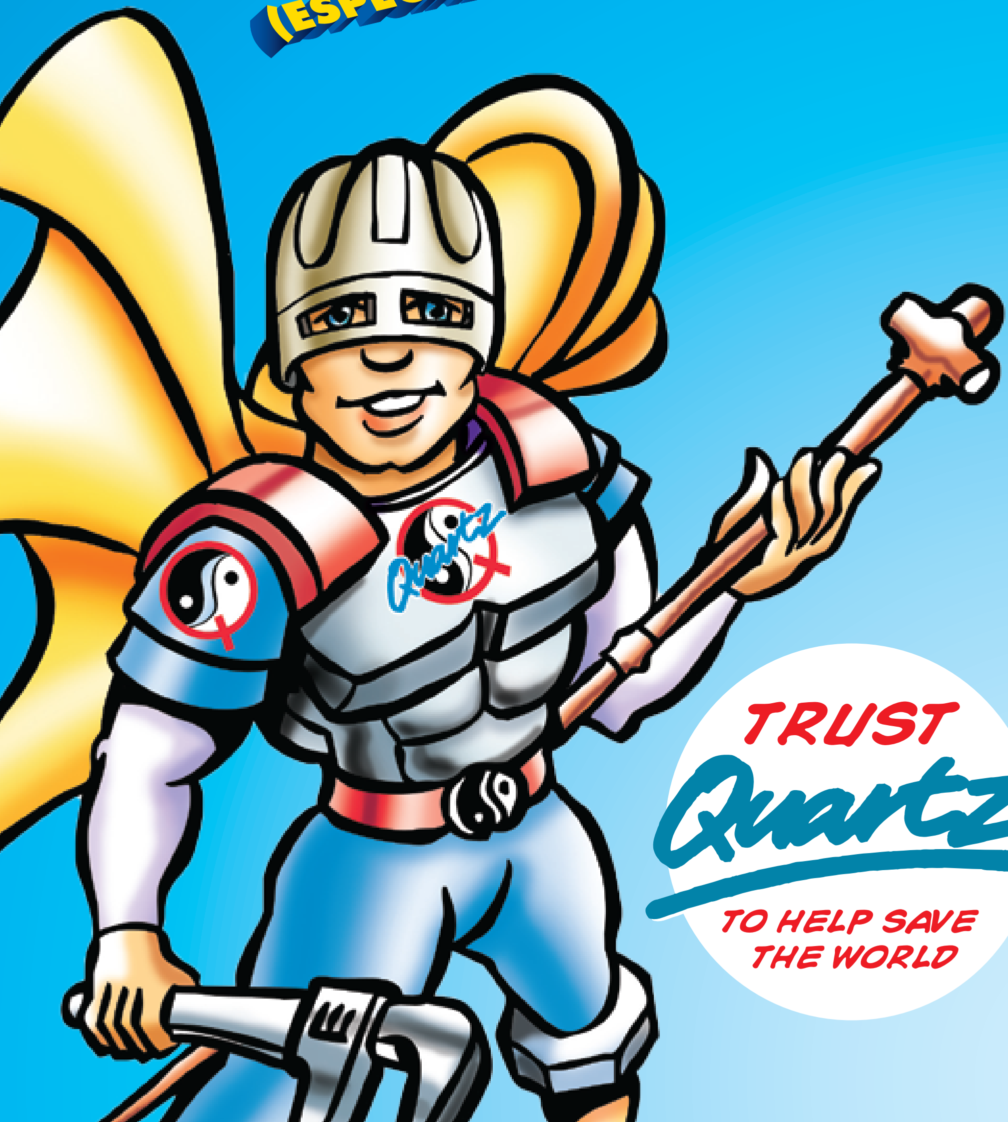
BALANCING IT'S NO ACT
(ESPECIALLY IN THE PLUMBING!)



TRUST
Quartz
TO HELP SAVE THE WORLD

Balancing – It's No Act!

(Especially In the Plumbing!)

Hydraulic Circuits, Why Balance?

