

# AIR CONDITIONING AND REFRIGERATION Journal

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## Hydronic Balancing and Stabilisation of the Differential Pressures.

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The main objective of heating and air conditioning plant design is to obtain comfortable indoor climate at minimal energy costs and without operational problems.

In theory, new control technologies can satisfy the most demanding requirements on indoor comfort and energy efficiency. In practice, however, even the most sophisticated controllers do not always control efficiently. This is because the conditions required for successful operation are not met. As a result, both comfort and cost savings can be compromised. This is not acceptable.

The following are common HVAC plant problems:

- The desired room temperature is not achieved in all rooms, especially after big load variations.
- When obtained, the required room temperature fluctuates even though sophisticated controllers are used on the terminal units. These variations usually occur at small and medium loads.
- Although the installed capacity is sufficient, this capacity cannot be transmitted at large loads and particularly not during start up.

These malfunctions cannot be corrected by installing even more sophisticated controllers. Often, the malfunctions occur because one or several of three fundamental conditions are not fulfilled.

1. The design flow must be available at all terminals.
2. The differential pressure across the control valves must not vary too much.
3. Flows must be compatible at system interfaces.

This article deals specifically with the second condition.

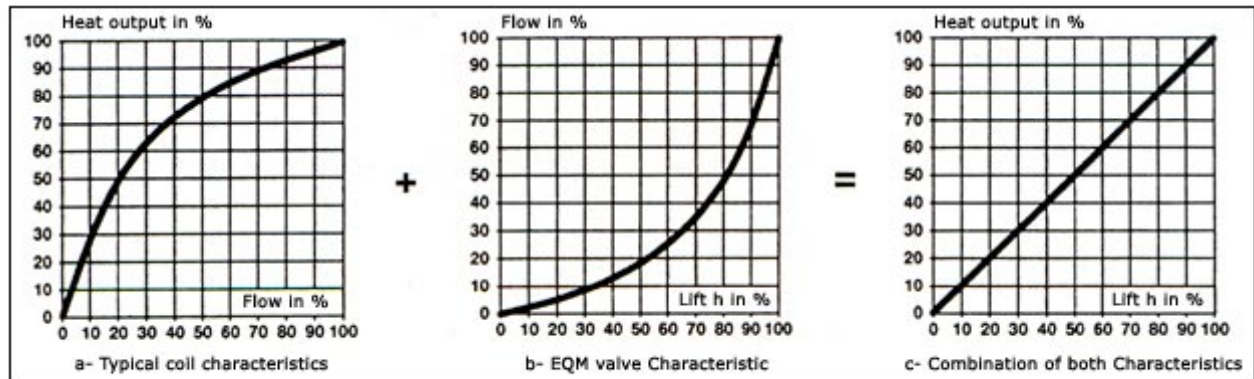


Figure 1 : Non-linearity of a coil characteristic compensated by adopting an inverse non-linear characteristic for the control valve.

## The Control valve characteristic

The characteristic of a control valve is defined by the relation between the water flow through the valve and the valve lift at constant differential pressure. Water flow and valve lift are expressed as a percentage of their maximum values.

For a valve with linear characteristic the water flow is proportional to the valve lift. Due to the non-linear characteristic of the terminal unit (**Figure 1a**), opening the control valve slightly can significantly increase the emission at small and medium loads. The control loop may therefore be unstable at small loads.

You can solve this problem by choosing a control valve characteristic to compensate for the non-linearity. This helps ensure that emission from the terminal unit is proportional to the valve lift.

Let's say that the output of the terminal unit is 50 percent of its design value when supplied by 20 percent of its design flow. The valve may then be designed to allow only 20 percent of the design flow when it is open 50 percent. When the valve is 50 percent open you can then obtain 50 percent of the heat output (**Figure 1c**). If this holds true for all flows, you can obtain a valve characteristic that compensates for the non-linearity of a typical controlled exchanger. This characteristic (**Figure 1b**) is called "equal percentage modified" (EQM).

