Saving Energy using PICVs

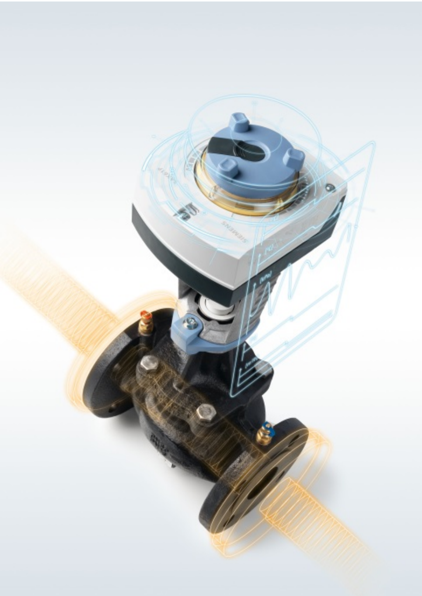
How Dynamic-Balancing of Hydronic Systems Yields up to 30% in Energy Distribution Savings

Keeping temperatures under control

PICVs combine cost savings and comfort
Pressure-independent combi valves (PICVs) play an important role in reducing energy consumption while maintaining building temperature at optimal setpoints. PICVs are effective because they use dynamic-balancing to handle pressure fluctuations in a building's hydronic system. Dynamic-balancing has two major functions. First, it prevents the oversupply of consumers and the subsequent hydronic interference. Second, it drastically reduces temperature swings. As a result, the system uses less energy to maintain occupant comfort.

In addition, PICVs have a pre-setting function that provides even finer temperature control accuracy, further eliminating temperature fluctuations and discomfort. As a result, occupants are less likely to raise or lower temperature settings, adding to the overall energy savings that the valves generate. PICVs also allow for advanced pump control strategies that reduce energy use even more. In total, PICVs can generate energy savings of up to 30%. They can be used in almost any heating and cooling application to provide year-round comfort for building occupants.

This paper discusses the energy savings methods in detail and includes a case study example that quantifies them.



PICVs in the Hydronic Context

Dynamic-Balancing Against Pressure Differences

Pressure-independent combi valves (PICVs) ensure that the flow of hot or cold water is solely dependent on valve travel. Within their range of operation, they are not affected by pressure fluctuations in the building's hydronic system. This is called dynamic-balancing or ***auto-balancing***.

This basic functionality is achieved by an internal differential pressure regulator (Figure 1, #3) working in series to the main flow control valve (#1) and regulating the pressure differential of the flow control valve using a pressure inlet and membrane. Hence the flow across the entire device is independent of the pressure changes in the system and is determined only by the travel of the control valve.

PICVs provide the same actuator interface as standard control valves. It isn't necessary to have additional external energy supply or an electrical sensor. The energy to operate the differential pressure controller is provided by the hydronic system itself.

Another core function of PICVs is to **limit the maximum desired flow**. Typically this is done either by limiting the flow control valve's travel or by limiting the free control path area (#2).

PICVs Are Relevant in the Whole Hydronic System

PICVs can be used in almost all heating and cooling applications in a building, including energy generation, distribution and consumption. The most typical are:

Energy Consumption

- Chilled ceilings
- Radiators
- Heating/chilled water zone control
- Heating/cooling coils in:
  - Fan coil units
  - Air handling units
  - VAV systems (Variable Air Volume)

Energy Distribution

- Heating group
- Chilled water group

Energy Generation

- District heating

Enabling Energy Savings in Three Different Ways

In heating and cooling applications in a building, the auto-balancing function generates energy savings in three different ways:

- It eliminates heat exchanger overflow at anytime and under any operating condition.
- It improves control accuracy by eliminating hydraulic cross-coupling between neighboring control loops.
- It enables advanced energy distribution strategies by eliminating the risk of heat exchanger starvation.

