ENGINEERING
TOMORROW

Danfoss

Whitepaper

Reconfiguring **Air Handling Unit control** for better **performance**

75%
reduction of the temperature fluctuation by using PICV

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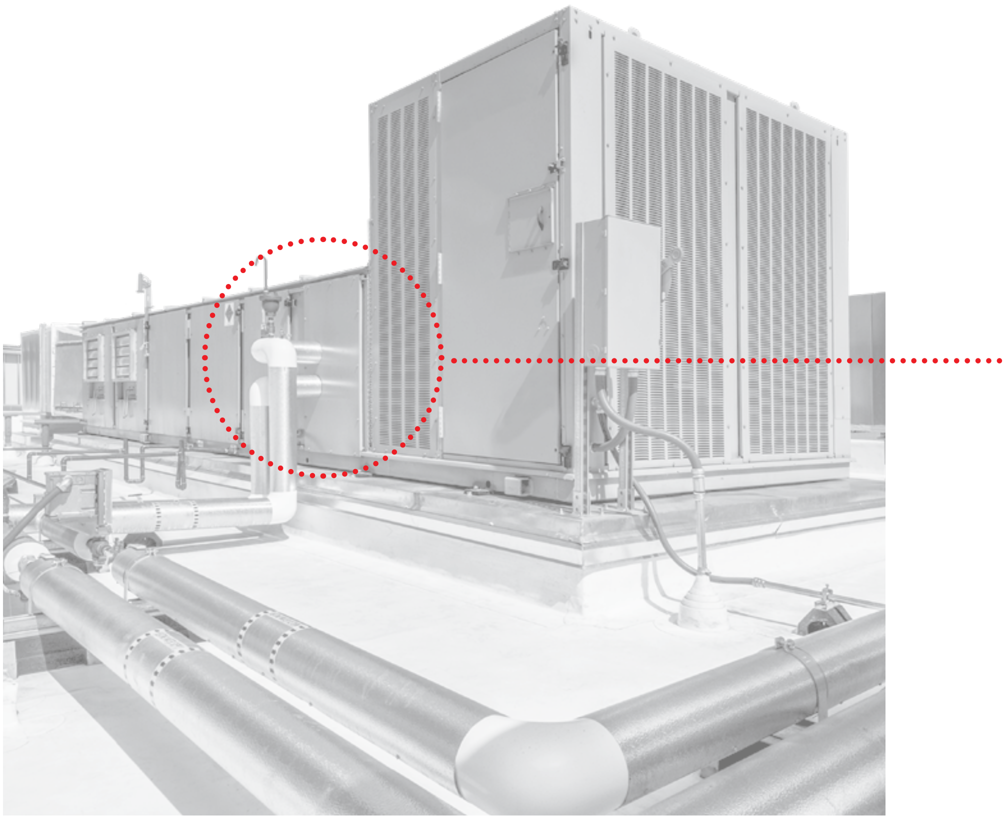
Content of this document

1. Purpose of this whitepaper

This whitepaper is intended to support HVAC professionals with creating reliable and energy efficient hydronic control solutions for Air Handling Unit (AHU) systems as used in a wide variety of commercial, institutional and multi-purpose buildings. The information and concluding recommendations are relevant for retrofit, renovation as well as new construction situations.

The whitepaper describes the hydronic control performance of an Air Handling Unit installed on a production facility which is in use for 24 hours a day. The AHU is tested and monitored using 3 different hydronic control solutions.
In the original situation a 3-way valve with modular actuator is used. For the purpose of this whitepaper two other solutions were added in parallel so at all of the test period one of the three solutions was operational.

When reading the whitepaper you can expect clear and practical to use explanations and recommendations. Topics such as control principles, control accuracy, load conditions and flow stability are brought together by specialists from Danfoss A/S.



2. Introduction

We tend to stick with what we know that works. But, sometimes, new technology comes on the market that forces us to rethink our set ways.

