**Calculations:**

i. Continuing the AB line to the saturation line to get the details of Point C (the ADP): The ADP

$t_c = 7{\cdot}5°C$ db  $g_c = 0{\cdot}0064$ kg/kg$_{da}$  $h_c = 23{\cdot}66$ kj/kg$_{da}$

1. Sometimes these definitions may be written in terms of wet-bulb temperatures, but the scale of wet-bulb temperatures is not linear on the psychrometric chart so there will be errors.

   This may be deemed acceptable if the margin of error is small. Most practical coil selections have typical contact factors of between 0·.8 and 0·.9, but this should be checked with the manufacturer before carrying out the final calculation.

2. The above equations for $Q_S$ and $Q_L$ are key to understanding the energy transfers involved in moving round the psychrometric chart.

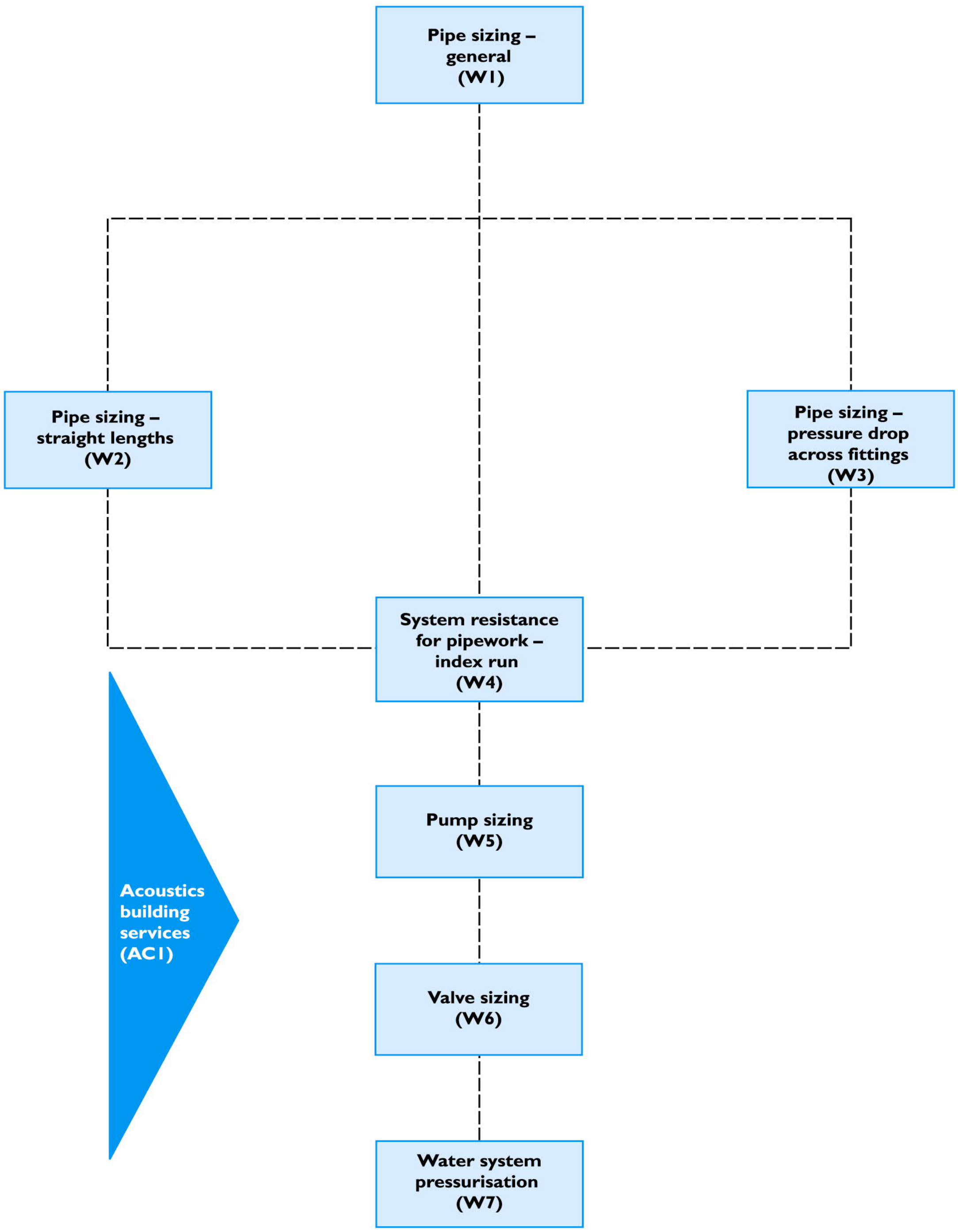
# WATER FLOW DISTRIBUTION SYSTEMS

charts of the relevant design and calculation processes.

The first flow chart shows the seven topics within this section.

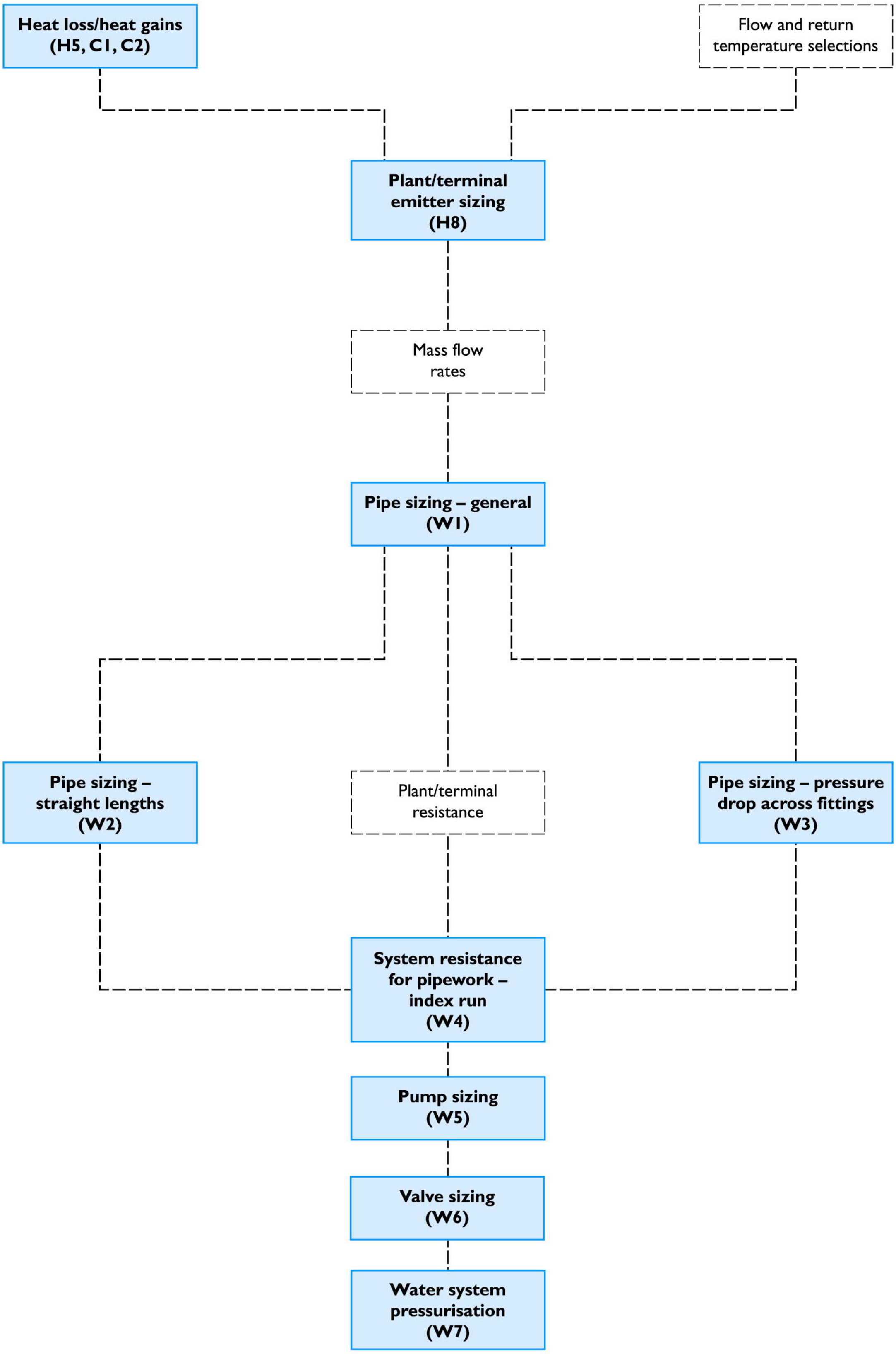
The second flow chart provides an overview of the process, showing some of the many related topics that need to be considered in the design of water flow distribution systems. The boxes highlighted in blue show an area that is fully or partially covered within one of the seven topic areas in this section, or in the rest of the guidance, with the appropriate reference numbers given.