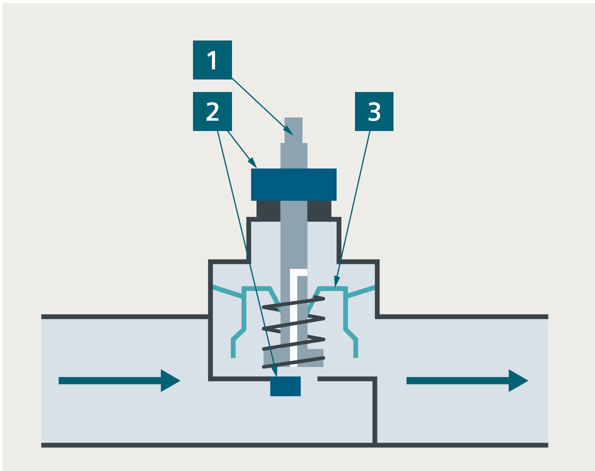


Figure 1: Schematics of a mechanical PICV

1. Flow control valve
2. Pre-setting
3. Differential pressure regulator

Avoiding Overflow

Different Resistance Leads to Under- or Oversupply

In hydronic heating and cooling systems, the hot or cold medium distributing the thermal energy from its generation to the consumer (water, either plain or mixed with an agent like glycol) is transported over piping sections of different lengths and diameters. In the case of multi-story buildings, the elevation to overcome may also vary. As a consequence, the hydraulic resistance along the path from the energy generator to each terminal unit is different.

To provide the required heating or cooling, each terminal unit is designed for a certain flow. When the flow is too low, the consumer does not receive enough energy (undersupply). In the opposite case, when an overflow (or oversupply) takes place, the flow is so high that the terminal unit cannot sufficiently exchange the thermal energy provided. As a consequence, the excess energy is sent back to the energy generator, which is then unable to operate at peak efficiency.

The Differences Are Normalized with Static Balancing

In order to ensure that every consumer receives the proper amount of heating/cooling energy, hydraulic resistance is introduced into the system. Conventionally, this so-called balancing is done by installing manual balancing valves (MBVs), which are installed in series to the standard regulator valves. In this method, the hydraulic resistance of the MBVs is dimensioned so that the system is perfectly balanced for nominal operating condition. The system is "statically balanced." However, this can only be achieved for one given "ideal" operating condition (Fig. 2).

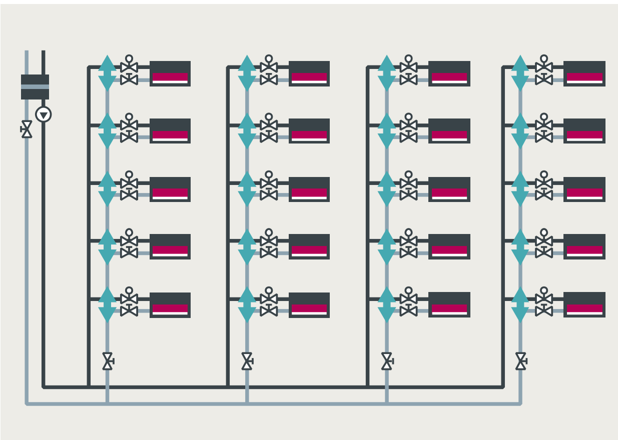


Figure 2: Statically balanced system operating at the design operating point.

Overflow Still Happens in Spite of Static Balancing

The reality looks quite different, however. In statically balanced systems, overflow may still occur in certain part-load conditions.

For example, if some of the circuits are only half open (part-load condition) and the rest are fully open (full-load condition), an overflow takes place in the latter circuits, which get excessive energy (Figure 3).

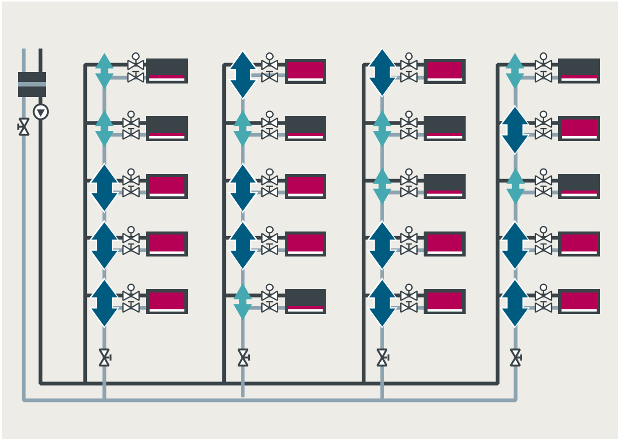


Figure 3: When certain circuits are in part-load or closed, others are in overflow (large blue arrows).