To obtain this compensation, two conditions must be fulfilled.

- The differential pressure across the control valve must be constant.

- The design flow must be obtained when the control valve is fully open.

If the differential pressure across the control valve is not constant, or if the valve is oversized, the control valve characteristic becomes distorted and the modulating control can be compromised.

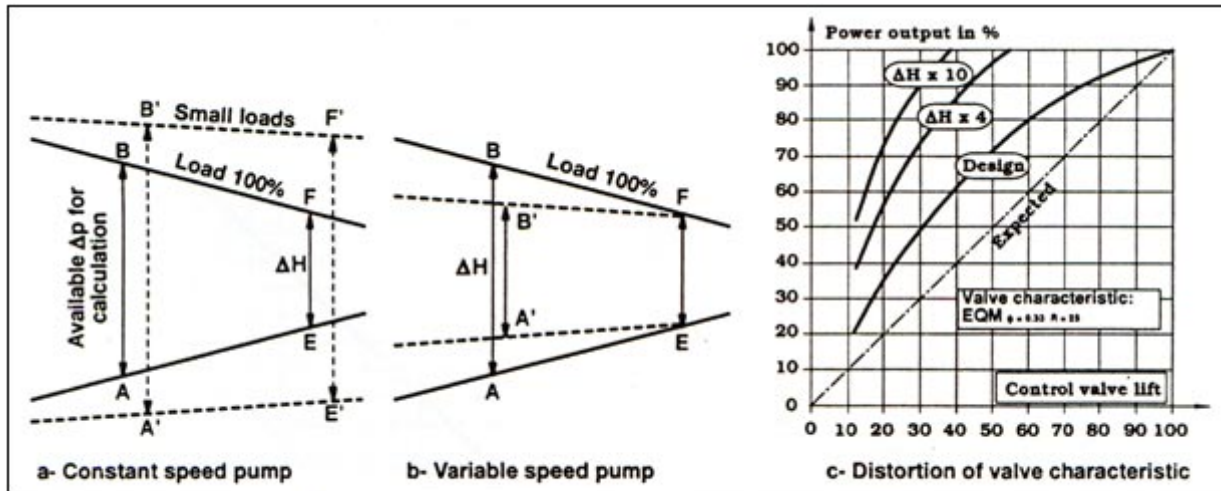


Figure 2 : The control valve authority is 0.25 in design condition. When the average load of the plant changes the differential pressure  $H$  on the circuit changes too. This further distorts the control valve characteristic.

## The control valve authority

When the control valve closes, the flow and the pressure drop are reduced in the terminal, pipes and accessories. The difference in pressure drop is applied to the control valve. This increase in the differential pressure distorts the control valve characteristic. This distortion can be represented by the control valve authority.

$$\beta = \text{valve authority} = \frac{\Delta p_{Vc}(\text{Pressure drop in the control valve fully open a design flow})}{\Delta p_{\text{valve shut}}}$$

The numerator is constant and depends only on the choice of the control valve and the value of design flow. The denominator corresponds with the available differential pressure,  $\Delta H$ , on the circuit. A balancing valve installed in series with the control valve selected does not change either factor and consequently does not affect the control valve authority.

The control valve is chosen to obtain the best possible authority. However, the control valve calculated is not available on the market. This is why most control valves are oversized. By using a balancing valve, you can obtain the design flow when the control valve is fully open. Because the characteristic is closer to that designed, the control function is improved (**Figure 3b**).

## Differential pressure changes with the average load in the plant

In a direct distribution (**Figure 2a**) the remote circuits experience the highest variations in differential pressure. At low flows when the control valve is subjected to almost all of the pump pressure, control valve authority is at its worst.

With a variable speed pump it is common to keep the differential pressure constant close to the last circuit (**Figure 2b**). Then, the problem of a varying  $\Delta H$  is reported to the first circuit.