# FLOW CHART 1 – TOPICS WITHIN THIS SECTION



# FLOW CHART 2 – OVERVIEW OF SYSTEM DESIGN PROCESS




This chart shows the design areas relevant to this design process. Where design areas are wholly or partially discussed in this document the relevant sheet references are given in brackets

# W1 PIPE SIZING - GENERAL

## Overview

This section makes numerous references to *CIBSE Guide C*. The 2001 edition (and previous editions) provided a range of pressure-loss data tables based on the Colebrook-White equation. The 2007 edition of the guide makes use of the Haaland equation and the pressure-loss tables are removed from the guide and replaced by an accompanying spreadsheet (supplied on CD). The spreadsheet can be used to calculate pressure loss based on the Haaland equation. The spreadsheet can also be used to generate pressure-loss data tables in the style of the previous editions of *CIBSE Guide C*.

Whenever a fluid flows along a pipe, there will be a loss of pressure due to friction. This pressure drop depends, among other factors, on the fluid velocity. So, for a required fluid flow rate, the pipe diameter and pressure loss are related. A small diameter pipe will result in high fluid velocity and so a high pressure loss; a larger pipe carrying the same flow rate will result in a lower velocity and pressure loss. Pipe sizing involves determining the most appropriate pipe diameters to use and the resulting velocities and pressure losses.

There are limits to acceptable fluid velocity. High velocities lead to noise and erosion while low velocity can give problems with air-locking (*CIBSE Guide C*, Table 4.6). While pipe capital costs are obviously related to diameter, the running costs for pumped systems, are proportional to pressure loss. Therefore, pipe sizing involves value engineering.

With gravity systems, (for example cold water down services), the available head is the limiting factor. Pipe sizing involves determining the pipe sizes which will deliver the design flow rate at a total pressure loss equal to this head.

Pressure loss is found to be proportional to velocity pressure:

$$\Delta P \propto \frac{1}{2}\rho v^2$$

For practical purposes, the pressure losses through straight pipes and pipe fittings are dealt with separately.

### Straight pipes

The equation above is written as:

$$\Delta P = \frac{\lambda l}{d} x \frac{1}{2}\rho v^2$$

(Known as the D'Arcy Equation)

Where:

- $\Delta P$ = pressure loss (Pa)
- $\rho$ = density of the fluid (kg/m$^3$)
- $\lambda$ = friction factor
- l = length of pipe (m)
- v = mean velocity of water flow (m/s)
- d = internal pipe diameter (m)

Values of $\lambda$ are calculated using the Haaland equation:

$$\frac{1}{\sqrt{\lambda}} = -1\cdot 8\log\left[\frac{6\cdot 9}{Re} + \left(\frac{k/d}{3\cdot 71}\right)^{1\cdot 11}\right]$$

Where:

- $\lambda$ = friction factor
- Re = Reynolds number
- k = equivalent roughness
- d = internal pipe diameter (m)

The Haaland equation is used as the basis for the pressure loss calculation procedure in the CIBSE Guide C spreadseheet.

(See sheet W2 Pipe sizing – straight lengths for a worked example.)

(See Design Watchpoint 1.)

### Pipe fittings

In this case the above equation is written as:

$$\Delta P = \zeta \text{ x } \frac{1}{2}\rho v^2$$

Where $\zeta$ is the coefficient of velocity pressure loss. Values of $\zeta$ are found from tables in Section 4 of *CIBSE Guide C*.

(See sheet W3 Pipe sizing – fittings for a worked example.)

### Pipe sizes

Standard pipe sizes quoted are nominal and are not the internal diameter. In *CIBSE Guide C* internal diameters are listed in tables 4.2, 4.3 or 4.4.

### Fluids other than water

See *CIBSE Guide C* Section 4.6 and 4.7 for guidance concerning the flow of steam and natural gas in pipes.

## Design information required

### Type of system supplied

For example radiators and cooling coils and batteries. This will determine what is acceptable in terms of flow temperatures, pressure drops and noise. Consult a senior engineer as necessary.

### Details of fluid

For example water, gas and glycol solution.

This will enable fluid properties to be determined such as fluid density and viscosity.

- **Design tip:** If the system fluid is chilled water containing glycol, then the specific heat capacity will need to be adjusted.

### Fluid temperature

For example whether hot or chilled water. Typical flow temperatures for low temperature hot water systems are 70-95 ºC, and for primary chilled water are 6-12 ºC.

### Design flow and return temperatures

To give the temperature drop across system. This will be needed to determine the required mass flow rate.

# W1 PIPE SIZING – GENERAL

➢ **Design tip**: Do not assume that 82/71°C must be used for low temperature hot water systems. Doubling the temperature drop will have a relatively small effect on the heating surface required but will reduce the flow rate required by half, therefore the pipe sizes and the pump duty will be smaller. The control of the heat output will also be improved.

**Pipe material**
For example copper, steel etc. This determines pipe roughness and hence the flow characteristics and pipe pressure losses.

