
# SMART VALVES EXPLAINED

## Introduction

Since their inception Pressure Independent Control Valves [PICVs] have revolutionised the building service industry. Offering the functionality of three different valve types in one valve [differential pressure regulator, 2-port control valve and a balancing valve], they have reduced pump energy consumption and the need to have three separate valves. The PICV saves space, time, and money throughout the design, construction and running of the system. It has become common place to find PICVs serving every terminal unit and heat exchanger in a hydronic system.

Smart Valves and Energy Valves are an evolution of the PICV. They still have the capability of being a dynamic control valve. In addition, Smart Valves can control temperature differential, pressure differential and power outputs.

## What exactly is a Smart Valve?

A Smart Valve is a PICV, supplied with an intelligent actuator, enhancing connectivity. It has the capability to be connected to different sensors, typically temperature and pressure sensors. These sensors allow the monitoring of flow rate, ΔP [the pressure difference between two points], inlet temperature, outlet temperature, ΔT [the temperature difference between two points] and energy consumption. These data points are communicated and viewed through a communication protocol such as BACnet or Modbus [other protocols are available]. Communication protocols also enable remote changes to the writable data points, such as design ΔT and maximum flow rate.

With the additional sensors Smart Valves are capable of different control modes. This can be a dynamic control valve with additional monitoring features, a differential pressure control valve, or an energy valve.

Not all Smart Valves are designed exactly in the same way. The main differentiator is how the flow rate is kept constant with changing differential pressure. There are two main categories: Mechanical Smart Valves and Electrical Smart Valves.

### Mechanical Smart Valves

A mechanical Smart Valve combines a mechanical PICV, which uses the three in one valve concept with a intelligent actuator with additional sensors. The intelligent actuator relays the data points from the sensors and any feedback signals to the BMS. When the controlling characteristic is outside of set parameters [which can be altered remotely] the valve position changes. The dynamic feature of a mechanical Smart Valve is achieved by the differential pressure regulator resulting in minimum actuator movements whilst maintaining flow rate pressure independency.

### Electronic Smart Valves

An electronic Smart Valve combines a 2-port control valve with an ultrasonic flow measuring device. The maximum flow rate is set on the 2-port's actuator. This restricts the maximum opening position, how far the valve can open, irrespective of the control signal.

The ultrasonic flow measuring device (UFMD) measures the flow rate by reflecting ultra-sonic waves off a reflective surface and converting these into a flowrate. If the UFMD senses the flow rate increasing beyond the maximum set point a signal is sent to the actuator on the 2-port control valve and the valve begins to restrict the flow further. Controlling flow rate this way means the actuator is constantly adjusting the valve as the pressures in the system change.

Some manufacturers offer a Smart Energy Valve with a MID-approved UFMD allowing for remote billing. This can be very useful when these valves are used in apartment blocks. Building managers can remotely send e-bills to the apartment's owners/tenants.

All Smart Valves can utilise the measure of ΔT to maximise efficiency [see Low ΔT Syndrome] and to detect valve anomalies. When a valve has been shut down for an extended period the temperature differential should be close to 0. If the temperature sensors measure a ΔT larger than what is expected after this period, the valve should be flagged and investigated as the valve is potentially passing water, which will greatly decrease the energy efficiency. Commercially, mechanical smart valves tend to be more cost-effective than their electronic equivalents.

## Low ΔT Syndrome

Low ΔT syndrome is a relatively common problem occurring in hydronic systems. Put simply, low ΔT syndrome is the occurrence of temperature differentials lower than design. This causes an increase in energy consumption from pumps and a decrease in system efficiency.

Heat exchangers are selected based on a load Q [kW] and a design ΔT. This ΔT and the corresponding load given in manufacturer's data is calculated based on experimental studies done in ideal situations. Equation (1) shows that the power output [Q] is directly proportional to mass flow rate [*m*] and temperature differential [ΔT]. Therefore, in an ideal system: as the flow rate increases, the temperature differential remains constant whilst the power output increases and vice versa.

$$Q = \dot{m} C_P \Delta T \quad (1)$$

However ideal systems don't exist! From equation (1), one would assume that the relationship between Q and *m* would be strictly linear. However, figure 1 shows an example demonstrating how the actual power output changes as the mass flow rate increases.