Locating the differential pressure sensor for the variable speed pump near the last circuit should in theory reduce pumping costs. This however causes problems for the circuits close to the pump. If the control valve has been selected according to the available  $\Delta H$  in design condition then the circuit will be in underflow for smaller  $\Delta H$  then, at design condition the circuit will be in overflow and the control valve will have a bad authority. To avoid these problems the differential pressure sensor should preferably be located at the middle of the plant. This can reduce differential pressure variations by more than 50 percent compared to those you would have with a constant speed pump.

**Figure 2c** shows the relationship between heat output and the valve lift for EQM control valves selected to obtain the correct flow when the available differential pressure applied on the circuit increases, the control valve characteristic may be distorted so much that it caused hunting of the control loop. In this case, a local differential pressure controller can be used to stabilize the differential pressure across the control valve and keep the valve authority close to 1 (**Figure 4a**)

## Selection of the modulating control valves

A two-way control valve is well-sized when:

1- the design flow is obtained for the control valve when fully open under design conditions.

2- the control valve authority is and remains sufficient that is generally above 0.25

The first condition is necessary to avoid an overflow, which creates underflows in other circuits, when the control valve is open and remains so for a relatively long period. This occurs (1) during start-up such as each morning after a night set back, (2) when the coil has been undersize, (3) when the thermostat is set on the control loop is not stable.

To obtain the design flow in design condition, the pressure drop in the control valve when fully open and at design flow, must be equal to the local available differential pressure  $\Delta H$  minus the design pressure drop in the coil and accessories (**Figure 3a**)

Now, assume that information about these pressure drops is available before selecting the control valve. For a flow of for instance 1.6 liters per second, what is available on the

market? One control valve that creates a pressure droop of 13 kPa, another that creates 30Kpa and a third that creates 70 kPa. If 45 kPa must be created in the fully open control valve, then such a valve is not available on the market. As a result, control valves are generally oversized. A balancing valve is then needed to obtain the design flow in design conditions. The balancing valve improves the control valve characteristic without creating any unnecessary pressure drop (**Figure 3b**)

Once the control valve has been selected, we must verify if its authority  $\Delta p_{Vc} / \Delta H$  max is sufficient. If it is insufficient, the plant design must be reconsidered to allow a higher pressure drop across a smaller control valve.