**Pipe insulation details**
Whether pipes are insulated and, if so, insulation details – this governs losses from the pipes and the extra heating or cooling required to compensate for this.

**Pipe system layout**
Including pipe lengths, number and type of fittings etc.

**Distribution space available**
Horizontally and vertically such as false ceiling depths and risers.

**Details of ambient conditions**
Surrounding air temperature and whether the pipes will have to run through chilled or outdoor spaces.

## Key design inputs

- Design mass flow rates in kg/s
- Limiting maximum pipe pressure loss per metre run in Pa/m
- Limiting maximum and minimum flow velocity in metres per second

➢ **Design tip:** A minimum velocity may also be set to avoid scale settling etc.

## Design outputs

- Schematic of pipework layout and associated plant showing required flow rates
- Schedule of pipe sizes and lengths, and fittings such as elbows and valves

## Design approach

Pipe sizing should ensure that both pressure drop and velocity are acceptable to ensure efficient operation. Pipe diameter is therefore often selected on a pre-determined pressure drop per unit length or a pre-determined velocity. The design criteria may require a system that is designed with a pre-selected pressure drop but also operates within a maximum velocity limit. Note the following:

Design should minimise pipe and valve noise, erosion, installation and operating costs.
Small pipe sizes can result in high flow velocities, noise, erosion, and high pumping costs.
Large pipe sizes will increase installation costs and make it difficult to vent air.

## Rule of thumb design data

**Water flow temperature – heating**
LTHW: 70-95°C
MTHW: 100-120°C
HTHW: over 120°C
(Above 95°C the system should be pressurised to avoid the risk of flash steam formation.)

**Water flow temperatures – chilled water**
Chilled water primary circuits flow temperatures: 6-12 °C
Chilled water secondary circuits flow temperatures: 10-15 °C

**Water velocities**
Steel pipe up to 50 mm diameter: 0·75-1·5 m/s
Steel pipe over 50 mm diameter: 1·25-3 m/s
Small bore systems: <1 m/s
Microbore systems: 1·2 m/s
Corrosive water systems: 2m/s maximum.

**Pressure drop**
Typical range for re-circulating system pipe sizes over 50 mm is 100-300 Pa/m. For under 50 mm a similar range may be used but it is essential to check that the velocity is acceptable. *CIBSE Guide C*, suggests a suitable starting point of 250 Pa/m.

Further information is available in *CIBSE Guide C*, section 4 and *CIBSE Guide B1*, Section 5.1.3 and appendix A1.3/ *Guide B*, Section 1.5.1.3 and appendix 1.A1.3.

## References

CIBSE Guide B1, *Heating*, Section 5.1.3 and appendix A1.3, 2002, ISBN 1 9032 8720 0
CIBSE Guide B, Section 1.5.1.3 and appendix 1.A1.3, 1005, ISBN 1 90328720 58 8
CIBSE Guide C, *Reference Data*, Section 1, 2007, ISBN 978 1903287 80 4
BSRIA, *Rules of Thumb*, BG 14/2003, BSRIA 2003, ISBN 0 86022 626 3
Lawrence Race G, Pennycook K, *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers* – sheets 28 and 46, BG 4/2007, BSRIA 2007, ISBN 978 086022 669 7

## See also:

Sheet W2 Pipe sizing - Straight lengths
Sheet W3 Pipe sizing - Pressure drop across fittings
Sheet W4 System resistance for pipework - Index run

### DESIGN WATCHPOINTS

1. If pipe materials or flow temperatures differ markedly from the standard tables then pipe sizing should be done using initial fluid flow equations with appropriate data. Otherwise errors could occur, resulting in incorrectly sized pumps and inadequate heat delivery.
2. Check that both flow velocities and pressure drops are within acceptable limits.
3. Check pipes and fittings can withstand maximum system working pressure.
4. Check that all of the system operates under positive static pressure to ensure any leaks are obvious and air does not enter system.
5. Pipework systems can suffer from a number of problems that must be considered during design – including:
   - dirt blockages
   - air locking
   - erosion - due to cavitation effect and the scouring effect of dirt particles
   - corrosion - if system materials and water quality are not carefully considered.

# W2 PIPE SIZING – STRAIGHT LENGTHS

## Overview

In order to size pipework both straight lengths and fittings need to be considered. Initial pipe sizing is done by considering straight runs alone, but for complete system design and pump sizing both straight runs and fittings need to be considered.

The examples in the pipe sizing, index run and pump sizing sheets (W2-5) are shown as manual calculations. Although calculations are often done on a spreadsheet or by using a computer sizing package, these will still require input and design decisions that require familiarity with the fundamental theory and manual sizing procedures.

## Design information required

**Pipe length in metres**

This may already have been provided on schematics.

(See also sheet W1.)
(See Design Watchpoint 1.)

**Fluid type and operating temperature**

The specific heat capacity, density and viscosity of fluids will depend on the type used. (Properties of various fluids are given in *CIBSE Guide C* Appendix 4.A1.)

**Temperature drop across system (K)**

$\Delta t$ across the system.

**Pipe material**

## Calculation procedure (manual pipe sizing)

**Step 1.** If not already laid out, sketch the system under consideration, indicating pipe lengths and unit loads (kW). Allocate a reference number to each length of pipework.

**Step 2.** Estimate the heat loss for each section (often taken as a percentage of unit load such as 5-10%, or as a typical value such as 25 W/m run for insulated heating pipes, 100 W/m run for un-insulated pipes) to give the total load for each section. The heat loss will depend on pipe orientation (vertical/horizontal) and the quality and installation of insulation. Heat losses can be less than 5% if the pipes are well insulated.

- **Design tip:** Typical values can be obtained by estimating the pipe size and reviewing heat loss data in tables 3.19 - 3.26 of *CIBSE Guide C*.
- **Design tip:** Part L of the *Building Regulations* covers *Conservation of Fuel and Powers*. Maximum permissible heat losses for hot water, heating and cooling pipes can be obtained from the *Non-Domestic Heating, Cooling and Ventilation Compliance Guide.*

**Step 3.** Select an appropriate temperature drop across the system, such as 10-20 K for low pressure hot water and, assuming this to be constant across the system, calculate the mass flow rate in each section.

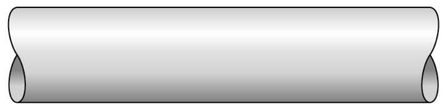
**Step 4.** Select an acceptable design value for either pressure drop per unit length or velocity. (See sheet W1 and seek advice from senior engineer as required.)

**Step 5.** Size pipe using the *CIBSE Guide C* pipe sizing spreadsheet. Select an appropriate pipesize using the mass flow rate and the selected value of either pressure drop per metre run or velocity.

- **Design tip:** Pipe sizing and pressure loss data for a system can be laid out in a tabular format and converted to a spreadsheet.

## Example

Find the pipe size for a 10 m straight run of medium steel heating pipe carrying water at 75 °C and serving four fan convectors, each rated at 4·15 kW output.




