Piping system design considerations

This month we begin a three-part series on the design considerations for piping systems in heating and cooling systems.

The point of departure for a piping system design

The first thing to establish when undertaking the design of a piping system for a heating or cooling system is the load to be handled by each terminal heat exchanger (coil, radiator, etc). These loads depend on the type of air conditioning system and the thermal properties of the spaces being served.

Next, the temperature of the heating or cooling fluid, the temperature drop between flow and return, and the type of fluid to be used are decided. The temperature drop determines the flow required at each heat exchanger.

Therefore, in HVAC plant design, each piping system is a sub-system that interacts with many other sub-systems, and although the piping system is generally sized and costed in isolation, the designer should not lose sight of the effect that fixing the various design parameters has on the total HVAC system design, including total cost.

Factors affecting piping system design

The following factors will be explored in this issue:

- The fluid temperature
- The type of fluid used
- The temperature drop between flow and return
- The type of control
- The type of distribution system (open and closed circuit systems)

The major objective when designing a piping system is to minimise the total cost of the system, while maintaining an acceptable level of control of the terminal devices delivering the heating or cooling effect under all conditions of load.

The total cost includes the capital cost of the system, the owning and operating costs including maintenance costs and, the cost of commissioning the piping system.

Each of the above listed factors interact with each other and affect the piping system design and the total cost of the system in varying ways.

The fluid temperature

Generally speaking, the larger the temperature difference between the circulating fluid and the air being heated or cooled, the smaller (and cheaper) the terminal devices. For heating systems, the higher the mean temperature, and for cooling the lower the mean temperature, the more efficient the heat transfer is at the terminal device. There are obvious limits to this, however, and the higher (in the case of heating) or lower (in the case of cooling) the temperature is, the more expensive the cost of the primary heating and/or cooling plant. For heating, once the temperature approaches the boiling point, the system, unless it is pressurised, is no longer a liquid circulating system but a vapour system – in the case of water, a steam system. In practice, the supply temperature of hot water heating systems is usually around 82°C. For cooling the temperature must be high enough to avoid freezing and chilled water system temperatures are usually around 6°C.

Additives to the cooling water such as glycol allow lower chilled water temperatures as these lower the freezing point of the fluid, although special precautions may then be required on the air side of the terminal units to prevent freezing or frost.

If the piping system is pressurised then the hot water temperature can exceed the boiling point. Medium temperature (pressure) hot water systems use water temperatures around 120°C. High temperature (pressure) hot water systems are usually in the region of 180 to 200°C. Such systems allow larger temperature differences between the main supply and return and hence, the heat capacity (kW/kg) is much higher ie. the higher the temperature difference the lower the quantity of water that has to be circulated and hence the lower the piping cost and pumping power. There is a slight compensating affect, however, in that the density of water is lower at higher temperatures. This increases the water flow required for the same mass flow (heat capacity). The pressure loss in the piping system is slightly lower because of the reduction in viscosity. These systems, however, involve additional capital costs because of the pressurisation equipment, more expensive primary plant (boilers) and controls. For extensive systems such as airports, service establishments and district heating systems, these extra capital costs can be offset by the saving in piping and operating costs. They have other problems, however, (eg. large pipe expansion, safety, etc) that need to be carefully evaluated if such systems are to be considered.

To reduce the energy consumption, installation and operating costs of heating systems, solar heating or heat reclaim systems are options worth considering. Storage tanks, however, are required to store the hot water and these increase the capital costs. The lower temperatures that occur in this form of low grade heat generation may also result in additional problems with supplementary heating plant (eg. low temperature water boilers can cause inefficient combustion and hence stack corrosion) necessitating the use of additional heat exchangers that increase the capital and maintenance costs.

A higher temperature heating fluid results in higher heat losses with a consequent increase in energy consumption or additional expense for added insulation. In cooling systems, the extra heat gain due to lower fluid temperature is not as significant because the limit due to freezing restricts the range of temperatures that can be used. Cooling systems, however, present additional problems over heating systems, as condensation can occur, particularly in humid climates, and special precautions have to be made with respect to vapour sealing which adds to the costs of installation.