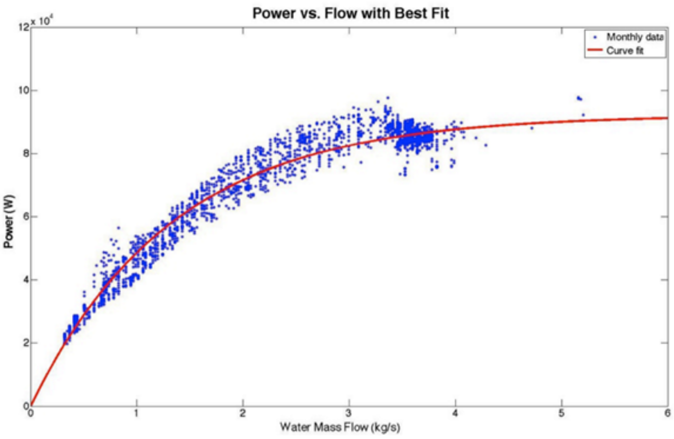


Figure 1 Power Output v Flow Rate [1]

Evidently this is more of a logarithmic relationship. The variance from the best fit line (shown in red) are due to external factors affecting heat transfer. These include but are not limited to air inlet temperature, air flow rate and the air humidity ratio.

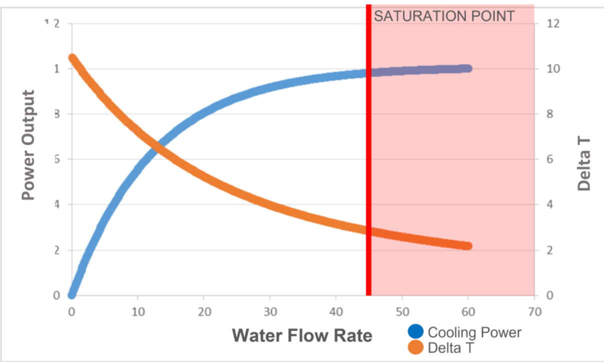


Figure 2 Coil Heat Transfer Behaviour [2]

To explain the plateauing of the above power curve it is important to look at the relationship between flow rate and ΔT. Figure 2 shows that as flow rate increases the temperature differential decreases, and as the ΔT decreases the power output gradually plateaus to the coil's saturation point. A coil is said to be saturated when the rate of change in power output is minimal, i.e. the point where a significant increase in flow rate does not yield a significant change in power output.

So, what causes Low ΔT Syndrome? Some of the most common causes are briefly outlined in the following paragraphs.

After years of operation, terminals can be subject to coil fouling. On the waterside this is the build-up of debris inside the coil. This restriction requires an increase in flow rate, which may go beyond the coil's saturation point. The ΔT across the coil will decrease significantly - a sure sign of Low ΔT Syndrome.

On a similar note, the air side of the unit can be subject to fouling. Air filters can become blocked, limiting the air flow rate, which reduces the heat transfer due to the reduction in forced convection between the coils and air and again, reducing the ΔT across the coil.

In the design and construction stages of buildings, terminal units are sized by manufacturers, many of which use empirical data. This may lead to undersized coils as the empirical data can overestimate the coil's capacity [3]. Coils can also be undersized due to supply issues, or a poor selecting process. When the coils are undersized the water flow rate through the coil must increase to meet demand.

### Effects on Building Energy Consumption and Efficiency

When flow rate flowing through a heat exchanger is close to the saturation point of the heat exchanger, we have already established that the rate of change of the power output reduces. The effect in power consumption on the hydronic system can be established using the Pump Affinity Laws [Equations (2), (3) and (4)]. For a pump working against a fixed resistance, the change in pump speed gives the following relations:

| | |
|---|---|
| $Q_2 = Q_1 \left(\frac{N_2}{N_1}\right)$ | (2) |
| $\Delta p_2 = \Delta p_1 \left(\frac{N_2}{N_1}\right)^2$ | (3) |
| $P_2 = P_1 \left(\frac{N_2}{N_1}\right)^3$ | (4) |

Where N is the pump impeller speed (rev/s), Q is flow rate ($m^3/s$), Δp is the differential pressure across the pump and P is the pump power.

If a terminal unit's demand calls for a 10% increase in flow rate:

- The pump speed increases by 10%
- The differential pressure across the pump increases by 21%
- The pump power increases by 33%

At the saturation point of the terminal unit this increase in power usage of the pump yields little to no benefit regarding power output of the system equipment.

Smart Valves can monitor the ΔT across a certain piece of equipment or across a section of the hydronic system in a control mode where the ΔT is to be kept constant. The efficiency of the heat exchanger can be maximised. Plant equipment work on an assumed ΔT value. Any deviation from the design value negatively affects efficiency.

Therefore, the ability to monitor and keep the ΔT allows a piece of hydronic equipment to run in an efficient manner.

## Data Points and Connectivity

The requirements of buildings change from month to month with seasons and habits of the building's occupants changing.

Intelligent actuators allow the tracking and monitoring of different data points: differential pressure, inlet temperature, outlet temperature, temperature differential, flow rate, power output.