**Step 1.** A simple sketch above shows the necessary information

**Step 2.** Estimate the heat loss with an assumed estimated loss as 6% of the load.

Hence:
Total fan coil load = 4 x 4·15 = 16·6 kW,
6% of 16·6 = 0·996 kW
Total load = 17·6 kW

**Step 3.** Temperature drop across system assumed as 10K, from

$$Q = \dot{m} \times Cp \times \Delta t$$

Where:
Q = load (kW)
Cp = specific heat capacity of water (kJ/kg.K)
$\Delta t$ = temperature difference (K)

Mass flow rate is therefore:

$$\dot{m} = \frac{17 \cdot 6}{4 \cdot 2 \times 10} = 0 \cdot 42 \text{ kg/s}$$

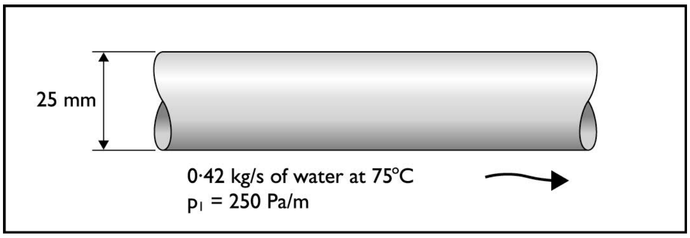
**Step 4.** A nominal pressure drop per metre run of 250 Pa/m is selected

**Step 5.** Using the *CIBSE Guide C* pipe sizing spreadsheet for medium grade steel pipe with winter at 75 °C, size the pipe to give the required mass flow rate and pressure drop per metre run. Using the individual results section of the spreadsheet it can be found that a 25 mm diameter pipe will give a velocity of 0·73 m/s with a pressure loss of 241 Pa/m. Alternatively the spreadsheet can be used to produce a pressure-loss data table.

Note that a worked example demonstrating the calculation procedure used by the CIBSE pipesizing spreadsheet is provided in Section 4.A2.1 of *CIBSE Guide C*.

Cross-check: a velocity of 0·73 m/s is acceptable for 25 mm steel pipe

# W2 PIPE SIZING – STRAIGHT LENGTHS




Note that as an alternative approach to step 2, an experienced estimate of pipe size of 25 mm gives a heat loss for uninsulated steel pipe of 92 W/m run ( *CIBSE Guide C*, table 3.19), in other words 920 W. This is 5·55 % of the total load, therefore the original assumed loss of 6% is reasonable.

- **Design tip:** Review the impact of a change of temperature drop across the system. Larger temperature drops (20K is common in Europe) can reduce pipe sizes considerably, but this will require more careful balancing of the system when commissioning.
- **Design tip:** For occupied spaces consider omitting heat losses from radiator sizes. Any heat loss from the pipes to the occupied space is useful heating. As long as the total design capacity is available, it does not matter that some comes from the pipes and some from the emitters. This will also reduce pipe size, and reduce unnecessary system over sizing

## DESIGN WATCHPOINTS

1. If taking dimensions from drawings use dimensions shown rather than scaling off, as drawings can become distorted if photocopied.
2. If pressure drop was selected, check that the velocity falls within a reasonable range and vice versa.

## References

CIBSE Guide B1, *Heating*, Section 5.1.3, and appendix A1.3, 2002, ISBN 19032 8720 0/CIBSE Guide B, Section 1.5.1.3, appendix 1.A1.3, 2005, ISBN 1 9032 8720
CIBSE Guide C, *Reference Data*, Section 1, 2007, ISBN 978 1903287 80 4
BSRIA, *Rules of Thumb*, BG 14/2003, BSRIA 2003, ISBN 0 86022 626 3
Lawrence Race G, Pennycook K, *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers* – sheets 26 and 46, BG 4/2007, BSRIA 2007, ISBN 978 086022 669 7
Department for Communities and Local Government, *Non-Domestic Heating, Cooling and Ventilation Compliance Guide*

## See also:

Sheet W1 Pipe sizing - General
Sheet W3 Pipe sizing - Pressure drop across fittings
Sheet W4 System resistance for pipework - Index run

# W3 PIPE SIZING – PRESSURE DROP ACROSS FITTINGS

## Overview

There are two methods of calculating the total pressure loss through a fitting:

$$\Delta P = 5 \times Pv = \zeta \times 0 \cdot 5 \times \rho \times v^2$$ *CIBSE Guide C*, equation 4·11)

Where:

$\Delta P$ = total pressure loss (Pa),
$\zeta$ = pressure loss factor
$\rho$ = density (kg/m$^3$)
$v$ = velocity (m/s)
$P_V$ = $0 \cdot 5x \times p \times v^2$ = velocity pressure

Values of $\Delta P/1$ can be determined using the *CIBSE Guide C* pipe sizing spreadsheet. The spreadsheet also calculates the velocity pressure ($P_V$).

The $\zeta$ values represent the fraction of one velocity pressure that has the same pressure loss as the fitting.

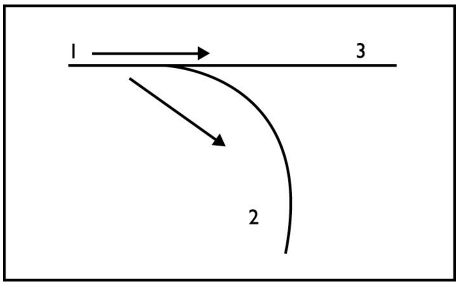
## Design information required

(See also sheet W1 pipe sizing – general)

**Pipe system layout**
Pipe lengths, location, number and type of fittings,

**Pipe sizes**
When the straight length diameters have been calculated, the corresponding $l_e$ and $\Delta P/l$ for each section may be required. When calculating the pressure drop across a branch fitting, the $\zeta$ for the straight section and branch section will be determined separately These will then be used to calculate the pressure drop across both parts of the branch.

**Mass flow rate**
The mass flow rate through each section and therefore through the fittings is required. Again, with a fitting such as a swept diverging tee, (such as a branch), the mass flow-rate at each part of the tee will be required. For example, one flow into the tee (1) and two flows out of the tee (2 and 3) as shown below:




## Calculation procedure

To calculate the pressure loss through a fitting the following steps are required:

**Step 1.** Find the appropriate velocity pressure loss factor ($\zeta$) value for the fitting in tables 4.20-4.39 of *CIBSE Guide C.*

**Step 2.** Determine the velocity pressure in the pipe using the *Guide C* pipe sizing spreadsheet.

**Step 3.** Calculate $\Delta P$ using *CIBSE Guide C* equation 4.11.

Note that velocity pressures ($P_V$) are also available in *CIBSE Guide C* Table 4.10.

## Example

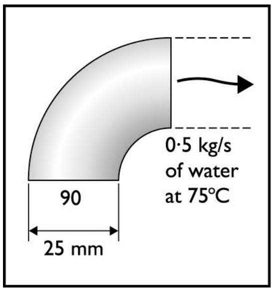
Calculate the pressure loss through a 90° sharp elbow with a smooth radiused inner of 25 mm diameter connected to a medium grade steel pipe and passing a water flow rate of 0·5 kg/s at 75°C.