All heat transfer terminal units, whether they use direct expansion refrigerant or water as the heat transfer medium, have the common characteristic that their duty (heating or cooling) is specific to a number of key parameters (air temperature, airflow volume etc). In other words, it is rather like a snapshot in time when all key parameters are at their design point. For units utilising water as the transfer medium, a key parameter is the water volume flow rate. The design duty is only achieved when the exact flow rate for the given set of parameters flows through the coil. Likewise, the chiller, heat pump or boiler that generates the cooling or heating for the system requires an exact flow rate if it is to provide the design duty.

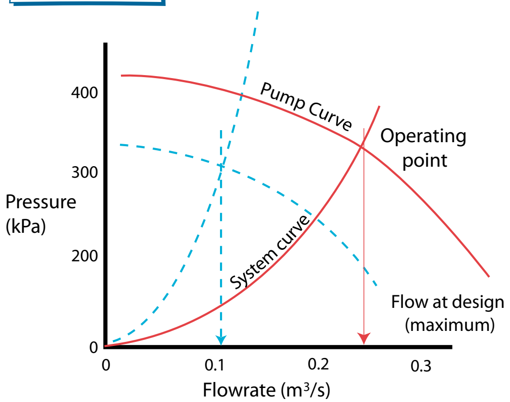
The volume flow rate in any hydraulic circuit is directly proportional to the available pressure at the entry to any component and to the resistance of that component to the flow. In simple terms, the higher the resistance of the component, the lower the flow for a given available pressure. The available pressure is generated by a pump that is usually located adjacent to, or even as a component of, the chiller, heat pump or boiler. As the interconnecting pipe work of the system is also a component and has a resistance to flow, it can be readily seen that the available pressure at terminal units is going to be different depending upon how much pipe work exists between the pump and the unit. Furthermore, not all units are identical in size and hydraulic characteristic and this will result in compounding the difference in volume flow rate from the design figure.

In order to eliminate all of these variables, balancing valves are added to the system, usually at each terminal unit, on main legs of pipe work and on risers. These valves are basically adjustable restrictions and the balancing process involves generating at least the design pressure for the worst possible unit on the system (the "index" unit) and then increasing the resistance at every other unit until the correct volume flow rate for each unit is achieved. The other way to put this is that the index unit is supplied with the correct volume flow, the others are oversupplied, so we throttle them down to obtain the correct figure. This process is known as proportional balancing. Even with this simple description it can be seen that the whole process can be expensive in terms of capital plant and commissioning engineers time.

Problems with Balancing

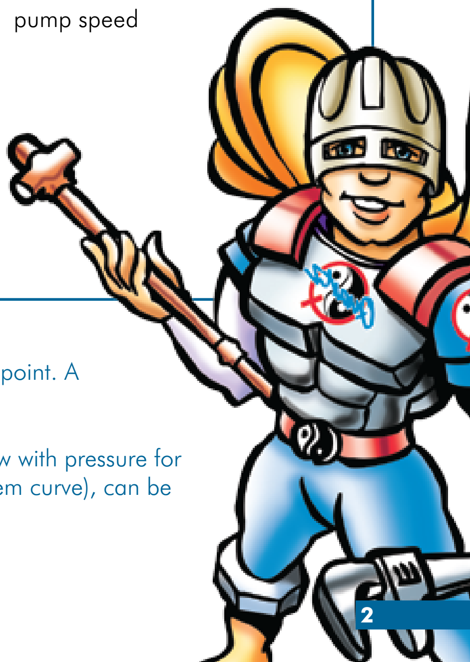
It can be readily seen that, when balanced, the components on the system achieve their design flow rate for that specific design set up. Change a single parameter (e.g. one terminal unit closes down due to the zone being satisfied) and all other units will get a higher than design flow rate. To overcome this, three and four port control valves have traditionally been utilised. These valves, when closed, bypass the water that would have gone through the coil thereby attempting to maintain a constant volume flow. However, unless the pressure drop of the bypass leg is equal to the pressure drop caused by passing through the coil (which it invariably is not), variations in flow will still occur. Maintaining constant volume flow in the entire system requires the pump to operate continuously at full design speed and this is regarded as being energy inefficient, especially when the system is operating at 50% of maximum duty or less, for large parts of its life. To reduce energy usage, it is now common practice to use variable speed pumps in conjunction with two port valves. Two port valves are required in order for the pump controls to detect a required reduction in flow by measurement of differential pressure across the circuit. If a valve shuts down, the differential pressure will increase and, detecting this, the pump will reduce speed and hence flow in