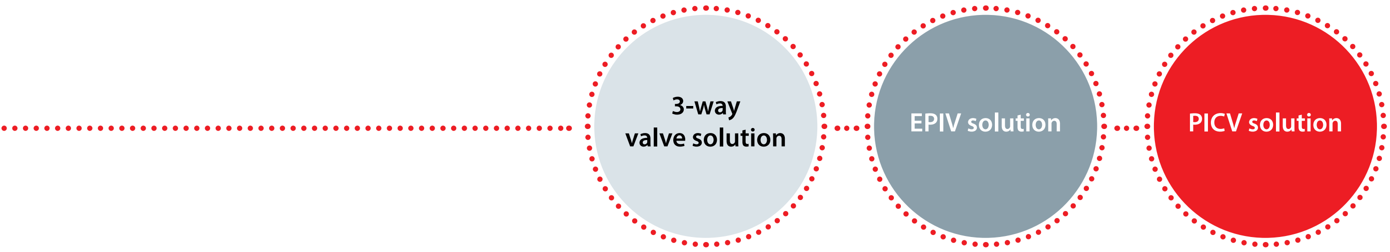
For decades 2- and 3-way valves have been used for controlling all kinds of applications, like fan coil units, radiators and air handling units. Not too long ago Pressure Independent Control Valves (PICV) took the stage and they are now used predominantly in most of the world. The convenience and precise control of the PICV made it an excellent reason to change the thinking around control valves and augment existing designs. However, not everybody is convinced PICV is the best solution for all applications.

One specific holdout is the motorized 3-way valve on the Air Handling Units (AHU) and the valve on the heating coil specifically. This has always been the territory of 3-way valves because if the AHU is (partially) using outside air, the heating coil can be at risk of freezing. Therefore, a constant flow of water on the coil was required. The simplest way of doing that was to use a 3-way valve and a circulation pump on the AHU. See page 4 for more details.

In this paper we're elaborating how to replace the 3-way valve with a more modern solution and we're going to focus on control performance specifically. We'll be testing 2 new solutions; the tried and tested PICV and the electronically controlled valve, which is a new solution that is offered by a number of companies.

The hydronic control and it's accuracy is critical because it provides comfort for the building's occupants, obviously, but also because ensuring a stable control in the supply air to the building will also create better conditions for controlling the humidity inside the building. Therefore it is important to ensure precise and stable control. Additionally we want to maintain the characteristics of the 3-way valves solution (constant flow on the coil for frost protection) so we are retaining the circulation pump and the bypass to make the 2-way valve solution functionally the same.

For more information on how and AHU works please check **this video**.



3. Which solutions did we test?

In this article we will look at three fundamentally different control principles:

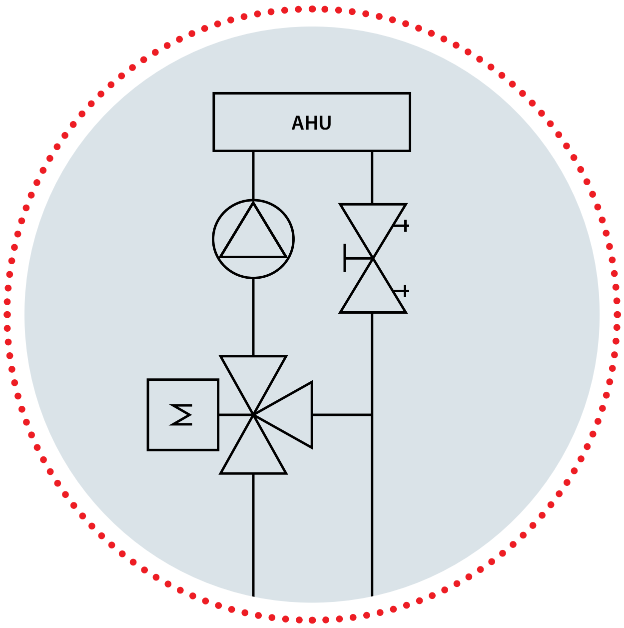
3.1 3-way valve with manual balancing valve

This solution can be considered the traditional way of doing temperature control on a heating coil for an AHU and it has been used this way for decades. This was the existing solution on this particular AHU so it functions as the baseline to compare the new solutions against.

The application is designed this way to reduce the risk of freezing when outside air is used. The pump will keep a flow through the coil. The 3-way principle allows the pump to maintain the flow because it ensures that water is either circulated or warm water is drawn from the source. Additionally, 3-way valves are considered to provide control with high precision.

A manual balancing valve is used for setting the maximum flow through the AHU.

3-way valve



3.2 Control (ball) valve with flow measuring device

This concept has seen increased attention recently because of an increased market demand for more energy data.