An overflow might last for quite some time before the room temperature controller reacts to the increased or decreased temperature. Such transient overflow phases usually occur either due to a change of load (e.g., change of occupancy of a room) or due to a change of setpoint (e.g., start-up phase in the morning).

Overflow Leads to Energy Inefficiencies

Depending on the type of energy generators, this overflow may lead to two negative side effects. First, overflow leads to the transportation of water through the system that doesn't carry a proper amount of additional energy to the consumers,[1] and hence a low temperature difference across the heat exchanger. Second, in the case of chillers and heat pumps, overflow causes inefficiencies in the energy generators. Overflow of dedicated consumers can lead to a return temperature lower than the nominal design value in cooling mode and a return temperature higher than the nominal design value in heating mode, decreasing the energy efficiency of boilers and chillers by 2% and 3%, respectively.[2]

[1] Heat transfer by the heat exchanger is directly proportional to the flow rate and the temperature difference across the heat exchanger. Flow rate and temperature difference are inversely proportional to each other in a closed system.

[2] A decrease of the evaporation temperature of a chiller below its design value by 1 degree decreases its performance by around 3%. Increasing the condensing temperature of a heat pump over its design value by 1 degree decreases its performance by around 2%.

Improving Control Accuracy

PICVs Eliminate Overflows with Dynamic-Balancing

As stated in the description of the PICV working principle, the use of PICVs limits the maximum flow at part-load conditions and thus avoids the mentioned increase of direct energy demand (generation, consumption) and indirect energy demand (transport, distribution).

Hydraulic Cross-Coupling Triggers Variations of Temperature in the Building

As described above, a section of the heating or cooling system may temporarily increase (or decrease) its energy demand, for instance when a meeting room is filled with people at the beginning of a workshop or empties at the end. This happens everywhere in the building, at different moments, in different places.

This increase in energy demand in certain sections of the system leads to a reduction of the energy supplied to other areas of the building. The temperature of these areas then deviates from the setpoint and it takes time until the room thermostat triggers the appropriate response. The temperature will then follow a cycle of increases and decreases of temperature and stabilize again over time around the desired setpoint (Figure 4). This effect is called "hydraulic cross-coupling."

The first issue with hydraulic cross-coupling is that users of the building experience periods of discomfort when the temperature is at its lowest or highest point in the cycle.

Users Shift the Setpoint to Reduce Discomfort

The second issue is that users will typically change the temperature setpoint when they experience some degree of discomfort. For example, when the temperature is at its lowest point in the cycle during the cold months, they may increase the setpoint by a couple of notches. The whole curve is shifted up one or two degrees. However, they will likely not react an hour later, when the room temperature is a bit higher than usual. The setpoint shift stays for the whole season.

A similar scenario takes place during the hot months. When the room is at the hottest temperature in the cycle, the users may crank up the cooling, without turning it back down later on when the temperature is at the lowest point.

In both heating and cooling cases, the overall energy demand is increased because of the variations in temperature caused by the hydraulic disturbances.

PICVs Nearly Eliminate Temperature Variations

When PICVs are used, their auto-balancing functionality compensates for the variations in pressure. They allow for much better control accuracy at the setpoint and hence virutally eliminate the temperature swings (Figure 5).

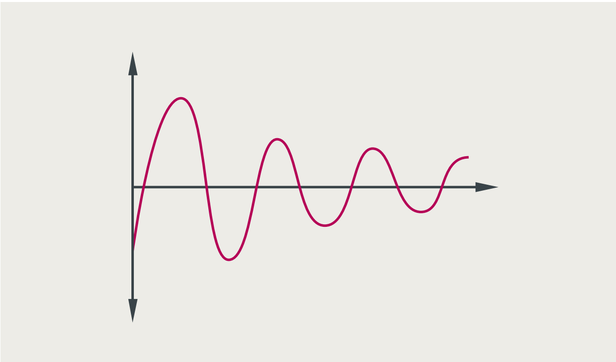


Figure 4: Because of cross-coupling, the temperature deviates from the setpoint. Delayed correction of the room temperature leads to wide temperature fluctuation, less comfort and energy loss.