Figure 1



Blue indicates at Low loads, reduced pump speed

Red indicates at maximum loads, maximum pump speed

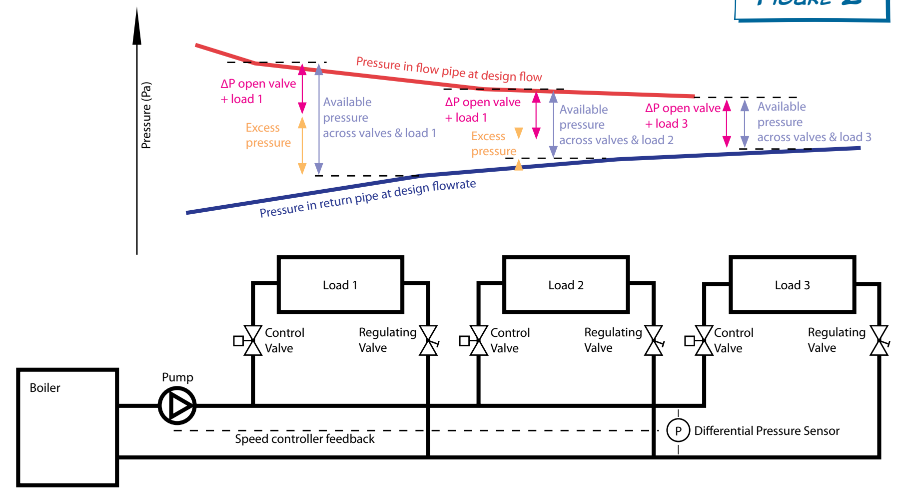


order to reduce the differential pressure back to the set point. A graph depicting this effect is shown in figure 1 above.

Referring to the diagram in figure 1, the variation of flow with pressure for the pump (pump curve) and the connected system (system curve), can be easily seen. The red curves demonstrate the design condition and where the two curves intersect describes the operating point for this design condition. Closure of any control valve changes the pressure characteristic which is detected by a differential pressure sensor that is placed across the flow and return pipes, usually about 2/3rd's of the way along in order to get a reasonably average figure. This causes the pump to slow down and it therefore has a new curve which is shown in blue in the figure. The system characteristics have also changed and the new system curve is shown in blue. Where these two new curves intersect is the new operation point for the system which has moved to the left and down from the design point.

Even this arrangement is not foolproof as not all of the pressure drop of the interconnecting pipe work can be detected by the pump sensor. The net effect is that most units upstream of the sensor will receive less flow than design whilst the units downstream of the sensor obtain more flow than they require. A diagram that illustrates this is shown in Figure 2 below.
The reason that the position of 2/3rd is chosen is to provide the best average situation.

FIGURE 2



Balancing Effects on Control Valves

The control valves on a hydraulic system must be selected such that their operation has a controlling effect for a significant proportion of their movement. To illustrate what is meant by this, consider a valve that is far too large for the coil which it controls, a 150mm valve on a 15mm coil for example. It is easy to see that the vast majority of the valve movement would have no effect on the coil and it would only be the last bit of movement that would be effective. This silly arrangement would act as a simple on/off valve with no control on flow and hence performance. The valve sizing therefore has to match the coil and, in pressure terms, the pressure drop of the valve when fully open should be of similar order to the pressure drop of the coil to be controlled at design flow rate. This influence of the valve on the coil is known as the valve authority and is given by $\Delta P_v/(\Delta P_s + \Delta P_v)$ where ΔP_v is the pressure drop across the fully open valve and ΔP_s is the pressure drop across the coil being controlled. It can be seen that if the pressure drops are equal the valve authority will be 0.5. For constant volume systems that utilise 3 & 4 port valves and where the coil pressure drop is known, it is relatively easy to size the valves and achieve an authority of 0.5. In some instances, valve authorities as low as 0.3 are used which gives adequate control whilst reducing the pumping head and hence energy use.