The type of fluid

The type of fluid used for most air conditioning piping systems is water.

Where temperatures approaching freezing point are required on the air side of cooling coils, fluids with a lower freezing point (eg. a mixture of water and glycol which can have a freezing point of as low as – 50°C depending on the concentration of glycol) can be employed. These systems, however, often have additional problems such as corrosion that have to be addressed in the design and carefully monitored in the operation of the plant. Additives such as glycol have much greater penetration power at joints than water and this can cause leaks which can lead to corrosion. These solutions are also poisonous, adding significantly to the problems of the leakage. When additives are used consideration must be given to safe disposal if the fluid cannot be re-used when the system has to be drained.

For heating systems, higher temperatures can be achieved by the use of fluids with a higher boiling point or by reverting to the use of steam. The boiling point of water can be raised by applying pressure to the system as discussed previously. Other fluids such as certain oils might be considered but these require special boilers and other ancillary equipment and are usually only used in very specialised applications, eg. hot oil irons in laundries.

The temperature drop

The larger the temperature drop between the supply and return, the smaller the amount of fluid that has to be circulated around the piping system. For extensive piping systems such as airports, and district heating/cooling systems, this is an important consideration as it can result in significant savings in piping and pipe insulation costs and pumping costs.

The larger the temperature drop, however, the lower the mean temperature difference between the heating/cooling fluid and the air being conditioned. This leads to a larger heat transfer surface area and hence increased costs associated with the air heating/cooling coils or other heat transfer devices. The same applies to the primary plant resulting in higher costs of chillers and boilers.

Another important consideration is the effects of temperature and temperature drop on the controllability of control valves in the system. The higher the temperature drop available at the coil and the smaller the difference between the mean fluid and mean air temperature the easier it is to obtain good control.

In practice, temperature drops of around 6K for cooling systems and from 10 to 12 K for central heating systems are the most economical for systems which are not extensive eg. within a single building. Where the piping is extensive, cooling temperature drops can be as high as 12K. For heating, larger temperature drops are usually associated with pressurised medium or high temperature water to maintain a reasonable mean temperature difference.

The type of control

There are several common methods of controlling the heat output or heat extraction rate of the terminal heat exchangers including water flow control, water temperature control and air flow control.

Water flow control is the simplest and can be simple manual on/off control as often employed in hot water radiator systems or on/off or modulating control via a space thermostat.

Modulating flow control can be achieved using either two-way (series) control valves (see Fig. 1) or three-way mixing or diverting valves (see Fig. 2 and 3) where water is bypassed (diverted) around the heat exchanger. With series control the flow in the mains varies as the loads vary and this causes change in the available pressure to each sub circuit containing the respective heat exchangers. This in turn can cause difficulties with maintaining controllability unless a bypass is used to maintain the required design pressure across the system or speed control of the pump motor(s) is employed, this latter option giving the additional benefit of energy savings.

With three-way valve control, the flow through each sub-circuit (and hence the pressure drop) is maintained theoretically constant. Just how close to constant the water flow is, in practice, depends on the valve characteristics and the system design. In general it can be assumed that the flow will only be maintained within 20 per cent of design requirements under partial load conditions. Hence as the load varies, pressure changes will still occur at each of the terminals in the system although not as significantly as in two-way valve systems. Three-way valve systems are on the other hand more expensive because:

(a) the control valves are more expensive

(b) the piping costs are usually higher because there is no diversity of flow in any of the pipes if full flow is maintained at all times

(c) three-way valve systems employ constant speed pumping whereas two-way valve systems can sometimes employ speed control on the pumps and hence save energy.

A disadvantage of series (two-way diverting) control is that with reduced flow in the mains at low load, the system reaction can become sluggish.

With modulating flow control, whether it be heating or cooling with two or three-way valves, the output of heating and cooling coils does not vary linearly with flow. Specially designed valves that generally compensate for this, however, can be employed.

