when pressure losses differ substantially between the terminals

If the terminals pressure losses differ substantially, a ΔpR of 3 kPa in the Reference valve may not be sufficient to give the necessary differential pressure for the other terminals. This problem is solved in the Proportional Method by using the same flow ratio for the Reference valve as the flow ratio measured in the index circuit. But the Proportional Method often overestimates the ΔpR and balancing is not optimised (unnecessarily high pressure loss in the balancing valves). A way to achieve a suitable value for ΔpR is presented below.

The branch in figure 5.6 has terminals with different pressure losses.

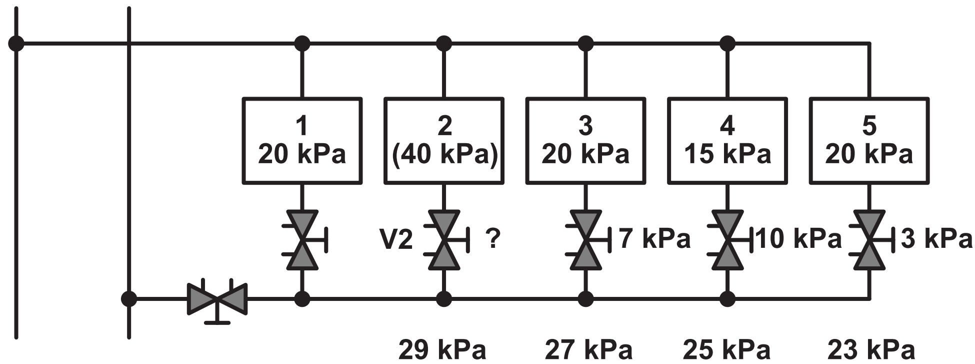


Fig 5.6: If 3 kPa is selected for the Reference valve, the differential pressure may be too low for the index circuit, here terminal 2.

Select ΔpR based as recommended in section 5.3, normally 3 kPa. We call this preliminary value ΔpRo. Proceed with balancing according to the Compensated Method.

When you reach the index circuit, you will note that it is impossible to obtain design flow since the differential pressure is only 29 kPa, while it would take more than 40 kPa to obtain design flow. Perform the following steps:

1. Shut the balancing valve (V2) of the index circuit and readjust the correct flow in the reference with the Partner valve. Measure the differential pressure across V2. Call this value Δpo.
2. Preset V2 so that its pressure drop will be approximately 3 kPa for design flow.
3. Open the partner valve to obtain the design flow in the index circuit.
4. Measure the flow in the reference circuit. Calculate the flow ratio λ = flow measured/design flow.
5. The new value of ΔpR to be set on the Reference valve is given by the formula:

$$\text{New } \Delta pR = \Delta pRo + \Delta po \text{ x } (\lambda^2 - 1)$$

6. Preset the Reference valve to obtain this pressure loss for design flow, and *rebalance the entire branch.*

Compared with fig 5.6, the result of this procedure is given in fig 5.7.

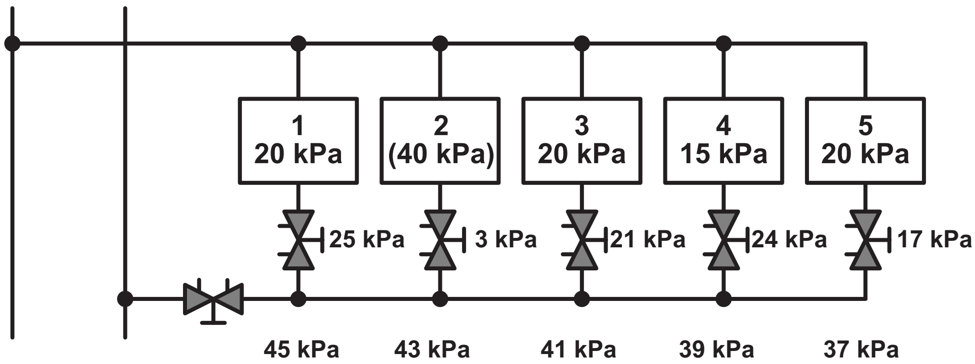


Fig 5.7: Differential pressure across circuits and pressure losses in balancing valves and terminals.

The TA Balance Method is a computer program built into the CBI balancing instrument with the same three main advantages of the Compensated Method plus the possibility for one man and one CBI to balance an entire system:

These advantages are the following:

***Staged commissioning:** You can balance the plant in stages as construction goes on, without having to rebalance the entire building when it is completed.*
Quicker commissioning: It reduces time consumption significantly since it is not necessary to measure the flows in all balancing valves and calculate all flow ratios. It also requires just one flow adjustment at each balancing valve.

***Pumping costs may be minimised:** When balancing is finished, you can read off the pump over-sizing directly on the main balancing valve. The pump pressure may be reduced correspondingly. Frequently, large energy savings can be made, particularly in cooling plants.*

***One man and one instrument:** After having carried out pressure and flow measurements, the program calculates the correct settings of the balancing valves in order to achieve the desired flows.*

The program assumes that the plant is divided into modules. Let us remember that a module is created out of several circuits connected in direct return to the same supply and return pipes. Each circuit has its own balancing valve and the module has a common balancing valve called the Partner valve.

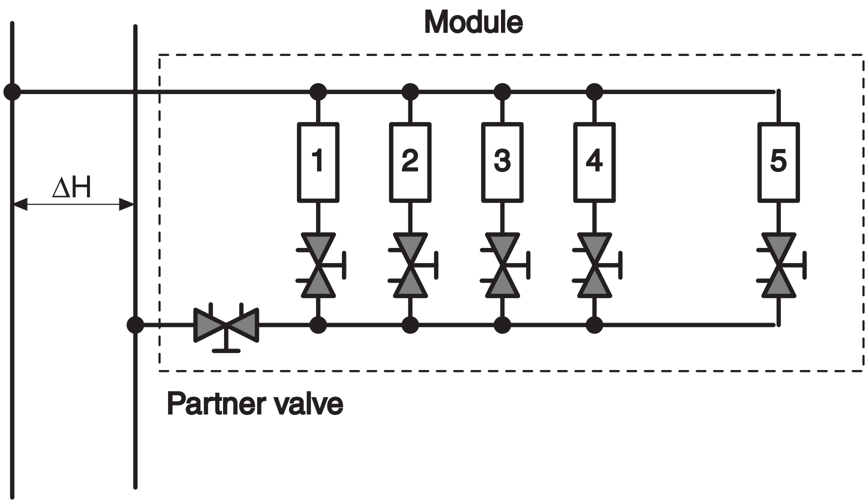


Fig 6.1: A module is created of several circuits connected to the same supply and return pipes.

6.1 Preparing the procedure

During the measurements, the differential pressure ”ΔH”, at the inlet of the module, should be constant. The value of this ”ΔH” is not important unless there is insufficient pressure to obtain good measurements. For this reason, the risers or modules not yet balanced, which can create big overflows, have to be isolated. To be sure that the pressure drops in the balancing valves will be sufficient to obtain a correct measurement, set the balancing valves on 50% opening (STAD = 2 turns), or at the precalculated positions if any. The Partner Valve of the module to be balanced must be fully open during the procedure.

The TA Balance Method demands that the valves be numbered according to the figure 1. The first valve after the Partner valve must be number one, with following valves being numbered successively (See Fig 6.1). The Partner valve is not numbered.

6.2 The procedure

Measure one module at a time.

CBI gives directions on the display of each step of the procedure.

For each valve in the module, in any order, the following procedure is applied:

1. Enter the reference number, type, size and current position (e.g. 1, STAD, DN 20, 2 turns).
2. Enter the desired flow.
3. A flow measurement is then automatically performed.
4. Shut the valve completely.
5. A differential pressure measurement is automatically performed.
6. Reopen the valve to its original position.
7. When all the balancing valves in the module have been measured, the CBI requires the measurement of the Δp across the Partner valve in the fully shut position.

When all these procedures have been carried out, the CBI calculates the correct handwheel setting for the balancing valves within the module. Adjust the balancing valves to these settings.

The CBI has ”discovered” the index circuit (the circuit requiring the highest differential pressure) and has given the index balancing valve the minimum pressure drop that is necessary to measure the flow correctly. This value is normally 3 kPa, but can be changed if you want. The settings of other balancing valves are calculated automatically to obtain a relative balancing of the elements in the module. These settings do no depend on the current differential pressure ΔH applied on the module.

At this moment, the design flows are not yet achieved. This will happen when the Partner valve has been adjusted to its correct flow. This operation is carried out later on in the procedure.

6.3 Balancing the modules of a riser between themselves

When all the modules in one riser have been balanced individually, these modules are balanced between themselves. Each module is now looked upon as a circuit whose balancing valve is the Partner valve in the module. The balancing procedure consists of calculating the setting of the Partner valves of modules 1, 2 and 3 of the riser, using the TA Balance Method.

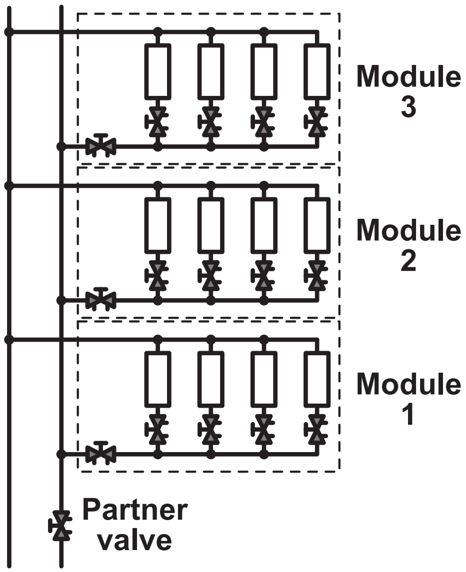


Fig 6.2: The riser module is created of modules 1, 2 and 3 when these are calculated and set.

This riser module should now be measured and calculated in the same way as described earlier.

6.4 Balancing the risers between themselves

When all risers have been balanced individually, they constitute a module. The Partner valve of this module is the main balancing valve associated with the pump.

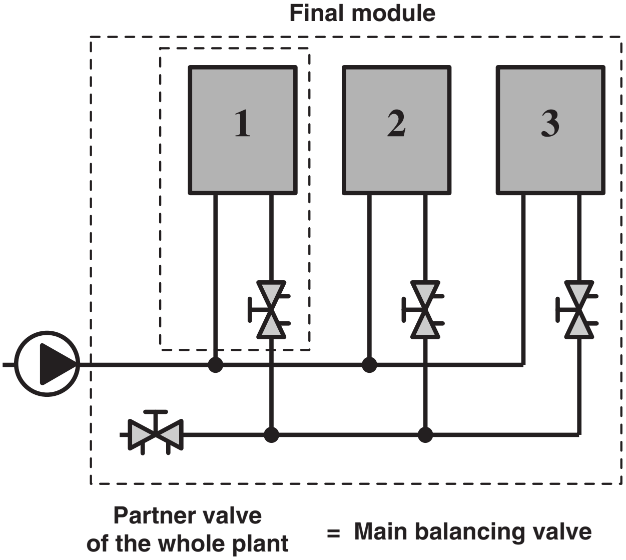


Fig 6.3: All the risers constitute the final module

In this new module, the risers are balanced between themselves following the same procedure.

Finally, the total flow is adjusted with the main balancing valve. When this operation is completed, all circuits in the plant will have the desired flows. To verify this, flow measurements can be done on some balancing valves.

Printout via a PC provides a list of settings and verified data if these values have been stored in the CBI.

All the overpressure is located in the main balancing valve. If this overpressure is important, the maximum pump speed can be reduced (variable speed pump), or with a constant speed pump, the impeller may be changed to reduce the pump head to save pumping costs. In some cases, the pump oversizing is so high that the pump is changed for a smaller size.

With a variable speed pump, the main balancing valve is not necessary. The maximum speed is adjusted to obtain the design flow in the Partner valve of one of the risers. All the other flows will be automatically at design value.

Notes:

1. During the measurements in one module, external disturbances (isolation of an other riser ...) have to be avoided. They may create some errors in the mathematical model elaborated by the CBI and some deviations in the flows obtained with the settings calculated.

2. When measuring the differential pressure across a balancing valve fully shut, remember that the mechanical protection of the CBI will intervene automatically when this differential pressure is higher than 200 kPa.

3. TA Balance Method is generally the fastest balancing method, as it requires only one engineer using this very simple procedure. However, in comparison with the Compensated Method, the engineer has to visit more times each balancing valve (to make the measurements). Consequently, if the balancing valves are very difficult to reach, the Compensated Method can be sometimes more economical.