In variable flow systems that utilise modulating 2 port valves the pressure drop that must be considered is that for all of the losses back to the branch connection and can include pipework, regulating valve, flexible hoses, strainers etc. As a result, each valve will have to be sized individually.

In a system operating at design point, the control valves will operate perfectly with their design authority however, like all other components, when a single parameter changes their operating point changes and their control effect can be altered. If one were to consider a system when certain units are satisfied and the valves have closed, then an increase in pressure and hence flow will occur at the valves that are still open. This will result in an increase or decrease in room temperature (increase if heating, decrease if cooling). This change is detected by the temperature sensor and the control system responds to restore the status quo. The entire process takes time to respond. To compensate for this overflow, the valve will close slightly and hence reduce the potential travel for control purposes. The control valves range is thus reduced and, in extreme cases, proper control will be lost for the same reasons as described at the beginning of this chapter.

A way of removing the pressure changes in the circuit is to fit a differential pressure control valve across the flow and return although these are usually restricted to main runs as it is prohibitively costly to fit them at each terminal unit.

Automation – Removing the Hassle

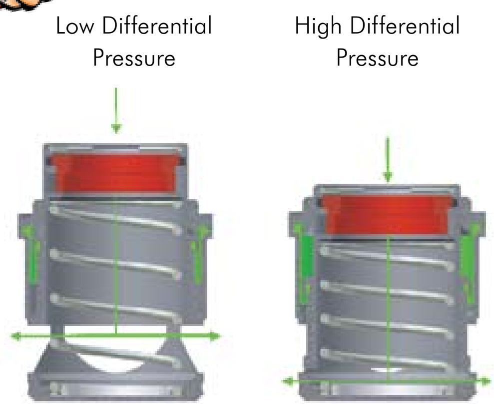
Given the difficulties described above, it is not surprising that a mystique exists and that an industry has developed around what should be a simple system for providing comfort. To remove all of these difficulties the concept of automatic balancing was developed by several companies, some using the idea of differential pressure ports within the valve body and some with the concept of a spring loaded cartridge that would, by moving against the spring as the pressure increased, adjust the size of the opening through which the water could pass thus maintaining a constant flow. The cartridge approach offered the benefit over the internal porting approach of allowing the cartridge to be removed for system flushing and of being much less susceptible to blockage from foreign objects.

FIGURE 3

As briefly described above, the cartridge approach works on the basis of maintaining a constant flow as the pressure varies. Any surplus pressure is taken up by the internal spring. It can immediately be seen that the valve must be able to be adjusted to pass the desired flow rate. This, in the early versions, depended upon the size (and shape) of the holes in the cartridge and adjustment was made by changing the cartridge. In some more modern designs, adjustment is by changing an orifice plate that forms part of the cartridge.

Early cartridges were quite simple in construction being formed from deep drawn stainless steel and operating within a stainless steel liner also manufactured from sheet stainless steel. Whilst they worked successfully, they could rattle and generate noise in the system and the bypass slots on the sides could become blocked by foreign objects. Current generation cartridges in are high quality, machined components that operate within valve bodies also machined to high tolerance. The performance, repeatability of operation and longevity of the valve is substantially improved. A picture showing several sizes of the cartridge and the differing orifices is shown in figure 3 above.

FIGURE 4



As previously explained, the principle of operation is simple however, there is a minimum pressure requirement before the valve enters its control envelope. Simply put, as the water starts flowing through the cartridge there is a pressure drop associated with it. When the design flow rate for the orifice is achieved the pressure drop is in the region of 15kPa, therefore, there must be at least 15kPa available before the cartridge comes into operation. Any excess pressure does not result in increased flow but in movement of the cartridge against the spring. This is shown in the diagram below left (figure 4).

Because of the requirement to generate a minimum pressure for correct operation, it is normal to fit these automatic balancing valves in the return leg (i.e. after the pressure drop of the coil has been taken care of) in order to ensure that, at the index unit, sufficient pressure to cover all components has been generated by the pump.