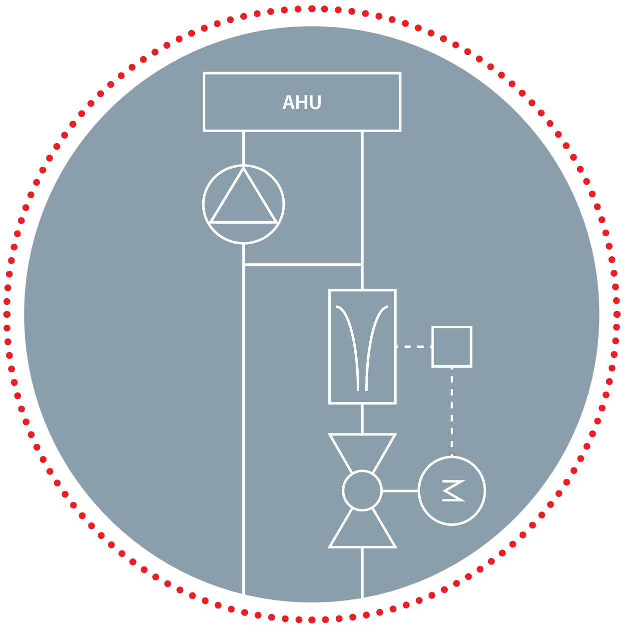
Essentially, the concept is to combine a normal control valve with a flow measuring device and 2 temperature sensors. The control software of the solution takes the flow data from the sensor and the input from the AHU controller (or BMS) and determines the position of the actuator which opens or closes the valve accordingly.
The flow and the ΔT can be combined to indicate the energy consumption of the AHU.

In this solution the control valve has multiple functions because it also needs to ensure the balance in the system since there is no other device in the system, like a pressure controller, to ensure the correct flow.

The solution has been converted to a 2-way valve with a by-pass. That way the pump can still ensure the freezing risk is low but a 2-way valve can be used. That means the solution is functionally a one to one replacement.

The control valve with flow measuring device is offered by multiple companies nowadays in different configurations. configurations. We tested a commonly used EPIV with a ball valve for control.

EPIV

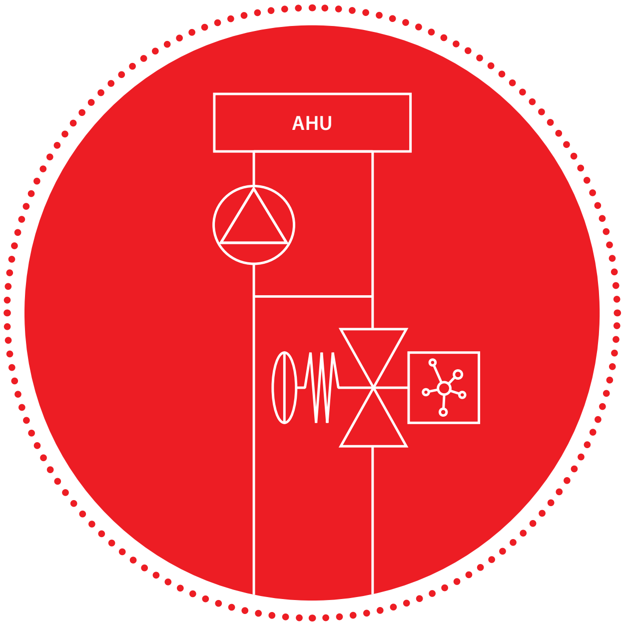


3.3 PICV with digital IoT actuator

In the last 15 years PICVs have become a worldwide standard for precise control and automatic balancing (For more information on PICVs see **this video**). The concept is more straightforward in the sense that the built-in pressure controller takes care of the balancing function, while the control valve just needs to control the application. If combined with a digital actuator and two temperature sensors the PICV can calculate the energy consumption of the AHU, which can be communicated with the Building Management System (BMS). If high accuracy is needed to measure the energy consumption, the PICV can be expanded with a flow measuring device and temperature sensors.

Compared an EPIV solution, the set up is less complicated because the PICV does not need the flow measuring data to control the flow. A PCIV is a control and balancing valve so it does not need additional control logic or flow measurement data to control and limit the flow.

PICV



4. The test

To get an accurate representation of how these different solutions behave in real life, as opposed to a laboratory setting, we used an AHU that is part of a functioning building, in this case our own factory in Ljubljana, Slovenia.
The temperatures were measured and logged for several days with each solution. Periods of similar loads were selected to be able to make an apple to apple comparison.