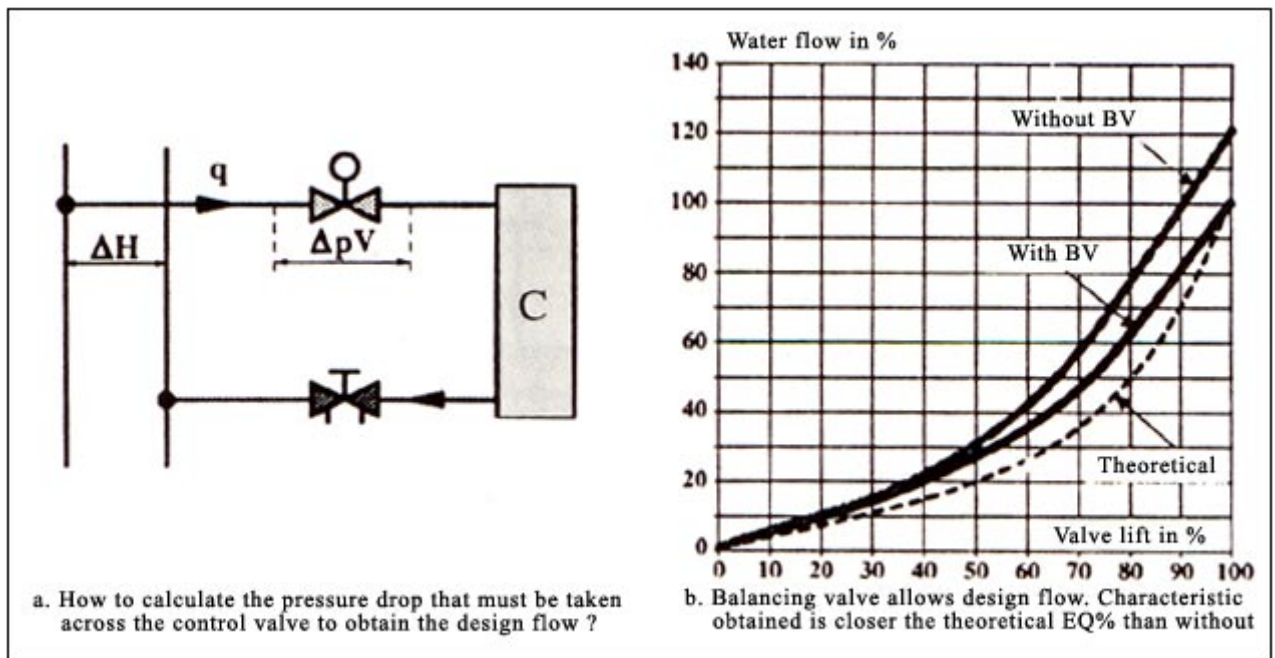


Figure 3 : If the valve is oversized a balancing valve improves the control valve characteristic

### Special designs to solve local problems.

Providing separate treatment for special cases usually results in better operating conditions than forcing the rest of the system to respond to abnormal condition.

When control valve selection is critical or when the circuit is subjected to major changes in  $\Delta H$  a local differential pressure across the control valve (**Figure 4a**) This is generally the case when the control valve authority can drop below 0.25.

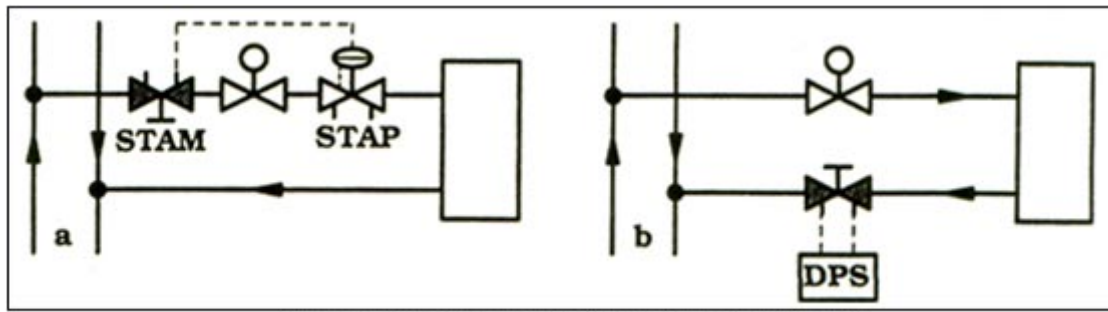


Figure 4 : Limitation of the flow across a terminal unit

The principle is simple. The membrane of the STAP differential pressure controller is connected on the inlet and the outlet of the temperature control valve. When the differential pressure increases, the force on the membrane increases and shuts STAP proportionally. STAP keeps the differential pressure on the control valve almost constant. This differential pressure is selected to obtain the design flow, measurable at STAM, when the control valve is fully opened. The control valve is never oversized and valve authority is close to 1.

All additional differential pressure is applied to STAP. The control of the differential pressure is quite easy in comparison with a temperature control and a sufficient proportional band can be used to avoid hunting.

Combining local differential pressure controllers with a variable speed pump ensures the best conditions for control. The comfort is improved with substantial energy savings, and the risk of noise is reduced considerably. For economic reasons, this solution is normally reserved for small units.

For larger units for which the differential pressure varies widely, you can limit the maximum Kvs by using a differential pressure sensor connected to a balancing valve (**Figure 4b**). When the differential pressure measured corresponds to the design flow, the control valve is not permitted to open further. This solution can be suitable when the building management system requires a flow measurement.