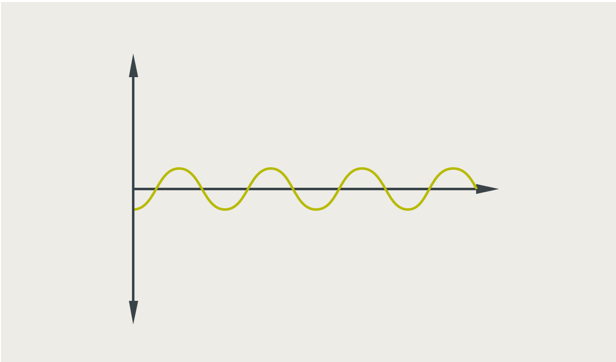


Figure 5: PICVs automatically compensate for the variations in pressure and maintain the room temperature very close to the setpoint.

Full-Stroke Further Increases Control Accuracy

Even finer control accuracy is provided by Siemens PICVs, in which pre-setting is obtained by limiting the free control path area. Since the full travel of the flow control valve is available to manage the opening, the volumetric flow can be defined using a much larger number of steps (Figure 6). The temperature can be reached in smaller increments, thus reducing even further the temperature fluctuations and discomfort.

Preventing the Setpoint Shift Leads to Energy Savings

As a consequence, users do not experience any discomfort at the original setpoint and will not shift energy demand up to compensate for the peaks of temperature variations. When carried over the entire building for an entire season, this adds up to substantial energy savings.

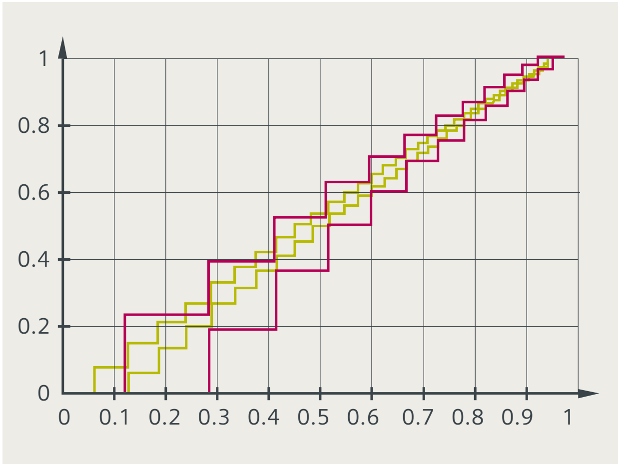


Figure 6: PICVs with pre-setting obtained by limiting the flow control valve's travel (stroke limitation) have reduced control accuracy (purple). Siemens PICVs with pre-setting obtained by limiting the free control path area still have the full stroke available and provide a much more granular control of the flow and temperature (green).

Enabling Optimal Distribution Strategies

Conventional Systems Require Constant Pressure

Modern energy transportation systems, such as variable-speed controlled pumps, adapt the delivery head of a pump and the volume flow to the demand load. There are a variety of control strategies on the market today. Control can be done in connection with differential pressure, effective volume flow through a flow sensor, differential temperature, outside temperature, or supply temperature.

As explained above, a conventional hydronic system is "statically balanced." The hydraulic resistance of the MBVs is dimensioned so that the system is perfectly balanced for a nominal operating condition. Typically, since such a system might still be sensitive to pressure differences, the pump control strategy is designed to ensure a constant differential pressure in the system (Figure 7).