On the practical front, the cartridge and the valve body are designed such that it is easy to remove the cartridge for changing of orifice plate or for flushing purposes. This latter benefit was introduced to overcome criticism from the market that the fitting of automatic balancing valves prevented flushing and system cleaning. Indeed the design of the cartridge enables back flushing to be performed without removal of the cartridge.

Automatic balancing valves bring a major benefit when used with variable speed pumps. The features of the valve results in such pumps operating at their optimum condition at all times thus reducing energy usage. As more and more steps are taken to reduce carbon emissions and as legislation on this matter becomes ever more stringent, this benefit will become paramount in the design and selection of components for water circuits.

Getting Clever – Balancing & Control, Step 1

The fitting of an automatic balancing valve at each fan coil removes the requirement for manually adjustable valves at the fan coil, manually adjustable balancing valves on the main runs and risers and eliminates the requirement for waterside balancing. Each fan coil will still require a control valve of some sort and, in the early days of automatic balancing, this was a separate valve. The first development in integration of the balancing valve and the control valve was to incorporate the self balancing cartridge into the body of a two port on\off valve. A typical example of this is shown in figure 5.

The balancing cartridge is contained in the angled portion of the body

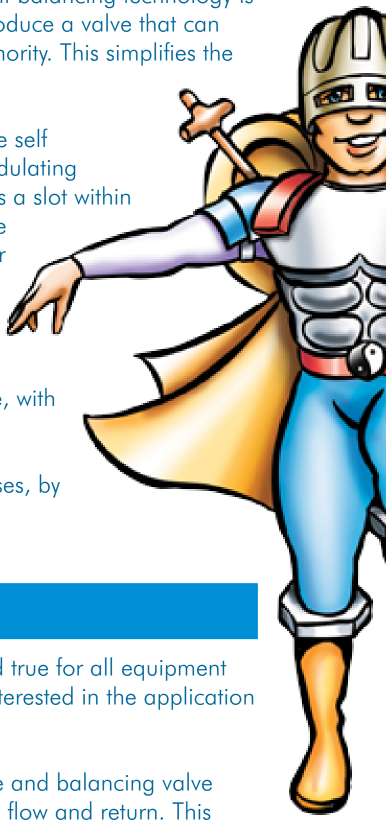
Figure 5

with the control valve adjacent to it. With on\off control the variations in differential pressure and the effects on control valves described above are not relevant and compensation within the valve or externally for differential pressure fluctuations is not required. Such a simple valve replaces, at the fan coil, the two components of a double regulating valve and a two port control valve plus the interconnection components. In addition, because automatic balancing valves are utilised, double regulating valves on the main runs and risers are also eliminated, as is the requirement for commissioning.

Stepped to Stepless & Balanced as Well!

Whilst on/off valves provide a form of control and are acceptable in some applications, they do not provide sufficient control for most applications. What is normally required is modulating control where the flow rate to the fan coil can be infinitely adjusted from full to zero flow. This provides infinite load capacity adjustment, quality control over comfort and results in highly efficient operation. The latest development in self balancing technology is to incorporate full stroke modulation with self balancing and produce a valve that can be selected purely on flow rate rather than on flow rate and authority. This simplifies the design process and removes possible error in fitting of valves.

At the heart of the valve lie two specialist components, one is the self balancing cartridge as described previously; the other is the modulating control that incorporates the flow regulator. This flow regulator is a slot within the component that can be adjusted in size by rotating about the vertical axis of the valve. By incorporating a rotary flow regulator as a dedicated item, the length of stroke of the modulating component is unaffected thereby ensuring that full stroke modulation occurs over the whole flow range. This is not the case with other valves where flow restriction is achieved by restricting the stroke of the valve. A transparent view of the valve, with the components identified, is shown in Figure 6.