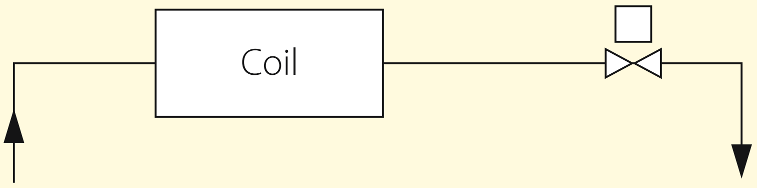

Figure. 1: Two-way valve (series) control

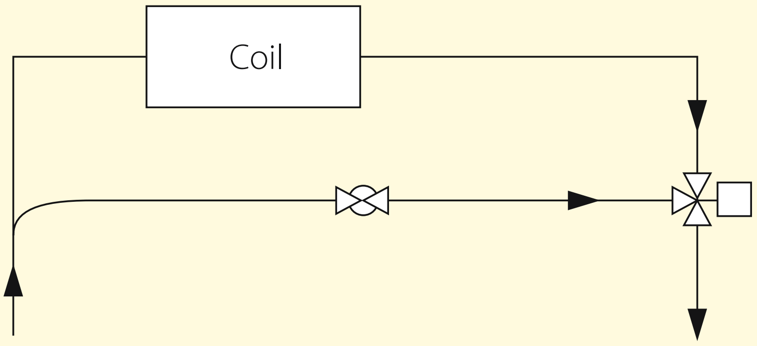

Figure. 2: Diverting control with three-way mixing valve

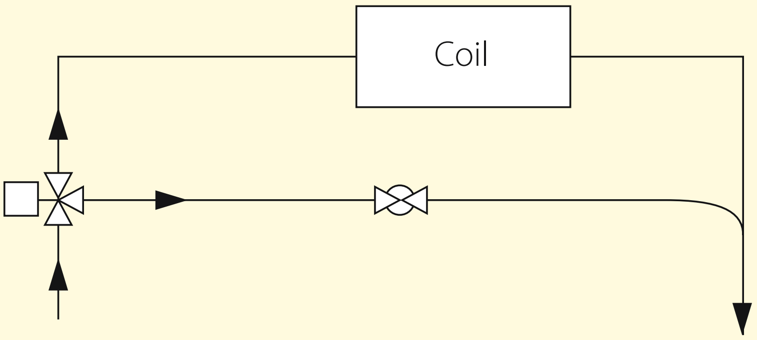

Figure. 3: Diverting control with three-way diverting valve

Supply water temperature control is the most effective method of controlling output from water coils, panels, radiators, etc., because coil output is more linearly related to temperature. Where a single large space is being heated by panel radiators or under floor heating coils, the water temperature can be controlled at the primary plant (ie the boiler). For other situations a separate pump in each sub-circuit could be used as illustrated in Fig. 4. This, although best for control, is often too expensive because of the extra pumps involved. Multiple pump systems are generally only used for overcoming large piping pressure drops in parts of the system (eg. remote plant rooms) or where parts of the system may be operated at different times and there are significant energy savings if multiple pumps are used. If savings in pipe sizes and running costs can be made, the use of multiple pumps in smaller systems should be considered particularly if good control is required.

It should be noted that in the configuration illustrated in Fig. 4, a three-way valve cannot be used as this would result in a variable flow through the terminal. When the three-way valve is open the pump would operate in series with the main circulating pump. When it is closed its operation would be isolated from the main pump. The bypass pipe in the two-way valve arrangement decouples the terminal circuit from the main circuit.