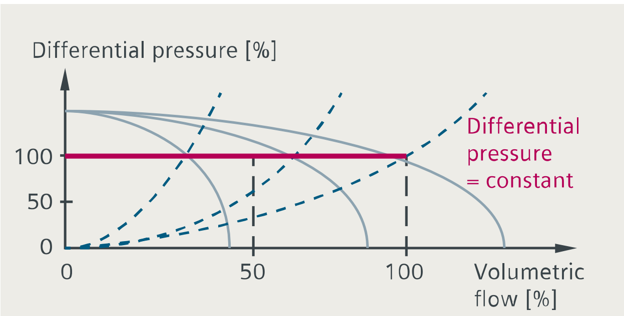


Figure 7: Pump control strategy ensuring that differential pressure is constantly maintained at the desired value.

Pumps Have to Battle against Unnecessary Resistance

Any reduction of the pressure difference could lead to the starvation of some terminal units. Even when fully opened, they do not get the necessary flow required. As a consequence, the energy exchange is insufficient and the temperature setpoint cannot be ensured anymore.

To ensure the necessary flow, pumps have to operate against the hydraulic resistance that has been introduced into the system to ensure a nominal operating condition, even if the actual operating conditions are much different.

As PICVs Maintain Flow, Pumps Optimize Pressure

On the other hand, PICVs make it possible to deliver the same flow at a lower pressure difference. As long as the pressure difference remains in the allowed PICV operating range, the flow will be maintained at the set level (auto-balancing feature).

This opens the door for advanced pump control strategies, where the same flow is delivered at a lower pressure difference, somewhere between the lowest possible point (to remain in the PICV's operating range) and the nominal point (Figure 8).

The pump battles against less resistance. It can operate at an optimal speed and requires substantially less energy to provide the same performance.

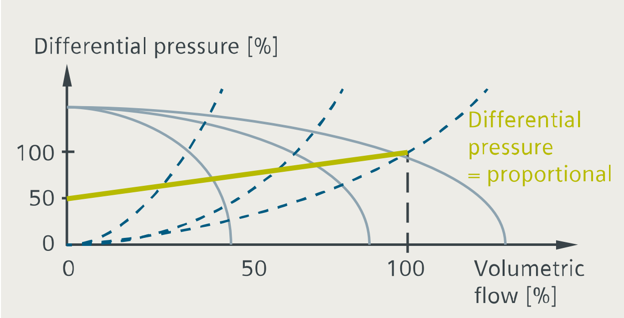


Figure 8: Pump control strategy with variation of differential pressure.

Savings from a Real Case

Application in Real Life Case Study

The three ways to generate savings described in this paper were implemented in a campus with several buildings in a large Saudi Arabian city that has a representative number of heating and cooling days.

This building features air handling and fan coil units, with chilled water for cooling and electrical re-heaters for heating. The chilled water system incorporates the following components:

- 10 chillers. Located at utility building. Nine duty and one standby, capacity: 1370 kW each.
- 10 primary chilled water pumps, constant speed. Located at utility building. Nine duty and one standby, capacity: 55 l/s (198 m3/h) @ 30m head. The ratio of installed pump capacity and installed cooling capacity (chillers) is approximately 1.5%.
- 10 secondary chilled water pumps, variable speed. Located at utility building. Nine duty and one standby, capacity: 55 l/s (198 m3/h) @ 55m head. The ratio of installed pump capacity and installed cooling capacity (chillers) is approximately 2.5%.
- Different sizes of air handling units (AHUs) and fan coil units (FCUs) located at each building as per demand cooling loads. Control valves with electrical actuators installed on the chilled water return pipes of the cooling units (AHUs and FCUs).

Up to 30% Savings with PICVs

Using actual operating and climatic data, energy savings were generated for both energy distribution and energy generation using the following three methods:

- Eliminating heat exchanger overflow at any time and under any operating condition
- Improving control accuracy by eliminating hydraulic cross-coupling between neighboring control loops
- Enabling advanced energy distribution strategies by eliminating the risk of heat exchanger / cooling coils starvation

In this case, conservative calculations demonstrated that using PICVs in the building yielded ***savings of up to 25-30% in energy distribution*** and ***savings of 2-5% for energy generation***.

In absolute annual figures, these savings amounted to approximately *330 MWh and approximately 200 MWh*, respectively, or a total annual cost saving of around ***34000 EUR***.

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