These data points can be read showing the current valve conditions but also allow for tracking of the temperature differential, power output or flow rate for example over a period of time.

This enables engineers to analyse the performance of hydronic equipment and optimise the said equipment. This can be particularly useful in retrofitted systems, where system information can be inaccurate or non-existent. A Smart Valve can be installed before pre-commissioning checks to gather data within an allotted period, the longer, the more reliable the data set. At the end of this period, there is data on flow rates, system pressures, temperatures and how the power demand changes with the time of day/week/month.

Traditionally, actuators have a limited number of settings that can be changed onsite. These can include Normally Closed/Open, or Equal Percentage/Linear control. Any changes that are required must be done at the valve, taking time out of any facilities manager's day.

With the inception of smart actuators the number of configurations has increased significantly and with direct connectivity to the BMS, smart actuators can have their configuration changed remotely.

Smart actuators have various methods of connectivity to a laptop or smartphone. The most basic way of connection is using a physical wire to connect to a laptop, directly or via an intermediary piece of electrical equipment. This is a reliable form of communication, however, requires engineers to carry around a length of cable and a laptop and often requires low level access equipment [LLAE] to access the valve.

Access via a smart phone can be done using WLAN or NFC. Both these methods require the download of an app specific to the valve's manufacturer. NFC requires the phone to be close to the actuator to establish a connection. Again, this can require the use of LLAE. Often Smart Valves are installed in ceiling voids next to pipe work, other valves, and hydronic equipment. The NFC point on the actuator can therefore be very difficult to access, but the NFC connection doesn't require power to the actuator for a connection to be made to a mobile phone.

WLAN on the other hand allows remote connection, which removes any requirement for LLAE and contorting past pipes. However, this can lead to confusion when multiple Smart Valves are installed in close proximity. Tapping your smartphone against the valve you want to communicate with removes any possibility of involuntarily editing the setup of a valve which doesn't require it. The name of the valve typically contains the valve type and valve serial number.

Without that information prior to connection, it is difficult to connect to the correct valve.

A caveat is required for these newer forms of connectivity. Clients can be tempted to pay a substantial premium price for the perceived advantage of connecting to valves from the smartphone. Such investment is only worthwhile if the valve population can be easily accessed and connected to a mobile phone. If the Smart Valve is installed against a wall, where a connection cannot be made there is no benefit paying extra for this technology. New and expensive is not always the best solution for your application!

## Remote Commissioning

Smart Valves can be remotely commissioned: Connecting to the valve is done via a communication protocol, the cloud or through a mobile app. Through this connection the valve can be configured to different control modes/characteristics, control signal range and the network settings can be viewed and updated.

Currently BSRIA [4] recommends the following procedure for commissioning a variable flow system consisting of terminal units such as Fan Coil Units, Air Handling Units or Chilled Beams fitted with PICVs [5]. Once all isolation valves on terminal branches have been opened and each PICV has been set to its design setting the system is ready to be commissioned. The differential pressure across the PICV mounted on the index unit should be taken. If the differential pressure is within the manufacturer's stated operational range the system can be signed off as balanced. However, standard practice in the UK requires the flow rate to be verified using a metering station.

Smart valve's additional sensors can be utilised to commission remotely. Mechanical smart valves can use ΔP sensors to verify that the ΔP across the valve is within the operating window stated by the manufacturer. Electronic valves can also be used for remote commissioning utilising the UFMD, which relays real time flow rate data. This data is therefore used to verify whether the system is balanced or not.

In addition to remote commissioning, the configuration of both mechanical and electronic Smart Valves can be changed remotely, such as the maximum flow, design temperature differential and the control modes.

## Application and Control Modes

Traditionally actuators have a limited number of settings that can be changed onsite.

With the inception of smart actuators, the number of configurations has increased significantly. Manufacturers have set up several "control modes", which configure the smart actuator to behave in certain ways.

### Delta T Control

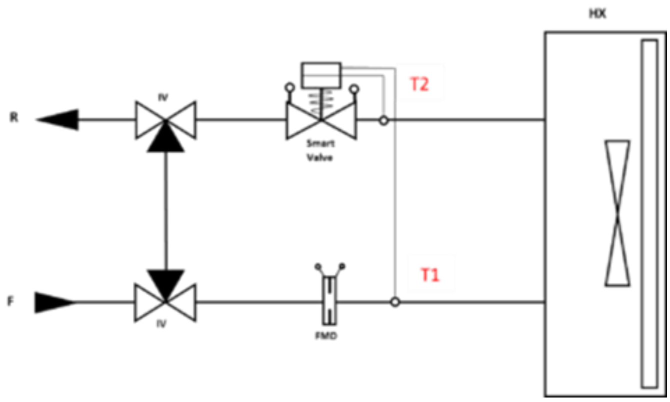


Figure 3 Delta T Control Schematic

Using the two Temperature sensors T1 and T2 the temperature differential across the heat exchanger (HX) can be monitored. A constant ΔT allows maximum power output of a heat exchanger. Any overflows for a given demand greatly increases the amount of energy used in pumping the fluid. Setting up the valve to maintain a constant ΔT negates the possibility of an overflow keeping pumping energy to a minimum and increasing efficiency, avoiding the heat exchanger operating beyond its saturation point.