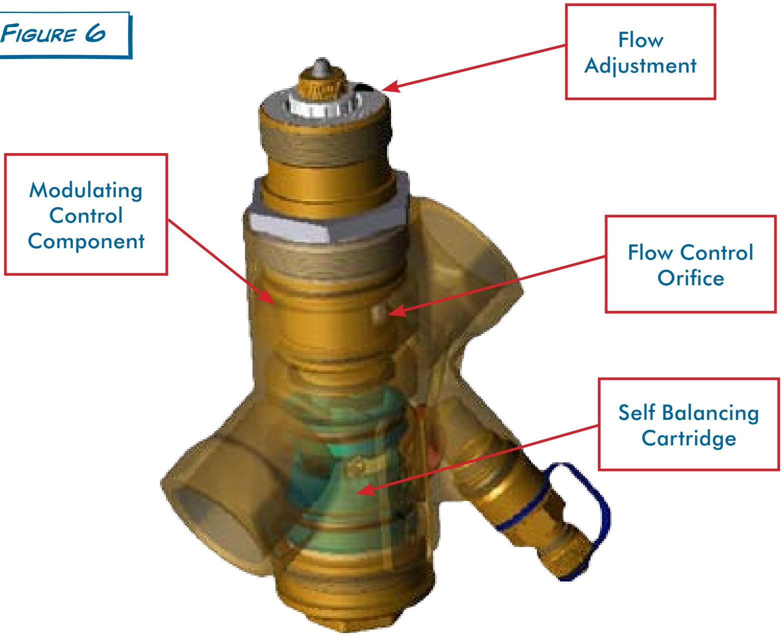
The self balancing cartridge can be removed for flushing purposes, by unscrewing the cap on the base.

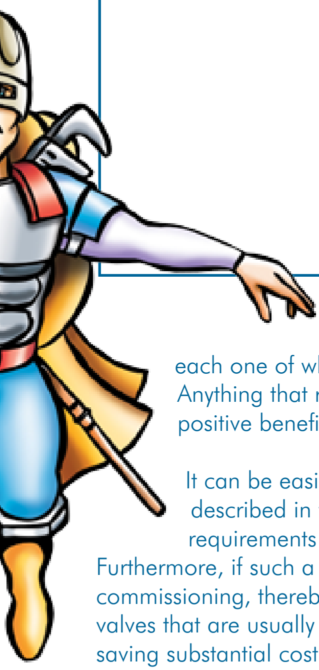
Fan Coils, Valves & Balancing

Although the comments made in the preceding paragraphs hold true for all equipment that utilises water for heat transfer, within Quartz we are most interested in the application to fan coils.

Every fan coil within a system is usually fitted with a control valve and balancing valve in addition to the shut off (isolating) valves that are fitted to both flow and return. This entire combination is expensive and results in a substantial number of pipe connections,

Figure 6





each one of which is a potential failure area and requires labour time to construct. Anything that reduces the complexity and failure potential of this arrangement is a positive benefit.

It can be easily seen that the full stroke, modulating and self balancing valve described in the previous chapter and shown in figure 6, fulfils all of the requirements needed to eliminate joints, labour, cost and failure potential. Furthermore, if such a valve is utilised, set to the design flow rate required, it will not require commissioning, thereby saving the expense involved with this operation. Lastly, the balancing valves that are usually located on the main runs and risers can also be eliminated thereby saving substantial cost.

If such an arrangement sounds rather like hydraulic Shangri-La and must therefore cost the Earth, you would be seriously wrong. The valve costs are similar to the overall cost of the individual control and balancing valves but with savings being made on assembly labour and commissioning. We in Quartz, can offer these valves, factory fitted and set to the design flow rate specified by the selection software. This is the way to go in the 21st Century!

To Summarise

This booklet aims to set out in simple terms, the reasons for balancing hydraulic circuits and the pitfalls that can still be encountered even with a correctly balanced system. The key features are listed below;

Balanced System

One in which the pressure drops of the balancing devices have been adjusted such that every component of the system, at design conditions, receives the correct water flow volume. Any variation from the design set-up, such as a control valve closing, will result in a deviation from the balanced condition.