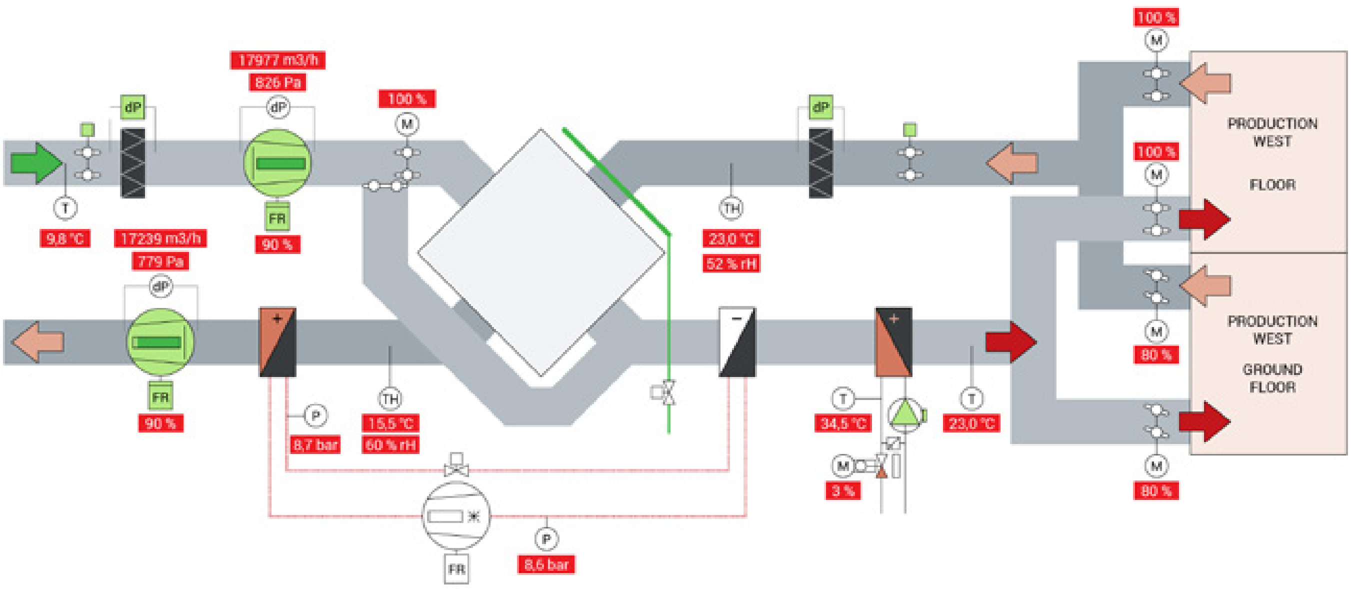
It is also important to note that we measured during periods where the flow through the heating coil was relatively low, for two reasons:

1. In practice, due to the shape of the coil characteristic, the annual load profile and overdimensioning in the design stage, the flow on the coil tends to be quite low during the heating season (see appendix).
2. Controlling smaller flows is more challenging. However, as has been noted in point 1., it is a very common operational condition and a huge part of the comfort in the building

The air handling unit has a fairly standard set-up, with a cooling coil, a heating coil and a crossflow heat recovery unit to recover energy from the exhaust air before it is expelled outside. The control solution is designed to maintain a stable supply air temperature.

Basic data of the AHU:

Airflow: 17.500 m^3/h
Heating coil capacity: 102 kW
Circulation pump: UPS32-60 F, 185W

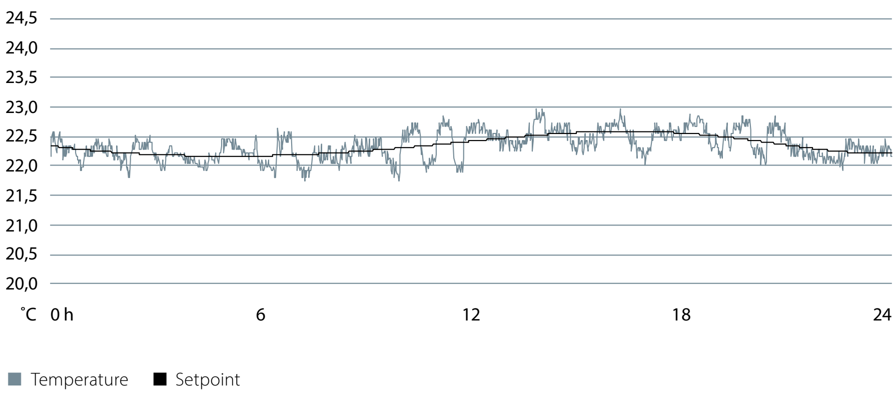


4.1 Results A

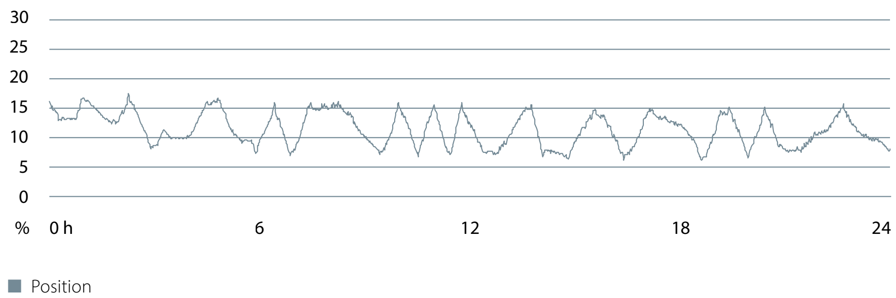
3-way valve Danfoss

Type: VRB3 + AME435
Valve size: DN40
Kvs: 25 m^3
Design flow: 6300 l/h

Supply air temperature [°C]