7.1 Variable flow system with balancing valves

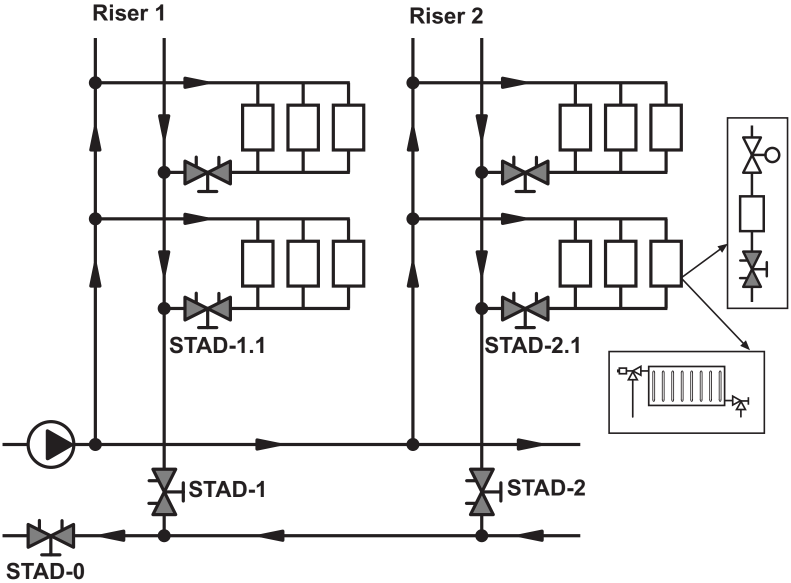


Fig 7.1: General example of a hydronic distribution.

The system is divided in modules.

STAD-1.1 is the Partner valve of the first branch of the first riser.

STAD-1 is the Partner valve of the riser module and STAD-0 is the main Partner valve.

When the terminal units are radiators, the thermostatic valves are preset based on a pressure drop of 10 kPa for design flow. Hydronic balancing is normally done before installing the thermostatic heads.

To balance this typical system, we recommend the Compensated Method (chapter 5) or the TA Balance Method (chapter 6). The main balancing valve STAD-0 shows the pump-oversizing and suitable adjustment of the pump is made accordingly. If the pump is a variable speed pump, STAD-0 is not required; the speed of the pump is adjusted to obtain the design flow in the balancing valve of one of the risers.

7.2 System with BPV and balancing valves

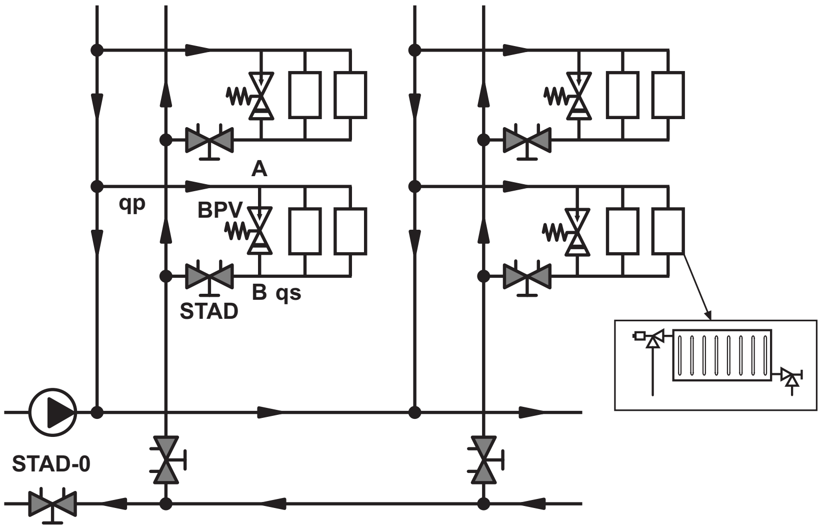


Fig 7.2: On each branch a pressure relief valve keeps constant the differential pressure AB.

This system is mainly used in heating plants with radiators.

On each branch, serving several radiators or terminal units, the balancing valve is associated with a pressure relief valve BPV.

If some terminal control valves shut, the differential pressure AB has the tendency to increase. If this differential pressure increases above the set point of the BPV, the BPV starts to open. The increasing flow in the BPV creates a sufficient pressure drop in the balancing valve STAD to keep approximately constant the differential pressure across A and B. Without a balancing valve, the BPV, open or shut, will be submitted directly to the differential pressure between supply and return riser pipes. The BPV cannot alone stabilise the secondary differential pressure, it must be associated with a balancing valve.

The radiator valves are preset based on a pressure drop of 10 kPa for design flow. The plant is balanced as for figure 7.1 with all BPV fully shut. When the plant is fully balanced, the setting of the BPV is chosen equal to the 10 kPa adopted for the thermostatic valves plus 5 kPa, that means 15 kPa. There are other ways to set the BPV but the method suggested above is the simplest.

Example:
The primary differential pressure available is 40 kPa. During the balancing procedure a pressure drop of 27 kPa was created in the branch-balancing valve to obtain the correct water flow of 600 l/h in the branch. That means a differential pressure of 40 - 27 = 13 kPa between A and B at design condition. The radiator valves have been set for a differential pressure of 10 kPa, but to obtain the total correct flow, this differential pressure of 10 kPa has to be situated in the middle of the branch, with more than 10 kPa at its beginning (13 kPa).

Now let us consider that some thermostatic valves shut, decreasing the secondary flow qs. The table below gives some values showing the evolution of the flows and differential pressure.

Secondary flow qs	**Flow in BPV**	**Δp AB**	**Primary flow qp**
600	0	13.0	600
576	1	15.0	577
562	14	15.1	576
400	162	16.5	562
100	430	18.9	530
0	525	20.6	525

Table 7.1: When the thermostatic valves shut, the BPV opens progressively.

As the primary flow has only decreased from 600 l/h to 525 l/h, the primary differential pressure of 40 kPa remains practically unchanged.

The BPV starts to open when ΔpAB reaches the set point of 15 kPa. When all thermostatic valves are shut, the differential pressure ΔpAB reaches 20,6 kPa instead of more than 40 kPa without the BPV.

The main balancing valve STAD-0 shows the pump-oversizing and suitable action on the pump is made accordingly. If the pump is a variable speed pump, STAD-0 is not required; the speed of the pump is adjusted to obtain the design flow in the balancing valve of one of the risers.

7.3 System with STAP on each riser

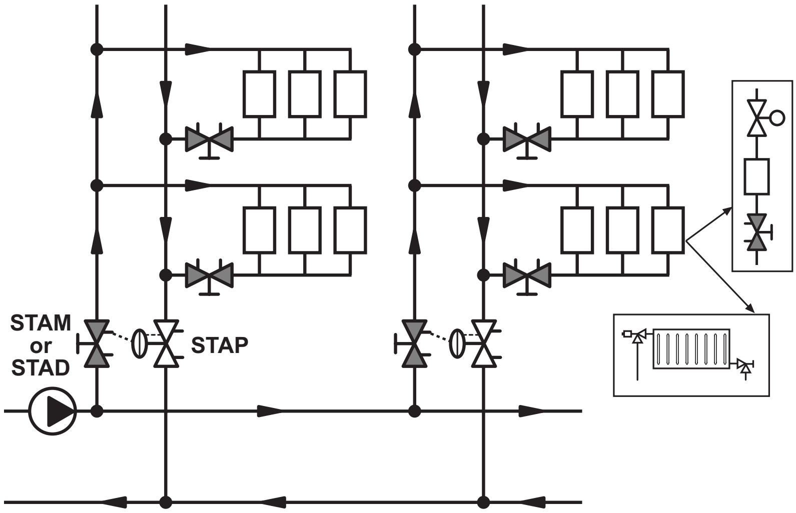


Fig 7.3: A controller STAP stabilises the differential pressure on each riser.

For large systems, the pump head may be too high or variable for some terminals. In this case, the differential pressure is stabilised at the bottom of each riser, at a suitable value, with a STAP differential controller.

Each riser is a module that can be considered independent from the others for the balancing procedure. Before starting the balancing of one riser, its STAP should be put out of function and fully open to be sure of obtaining the required water flows during the balancing procedure. An easy way to do it is to shut the drain on the STAM or STAD in the supply and to purge the top of the membrane (Plug a CBI needle in the top of the STAP).

When the terminals are radiators, the thermostatic valves are first preset at design flow for a differential pressure of 10 kPa.

When each terminal has its own balancing valve, the terminals are balanced against themselves on each branch before balancing the branches against themselves with the Compensated Method or the TA Balance Method.

When a riser is balanced, the set point of its STAP is adjusted to obtain the design flow that can be measured with the STAM (STAD) valve situated at the bottom of this riser. The risers are not balanced between themselves.

Note:
Some designers provide a pressure relief valve (BPV) at the end of each riser to obtain a minimum flow when all control valves are shut. Another method is to provide some terminal units with a three-way valve instead of a two-way control valve. Obtaining this minimum flow has several advantages:

1. The flow of water in the pump does not drop below a minimum value.
2. When the water flow is too low, the pipes heat losses create a higher ΔT in the pipes and the circuits remaining in function cannot deliver their full capacity if required as their supply water temperature is too low in heating or too high in cooling. A minimum flow in the circuit reduces this effect.
3. If all the control valves shut, the differential control valve STAP will also shut. All the return piping of this riser decreases in static pressure as the water is cooling down in a closed area. The differential pressure across the control valves will be so high that the control valve that reopens first will be extremely noisy. The minimum flow created avoids such a problem.

The setting of the BPV is done according to the following procedure:

- The STAP being in normal operation, all the branches of the riser are isolated.
- The STAM(STAD) is preset to obtain at least a pressure drop of 3 kPa for 25% of design flow.
- The BPV is set to obtain 25% of the riser design flow measurable at STAM(STAD).
- The STAM(STAD) is then reopened fully and all branches are put again in normal operation.

7.4 System with STAP on each branch

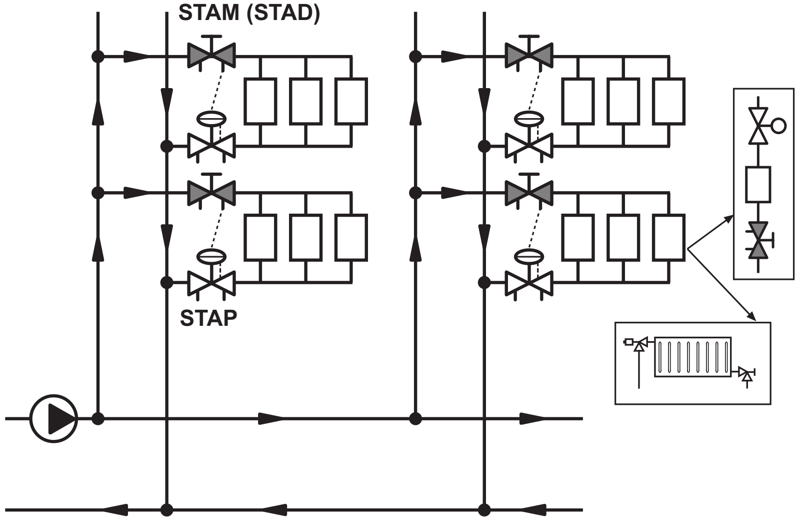


Fig 7.4a: A controller STAP stabilises the differential pressure on each branch.

The differential pressure being stabilised on each branch, the terminals are supplied with a convenient differential pressure. Each branch is balanced independently of the others.

When the terminals are radiators, the thermostatic valves are first preset for a differential pressure of 10 kPa at design flow.

When each terminal has its own balancing valve, they are balanced between themselves using the Compensate method or the TA Balance Method.

When a branch is balanced, the set point of its STAP is adjusted to obtain the design flow that can be measured with the STAM (STAD) valve situated at the supply of the branch

Some designers provide a pressure relief valve (BPV) at the end of each branch to obtain a minimum flow when all control valves are shut. This gives simultaneously a minimum flow for the pump when all terminal control valves are shut. See the note in section 7.3 and also the example hereafter.

It is not necessary to balance the branches between themselves and the risers between themselves.

Example:
It is quite common to provide each apartment of a residential building with one STAP according to figure 7.4b. An On-Off control valve is associated with a room thermostat to control the ambience.

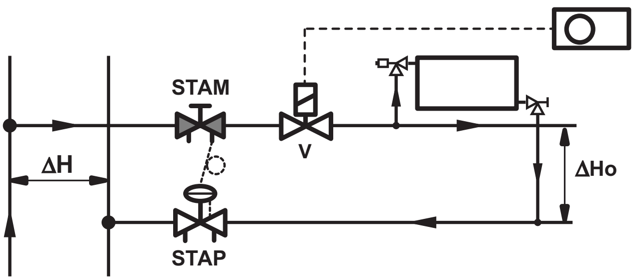


Fig 7.4b: Wrong design with the control valve situated downstream the measuring valve STAM.