This could be installed on every heat exchanger in a hydronic system including chillers, boilers, radiators, fan coil units and AHUs. However, large plant equipment like chillers and boilers consume the most energy in a system, e.g. chillers consume around 40% of a commercial/industrial building's energy [5], and therefore benefit most from optimisation.

This ΔT can be combined with a power-limiting type of control, which for any given piece of equipment can limit the amount of thermal power supplied to it. This is particularly useful as equipment tends to be selected above the design value. Oversized chillers, in combination with oversized pumps and control valves lead to system inefficiency as the chiller can operate beyond its saturation point. Limiting the amount of thermal energy supplied to the chiller can mitigate the effects of these oversized components.

Controlling the ΔT across terminal units is possible. However, this control mode prioritises efficiency over power output. In applications where the heat exchanger's output directly impacts the occupant comfort, maximum power output depending on demand should be prioritised.

### Thermal End of Line By-Pass

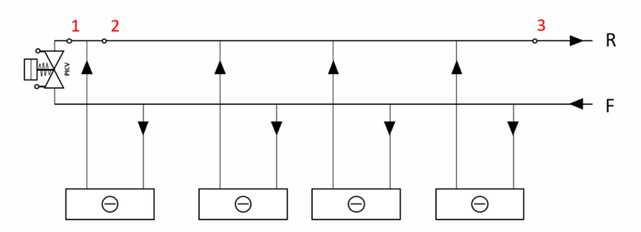


Figure 4 Schematic Thermal End of Line By-pass

Currently end of line by-passes are Constant Flow Valves sized at 2% of the branch's flow rate. This 2% of flow allows sufficient heat transfer in the return branch to keep the ΔT across the branch large enough to avoid any dead legs in the system. However, this does require a 2% overflow from the pumps decreasing system efficiency.

Instead of using Smart Valves to control ΔT across each individual unit [as per figure 3], which would be costly and potentially compromise occupant comfort, a Smart Valve can be installed as a thermal by-pass. The question, which this application raises is where does the temperature sensor should be installed and how is the valve sized? Figure 4 shows 3 different possible locations for the temperature sensor measuring the return temperature*. It would be interesting to see these different locations tested and the resulting effects in system efficiencies.

## Retrofit and Monitoring

As governments and the general public put increasing pressure on companies to become more sustainable, the need for retrofitting existing hydronic systems with new technology to boost the system's efficiency is growing.

In addition to the different control modes and the possibility to mitigate inefficiencies, Smart Valves enable additional data points to be gathered, monitored, and stored, allowing contractors and designers to get a better view on a system's requirements and demands.

Some mechanical smart valves are well suited to retro-fitting applications. If a mechanical PICV is already in-stalled in a hydronic system, the valve can be left in situ and all that requires changing is the actuator, reducing the need for costly system drain downs and replacing of expensive valves.

Smart Valves installed in terminal unit branches allow the monitoring of the changing system demand, providing consultants with a real time view on the diversity of the system.

Similarly, having these valves installed serving different plant equipment, allows accurate monitoring of a system's changing load and the equipment's saturation point. This data paired with design requirements for any retrofitted floors in a building allows accurate selection of any additional equipment required to meet demand.

Both mechanical and electrical Smart Valves offer remote monitoring, typically done through the BMS (e.g., BACnet), however electronic Smart Valves offer communication and monitoring via the Cloud.

The cloud-based monitoring allows a user who is not connected to the BMS to access current and historical data of a valve. In a retrofit application this will allow consultants, contactors, and manufacturers to have access to the data that the Energy Valve collects. This data can then be used as real system characteristics to size various pieces of hydronic equipment.

## Conclusion

The building service industry is and will continue to call for more energy efficient buildings. With heating and cooling systems being responsible for such a large proportion of a building's energy use, there is a big focus on boosting the hydronic system's efficiency. One of the ways this can be done is using Smart Valves. When used smartly, they can boost HX efficiency by mitigating the negative effects of low ΔT syndrome. Besides, they support greater efficiency in the commissioning process due to remote communication.

The two main categories of Smart Valves, mechanical and electronic, have their pros and cons. It is up to engineers to select the correct valve for the specific application.

References:

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