Valve position [%]



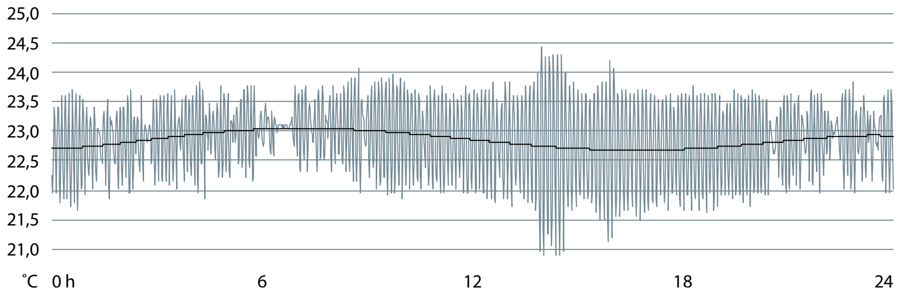
As we can see, the existing solution with 3-way valve works pretty much as expected. The supply air temperature setpoint varies slightly (black line), based on the room temperature feedback, but the actual supply air temperature (dark grey line) follows the demand quite closely.

In the bottom graph we can see that the opening degree of the valve is quite low, roughly 5-15%, because the load on the coil is quite low. It can also be seen that the valve is relatively stable. While small corrections are required, the valve doesn't move that much, despite the low load.

4.2 Results B

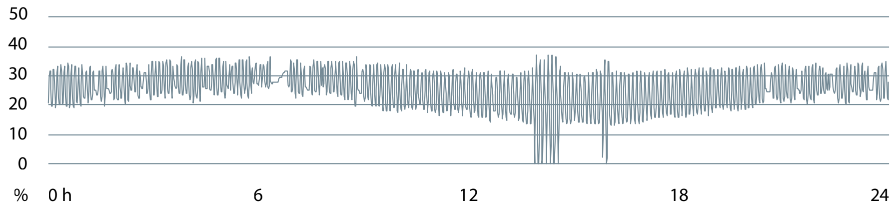
2-way valve
Type: EPIV
Valve size: DN40
Qnom: 9 m^3/h
Design flow: 6300 l/h

Supply air temperature [°C]



Temperature Setpoint

Valve position [%]



Position

If you compare this graph to the one of the 3-way valve previously, you can see that the temperature demand for the supply air is quite similar (black line). The control response is quite different though.

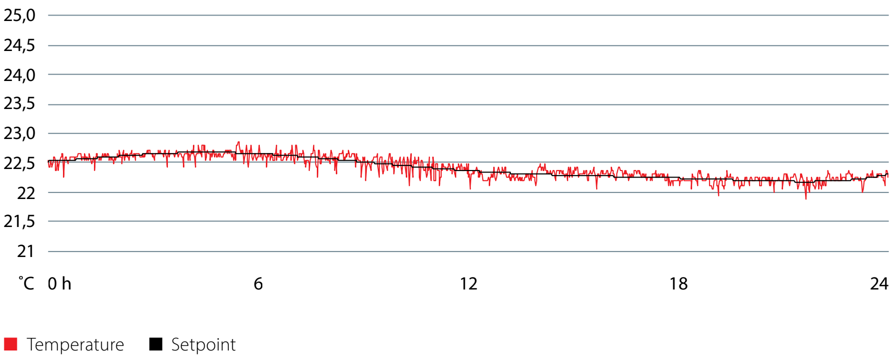
While a case could be made that on average the temperature is roughly what is required there are quite big temperature fluctuations in the supply air (dark grey line), about 1,5 to 2 K. This could cause issues with comfort since quick temperature changes of the air blown into the room are uncomfortable and are likely to lead to complaints from the building's occupants.

If we look at the bottom graph it is clear the valve is hunting a lot. It is constantly opening and closing and it is unable to catch a stable position. Quick erratic movements like this are increasing the wear and tear on the valve and actuator substantially.