When the control valve is situated as in the figure 7.4b, the differential pressure ΔHo corresponds with the differential pressure obtained with the STAP minus the variable pressure drop in the control valve V. So ΔHo is not really well stabilised.

A second problem is the following: When the control valve ”V” shuts, the STAP is submitted to the primary differential pressure ΔH and it also shuts. All the ”secondary” circuit decreases in static pressure as the water is cooling down in a closed area. The Δp across valve ”V” and STAP increases dramatically. When the control valve ”V” starts to reopen, it can probably be very noisy due to cavitations in the valve ”V”. This problem can be solved if the control valve is placed on the return, close to the STAP.

The correct design for the system is shown in figure 7.4c.

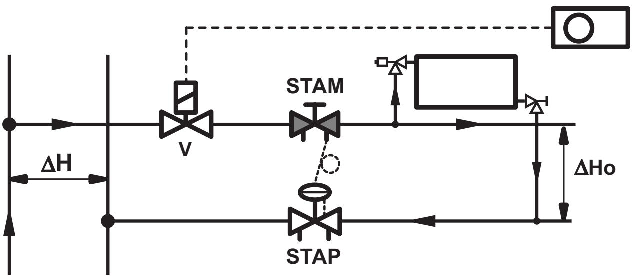


Fig 7.4c: The control valve is situated upstream the measuring valve STAM.

In figure 7.4c, when the control valve shuts, the differential pressure ΔHo drops to zero and the STAP opens fully. The secondary circuit remains in contact with the distribution and its static pressure remains unchanged, avoiding the problem discussed for figure 7.4b. Moreover, the differential pressure ΔHo is much bettered stabilised.

As we can see, a small change in the design of the system can modify dramatically its working conditions.

7.5 System with STAP on each two-way control valve

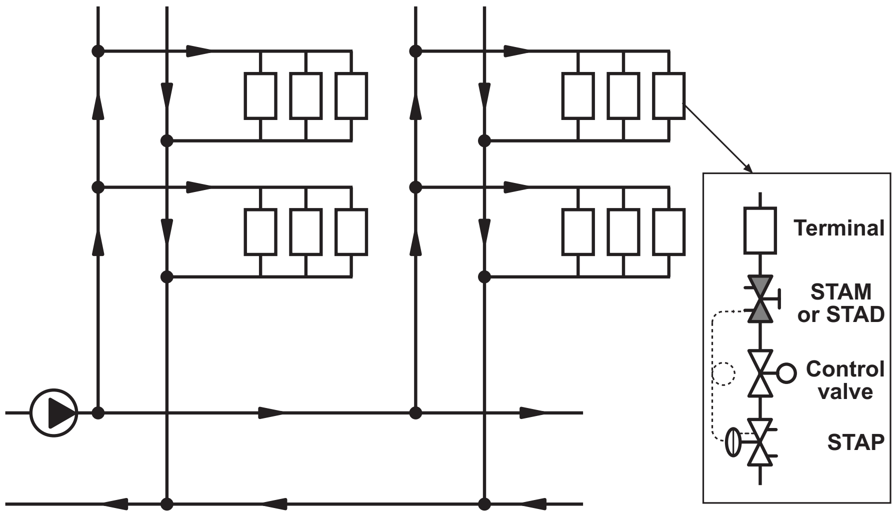


Fig 7.5: The differential pressure is kept constant on each control valve with a STAP.

Each control valve is associated with a Δp controller STAP. From the control point of view, this is the best solution. Furthermore automatic balancing is obtained.

For each terminal successively, the control valve is fully open and the set point of the STAP is chosen to obtain the design flow. Each time the control valve is fully open, the design flow is obtained and the control valve is never oversized. As the differential pressure across the control valve is constant, its authority is close to one.

The balancing procedure is limited to the above description. Terminals, branches and risers are not to be balanced between them as this is obtained automatically.

What happens if only some control valves are combined with STAP and the others are not?

In this case, we are back to figure 7.1 with balancing valves installed on branches and risers. The complete balancing is made with the STAPs fully open. Please note that a STAD is recommended in this case instead of a STAM. This STAD is used as a normal balancing valve during the balancing procedure. When the plant is balanced, the procedure for each STAP successively is as follows:

- The STAD coupled with the STAP is reopenned and preset to obtain at least 3 kPa for design flow.
- The set point of the STAP is adjusted to obtain the design flow across its control valve fully open, the flow being measured by means of the balancing valve STAD.

7.6 Constant flow distribution with secondary pumps

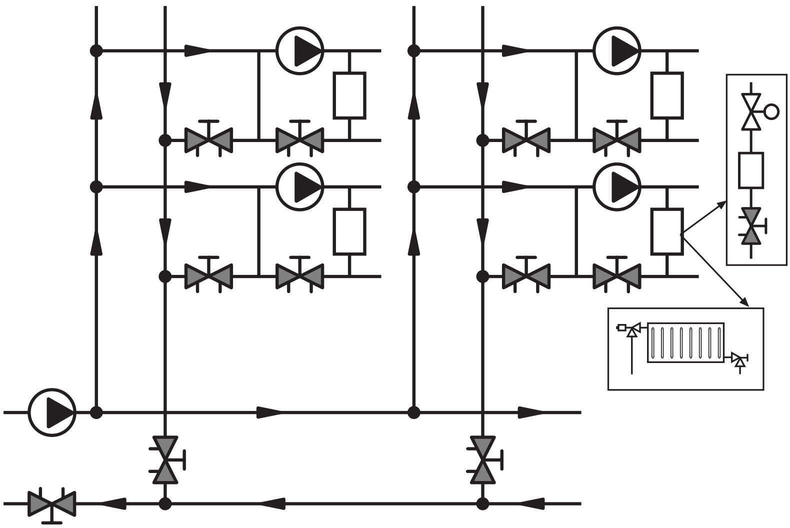


Fig 7.6: Constant flow distribution in the primary side and variable flow in the secondary circuits.

When there is just only one production unit, a constant flow distribution is the most suitable choice. The head of the primary pump has just to cover the pressure drops in the production unit and the primary distribution pipes. Each circuit is provided with a secondary pump.

To avoid interactivity between the primary pump and the secondary pumps, each circuit is provided with a bypass line.

Each circuit is balanced independently of the others.

The primary circuit is balanced separately as for system 7.1 with the following remark: to avoid a short circuit with extreme overflows, it is recommended that all balancing valves on the primary distribution are set to 50% opening before starting the balancing procedure.

7.7 Constant flow distribution with three-way valves

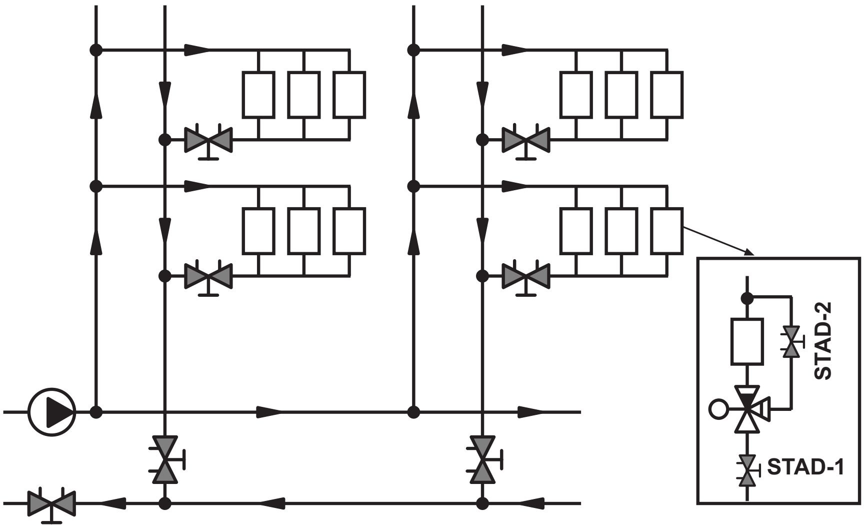


Fig 7.7: The primary flow is maintained constant with a three-way valve in diverting function on each terminal.

The balancing of this system is the same as for figure 7.1. For each three-way valve, a balancing valve STAD-1, in the constant flow, is essential for the balancing procedure. The balancing valve STAD-2 in the bypass has normally to create the same pressure drop as for the coil. In this case, the water flow will be the same when the three-way valve is fully open or fully shut. However, this balancing valve STAD-2 is not necessary when the design pressure drop in the coil is lower than 25% of the design differential pressure available on the circuit.

7.8 Domestic hot water distribution with balancing valves

In domestic hot water distribution, temperature of the water in the pipes drops significantly when consumption is low or zero. As a result, people have to wait a long time to obtain hot water when required. Moreover, below 55°C, the bacteria (Legionella) proliferate dangerously.

To keep the water hot, a permanent circulation is maintained in pipes to compensate for heat losses. A circulation pump is therefore installed guaranteeing a minimum flow q_1 in the loop (Fig 7.8a)

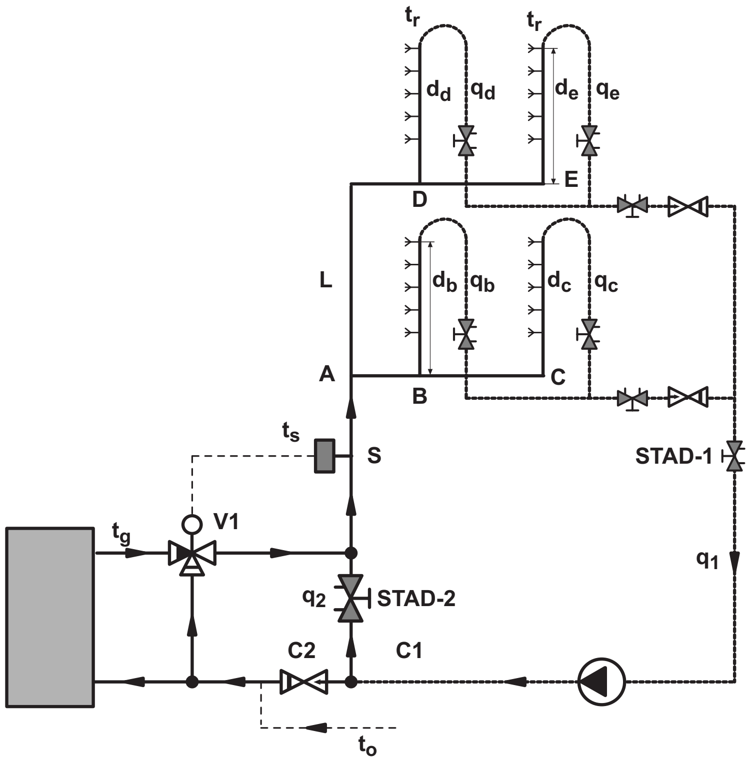


Fig 7.8a: A circulation pump maintains the temperature of water distribution.

Determination of circulation flows

If we accept the most unfavoured user is supplied at a temperature of ΔT below the water supply temperature ts, we can calculate the minimum circulation flow q_1.

$$q_1 = \frac{0.86\ P_m}{\Delta T}$$

where:

P_m: Heat losses in Watt of the **supply** pipes.
Pipes concerned: $\Sigma L + \Sigma d = [SA+AC+AE] + [d_b+d_c+d_d+d_e]$.

ΔT: Admissible temperature drop (5K).

q_1 : In l/h.

For a ΔT of 40K between the water and the ambience, the heat losses are situated around 10W/metre, independently of the pipe diameter. This is valid if the thickness of the insulation in mm (λ=0.036) equals 0.7 x external pipe diameter (without insulation).

Obviously the best procedure is normally to calculate flows according to the insulation installed. A much better estimation can be done using the following empirical formula:

$$P = \frac{\Delta T}{40}\left(3 + \frac{5\ de}{3.5 + \frac{0.036\ I}{\lambda}}\right)$$ with P in W/m, de external pipe diameter in mm (without insulation)

I = thickness of the insulation in mm, λ in W/m.K.
For ΔT = 40 and λ = 0.036 (Foam glass), this formula becomes:

$$P = \left(3 + \frac{5\ de}{3.5 + I}\right)$$ with de < 100 mm.

If the distribution is well balanced, a wrong estimation of the total flow does not seem dramatic. If the flow is reduced by 50%, and for a supply water temperature of 60°C, the most unfavoured user will have 51°C instead of 55°C. In this case however, the risk of proliferation of legionella increases.