**Step 1.** From *CIBSE Guide C* table C4.21 (pressure loss factors for elbows) the $\zeta$ value for a 90° sharp elbow with a smooth radiused inner with a 25 mm diameter is 0·8.

**Step 2.** From the *CIBSE Guide C* spreadsheet a velocity pressure of 369 Pa is obtained.

**Step 3.** The pressure loss associated with the elbow can be calculated from

$$\Delta P = \zeta \times P_V = 0 \cdot 8 \times 369 = 295\text{Pa}$$




## References

CIBSE Guide B1, *Heating*, Section 5.1.3, and appendix A1.3, 2002, ISBN 19032 8720 0/ *Guide B*, Section 1.5.1.3 and appendix A1.3, 2005, ISBN 1 903287 58 8
CIBSE Guide C, *Reference Data*, Section 1, 2007, ISBN 978 1903287 80 4
BSRIA, *Rules of Thumb*, BG 14/2003, BSRIA 2003, ISBN 0 86022 626 3
Lawrence Race G, Pennycook K, *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers* – sheets 28 and 46, BG 4/2007, BSRIA 2007, ISBN 978 086022 669 7

## See also:

Sheet W1 Pipe sizing - General
Sheet W2 Pipe sizing - Straight lengths
Sheet W4 System resistance for pipework - Index run

**DESIGN WATCHPOINTS**

1. A common mistake is to apply the $\zeta$ for a tee piece to the wrong part of the branch. The values of $\zeta$ in *CIBSE Guide C* should be used with the velocity pressure ($P_V$) of the combined flow.

# W4 SYSTEM RESISTANCE FOR PIPEWORK – INDEX RUN

## Overview

The index run within a system is the circuit that has the highest resistance to the flow of water and supplies the index heat emitter. This is the worst case possible when considering pressure losses within a system. It is usually, but not always, the longest circuit in the system. Sometimes a shorter run with a greater number of fittings or items of equipment can be the index run.

The index pd (pressure drop) is required in order to successfully size the pump for the system. If the pump can work to the pressure demands of the index run then all other circuits will work.

To identify the index run, the pressure drop for several circuits may need to be found. The pressure drop across each length of pipe, fitting and terminal within these circuits will need to be calculated to determine the total pressure drop for each circuit. The one with the largest pressure drop will be the index.

- **Design tip:** Balancing a system is necessary to achieve the correct pressure losses and flow rates through the different components of a system. If the layout of the system is symmetrical, then the amount of commissioning required to balance the system is reduced. This is true for both water and air systems.

## Design information required

See also sheet W1 Pipe sizing – general.

**Number of circuits**

Each circuit within a multi-circuit system needs to be clearly identified.

**Pipe sizing details**

All pipework and fittings should have been sized with pressure drop per unit length ($\Delta P/l$) velocity pressure ($P_V$) and pressure loss factor ($\zeta$). Data is available from tables such as those found in section 4 of *CIBSE Guide C* and the pie sizing spreadsheet.

- **Design tip:** Often the longest circuit is the index run but there is always the possibility of a shorter circuit with many fittings being the index run.

## Calculation procedure

**Step 1.** Identify each section and where it begins and ends. For example, section 1 starts at the combined flow side of the tee fitting in the return, goes through the boiler and ends at the combined flow side of the tee fitting in the flow. Assign a reference to each section. Identify each fitting within each section and determine the design details: pressure drop per unit length ($\Delta/Pl$) velocity pressure ($P_v$) and pressure loss factor ($\zeta$).

**Step 4.** Identify each circuit by the sections it consists of, for example: circuit A = 1,2,3, circuit B = 2,3,4 and so on.

**Step 5.** Calculate all direct pressure losses across fittings and pipe work in each section

For fittings use:

$\Delta P = \zeta \times P_v$

For straight pipe use:

$\Delta P = (\Delta P/l) \times l$

**Step 2.** Add up the total direct pressure losses from each section within a circuit to give a circuit pressure drop.

**Step 3.** Identify the index run by examining each circuit pressure drop to identify the highest pressure drop.

## Example

Identify the index run and calculate the index run pressure drop for the following two-pipe system serving two panel radiators, each rated at 4·15 kW. The water temperature is 75°C.

**Design data**

**Heat Emitters**

For two heat emitters at 4·15 kW each, a 6% emission loss from pipework has been added when calculating the mass flow rate.

Assume a $\Delta t$ of 10K across the system.

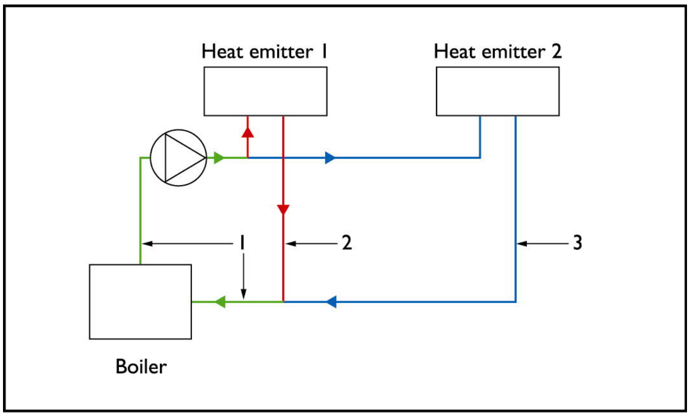
$$Cp = 4\cdot2\,kJ/kgK$$
$$Q = (2 \times 4\cdot15) \times 1\cdot06 = 8\cdot8kw$$

From:

$$Q = \dot{m}cp\Delta t$$
$$\dot{m} = \frac{8\cdot8}{4\cdot2 \times 10} = 0\cdot21kg/s$$

From the *CIBSE Guide C* pipe sizing spreadsheet, a 20 mm pipe with a flow of 0·2 kg/s gives a $\Delta P/l$ of 212 Pa/m and a velocity pressure ($P_V$) of 165 Pa.

**Step 1.** Identify the different sections and their design details.




Section 1: Green
Section 2: Red
Section 3: Blue

**Section details**

**Section 1**

**Straight Pipe work:** length 25 m, $\dot{m}$ = 0·21 kg/s, diameter = 20 mm.

**Elbow: Smooth radiused inner diameter:** 20 mm, $\zeta$ value: 0·75 (Table 4.21 *CIBSE Guide C.*)

**Boiler:** Sectional boiler $\zeta$ value: 1·5.

# W4 SYSTEM RESISTANCE FOR PIPEWORK – INDEX RUN

**Section 2**

**Straight pipe work:** length 8 m, ṁ = 0·105 kg/s, diameter = 15 mm, $\Delta P / l = 251 Pa/m, P_v = 133 Pa$.
**Radiator:** panel radiator ζ value: 2·5.
**Diverging tee with reduction:** ζ value = 1·30 (Table 4.33 *CIBSE Guide C*).
**Converging tee with enlargement:** ζ value = 2·98, (Table 4.34 *CIBSE Guide C*).