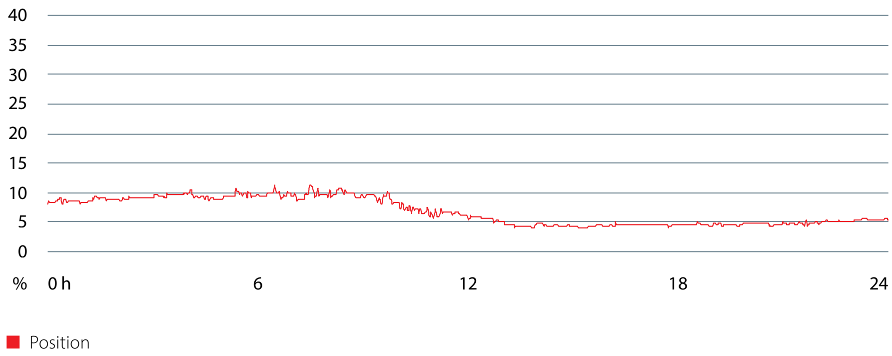
4.3 Results C

2-way PICV valve Danfoss
Type: AB-QM + NovoCon® M
Valve size: DN40
Qnom: 7,5 m^3/h
Design flow: 6300 l/h

Supply air temperature [°C]



Valve position [%]



Again, we see a similar demand for the supply air temperature (black line).
The AB-QM closely matches the demand and the supply temperature is very close to the setpoint.
If we look at the valve position we see that the AB-QM is very stable. Only very small fluctuations can be seen, even on such low flows.

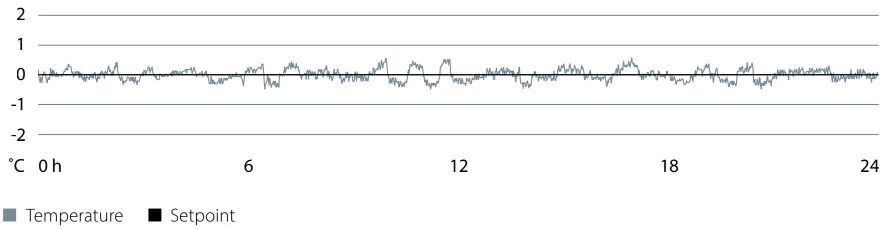
5. Intermediary conclusion from the test

If we rate the three solutions, we can see that the EPIV solution is the least precise, so with the highest deviation versus the setpoint, followed by the 3-way valve. The most precise control is provided by the PICV solution.

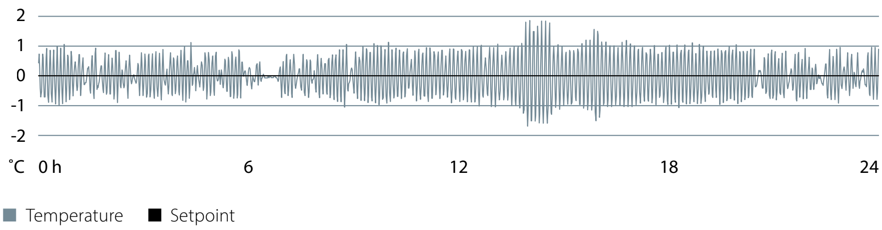
When we compare the largest oscillations between the EPIV and PICV solutions, the temperature fluctuation is reduced up to 75% in case a PICV solution is used.

Oscillations around setpoint:

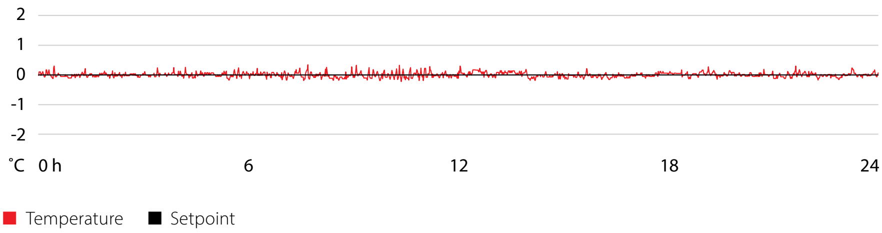
3-way valve solution



EPIV solution



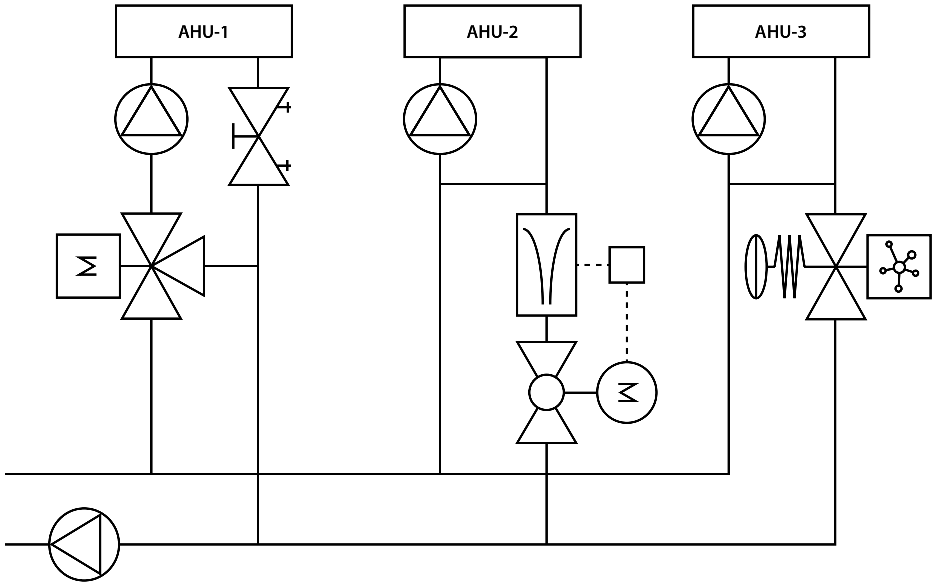
PICV solution

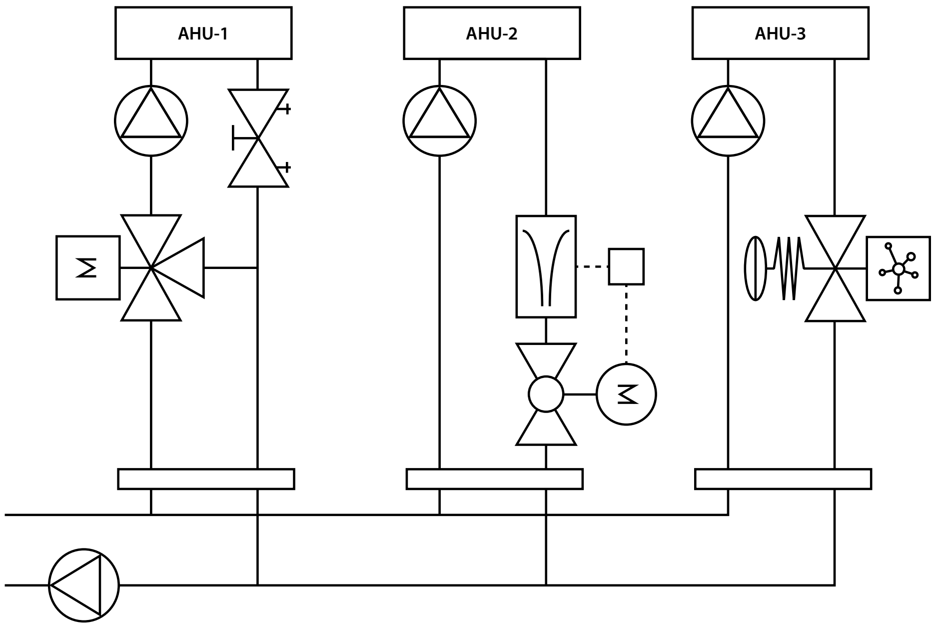


6. Analysis

From the measurement we have described it is clear the different solutions generate different results, especially when we're looking at control stability. It is interesting to determine what causes those differences. Obviously we have 2 different set-ups, one with a 3-way valve and two with 2-way valves. However, that does not have the most profound effect on the control stability. The 3-way valve is actually in the middle of the three solutions.

The main distinction between the solutions is how the valves are exposed to pressure drops. The 3-way valve is, in this particular instance, not exposed to big pressure fluctuations. The main pump is in this case designed in such a way that it has just enough pump head to deliver the water to the 3-way valve. An alternative design would have a hydronic decoupler near the 3-way valve, which would have the added benefit of keeping warm water circulating close to the AHU. Effectively that means that in both designs the 3-way valve is isolated from pressure fluctuations.





The 2-way valve solutions (EPIV and PICV) are exposed to the pump head of the main pump though, since that is used to inject the water into the constantly circulating AHU circuit. Therefore, the pressures drop on the valves does change because that part of the system is functioning as a standard variable flow system. When the valve closes, the pressure drop increases and the pressure drop fluctuates when other valves in the system open or close.