Hereafter, in the examples, we will consider the following hypothesis:
ts = 60°C, tr = 55°C and P = 10 W/metre. Consequently:

$$q_1 = \frac{0.86 \times 10}{(60-55)}(\Sigma L + \Sigma d) = 1.72\ (\Sigma L + \Sigma d)$$

The total flow being known, we have to calculate the flow in each branch. Starting from point S (Fig7.8a) where the temperature sensor is located, the water temperature at the inlet of branch A can be calculated.

$$t_A = t_S - \frac{0.86\ P_{SA}}{q_1}$$ with P_{SA} = heat losses section SA.

For the first branch, the pipes heat losses are $Z_{AC} = P_{AC}+Pd_b+Pd_c$. So we can calculate successively the temperatures at the nodes and the required flows as shown hereafter.

$q_{AB} = \dfrac{0.86\ Z_{AC}}{t_A - 55}$	$t_B = t_A - \dfrac{0.86\ P_{AB}}{q_{AB}}$	$q_b = \dfrac{0.86\ P_{db}}{t_B - 55}$
$q_{BC} = q_{AB} - q_b$	$t_C = t_B - \dfrac{0.86\ P_{BC}}{q_{BC}}$	$q_c = \dfrac{0.86\ P_{dc}}{t_C - 55}$

The flow $q_{AD} = q_1 - q_{AB}$, so we can calculate t_D and the second branch as above. This systematic and simple procedure can be used even for complicated systems.

Knowing the flows, the plant can be balanced normally, using the Compensated Method or the TA Balance Method.

For a rough estimation of the pump head, the pressure losses in the supply pipes can be neglected. Considering just the return pipes, we suggest H [kPa]= 10+0,15 (L_{SE}+de) +3 kPa for each balancing valve in series (3 in this example). If L_{SE}+de = 100 metres for example, H = 10+15+9 = 34 kPa. In this formula we consider 10 kPa pressure drop for the exchanger, check valve and accessories and a pressure drop in the return pipes of 0.15 kPa/m.

Considering just the branch AC in figure 7.8a, but with 4 distribution circuits, we can use the above formulas to calculate the flows. These formulas can be translated in another form, more suitable for a systematic calculation. This other form is explained based on an example hereafter.

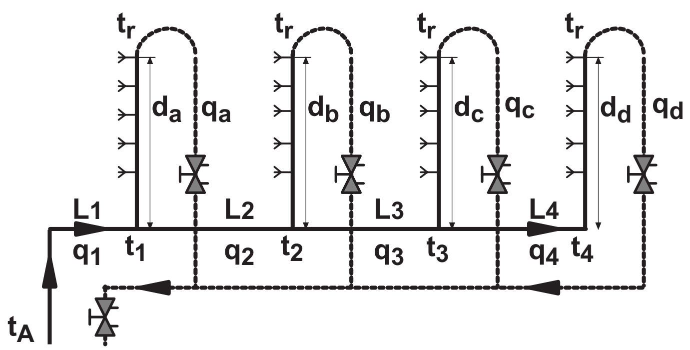


Fig 7.8b: One branch of the distribution with 4 circuits.

Following lengths of pipe (in metres) have been adopted:

L_1	L_2	L_3	L_4
40	25	20	35
d_a	d_b	d_c	d_d
10	9	11	12

Pipe lengths in metres.

The temperature at the supply of the branch is tA and the expected return temperature is t_r. For instance t_A = 59°C (considering 1°C loss between S and A in figure 7.8a) and t_r = 55°C.

For a $\Delta T = t_A - t_r$ = 4K, and heat losses per metre of pipe equals 10 W/m in average, the total flow q_1 is:

$$q_1 = 0.86 \text{ x } 10\ (\Sigma Li+\Sigma di)/(t_A - t_r)$$

so

$$q_1 = 2.15\ (40+25+20+35+10+9+11+12) = 348 \text{ l/h.}$$

$$\text{and } t_1 = (t_A - 8.6\ L_1/q_1)$$

In order to obtain a more convenient formula, let us transform it in the following way:

$t_1 = 8.6((t_A - t_r)/8.6 - L_1/q_1)+t_r$. We call $(t_A - t_r)/8.6 = \lambda$ and $D_1 = \lambda - L_1/q_1$

Finally $t_1 = 8.6\ D_1 + t_r$. In this example $\lambda = 0.465$.

$D_1= \lambda\text{-}L_1/q_1$	$q_a=d_a/D_1$	$q_2=q_1\text{-}q_a$	$t_1 = 8.6\ D_1+t_r$
$D_2=D_1\text{-}L_2/q_2$	$q_b=d_b/D_2$	$q_3=q_2\text{-}q_b$	$t_2 = 8.6\ D_2+t_r$
$D_3=D_2\text{-}L_3/q_3$	$q_c=d_c/D_3$	$q_4=q_3\text{-}q_c$	$t_3 = 8.6\ D_3+t_r$
$D_4=D_3\text{-}L_4/q_4$	$q_d=d_d/D_4$		$t_4 = 8.6\ D_4+t_r$

Formulas used.

These formulas can be extended the same way for more circuits. We have used them to calculate the flows. *Calculations of the temperatures are not necessary but are given for information.*

D_1=0.465-40/348=0.351	q_a=10/0.351= 29	q_2=348-29=319	t_1=8.6x0.351+55=58.0
D_2=0.351-25/319=0.272	q_b= 9/0.272= 33	q_3=319-33=286	t_2=8.6x0.272+55=57.3
D_3=0.272-20/286=0.202	q_c=11/0.202= 54	q_4=286-54=232	t_3=8.6x0.202+55=56.7
D_4=0.202-35/232=0.051	q_d=12/0.051=232	q_4 is obviously = qd	t_4=8.6x0.051+55=55.4

Numerical calculations.

Let us point out that the last circuit requires 67% of the branch flow while the first circuit requires only 8%. On the contrary, if the distribution is not balanced, the first circuit will receive more flow than the last circuit.

A rough estimation of the required pump head is:

$$H=10+0.15\ (40+25+20+35+12)+3\text{x}3=39 \text{ kPa.}$$

7.9 Domestic hot water distribution with TA-Therm

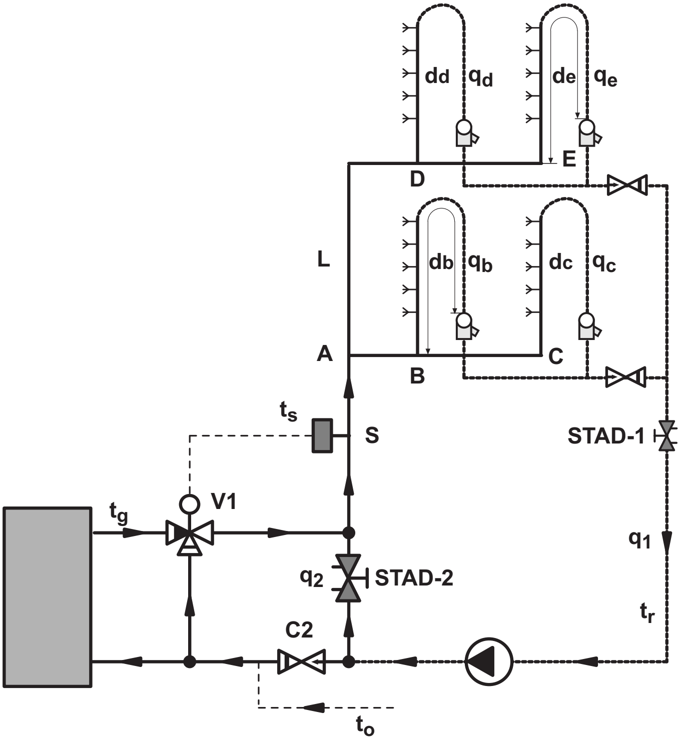


Fig 7.9: The return temperature of each branch is maintained automatically.

The return of each circuit is provided with a thermostatic valve (TA-Therm) that maintains the return water temperature at an adjustable value. A thermometer may be incorporated in the TA-Therm to measure the temperature obtained. The circulation flows are calculated (See figure 7.8b) to size the return pipes and the pump. For the most remote circuits, the pump head is roughly estimated as follows (for TA-Therm with a Kv=0.3):

$$\text{Circuit } q_e : H = 10 + 0.15\,(SE + d_e) + (0.01\, q_e / 0.3)^2 + 3$$
$$\text{Circuit } q_c : H = 10 + 0.15\,(SC + d_c) + (0.01\, q_c / 0.3)^2 + 3$$

The highest value of H is adopted.

The Kv of 0.3 given above corresponds with a deviation of 2°C, of the water temperature, relatively to the set point of the TA-Therm.

The Presetting method

The presetting method requires that the designer calculates the correct preset values for all balancing valves and notes them on the drawing. The advantage of this method is that it is rather simple for the installer to preset all balancing valves in conjunction with the installation.

The pressure losses at design flow are determined for each terminal and accessories (control valve, pipeline, valves and bends). The pressure losses between the pump and the least favoured circuit are summed up, giving the necessary pump head.

A pump with the nearest available standard pump head is than selected to meet the flow demand in the least favoured circuit. The difference between the head of the selected pump and theoretically necessary pump head is an excess pressure applied to the system. If it is significant, it should be eliminated in some way. In variable-flow systems, control valves may be resized to take up as much as possible of the excess pressure. The remaining difference can be compensated in balancing valves.

Preset values and flows are noted on the plant drawings. This considerably simplifies the task when balancing the plant.

Since the presetting method is applied on the drawing board, corrections will be necessary when the plant is completed. Plants are rarely installed exactly according to the drawings. Changes affect the flows. Real flows and changes relative to drawings must be noted in the final balancing report.

Recalculation of flows when terminals are oversized

When capacity demands are known, the flows for different terminals are also defined, provided that plant ΔT is selected. Use these formulas to calculate the flow:

$$q = \frac{0.86\ P}{\Delta T_c}\ (l/h) \quad \text{or}$$

$$q = \frac{0.86\ P}{4186\ \Delta T_c}\ (l/s)$$

But the terminals do not necessarily work with the design supply temperature. Neither is it to be taken for granted that terminals with the exact design output are installed in the plant. A terminal with a smaller capacity is rarely selected, but rather with the nearest higher standard value relative to the design requirements.

The capacity of a terminal is defined by the manufacturer under nominal conditions (subscript ”n”). Assume that a terminal is working under other conditions than the nominal conditions, for instance at another supply temperature, and that it is oversized a little. If we know the current supply temperature and the oversizing, we may recalculate the flow to see which flow is really required. This required flow is normally given by the manufacturers.

Use this formula for radiators:

$$t_r = t_i + \frac{(t_{sn} - t_{in})\ (t_{rn} - t_{in})}{(t_s - t_i)\ (P_n / P_c)^{2/n}} \qquad \text{with}$$

t_r = return water temperature (t_{rn} for nominal condition)
t_s = supply water temperature (t_{sn} for nominal condition)
t_i = room temperature (t_{in} for nominal condition)
P_c = Capacity in watt required for the radiator.
P_n = Capacity in watt, in nominal condition, really installed

If n in (2/n) is not given by radiator manufacturer, use n = 1.3.

Example:
A radiator shall give a design output of P_c = 1000 Watt at a room temperature of t_i = 22°C. The supply temperature is t_s = 75°C. The capacity of the installed radiator is P_n = 1500 W, defined for a supply temperature of t_{sn} = 80°C, a return temperature of t_{rn} = 60°C and a room temperature of t_{in} = 20°C.

What should be the flow in the radiator?

If we insert the values above in the formula, the return temperature t_r = 46°C. The real temperature drop is then ΔT = 75-46, that is 29K, and the flow q = 0.86x1000/29, that is 30 l/h.

Sizing of balancing valves

A balancing valve that is bigger than necessary does not only cost more. It also has to be adjusted close to its shut position, which may give poor flow accuracy.

The best operating range for a balancing range is between 50 and 100% of the maximum valve opening. Therefore, select the balancing valve so that the required pressure loss is obtained within this range, for the design flow.

At pressure losses below 3 kPa, the measurement accuracy is reduced because of disturbances before the balancing valve from pump, control valves, bend, etc. The formulas below can be used to size the balancing valve when the Δp to create is known.

$$Kv = \frac{0.01 \text{ x } q}{\sqrt{\Delta p}} \qquad q \text{ (l/h)}, \quad \Delta p \text{ (kPa)}$$

$$Kv = \frac{36 \text{ x } q}{\sqrt{\Delta p}} \qquad q \text{ (l/s)}, \quad \Delta p \text{ (kPa)}$$

Example:

A balancing valve has to create a pressure drop of 15 kPa for a flow of 2000 l/h. According to the formula above, Kv = 5.16.