**Section 3**

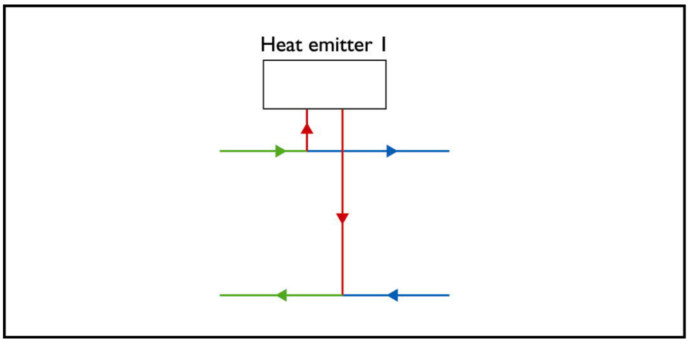
**Straight pipework:** length 13 m, ṁ = 0·105 kg/s, diameter = 15 mm, $\Delta P / l = 251 Pa/m, P_v = 133 Pa$.
**Elbow (two off):** Smooth radiused inner diameter 15mm, ζ value = 0·93 (Table 4.21 *CIBSE Guide C*).
**Radiator:** panel radiator ζ value = 2·5.
**Diverging tee with reduction:** ζ value = 0·57, (Table 4.33 *CIBSE Guide C*).
**Converging tee with enlargement:** ζ value = 1·63, (Table 4.34 *CIBSE Guide C*).

Values of ζ for radiators and boilers are found in table 9.1 of *Heating & Air Conditioning of Buildings* Faber & Kell, Ninth Edition. (See Design Watchpoint 1.)

**Step 2.** Now identify the circuits in the system;
Circuit A consists of section 1 and 2,
Circuit B consists of section 1 and 3.

**Step 3.** Calculate the pressure loss across each fitting and the pipework for each section. (See Design Watchpoint 2.)

There are two branches in this example. For both, the combined flow forms part of section 1; therefore as the velocity pressure ($P_v$) to be used is that of the combined flow, the value for this example is 165 Pa.




Section 1: Green
Section 2: Red
Section 3: Blue

**Pressure loss for each section**

**Section 1**

**Straight pipe:** 25 m × 212 Pa/m = 5300 Pa
**Elbow:** 0·75× 165 Pa = 124 Pa
**Boiler:** 1·5× 165 Pa = 248 Pa
**Total = 5672 Pa**

**Section 2**

**Straight pipe:** 8 m × 251 Pa/m = 2008 Pa
**Radiator:** 2·5× 133 Pa = 333 Pa
**Diverging tee:** 1·3 × 165 Pa = 215 Pa
**Converging tee:** 2·98 × 165 Pa = 492 Pa
**Total = 3048 Pa**

**Section 3**

**Straight pipe:** 13 m × 251 Pa/m = 3263 Pa
**Elbow (2 off):** 2 × 0·93 × 133 Pa = 247 Pa
**Radiator:** 2·5× 133 Pa = 333 Pa
**Diverging tee:** 0·57× 165 Pa = 94 Pa
**Converging tee:** 1·63× 165 Pa = 269 Pa
**Total = 4206 Pa**

**Step 4.** Add up total section losses for each circuit.
Circuit A Total pressure loss = 5672 Pa + 3048 Pa
= **8720 Pa, (8·7 kPa)**
Circuit B Total pressure loss = 5672 Pa + 4206 Pa
= **9879 Pa, (9·9 kPa)**

**Step 5.** The index circuit in this example is Circuit B.

- **Design tip:** Often, as in this case, the index circuit is obvious by inspection. But, if in doubt, check all circuits. Otherwise there is a risk of undersizing the pump and poor system performance.

## References


CIBSE Guide A, *Environmental Design*, 2006, ISBN 1 903287 669
CIBSE Guide B1, *Heating*, Section 5.1.3, and appendix A1.3, 2002, ISBN 19032 8720 0/Guide B, Section 1.5.1.3 and appendix A1.3, 2005, ISBN 1 903287 58 8
CIBSE Guide C, *Reference Data*, Section 1, 2007, ISBN 978 1903287 80 4
BSRIA, *Rules of Thumb*, BG 14/2003, BSRIA 2003, ISBN 0 86022 626 3
Lawrence Race G, Pennycook K, *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers* – sheets 28 and 46, BG 4/2007, BSRIA 2007, ISBN 978 086022 669 7
*Heating & Air Conditioning of Buildings*, Ninth Edition, Faber & Kell. ISBN 075 064 642 X


## See also:


Sheet W1 Pipe sizing - General
Sheet W2 Pipe sizing - Straight lengths
Sheet W3 Pipe sizing - Pressure drop across fittings
Sheet W5 Pump sizing.


**DESIGN WATCHPOINTS**

1. This example has the same heat emitters in both circuits. This may not always be the case.
2. When calculating the pressure loss through a fitting such as the branch fittings in this example, the velocity pressure ($P_V$) of the combined flow is used.

# W5 PUMP SIZING

## Overview

Pumps are required to transport the required fluid at a given mass flow rate around a system against the resistance to flow.

Centrifugal pumps are normally used for most building services applications. There are other types of pumps, such as positive displacement pumps, that are normally used in applications where high viscosity fluid is the system medium, such as heavy fuel oil. The two main designs of pumps that are used in building services are the in-line pump and the end-suction pump.

The basic information required to size a pump is the total mass flow rate required for the system and the total pressure drop (the index pressure drop).

Once these details have been confirmed, the next step is to determine what configuration of pumps are to be used (such as single, series or parallel), and then to compare the pump performance curve or characteristic to the system performance curve or characteristic. These issues are explained below and can be determined graphically or by calculation.

## Pump laws

Various pump laws show the relationships between pressure, flow rate, efficiency and power. These can be used to calculate each factor:

$Q \propto N$

$P \propto N^2$

$W \propto N^3$

$P \propto \rho$

$W \propto \rho$

$Q \propto D^3$

$P \propto D^2$

$W \propto D^5$

Where:

Q = volume flow rate
N = speed
P = pressure developed
W = power
D = diameter of the impeller
ρ = density.