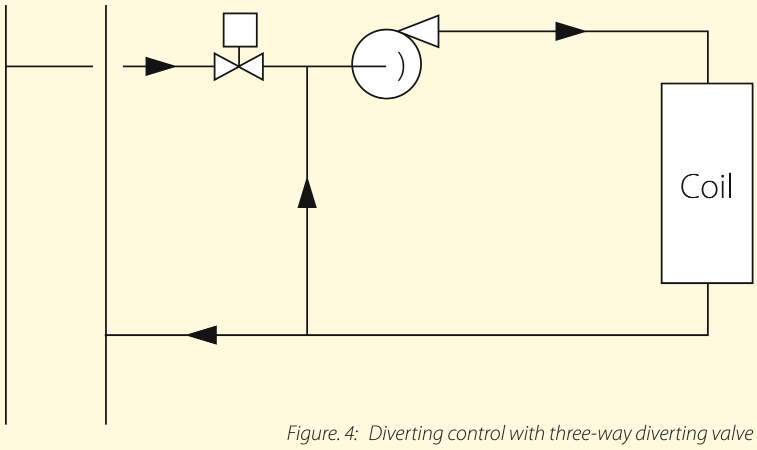

Figure. 4: Diverting control with three-way diverting valve

Various combinations of the above can be employed to advantage depending on the particular application eg. a separate pump can be supplied to groups of coils with similar loads – the east zone plants in a building might be on a separate sub-circuit to the west zone plants, each with their own secondary pump. Where a single pump circuit is employed, temperature control can also be applied if the loads are not too diverse and this can provide better controllability ie. the chilled and/or hot water supply temperature can be increased or reduced respectively in milder weather. This causes the control valves to operate closer to fully open at partial load and give better control.

With chilled water systems, however, care must be taken with resetting the chilled water supply temperature upwards if dehumidification is required or if a dew point controller is being used.

The type of distribution system

Many different piping circuits are possible for distributing the heating and/or cooling effect to the various terminal devices and returning the fluid to the primary plant.

Open and closed circuit systems

Open circuit systems are systems where some part of the system is open to atmosphere. In a closed circuit system the only connection to atmosphere (except in a pressurised system) is the expansion tank, this being required to allow for the expansion and contraction of the water in the system as it heats up and cools down.

In air conditioning systems open circuit systems are used in condenser water circuits which employ evaporative cooling in a cooling tower. Hence the water discharges to atmosphere over the tower fill. Another open system encountered in air conditioning is evaporative condensers, where a small secondary pump is used to pick up the water from a sump under the condenser coil and discharge the water in fine sprays over the coil to gain the benefit of evaporative cooling.

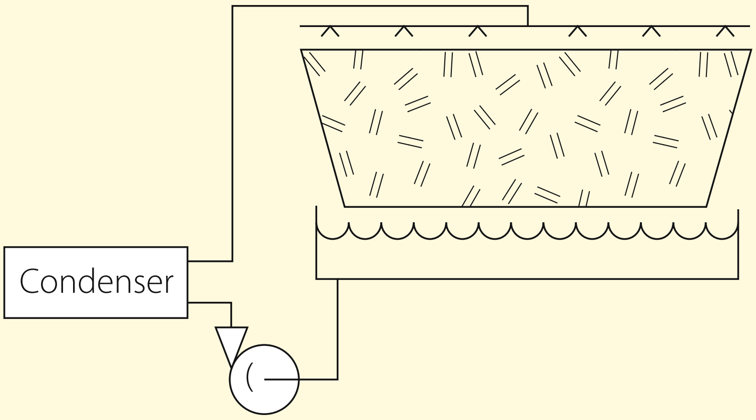

Figure. 5: Typical open circuit condenser water system

Most other piping systems for air conditioning applications are closed circuit systems. A closed circuit system is one in which the fluid is enclosed throughout the circuit, ie. at no point does the fluid come in contact with the atmosphere (except at the surface of an expansion tank). Because water expands and contracts with change in temperature, a closed circuit system has to have provision for expansion and this is usually achieved with an expansion tank or a pressurised make up tank. The major difference in the design of an open circuit as compared to a closed circuit system is:

(a) water treatment is a major consideration because the water is exposed to ambient air and there is much greater potential for corrosion and biological contamination.

(b) the friction losses in the same sized pipes may be higher due to greater scale and corrosion build up inside the pipes.

(c) different pipe materials are often used because of the much greater likelihood of corrosion.

(d) in systems with evaporative processes, the make up water introduces scale forming compounds which plate out on the warm heat exchanger surfaces.

The type of distribution system will continue next month.▲

Further reading

Further reading can be found in AIRAH's design application manual *DA16 Air conditioning water piping.* The manual provides advice on the design of air conditioning water piping systems and covers sizing heat loss/gain, selection of control valves, pipe stress, cost estimating etc. It includes data for steel, copper, plastic piping and numerous charts and tables. The manuals are available to purchase online at www.airah.org.au