The balancing valve having the nearest Kvs (table below) above 5.16 is the STAD20.

When the pressure drop required is unknown, selection may be done according to the table below

Table of selection								Pressure drop in pipes in Pa/m				Velocity in pipes in m/s			
STAD	Kvs	Water flow		Water flow		Valve open		Valve size + 1		Valve size		Valve size + 1		Valve size	
DN		l/h		l/s		Δp in kPa		Min	Max	Min	Max	Min	Max	Min	Max
10	1,47	100	430	0,028	0,119	0,5	8,6	17	390	76	1332	0,14	0,59	0,23	0,97
15	2,52	350	750	0,097	0,208	1,9	8,9	62	244	268	1085	0,27	0,57	0,48	1,04
20	5,7	650	1600	0,181	0,444	1,3	7,9	61	312	184	990	0,31	0,77	0,49	1,21
25	8,7	1300	2400	0,361	0,667	2,2	7,6	55	167	213	664	0,36	0,66	0,62	1,15
32	14,2	2000	3800	0,556	1,056	2,0	7,2	57	183	119	391	0,41	0,77	0,55	1,04
40	19,2	2800	5700	0,778	1,583	2,1	8,8	33	119	104	390	0,35	0,72	0,57	1,15
50	33,0	4500	11000	1,250	3,056	1,9	11,1	19	77	100	408	0,23	0,57	0,57	1,39
STA-DR															
15	2,00	200	450	0,056	0,125	1,0	5,1	21	97	96	438	0,15	0,34	0,28	0,62
20	2,00	200	600	0,056	0,167	1,0	9,0	7	53	21	167	0,10	0,29	0,15	0,46
25	4,01	600	1200	0,167	0,333	2,2	9,0	13	48	53	193	0,16	0,33	0,29	0,57
STAF		m3/h		l/s											
65	95,1	10	25	2,78	6,94	1,1	6,9	38	208	84	467	0,52	1,30	0,72	1,79
80	120	18	38	5,00	10,56	2,3	10,0	31	125	113	463	0,56	1,17	0,94	1,98
100	190	33	60	9,17	16,67	3,0	10,0	34	105	96	297	0,67	1,22	1,02	1,85
125	300	55	95	15,28	26,39	3,4	10,0	35	97	89	251	0,77	1,33	1,12	1,94
150	420	90	150	25,00	41,67	4,6	12,8	24	63	90	235	0,74	1,24	1,26	2,09
200	765	150	270	41,67	75,00	3,8	12,5	20	60	63	189	0,78	1,41	1,24	2,22
250	1185	270	420	75,00	116,67	5,2	12,6	25	58	60	138	1,00	1,55	1,41	2,19
300	1450	400	650	111,11	180,56	7,6	20,1	29	71	53	131	1,16	1,88	1,48	2,40

Selection of balancing valves to avoid oversizing when the pressure drop required is not known.

Example:
A balancing valve must be chosen for a water flow of 2000 l/h. The pressure drop required is not known. The flow being situated between 1300 and 2400 l/h, a STAD25 is selected.

For 2000 l/h, the pressure drop in a steel pipe DN25 is 530 Pa/m (See figure C1). As this pressure drop is too high, the selected size of the pipe is probably DN32.

It is also possible to choose a STAD32 to have the same diameter as the pipe. To obtain at least 3 kPa in a STAD32 for 2000 l/h, the STAD32 has to be set on position 3.45 (86% opening), (above 80% open is normally acceptable).

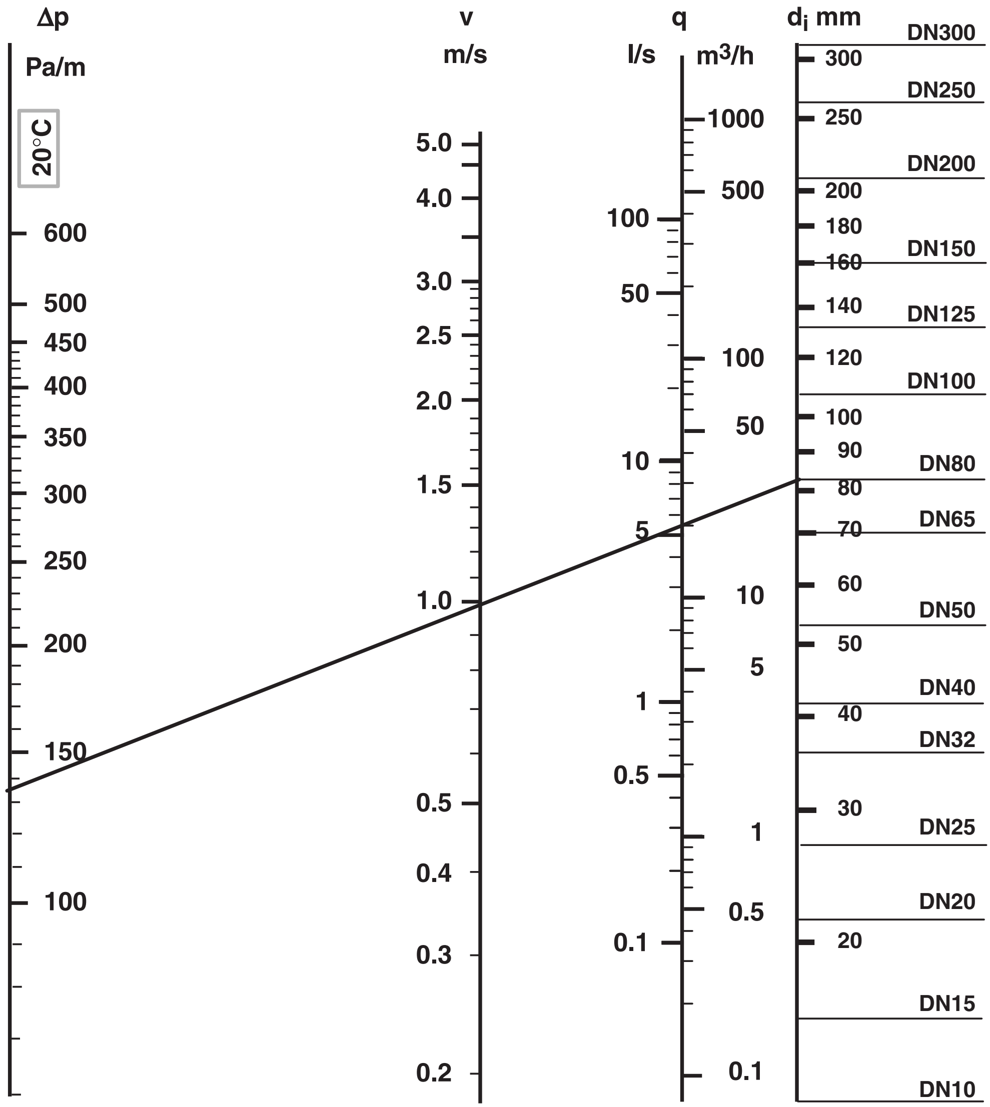


Fig C1: Pressure drops and velocities (steel pipes with a roughness of 0.05 mm) for water at 20°C.

This diagram gives the possibility to check if the size of the balancing valve chosen is compatible with the size of the pipe. Generally, the size of the pipe is the same or one size above the size of the balancing valve.

Example:

Pipe DN 80 and water flow 20 m^3/h: Velocity = 1m/s and Δp = 135 Pa/m

With this pipe, STAF65 and STAF80 are normally accepted.

Installation of balancing valves

In order to ensure accurate flow measurement to have balancing valves, it is normally sufficient with a straight pipe line of five pipe diameters before the balancing valve, and two pipe diameters after the valve.

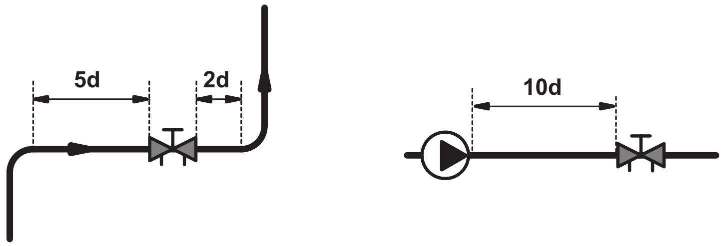


Fig D1: Straight pipe line before and after a balancing valve.

If the balancing valve is installed after something that creates strong disturbances, as for instance a pump or a control valve, we recommend a straight pipe line of minimum 10 pipe diameters before the balancing valve. Do not install anything in this pipe line that can create disturbances (like temperature sensors).

In supply or return?

Hydraulically, it makes no difference whether the balancing valve is located in the supply or in the return pipe. The supply water flow is of course the same as the return water flow.

However, it is customary to place balancing valves in the return pipe, particularly when the balancing valve contains a draining device located in such a way that the adjacent terminal can be drained. It is always preferable to install it so that the flow tends to open the valve (figure below) since this gives a more precise flow measurement and reduces the risk of noise.

In practice, balancing valve may be installed at the most accessible location, as long as turbulence before the valve is avoided.

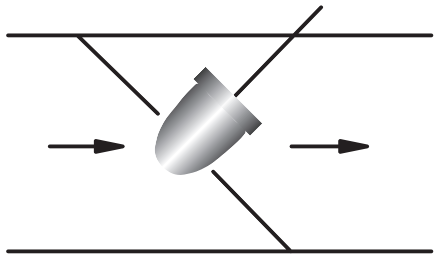


Fig D2: The flow tends to open the valve.

Detailed instructions for the preparation work

It happens that balancers have to waste time searching for simple items like a key to get into a room where a balancing valve is located, or to find a ”lost” balancing valve in a false ceiling, or to access practically inaccessible pressure tapping points.

A preliminary on-site inspection may save a lot of unnecessary work time, particularly in large plants. Such an inspection may involve the following:

- Check the drawings so that all flows are clearly noted for all balancing valves. Check also that the total flow corresponds to the partial flows. In a branch, for example, the sum of the terminal flows must be the same as the total flow in the branch.
- Check that the drawings show the plant as built. If necessary, correct principle circuit schemes and flows.
- Identify all balancing valves, and make sure they are accessible. Check their size and label them.
- Check that the piping is cleaned, that all filters are cleaned and that the piping is deaired.
- Check that all non-return valves are installed in the correct direction and that they are not blocked.
- If the terminals are oversized, check whether the flows have been recalculated (see Appendix B).
- Pressure losses in pipes vary by 20% between 20°C and 80°C. It is therefore important that balancing is carried out with the same temperature everywhere in the system.
- Charge the batteries for the CBI balancing instrument, and check that you have all other tools available and in good shape.

Just before you start

- Prepare report forms and the necessary equipment.
- Check that the static pressure is sufficient.
- Check that all shut-off valves are in the correct position.
- In radiator systems with thermostatic valves, you should remove the thermostats so that the valves open.
- Check all pumps for proper rotation. In the case of variable speed pump, check that the pump is running on full speed.

General design recommendations

The design of a hydronic plant depends on its characteristics and working conditions. However, for any variable flow distribution system with direct or reverse return, constant or variable speed pump, modulating or on-off control, the following recommendations are relevant:

1. Balance the plant hydraulically in design conditions. This ensures that the installed capacity can be delivered. There is no difference if modulating or on-off mode has been selected for control of the terminal units, they must be fully open.

2. Use either the Compensated Method or the TA Balance computer program for balancing of the plant. This avoids any scanning of the plant and significantly reduces labour costs. These two methods reveal pump oversizing and make it possible to reduce pumping costs.

3. Select modulating two-way control valves carefully based on:
   a) Correct characteristic (normally equal percentage).
   b) Correct size: the control, when fully open and at design flow, must take at least 50% of the available circuit differential pressure under design conditions.
   c) The control valve authority should not drop below 0.25.

4. If the last condition 3c cannot be fulfilled for some circuits, a local differential pressure controller is installed in these circuits to improve the control valve authority and decrease the risk of noise.

5. When using a variable speed pump, locate the differential pressure sensor to achieve the best compromise between the desire to minimise pumping costs and limit the differential pressure variations across all the control valves.

More about ”Why balance?”

Hydronic balancing - a necessity for good control

In theory, modern HVAC systems can satisfy the most demanding requirements for indoor climate and operating costs. In practice, however, not even the most sophisticated controllers always perform as promised. As a result, comfort is compromised and operational costs are higher than expected.

