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Flow Compatibility at System Interfaces

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If HVAC plants are well-designed and well-executed, then comfortable indoor climate is obtained while minimizing costs and operative problems. Unfortunately, in some cases, budget constraints do not allow optimal design. In these cases, the installation cannot provide comfortable indoor climate and low energy costs. On the hydronic side, some major malfunctions can be avoided of three fundamental conditions are fulfilled:

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

This article essentially deals with the third condition.

Making sure investments pay off

Production units, pumps, pipes and terminal units are selected to provide a certain maximum load even if the plant is calculated with a diversity factor. If this maximum load cannot be obtained because the plant is hydraulically unbalanced, the investments made are not valorized.

If the system never requires the maximum power installed, it means that the chillers, pumps and terminal units are oversized and the plant is not correctly designed. When the plant is a well-balanced, it is not necessary to oversize. This reduces both investments and operating costs.

It is obvious that overflows in some parts of the plant create underflows in other parts. Unfavoured circuits are unable 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 a heating system and higher in a cooling system due to incompatibility between production and distribution water flows.

Compatibility between production and distribution water flows

Figure 1 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, distributing heavily the function of the three-way mixing valves.

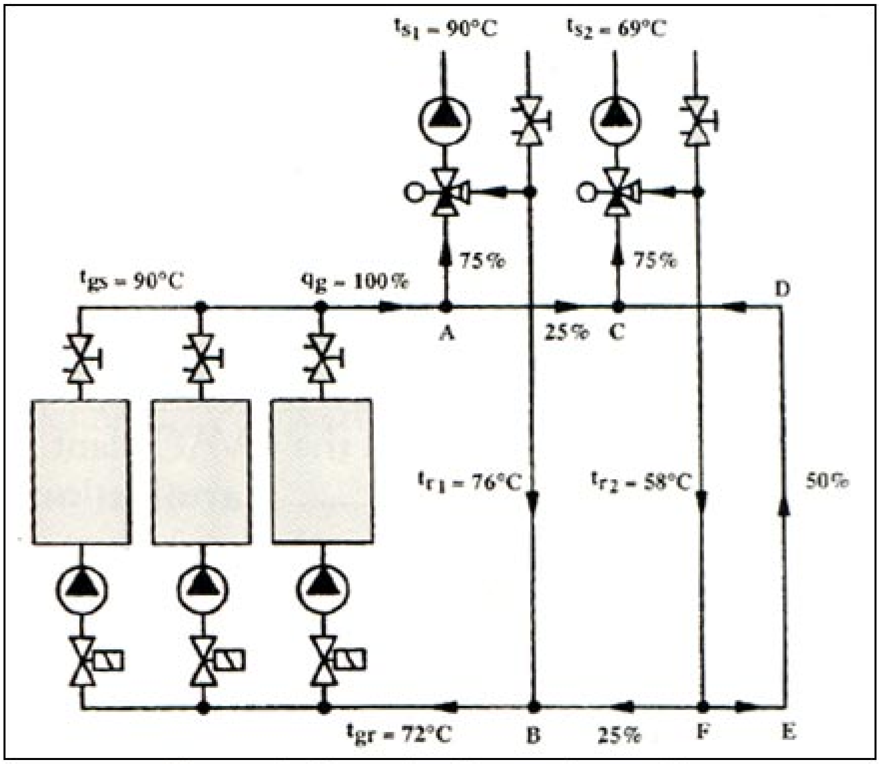

Figure 1: Two circuits are in overflow.

If the two circuits are identical, each must take 50% of the total flow qg Assume that each takes 75% instead. On point "A" the first circuit takes 75% of the total flow. That leaves 25% for the second circuit. The second circuit takes 75% of the flow and receives only 25% from upstream. It will then take 50% from its own return. On "C", 25% of the hot water is mixed with 50% of the return water from the second circuit.