The fundamental fluid flow laws can be found in various sources ranging from guides such as *CIBSE Guide B2*, section 5.11/*Guide B*, section 2.5.11, to text books such as *Woods Practical Guide to Fan Engineering.*

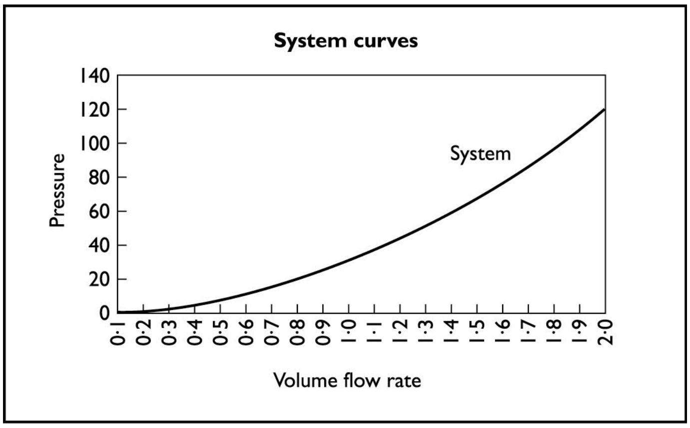
➢ **Design tip:** When using the pump laws only change one variable at a time. The value of the factors used will be individual to the pump, and the effect of changing one variable can be found by using the pump laws. If more that one factor is changed at any one time you may effectively be creating a different pump.

## System characteristics

The system performance can be expressed in the form of the equation $\Delta P = RQ^2$ for turbulent flow. The constant R is required as the equation is derived from $P \propto Q^2$. Most building services systems will use the turbulent flow equation.

Graph 1 shows the system characteristic on a pressure and volume flow rate graph.

**Graph 1**




Any system will have a resistance to flow due to the fittings, components, (such as heat exchangers) and the materials used. The flow of fluid through a system will vary according to the pressure developed by the pump.

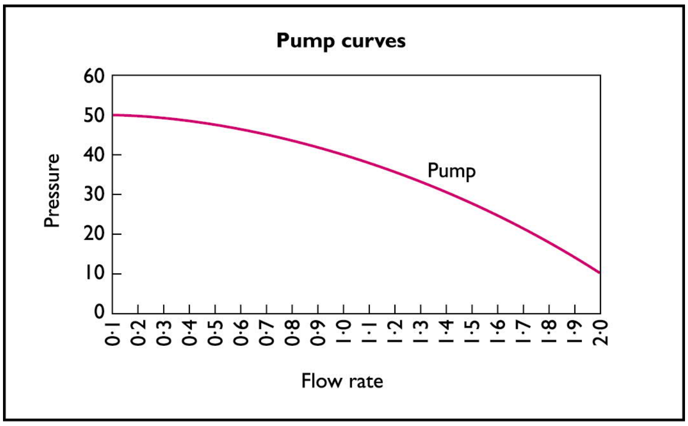
## Pump characteristics

Changes can be made easily to the points of operation by changing the speed of the pump. In more extreme cases either the pump impeller or the entire pump can be changed.

The pump characteristic curve shown below is also on a graph with pressure and volume flow rate axis. In the following examples where pumps are compared to one another, it is assumed that all pumps are individually identical in duty.

A pump curve for a single pump is shown in Graph 2:

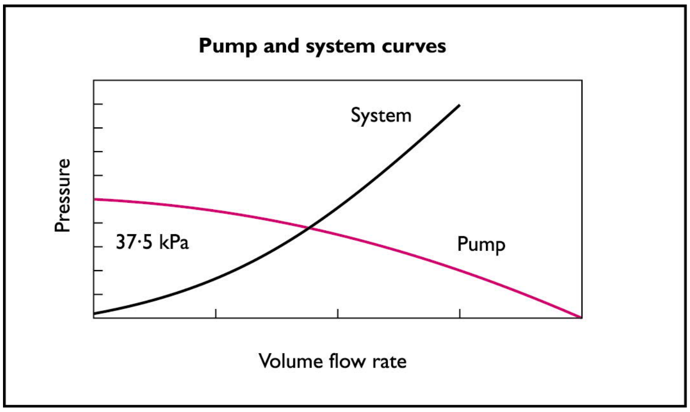
**Graph 2**



# W5 PUMP SIZING

When a system performance curve and pump performance are plotted on the same graph, the intersection is the operating point for that particular pump and system combination (see Graph 3). This is the point where the operating pressure and flow rate are the same for the system and pump performance curves. This is not necessarily the desired operating point.

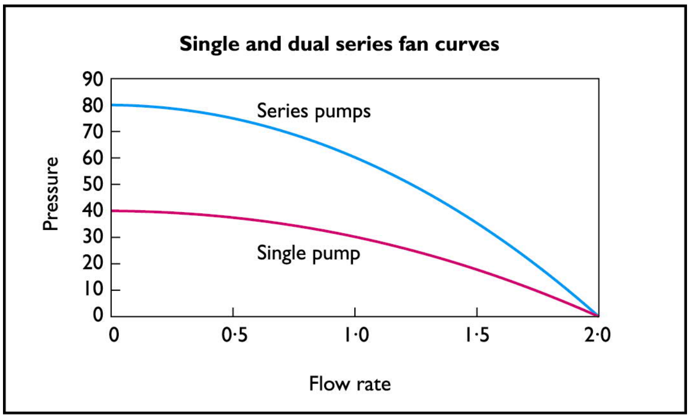
**Graph 3**




Dual pumps may sometimes be used for various reasons, such as for extra flow or to handle a high system resistance. It may be that the decision to install dual pumps for additional power instead of a single larger pump has been made due to economic costs.

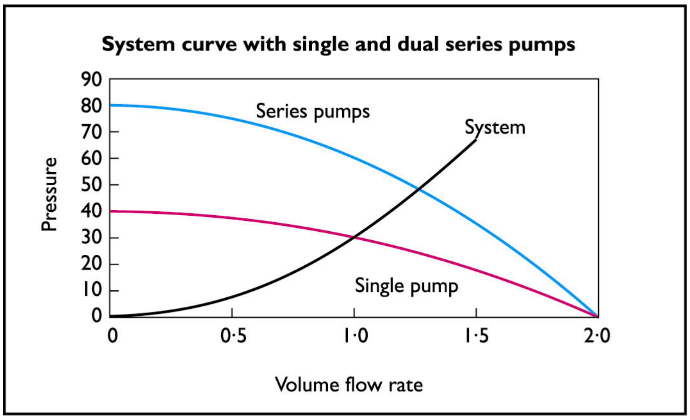
**Dual series pumps**
When comparing the pump characteristics of a single pump and dual pumps in series (all identical), the pressure is doubled for a given volume flow rate. The combined pumps give a new curve.

**Graph 4**



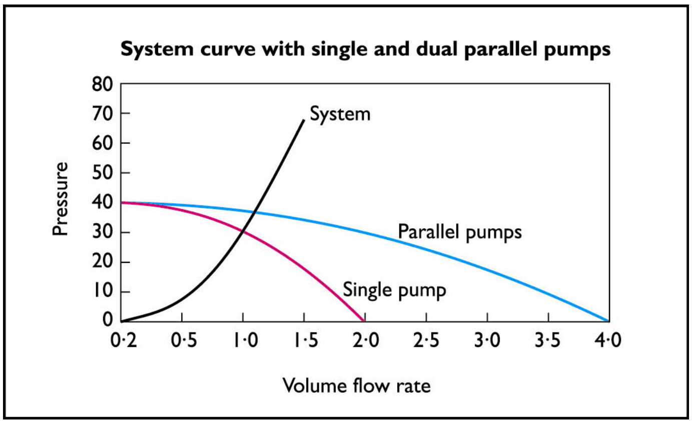

When the system curve is also plotted on the same graph the new operating point can be determined and compared with that of a single pump (see Graph 5).