If the plant has been calculated with a diversity factor, the maximum flow allowed is reduced during start up to obtain a homogenous flow distribution. The set point of the maximum flow can also be changed according to the requirements of priority circuits.

When terminal units are controlled with on-off or time proportional control valves, limitation of the differential pressure can help reduce noise and simplify balancing. In this case, a differential pressure controller keeps the (**Figure 5**) This solution also works for a set of small units controlled by modulating control valves. These examples are not restrictive, they just show that some particular problems can be solved by using specific solutions.

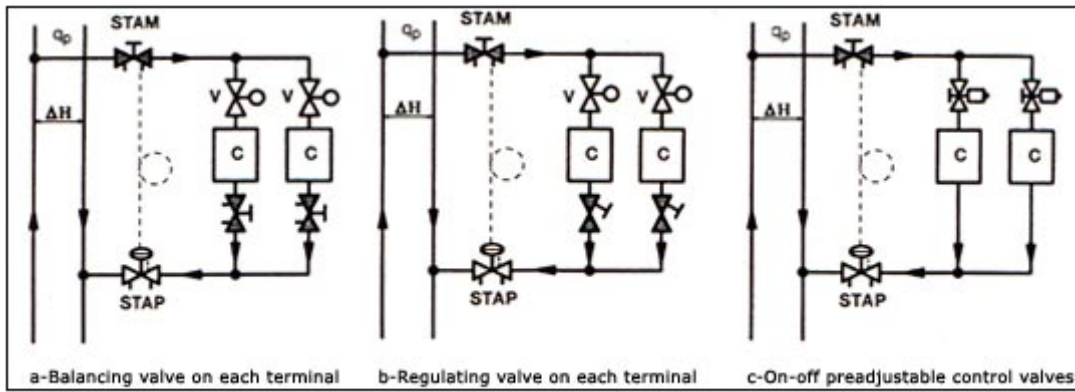


Figure 5 : The STAP keeps the differential pressure constant across a set of terminal units.

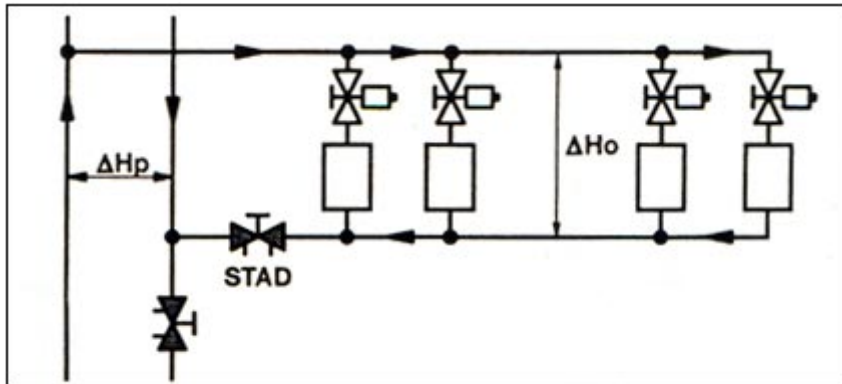


Figure 6 : Each radiator valve is adjusted as if it was subjected to the same differential pressure, normally 10 kPa

## Keeping the differential pressure constant in heating plants

### Variable flow distribution

In a radiator heating plant, the radiator valves are generally preset considering that the available differential pressure  $\Delta H_o$  equals 10 kPa.

During the balancing procedure the STAD balancing valve is set to obtain the right total flow in the branch. This justifies the presetting and the 10 kPa differential pressure expected is obtained at the center of the branch.

In radiator systems with available differential pressures over 30kPa, there is a risk of noise in the plant, especially when air remains in the water. In this case, you should use STAP to reduce the differential pressure and to keep it constant (**Figure 7**).