For this circuit, the maximum supply water temperature is 69°C. Under design conditions, with an outdoor temperature of (-) 10°C, as long a s the first circuit takes its maximum flow, the room temperature in the second circuit cannot exceed 14°C. When the room set point of first circuit is reached, its three-way control valves starts to shut. The supply water temperature of the second circuit increases to a maximum of 80°C with an available power that is 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 power installed is not completely transmittable., To avoid this problem, the total maximum flow absorbed by the circuits `must be equal to or lower than the maximum flow provided by the production units.

We may believe 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 is still necessary to balance there terminal units between themselves. If the overflow in the circuit results from not balancing, we can imagine that some circuits 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 allows the maximum power installed to be transmittable, thus making sure the investment pays off. The balancing investment typically represents less than one percent of the investment in the HVAC plant.

Let's take a look at a second example.

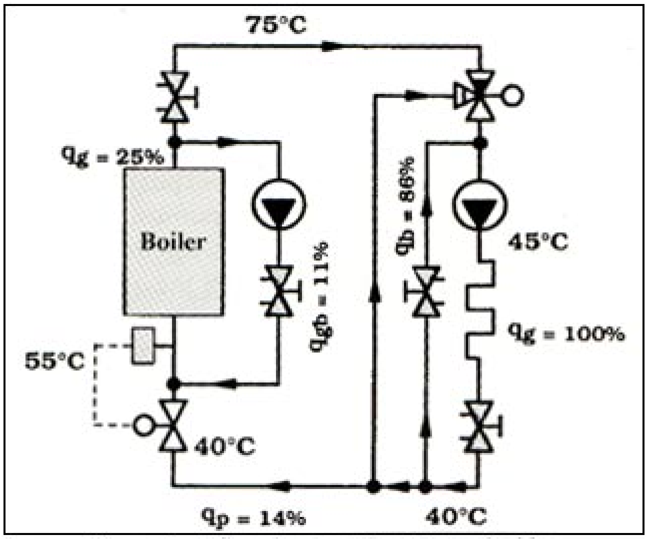

Figure 2: A floor-heating plant is supplied by a conventional boiler.

In a floor-heating plant, the supply water temperature may be 45°C for example, with a return water temperature of 40°C. The boiler must be protected against fume condensation and its water inlet temperature must be at least 55°C. In order to obtain correct operation of this plant, all flows must be adjusted to obtain the necessary temperatures.

Since the boiler is supplied at 55°C, and for a design ΔT of 20K, its outlet at full load is 75°C. If the flow through the floor-heating circuit is 100% for a ΔT of 5K, it will then be 100 x 5/20 = 25% flow in the boiler. To obtain 45°C at the supply to the heating circuit water at 75°C is available at the open three-way valve, a flow q_b has to be recycled so that:
q_b x 40 + (100 - q_b) x 75 - 100 x 45, which gives q_b = 86%.
The difference (100 -86 = 14%) therefore circulates through the pipes between the floor-heating circuit and the boiler. The boiler receives a flow of 14%. As the flow through the boiler must be 25%, a circulation flow q_{gb} = 11% is necessary.
As we can see, flows are not arbitrary and a will not be obtained by chance. They must be adjusted with balancing valves.

Compatibility between flows must also be obtained in cooling plants.

Figure 3a represents a chilled water plant with four chillers. If the distribution circuit is not balance, the maximum flow q_s may be higher than the production flow q_b. 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 power installed is not transmittable.

Figure 3b represents a terminal unit working at constant flow with a two-way valve in 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 power 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.

Balancing valves are also diagnostic tools, and a way to saves pumping costs.

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

Manual balancing valves must be adjusted. This is a beneficial constraint because the balancing procedure makes it possible to detect most hydronic anomalies during the commissioning operation. However, keep in mind that the old proportional balancing does not guarantee the lowest pumping energy as the pressure drops in balancing valves are not minimized. This is now accomplished by using the Compensated or TA Balance methods, which reports all the excess pump head on the main balancing valve close to the pump. The pump head is then corrected to obtain the design total flow with the main balancing valve reopened. This operation allows the minimum pumping costs in the distribution.