This is often because the mechanical design of the HVAC plant does not meet some conditions necessary for stable and accurate control. Three important conditions are:

1. The design flow must be available at all terminals.
2. The differential pressures across the control valves must not vary too much.
3. Flows must be compatible at system interfaces.

F.1 The design flow must be available at all terminals

Common problems

These problems are typical indications that condition number one (i.e. that the design flow is not available at each terminal) is not met:

- Higher than expected energy costs.
- Installed capacity is not deliverable at intermediate and/or high load.
- Too hot in some parts of the building, too cold in other parts.
- Long delay before the desired room temperatures are obtained when starting up after night setback.

Obtaining the correct flows

The power transmitted by a terminal unit depends on the supply water temperature and the water flow. These parameters are controlled to obtain the required room temperatures. Control is only possible if the required water flows are available.

Some people, however, seem to think that it is sufficient to indicate design flows on the drawings in order to obtain them in the pipes. But to obtain the required flows, they must be measured and adjusted. This is why specialists are convinced that hydronic balancing is essential. The discussion is limited to the question: how to do it? Is it, for instance, possible to obtain a correct flow distribution by sizing the plant carefully? The answer, in theory, is yes. But in practice it’s just a dream.

Production units, pipes, pumps and terminals are designed to cover the maximum needs (unless the plant is calculated with a diversity factor). If a link of the chain is not properly sized, the others will not perform optimally. As a result, the desired indoor climate will not be obtained and the comfort will be compromised.

One might think that designing the plant with some security factors would prevent most problems. However, even if some problems are solved that way, others are created, particularly on the control side. Some oversizing cannot be avoided, because components must be selected from existing commercial ranges. These generally do not fit the calculations made. Moreover, at design stage, the characteristics of some components are not known since the contractor will select them at a later stage. It is then necessary to make some corrections taking also into account the real installation, which frequently differs somewhat from the initial design.

Hydronic balancing enables the required flows to be obtained, compensates for oversizing and justifies the investments made.

Distribution systems with constant flow

In a distribution system with constant flow (Figure F.1a), the three-way valve is calculated to create a pressure drop at least equal to the design pressure drop in the coil ”C”. This means a control valve authority of at least 0.5, which is essential for good control. If the pressure drop in the coil plus the pressure drop of the control valve is 20 kPa and the available differential pressure ΔH is 80 kPa, then the balancing valve STAD-1 must take the difference of 60 kPa away. If not, this circuit will experience an overflow of 200%, making control difficult and disturbing the rest of the plant.

In figure 1b, the balancing valve STAD-2 is essential. Without it, the bypass AB will be a short circuit with an extreme overflow, creating underflows elsewhere in the plant. With STAD-2, the primary flow q_p is measured and adjusted to be a somewhat higher than the secondary design flow qs measured and adjusted with STAD-3. If qs > qp, the water flow reverses in the bypass AB, creating a mixing point on A. The supply water temperature will increase in cooling and decrease in heating and the design capacity will not be obtainable on the terminal units.

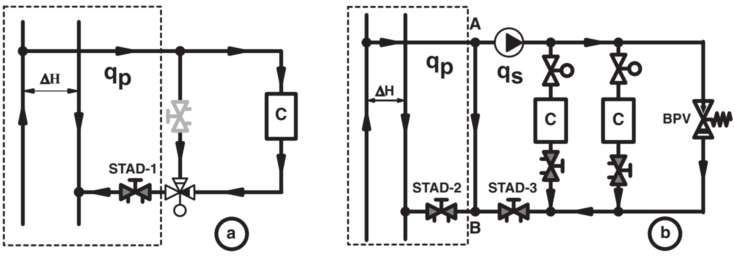


Fig F.1: Examples of circuits in constant flow distribution systems.

Balancing ensures correct flow distribution, prevents operational problems and lets controllers really control.

Distribution system with variable flow

In a distribution system with variable flow, underflow problems occur essentially at high loads.

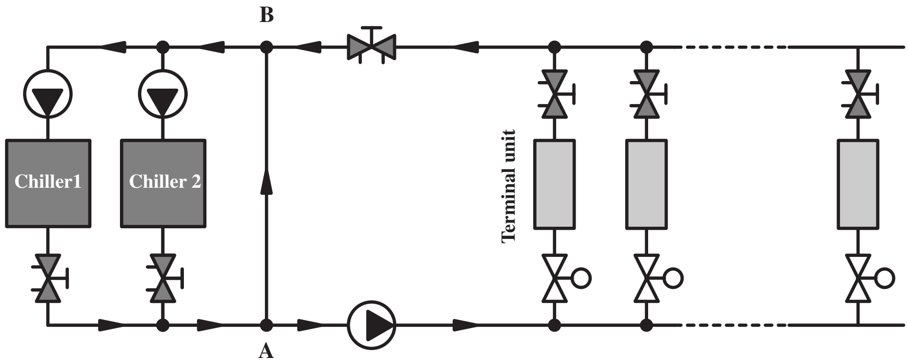


Fig F.2: Example of a variable flow distribution system.

At first glance, there appears to be no reason to balance a system with two-way control valves on the terminals, since the control valves are designed to modulate the flow to the required level. Hydronic balancing should therefore be obtained automatically. However, even after careful calculations, you find that control valves with exactly the required Kvs are not available on the market. Consequently, most control valves are oversized. Total opening of the control valves cannot be avoided in many situations, such as during start up, when big disturbances occur, when some thermostats are set at minimum or maximum value or when some coils have been undersized. In these cases and when balancing valves are not in place, overflows will result in some circuits. This will create underflow in other circuits.

Using a variable speed pump will not solve this problem since all the flows will change proportionally when the pump head is modified. Attempting to avoid overflows this way will simply make the underflows more significant.

The entire plant is designed to provide its maximum capacity at maximum load. It is then essential that this maximum capacity is available when required. Hydronic balancing, made in design conditions, guarantees that all terminals can receive their required flow, thus justifying the investments made. At partial loads, when some control valves close, the available differential pressures on the circuits can only increase. If underflows are avoided in design conditions, they will not occur in other conditions.

Morning start up

In distribution systems with variable flows, morning start-up after each night time setback is a serious consideration since most control valves are driven fully open. This creates overflows, which produce unpredictable pressure drops in some of the piping network, starving the terminals in the less favoured sections of the system. The unfavoured circuit will not receive adequate flow until the favoured spaces have reached thermostat set point (if these set points have been reasonably chosen), allowing their control valves to begin to throttle. Start up is therefore difficult and takes a longer time than expected. This is costly in terms of energy consumption. A non-uniform start-up makes management by a central controller and any form of optimisation practically impossible.

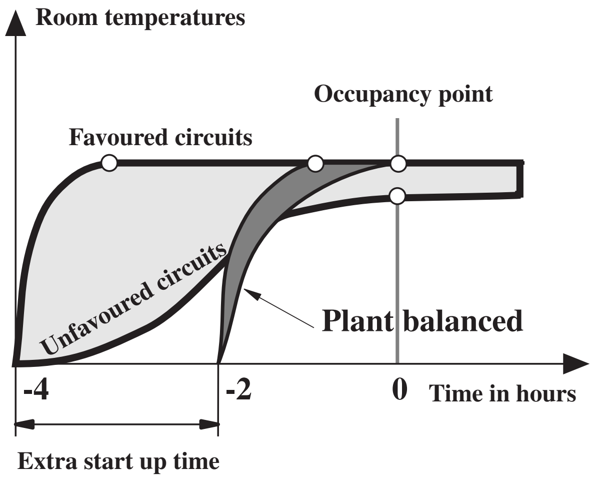


Fig F3: An unbalanced plant has to start up earlier, increasing the energy consumption.

In a distribution system with constant flow, underflows and overflows remain both during and after start up, making the problem much more difficult.

The tools required for balancing

To balance a plant, the required tools must meet following conditions:

- The flow must be measurable with an accuracy of around ± 5%. The balancing procedure makes it possible to check if the plant works as designed, to detect faults and to decide upon measures to correct them.
- The flow must be easy to adjust, thus making the plant flexible.
- The balancing device must guarantee a long-term reliability. It must be resistant to aggressive water.
- During flushing, the balancing devices should not have to be removed and should not require the use of special filters.
- The setting position must be easy to read and be protected by a hidden memory. Full throttling range should require at least four full turns of the handwheel to enable sufficient resolution of the setting.
- A balanced cone should be available for big sizes to reduce the torque required to set the valve against high differential pressures.
- A shut-off function must be included in the balancing valve.
- A measuring instrument must be available, so that flows can be measured easily, without having to use diagrams. The instrument should incorporate a simple balancing procedure and the possibility to print a balancing report. The instrument also enables the evolution of flows, differential pressures and temperatures to be registered for diagnostic purposes.

F.2 Stabilisation of the differential pressures

The control valve characteristic

The characteristic of a control valve is defined by the relation between the water flow through the valve and the valve lift at constant differential pressure. Water flow and valve lift are expressed as a percentage of their maximum values.

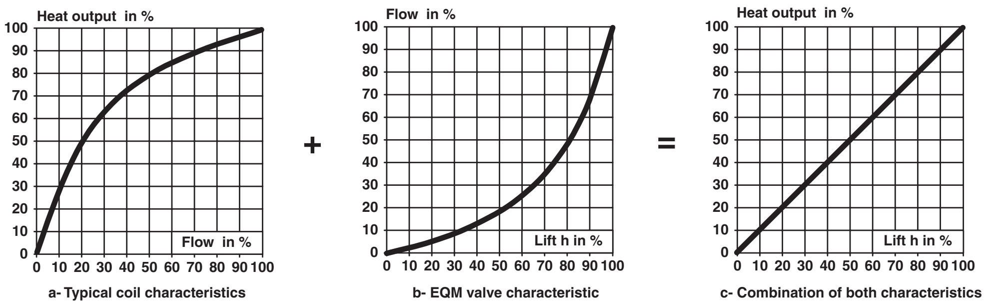


Fig F4: Adopting an inverse non-linear characteristic for the control valve compensates non-linearity of a coil characteristic.

For a valve with linear characteristic, the water flow is proportional to the valve lift. Due to the non-linear characteristic of the terminal unit (Figure F4a), opening the control valve slightly can significantly increase the emission at small and medium loads. The control loop may therefore be unstable at small loads.

Choosing a control valve characteristic to compensate for the non-linearity can solve this problem. This helps ensure that emission from the terminal unit is proportional to the valve lift.

Let's say that the output of the terminal unit is 50 percent of its design value when supplied by 20 percent of its design flow. The valve may then be designed to allow only 20 percent of the design flow when it is open 50 percent. When the valve is 50 percent, 50 percent of the heat output are obtained (Figure F4c). If this holds true for all flows, you can obtain a valve characteristic that compensates for the non-linearity of a typical controlled exchanger. This characteristic (Figure F4b) is called equal percentage modified ”EQM”.

To obtain this compensation, two conditions must be fulfilled:

- The differential pressure across the control valve must be constant.
- The design flow must be obtained when the control valve is fully open.

If the differential pressure across the control valve is not constant, or if the valve is oversized, the control valve characteristic becomes distorted and the modulating control can be compromised.

The control valve authority

When the control valve closes, the flow and the pressure drop are reduced in terminal, pipes and accessories. The difference in pressure drop is applied to the control valve. This increase in the differential pressure distorts the control valve characteristic. The control valve authority can represent this distortion.

$$ß = \text{Valve authority} = \frac{\Delta pVc \text{ (Pressure drop in the control valve fully open and design flow)}}{\Delta p \text{ valve shut}}$$

The numerator is constant and depends only on the choice of the control valve and the value of design flow. The denominator corresponds with the available differential pressure ΔH on the circuit. A balancing valve installed in series with the chosen control valve does not change any of these two factors and consequently does not affect the control valve authority.

The control valve is chosen to obtain the best possible authority. However, the control valve calculated is not available on the market. This is why most of the control valves are oversized. By using a balancing valve, the design flow may be obtained when the control valve is fully open. With the balancing valve, the characteristic obtained is closer to the required characteristic, improving the control function (Fig F6b).

If the balancing valves are well adjusted, they just take away the local overpressures, due to the non-homogeneity of the plant, to obtain the design flow in all coils in design conditions. If afterwards the balancing valves are fully open, the control valves are obliged to shut further. The friction energy can not be saved that way, it will just be transferred from the balancing valves to the control valves. It is then quite obvious that balancing valves do not create supplementary pressure drops.

Moreover, if the pump is oversized, the control valves will create overflows when fully open and take away this overpressure when operating. The pump oversizing will never be detected that way while a balancing procedure will reveal the overpressure, which can be compensated by set-up correctly, the variable speed pump for example.