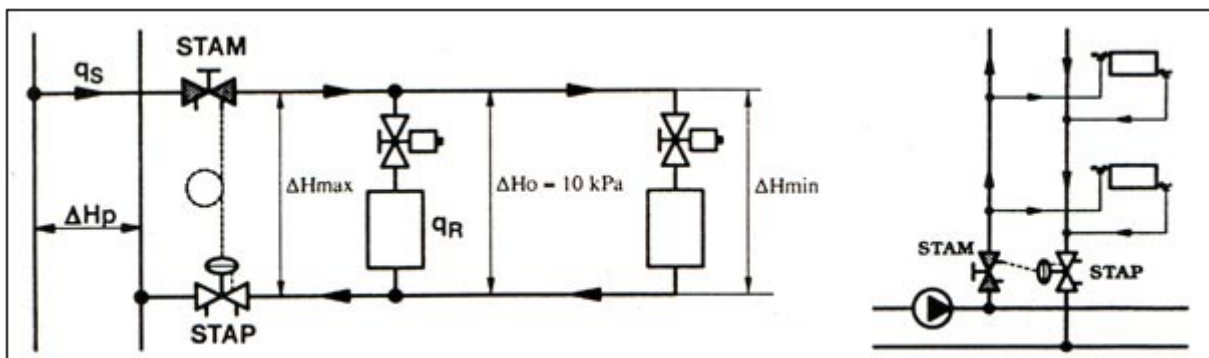


Figure 7 : A STAP keeps the differential pressure at the circuit inlet constant.

STAP keeps the differential pressure constant on each branch or small riser. The branch water flow ( $q_s$ ) is measured the thermostatic valves of excess pressure.

### Constant flow distribution

The supply water temperature in residential buildings is adjusted with a central controller according to the outdoor conditions.

The pump head may be high, which can cause noise in the thermostatic valves. If there is no restriction on the return water temperatures, a constant flow distribution may be used.

One solution is to provide each apartment with a bypass line AB and a balancing valve STAD-1 (**Figure 8a**). This balancing valve takes away the available  $\Delta H$ . A secondary pump with a pump head less than 30kPa serves the apartment. When the thermostatic valves close, the p across the thermostatic valves is acceptable and does not create any noise in the plant. The secondary design flow must be slightly lower than that of the primary flow to avoid a reverse flow in the bypass, which would create a mixing point at A and decrease the supply water temperature. This is why another balancing valve STAD-2 on the secondary is necessary.

Another solution is to install BPV, a proportional relief valve, for each apartment (**Figure 8b**). This eliminates the need for a secondary pump and also the need for the balancing valve STAD-2 BPV works with one STAD balancing valve to obtain the required primary flow. The BPV is set to suit the requirement of the radiator circuit. When the thermostatic valves close, the differential pressure between A and B increases beyond the set point. The BPV then opens and bypasses a flow that is proportional to the increase of differential pressure. This means the differential pressure remains almost constant across A and B.