The EPIV and PICV use different ways to handle this pressure challenge. The PICV solution with AB-QM has a built-in mechanic pressure controller, so pressure fluctuations are prevented from influencing the control valve. The EPIV uses a 2-way ball valve to compensate for pressure changes. That means that if the pressure drop rises but the demand from the application remains the same, the valve closes to prevent the flow from going up. This has 2 consequences. Because the pressure is constantly changing, the actuator keeps moving constantly and when the flow is small, very small movements of the valve create relatively big effects (see appendix). The effect is that the valve is frequently hunting for the right position and keeps moving.

Another issue is the load on the valves. If you have a high pressure drop on the valve and a small opening, small movements of the valve create very big effects and fluctuations. When you use a PICV, the pressure controller isolates the valve from increases in pressure and therefore it can control precisely over the full range. In the case of an electronic pressure compensation (EPIV), the control valve is not insulated from pressure increases. That means you're trying to control a small flow with a high and fluctuating pressure difference, which is too much for even the best algorithm.

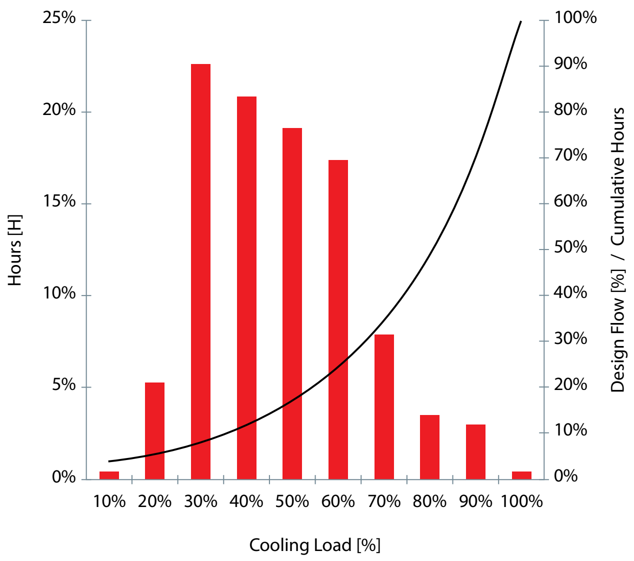
7. Conclusion

For air handling units with a need for a constant flow over the heat exchanger, a 3-way valve, provided it's properly designed, can give you very acceptable results.

An EPIV can provide more information on the energy consumption of the application but it does not really provide precise control due to the lack of a pressure controller.

The PICV combined with a digital actuator, optionally expanded with a flow sensor and temperature senors, will give you the best of both worlds and will combine precise and stable control with the ability to provide a wealth of data to the BMS.

8. Appendix

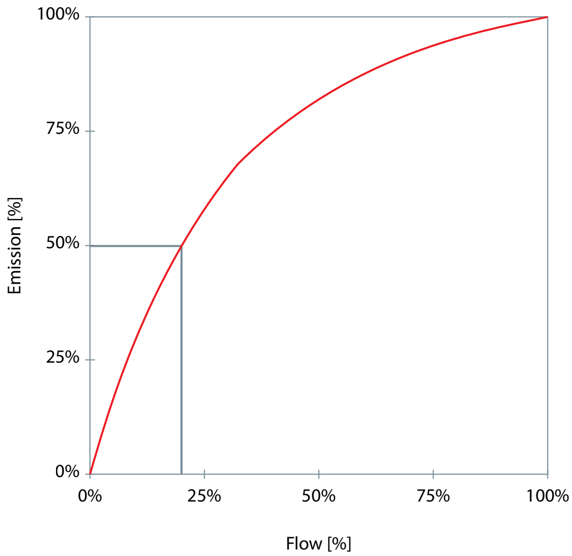


As can be seen from the graph above, full load is not common in HVAC systems. Several reasons for this can be identified:

- HVAC systems are designed for (outside) conditions that are extreme in order te ensure comfortable conditions even when the weather outside is very cold or hot. Those conditions don't occur that often.
- In temperate conditions, very low loads are quite common in the intermediate seasons, like spring and fall.
- During the design process, safety factors are in common use. That means that the systems are generally overdesigned. Exacerbating that are the sizing choices made. For example, if a radiator needs to deliver 2130 Watt and the catalogue offers a 2000 Watt and a 2500 Watt version, usually the larger option is chosen to be on the safe side, on top of existing safety factors.

So far we have been talking about the load but a 50% load does not represent a 50% flow through the system. Please look at a typical air-water coil characteristic:

Heat exchanger characteristics



The coil characteristic is quite aggessive. So, 50% of the maximum output can be achieved with only 20% of the flow.

So adding these two factors together, a predominantly low load profile and front loaded HEX characteristic and it's clear that low flows, 20% or less, are extremely common and need to be controlled precisely to ensure proper air temperature for maximum comfort.

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