In some exceptional cases, it's possible to find control valves with adjustable Kvs, but the problem is to adjust the Kvs at the correct value. This is impossible if the flow is not measurable and if the plant is not balanced to obtain the design differential pressure on each circuit. Balancing valves are then required anyway.

Differential pressure changes with the average load in the plant

In a direct return distribution (Fig F5a), the remote circuits experience the highest variations in differential pressure. At low flows, when the control valve is subjected to almost all the pump head, control valve authority is at its worst.

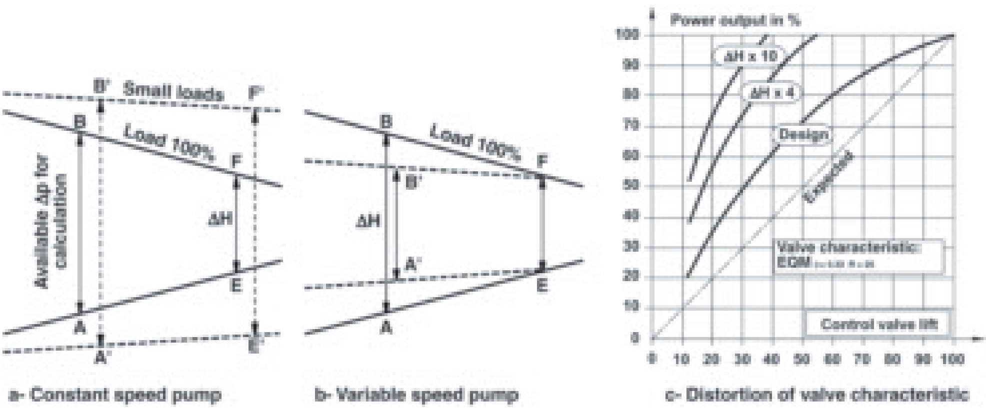


Fig F5: The control valve authority is 0.25 in design condition. When the average load of the plant changes, the differential pressure ΔH on the circuit increases dramatically. This further distorts the control valve characteristic.

With a variable speed pump, it is common to keep the differential pressure constant close to the last circuit (Fig F5b). Then, the problem of varying ΔH is reported to the first circuit.

Locating the differential pressure sensor for the variable speed pump near the last circuit should, in theory, reduce pumping costs. This however causes problems for the circuits close to the pump. If the control valve has been selected according to the available ΔH in design condition, then the circuit will be in underflow for smaller ΔH. If the control valve has been selected based on the minimum ΔH, then, at design condition, the circuit will be in overflow and the control valve will have a bad authority. As a compromise, the differential pressure sensor should preferably be located at the middle of the plant. This can reduce differential pressure variations by more than 50 percent compared to those obtained with constant speed pump.

Figure F5c shows the relation between the heat output and the valve lift for EQM control valves selected to obtain the correct flow when fully open and a valve authority of 0.25. When the available differential pressure applied on the circuit increases, the control valve characteristic is distorted so much that it causes hunting of the control loop. In this case, a local differential pressure controller can be used to stabilise the differential pressure across the control valve and keep the valve authority close to 1 (Fig F7a).

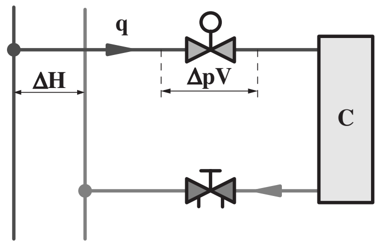
Selection of modulating control valves

A two-way control valve is well sized when:

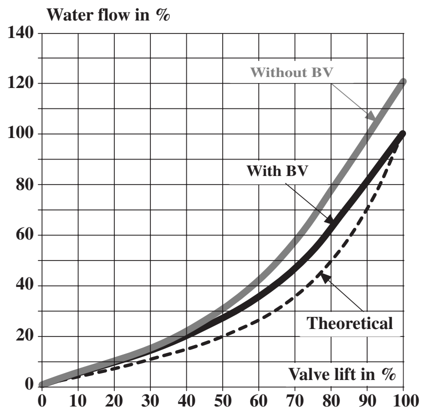
1. The design flow is obtained through the control valve when fully open under design conditions.

2. The control valve authority is and remains sufficient, that is, generally above 0.25.

The first condition is necessary to avoid an overflow, which creates underflows in other circuits, when the control valve is open and remains so for a relatively long period. This occurs (1) during start-up, such as each morning after a night set back, (2) when the coil has been undersized, (3) when the thermostat is set on minimum value in cooling, and (4) when the control loop is not stable.



a- How to calculate the pressure drop that must be taken across the control valve to obtain the design flow?



b- Balancing valve allows design flow. Characteristic obtained is closer the theoretical EQ% than without

Fig F6: If the control valve is oversized, a balancing valve improves the control valve characteristic.

To obtain the design flow at design condition, the pressure drop in the control valve when fully open and at design flow, must be equal to the local available differential pressure ΔH, minus the design pressure drop in the coil and accessories (Fig F6a).

Now, assume that this information is available (!) before selecting the control valve. For a flow of 1.6 l/s, what is available on the market? One control valve that creates a pressure drop of 13 kPa, another that creates 30 kPa and a third that creates 70 kPa. If 45 kPa must be created in the fully open control valve, then such a valve is not available on the market. As a result, control valves are generally oversized. A balancing valve is then needed to obtain the design flow. The balancing valve improves the control valve characteristic without creating any unnecessary pressure (Fig F6b).

Once the control valve has been selected, we must verify if its authority ΔpVc / ΔHmax is sufficient. If it is insufficient, the plant design must be reselected to allow a higher-pressure drop across a smaller control valve.

Some designs to solve local problems

Providing separate solutions for special cases usually results in better operating conditions than forcing the rest of the system to respond to abnormal conditions.

When control valve selection is critical or when the circuit is subjected to major changes in ΔH, a local differential pressure controller can stabilise the differential pressure across the control (Fig F7a). This is generally the case when the control valve authority can drop below 0.25.

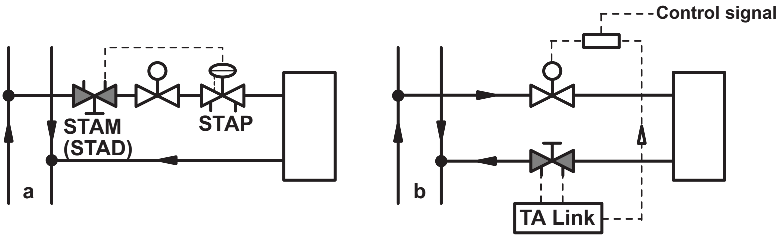


Fig F7: Limitation of the flow across a terminal unit.

The principle is simple. The membrane of the STAP differential pressure controller is connected on the inlet and the outlet of the temperature control valve. When the differential pressure increases, the force on the membrane increases and shuts STAP proportionally. STAP keeps the differential pressure on the control valve almost constant. This differential pressure is selected to obtain the design flow, measurable at STAM, when the control valve is fully opened. The control valve is never oversized and valve authority is close to 1.

All additional differential pressure is applied to STAP. The control of the differential pressure is quite easy in comparison with a temperature control and a sufficient proportional band is used to avoid hunting.

Combining local differential pressure controllers with a variable speed pump ensures the best conditions for control. The comfort is improved with substantial energy savings. The risk of noise is reduced considerably. For economic reasons, this solution is normally reserved for small units (pipe size lower than 65 mm).

For larger units, for which the differential pressure varies widely, the maximum Kvs can be limited by using a differential pressure sensor connected to a balancing valve (Fig F7b). When the differential pressure measured corresponds to the design flow, the control valve is not permitted to open furthermore.

If the plant has been calculated with a diversity factor, the maximum flow allowed is reduced during start up to obtain a homogeneous flow distribution. The set point of the maximum flow can also be changed according to the requirements of priority circuits.

When terminal units are controlled with on off or time proportional control valves, limitation of the differential pressure can help reduce noise and simplify balancing. In this case, a differential pressure controller keeps the differential pressure constant across a set of terminal units (Fig F8).

This solution also works for a set of small units controlled by modulating control valves.

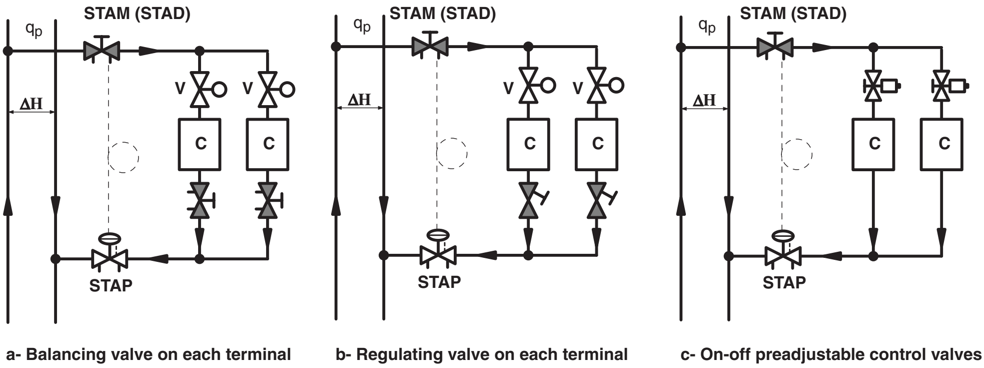


Fig F8: The STAP keeps the differential pressure constant across a set of terminal units.

These examples are not restrictive; they just show that using specific solutions can solve some particular problems.

Keeping the differential pressure constant in heating plants

Variable flow distribution

In a radiator heating plant, the radiator valves are generally preset considering that the available differential pressure ΔHo equals 10 kPa.

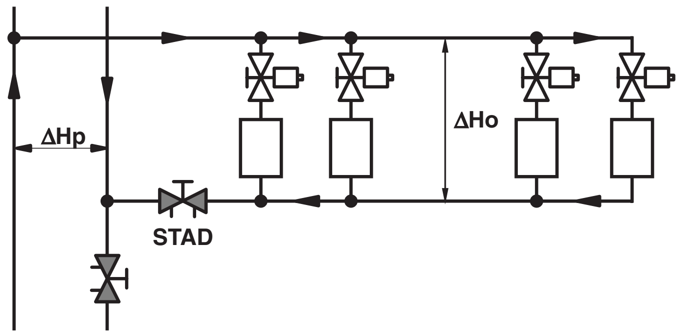


Fig F9: Each radiator valve is adjusted as if it was subjected to the same differential pressure of 10 kPa.

During the balancing procedure, the STAD balancing valve is set to obtain the right total flow in the branch. This justifies the presetting and the 10 kPa differential pressure expected is obtained at the centre of the branch.

In radiator systems with available differential pressure over 30 kPa, there is a risk of noise in the plant, especially when air remains in the water. In this case, you should use STAP to reduce the differential pressure and to keep it constant (Fig F10).

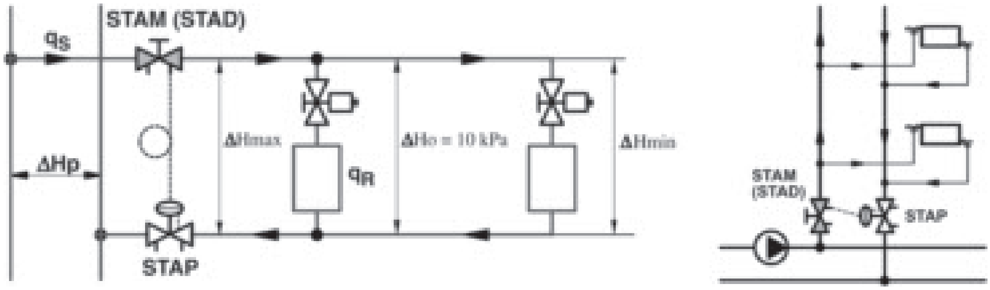


Fig F10: A STAP keeps the differential pressure at the circuit inlet constant.

STAP keeps the differential pressure constant on each branch or small riser. The branch water flow (qs) is measured with the STAM (STAD) measuring valve. This combination relieves the thermostatic valves of excess differential pressure.

Constant flow distribution

The supply water temperature, in a residential building, is adjusted with a central controller according to the outdoor conditions.

The pump head may be high, which can cause noise in the thermostatic valves. If there is no restriction on the return water temperature, a constant flow distribution may be used.