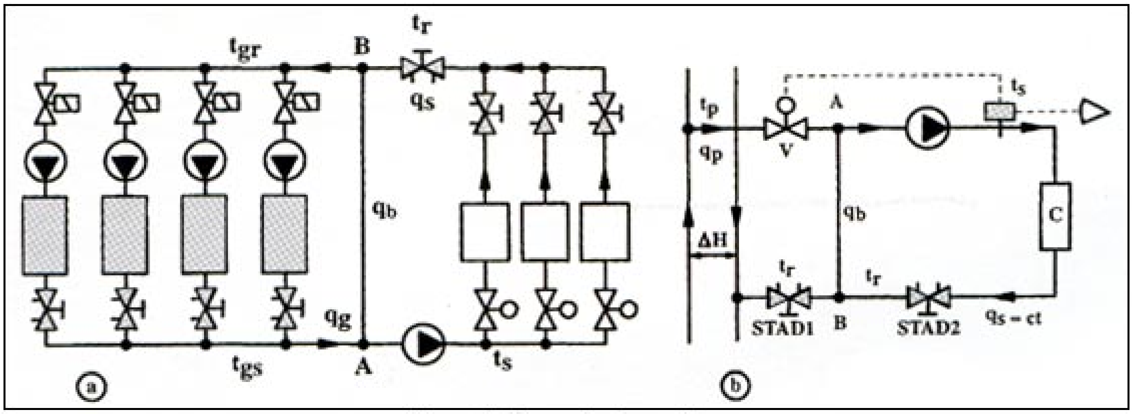

Figure 3: Examples in cooling.

Is it possible to balance a plant hydronically only with the control valve?

There is no discussion about the need to balance a plant working with constant flow distribution. It is well-known that an overflow somewhere creates permanent underflows in other places.

In variable flow distribution, some designers believe that two-way control valves can solve the problem since the valve should automatically provide the required flow in each terminal unit. This is correct if the control valves are well-sized, if the control loop is stable, if the set point of thermostat is not at extreme value, if the terminal units correspond with the maximum power required... a lot of "ifs".

In practice, the correct sizing of a two-way control valve is already problematic. The pressure drop in a fully open control valve and for the design flow must be equal to the local available differential pressure on the circuit minus the design pressure drop in the terminal unit and accessories. Who knows the available differential pressure on each circuit? And what is the pressure drop in the coil when coil selection depends upon a contractor who has yet not been chosen at the design stage? And even if we know these values, we cannot find the control valve calculated as the commercially available Kvs values vary by step of 60%.

The pressure drop depends on the square of the Kvs. If a control valve creates a pressure drop of 25 kPa for design flow, a Kvs just below determines a pressure drop of 64 kPa. There is nothing in between. In some exceptional cases, it may be possible to find control valves with adjustable Kvs, but the problem is then to adjust the Kvs to the correct value. This is impossible if the flow is not measurable. A balancing valve is then required anyway to measure the flow and also to provide a shut-off function! 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, for example, by correctly setting the variable speed pump.

Conclusions

A HVAC plant is designed for a certain maximum load. If full load cannot be obtained because the plant is not balanced for design condition, the investments made for the plant are not valorized. Control valves cannot manage this situation as they are fully open when maximum load is required. Sizing the two way control valves is difficult, and the valves calculated generally are not available on the market. Consequently, they are generally oversized. Hydronic balancing is then essential and typically represents less than one percent of the total HVAC investments.

Each morning, after a night set back, full power is necessary to recover comfort as soon as possible. A well-balanced plant does this quickly. Earning 30 minutes for start-up, related to 8 hours working time, saves approximately 6% of te energy consumption per day, which is more than all distribution pumping costs.

It is important to compensate for pump oversizing. Setting the balancing valves using the TA balance method reveals this oversizing. All overpressure is reported on the balancing valve close to the pump. After setting the correct pump head for a variable speed pump, or installing a correctly sized constant speed pump, this balancing valve is just reopened. Hydronic balancing requires the correct tools, up-to-date procedures and efficient measuring units. The manual balancing valve remains the most reliable and simple product to obtain the correct flows in design conditions, and make it possible to check the flows for diagnostic purposes.

Reference Total hydronic Balancing - R. Petitjean

Edition TA HYDRONICS 1997