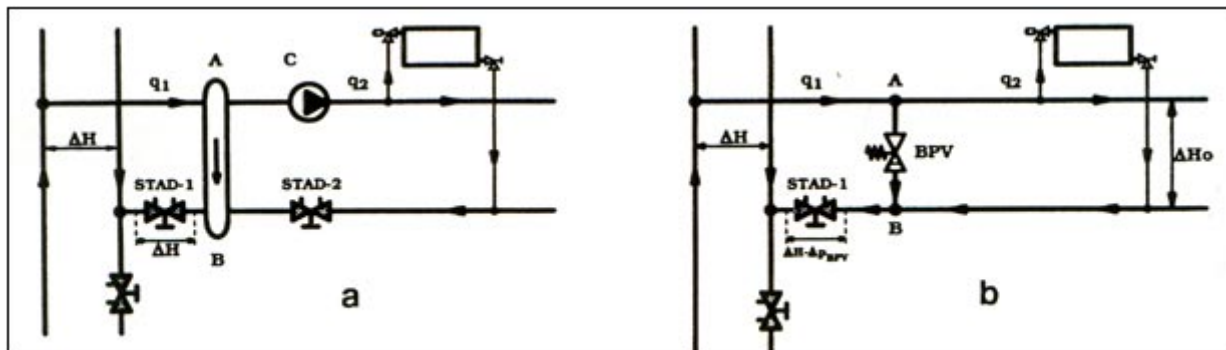


Figure 8 : Each apartment receives a differential pressure less than 30 kPa.

## General design recommendations

The specific design of a hydronic plant depends on its characteristics and working conditions. However, for any variable flow distribution system with direct or reverse return, constant or variable speed pump, modulating or on-off control, the following recommendations are relevant:

1. Because the plant hydraulically in design condition. This ensures that the installed powers can be delivered. There is no difference if modulating or on-off mode has been selected for control of the terminal units.
2. Use either the compensated method or the TA Balance computer program for balancing of the plant. This avoids any scanning of the plant methods reversal pump oversizing, and makes it possible to reduce pumping costs. The balancing procedure helps detect most hydronic problems. Manual balancing valves allow you to measure flows for diagnostic purposes.
3. Select modulating two-way control valves carefully based on:
  4. a. Correct characteristic (normally EQ% or EQM).
  5. b. Correct size: the control valve, when fully open and at design flow, must take most of the available circuit differential pressure under design conditions.
  6. c. The control valve authority should not drop below 0.25
7. If the last condition 3c, cannot be fulfilled for some circuits, a local differential pressure controller is installed in these circuits to improve the control valve authority and decrease the risk of noise.
8. When using a variable speeds pump, locate the differential pressure to achieve the best compromise between the desire to minimize pumping costs and the imperative to reduce differential pressure variations across the control valves. The optimal location for the sensor may be determined by a computer simulation.

## Conclusion

A HVAC plant is designed for a specific maximum load. If the plant cannot deliver full capacity in all circuits because it is not balanced for design condition, then the investments for the entire plant are not realized.

Control valves are fully open when maximum load is required and thus cannot manage this situation. Furthermore, control valves are generally oversized and they cannot contribute to balancing.

Hydronic balancing is then essential and represents less than one percent of the cost of the HVAC system. Each morning, after a night set back, full capacity is required to recover

the comfort as soon as possible. A well balanced plant does this quickly. If a plant starts up 30 minutes quicker, this saves 6 percent of the energy consumption per day. This is often more than all distribution pumping costs.

In a variable flow distribution, energy costs for pumping are generally less than 5 percent of the seasonal consumption of the chillers. Compare this with the cost of 10 to 16 percent of one degree too low temperature in the rooms. Obtaining the correct comfort is then the best way to save energy. Any actions to reduce pumping consumption must be taken so they do not adversely affect the cooperation of terminal unit control loops.

There are several ways to reduce pumping costs. One method is, whenever possible, to increase the design water rise or drop. Another is the use of variable speed pumps with optimal location of the differential pressure sensor. Introducing stable modulating PI controls that require lower flows at medium loads instead of on-off controls is a third option (Figure 1a). But the most important consideration is to compensate for pump oversizing. Balancing valves adjusted with the compensated method reveal the degree of pump oversizing. The total, excess pressure for the plant is shown on the balancing valves closest to the pump. Corrective action is then taken and this balancing valve is then reopened.

Hydronic balancing requires the correct tools up-to-date procedures and efficient measuring units. A manual balancing valve is the most reliable and simple product to obtain the correct flows in design conditions. It also allows the flows to be measured for diagnostic purposes. They can be associated with differential pressure controller when necessary.

Reference: Total Hydronic Balancing- Robert Petitjean Edition TA HYDRONICS - 1997.