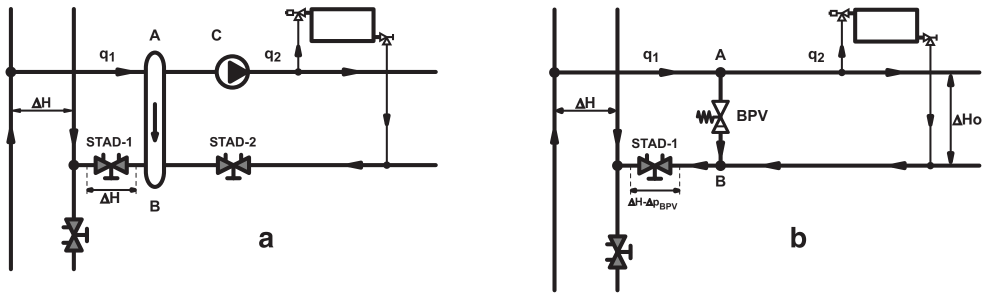


Fig F11: Each apartment receives a differential pressure less than 30 kPa.

One solution is to provide each apartment with a bypass line AB and a balancing valve STAD-1 (figure F11a). This balancing valve takes away the available ΔH. A secondary pump with a pump head less than 30 kPa, serves the apartment. When the thermostatic valves close, the Δp across the thermostatic valves is acceptable and does not create noise in the plant. The secondary design flow must be slightly lower than that of the primary flow to avoid a reverse flow in the bypass, which would create a mixing point at A and decrease the supply water temperature. This is why another balancing valve STAD-2 on the secondary is necessary.

Another solution is to install BPV, a proportional relief valve, for each apartment (Fig F11b). This eliminates the need for a secondary pump and for the balancing valve STAD-2. BPV works with one STAD balancing valve STAD-1 to stabilise the secondary differential pressure. The BPV is set to suit the requirement of the radiator circuit. When the thermostatic valves close, the differential pressure between A and B increases beyond the set point. The BPV then opens and bypasses a supplementary flow creating a sufficient pressure drop in the balancing valve to keep almost constant the differential pressure between A and B.

Let us suppose that the balancing valve STAD-1 is not installed. If the primary differential pressure ΔH increases, BPV will open, increasing the primary flow q_1. The resistance of the pipes between AB and the riser being negligible, the differential pressure across AB remains Practically equal to ΔH. Consequently, to stabilise the secondary differential pressure, the BPV must be coupled with a balancing valve STAD-1 that creates a sufficient pressure drop.

F.3 Flows must be compatible at system interfaces

To give value for investment made

Production units, pumps, pipes and terminal units are designed to provide a certain maximum load even if a diversity factor has been considered. If this maximum load cannot be obtained because the plant is hydraulically unbalanced, we don't give value for investment made.

If the system never requires the maximum capacity installed, it means that the chillers, pumps ... are oversized and the plant is not correctly designed. When the plant is well balanced, it's not necessary to oversize, which reduces the investment and the running costs.

It is quite obvious that overflows in some parts of the plant create underflows in other parts. Unfavoured circuits are not able to provide their full load when required. However another problem will occur. At full load, the supply water temperature will be lower than expected in heating and higher in cooling due to incompatibility between production and distribution water flows.

Example in heating

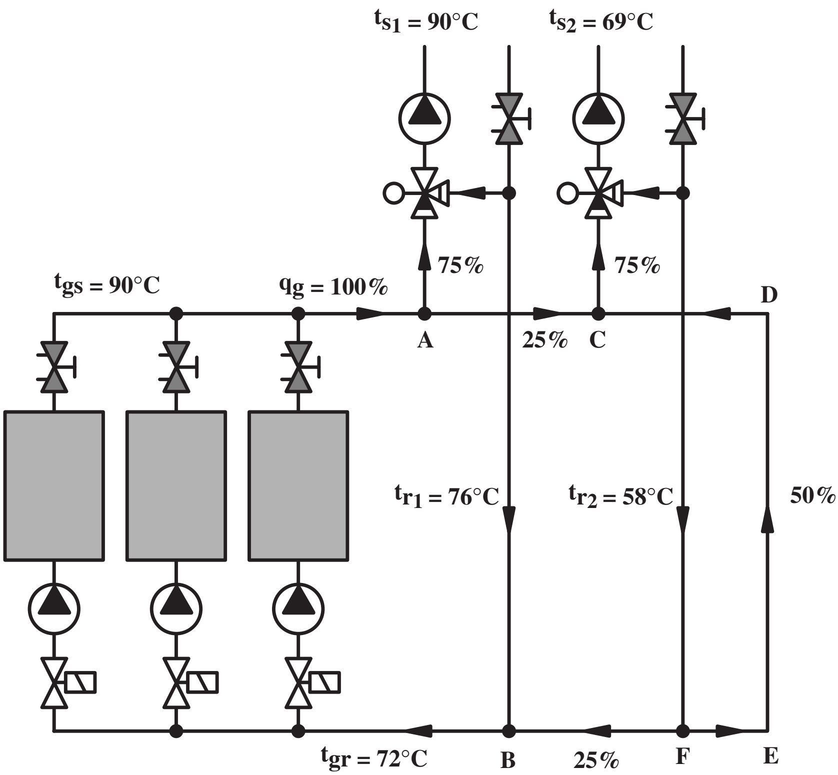


Fig F12: Two circuits are in overflow.

Figure F12 shows a heating plant with three boilers working in sequence. The distribution loop has a low resistance in order to avoid hydraulic interference between the boilers and between the circuits. For this reason any hydraulic resistance has to be avoided in the bypass ”DE”. A check valve between D and E, for instance, will put the secondary pumps in series with the primary pumps, disturbing heavily the function of the three-way mixing valves.

If the two circuits are identical, they have each to take 50% of the total flow. Assume that they take 75% instead. On point ”A”, the first circuit takes 75% of the total flow. It remains 25% for the second circuit. The second circuit takes 75% flow but receives only 25%. It will take 50% from its own return. At ”C”, 25% of hot water is mixed with 50% of the return water from circuit 2. For this circuit, the maximum supply water temperature is 69°C. In design conditions, with an outdoor temperature of -10°C, as long as the first circuit takes its maximum flow, the room temperatures in circuit 2 cannot exceed 14°C. When the room set point of circuit 1 is reached, its three-way control valve starts to shut.

The supply water temperature of the second circuit increases to a maximum of 80°C with an available capacity 10% below the design value. In these conditions, the maximum room temperature will be 17°C for the second circuit. Increasing the pump head of the second circuit to ”solve” the problem will make it worse.

Start up is much longer than expected and the capacity installed is not completely transmittable. To avoid this problem, the total maximum flow absorbed by the circuits must be equal or lower than the maximum flow provided by the production units.

We might think that it would be sufficient to reduce the secondary pump head, in one way or another, to limit the flows. Attempting to avoid overflows this way will simply make the underflows in unfavoured units more significant. Consequently it remains necessary to balance the terminal units between themselves. If the overflow in the circuit is the result of no balancing, we can imagine that some circuits will receive only 50% of their design flow. For these circuits, the situation is worse. The supply water temperature is 10°C lower than design and the flow is also reduced.

Balancing investment represents typically less than one percent of the total HVAC costs, allowing the maximum capacity installed to be transmittable, valorising all the investments made.

Example in cooling

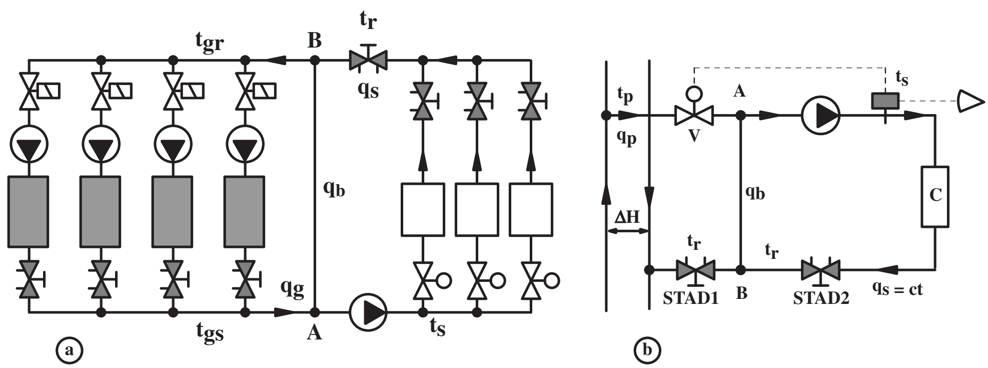


Fig F13: Examples in cooling.

Fig F13a represents a chilled water plant with four chillers. If the distribution circuit is not balanced, the maximum flow q_s may be higher than the production flow q_g. In this case, the flow q_b in the bypass reverses from B to A, creating a mixing point at A. The supply water temperature ts is then higher than design and the maximum capacity installed is not transmittable.

Fig F13b represents a terminal unit working at constant flow with a two-way valve controlling injection. If the flow in the terminal unit is too high, the flow q_b is always in the direction B to A. The supply water temperature ts is always higher than design and the maximum design capacity is never obtained in the terminal unit.

For both examples, an overflow of 50% in the distribution or through the coil will increase the supply water temperature from 6°C to 8°C.

Troubleshooting and system analysis

Hydronic balancing prevents overflows in certain circuits from causing underflows in others, detects possible oversizing of pumps and verifies that the plant does provide the functions and performances intended by the designer.

G.1 Common problems

Symptoms	Common and incorrect counter measures	Typical and usually neglected root causes	Correct solutions	Advantages
Too hot in some parts of the building, too cold in other parts	Increase pump head (main or secondary pump head	Overflow in some circuits create underflow in others No balancing of circuits downstream of Δp controllers	Balance distribution system using STAD/STAF balancing valves	• Correct room temperatures at optimised energy cost • Flows are verified and documented • Possibility to measure and log the flow and detect problems • Manual balancing identifies hydronic problems which can be solved at an early stage • Shortest possible start-up time after night setback • Possibility to minimise pump energy consumption • Avoid noises due to abnormal pump head • Stable and accurate temperature control • Low energy cost • Risk of noise reduced • With the control of the Δp across the control valves, with STAP, their authority remains close to one and the control valves are never oversized
Long time before all rooms reach correct temperature after night setback	Increase supply temperature (heating). Reduce when possible supply temperature (cooling) Cancel the night setback function Install additional boilers or chillers	Overflow in some circuits create underflow in others Distribution flow higher than production flow (compatibility between flows not obtained)	Balance distribution system using STAD/STAF balancing valves Make sure that production and distribution flow are compatible by adequate balancing	
Abnormal pump energy consumption		Pump is oversized and pump oversizing not detectable	Balance the plant with STAD/STAF to reveal pump oversizing Adjust consequently the pump speed or trim the impeller or change the pump Install secondary pumps to overcome special high losses	
Temperature controlled fluctuates Noise from control valves	Modify control software although it is a hydronic problem Replace correctly sized but hunting control valve by smaller ones	Plant not balanced Control valve authority is too low Wrong control parameters Control valve oversized or submitted to variable Δp.	Balance the plant using STAD/STAF balancing valves. Size the control valve in a better way. Adopt the correct characteristic and suitable control parameters Limit Δp variations using STAP Δp controllers	

G.2 Quick troubleshooting

CBI instrument makes it easier to put your finger on problems in hydronic systems. CBI measures and registers differential pressures, water flows and temperatures using balancing valves.

Here is a list of some typical faults that CBI can help you identify:

- Wrong flow in pipes and terminals.
- Too high or too low supply water temperature.
- Incorrect air temperatures.
- Production and distribution water flows are not compatible.
- Interactivity between production units.
- Abnormal pressure drops in elements with the possibility to detect blocked filters and clogged terminals.
- Shutoff valves that should be open but are closed.
- Improperly connected check valves.
- Dented pipes.
- Too high or too low available differential pressure across a circuit.
- Distribution pump oversized or undersized.
- Wrong rotation direction for a pump with a three-phase motor.
- Unstable rpm in a pump.
- Interactivity between circuits with sometimes reverse flows in pipes.
- Unstable control on terminals.
- Oversized control valve and possibility to calculate its authority.
- .....

One of the many benefits of manual balancing is that you detect many of these types of faults during the balancing procedure. It is much less expensive to correct faults at this stage than, for instance, after the false ceiling has been installed and tenants have moved into a building.

G.3 Accurate system analysis

To be able to correct especially tricky operating problems, it is sometimes necessary to perform an accurate system analysis. As a basis for such analysis, it is useful to know how differential pressure, flow and temperature vary over time at strategic points in the plant.

CBI can help. Connect the instrument to the plant and let it collect data for a while. Then connect CBI to a computer and print out the data in the form of easy-to-grasp chart that you can analyse at your leisure back in the office.

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