Self Balancing System

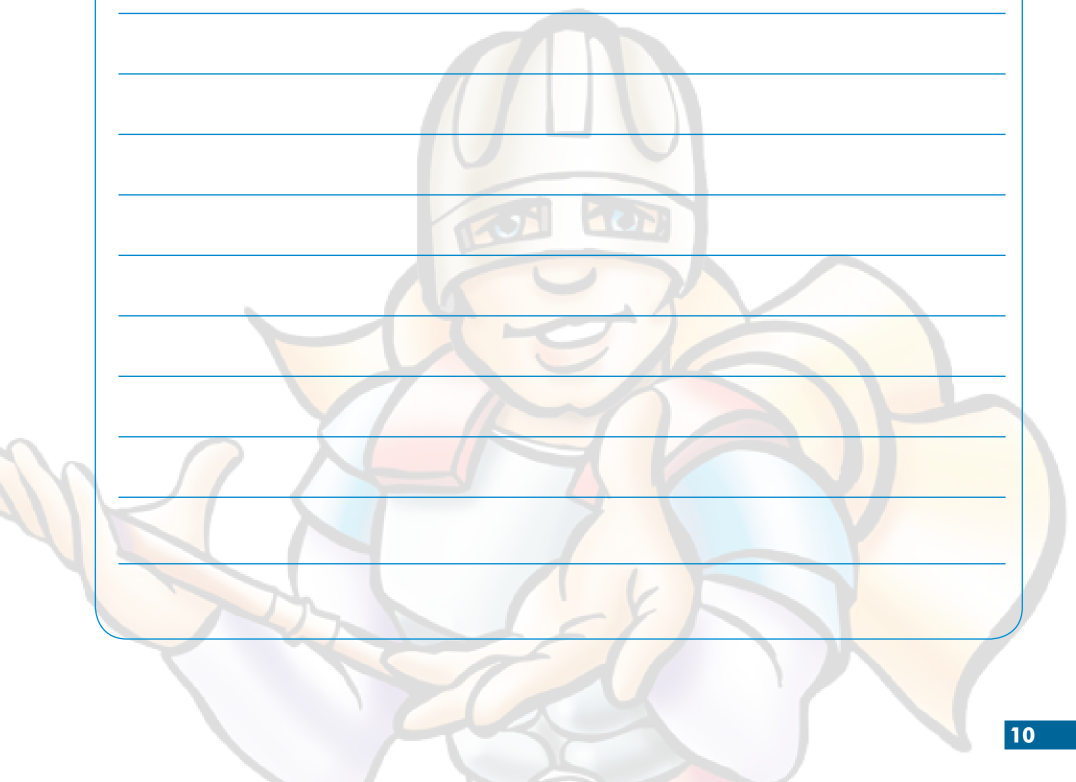
A system that utilises valves that incorporate spring loaded cartridges. Such valves will only pass the designed amount of water. Attempting to push any extra volume through the valve simply results in the cartridge moving against the spring. Providing that the water pump is capable of generating sufficient pressure to overcome the frictional resistance of the index run pipe work, the terminal unit pressure drop and approx 15kPa extra, the system will be in perfect balance and remain so despite changes in the control valve positions.

Full Stroke Modulation and Balancing

A system that incorporates Optima® control valves with all terminal units. These valves incorporate a self balancing cartridge, flow control device and modulating component. They always have full stroke movement no matter what flow rate is required.

The advantages of self balancing are substantial and can result in major cost savings on projects. There is no mystery as to how it is achieved and many examples are in existence that can be examined, should you desire to do so. Fan Coils that are factory fitted with such valves and set to the design flow rate, provide “plug & play” solutions that are becoming most popular in the market place. Is it not time to come down off the See Saw?

Notes



Useful Info

1000 litres = 1m3

1 l/s = 3.6 m3/h

100 kPa = 1 bar ≈ 9.8m head water

Pump power (kW) = Pressure (kPa) x flow rate (m3/h) / pump efficiency

1kWh electricity ≈ 0.5 kg CO2 released

Quartz Division, TEV Limited,
Armytage Road, Brighouse, West Yorkshire, UK HD6 1QF
sales@quartz.co.uk www.quartz.co.uk