**Graph 5**




**Dual parallel pumps**
The same applies with parallel pumps where the volume is doubled for a given pressure.

**Graph 6**




## Design Information Required

**Details of pipework system layout**
Including lengths and fittings, materials and insulation details.

**Details of possible locations**
Such as plant room location and layout, space available for installation of pumps and drives, permissible weights.

**Criticality of system served**

**Electrical supply**
One or three phase.

**Pump type**
Centrifugal (end-suction, in line, immersed rotor), displacement (helical or rotary).

**Drive type**
Belt or direct.

**Noise criteria**

# W5 PUMP SIZING

## Key design inputs

- Details of fluid, for example water, glycol solution or oil.
- Design flow and return temperatures (ºC)
- System mass flow rates (kg/s)
- System pressure drops (Pa)
- Ambient conditions including the surrounding air temperature (ºC)

## Design outputs

- Schematic of pump layout installation, mounting and pipework connections
- Schedule of pump types, flow rates, pressure and efficiencies including motor requirements, drive type and adjustment, speed control and stand by provision
- Media details, such as water/refrigerant, and temperature.
- A schedule of electricity supply requirements

## Calculation procedure

**Step 1.** Calculate the index run pressure drop and total system mass flow rate.

**Step 2.** Convert mass flow rate to volume flow rate in l/s.

**Step 3.** Determine system equations constant R. This can be done by substituting the required ΔP and Q into the equation $\Delta P = RQ^2$ and then solving for R.

**Step 4.** Select a pump that will operate within the required parameters and plot the system and pump characteristics on the same graph.

**Step 5.** Determine the operating point. Identify operating pressure and flow rate.

**Step 6.** Calculate pump speed to achieve required values or select another pump.

- **Design tip:** With belt-driven pumps it is easy to vary the speed by changing the pulleys. If the pump is inverter- driven this can be done automatically.
- **Design tip:** If you use an additional margin with the required pressure drop to allow for differences between design pipe work layout and physical installations on site, do so carefully, as over-sizing a pump will only result in excess energy usage.

## Example

A system has a volume flow rate requirement of 1 l/s with an index run ΔP of 30 kPa. Find an appropriate pump.

**Step 1. and 2.** Pressure drop and volume flow rate are available in the units required.

**Step 3.** The constant R in the system characteristic curve equation can be calculated as shown below:

$\Delta P = RQ^2$

Index run pd = 30 kPa

Volume flow rate = 1 l/s

$30 = R \times 1^2$

ie $R = \frac{30}{1} = 30$

$\Delta P = 30Q^2$

**Step 4.** A pump needs to be selected that will work within the parameters of pressure and volume flow rate already stated. Selection will also depend on the type of system and design features of the pump. (See Design Watchpoint 1.)

Once a pump has been selected that can work in the range required, the pump and system curve should be plotted on a single graph. Some manufacturers will provide a range of pump curves on a graph with efficiency and power curves underneath. If this is the case then the system curve can be drawn directly onto the graph and the operating points identified quickly. For this example it is assumed that the pump data is given in table form.

A manufacturer's catalogue gives the following information for a centrifugal pump operating at 12 rev/s:

P pressure (kPa)
Q volume Flow Rate (l/s)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *P* | 49·38 | 47·5 | 44·38 | 40 | 34·38 | 27·5 | 19·38 |
| *Q* | 0·25 | 0·5 | 0·75 | 1 | 1·25 | 1·5 | 1·75 |

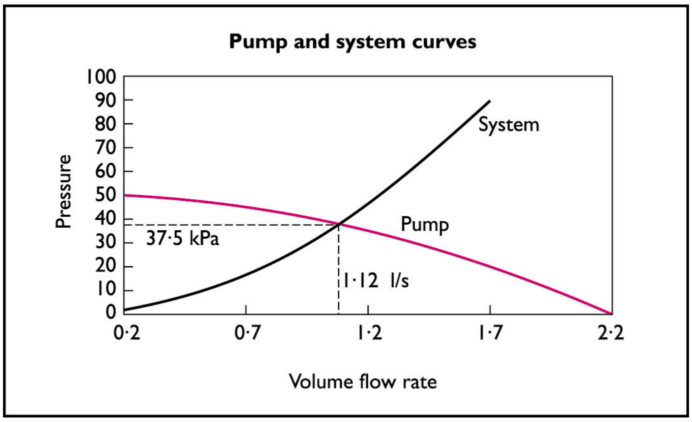
This particular pump has the following equation:

$\Delta P = 50 - 10Q^2$

With the system equation the two can be solved simultaneously, or the pressure against volume flow rate for both equations can be plotted to find the intersection point.

**Pump and system curves**

**Graph 7**




**Step 5.** The operating point occurs when the two curves intersect, 1·12 l/s at 37·5 kPa

**Step 6.** As 1·12 l/s is too high, the pump will need to be slowed down in order to achieve the required flow rate. Alternatively, a different pump may give a closer value. This is worth considering when comparing the efficiency of different pumps at different speeds and pressures.

# W5 PUMP SIZING

By using the pump law $Q \propto N$:

$$\frac{Q_{des}}{Q} = \frac{N_{des}}{N}$$

Where:

$Q_{des}$ = desired volume flow rate

$N_{des}$ = desired pump rotational speed

The required speed can be determined that is needed to provide 1 ·0 l/s.

Therefore:

$$N_{des} = \frac{1 \cdot 0}{1 \cdot 12} \times 12 = 10 \cdot 7 \text{ rev/s}$$

This can also be achieved by using the pump law $P \propto N^2$, for example:

$$\frac{P_{des}}{P} = \frac{N_{des}^2}{N^2}$$

Therefore:

$$N_{des}^2 = \frac{30}{37 \cdot 5} \times 12^2 = 115 \cdot 2$$

$$N_{des} = \sqrt{115 \cdot 2} = 10 \cdot 7 \text{ rev/s}$$

- **Design tip:** A functioning pump will have operating losses such belt or drive losses. The pump and system performance curves do not take this into account.
- **Design tip**: The use of inverters to control the speed of the pump is the most efficient method of controlling and restricting the flow. The cost and maintenance requirements of the inverter need to be considered. An alternate method is to adjust a globe valve on the pump discharge side to achieve the required flow. However the latter method is wasteful of energy and only works if all other parameters remain constant.

**Net Positive Suction Head (NPSH)**

Net positive suction head is the total inlet head, plus the head corresponding to the atmospheric pressure, minus the head corresponding to the vapour pressure. The total inlet head is the sum of static, positive and velocity heads at the inlet section of the pump.

The term head is often used to mean pressure developed by a pump or column of liquid. Centrifugal pumps are not able to develop suction pressure unless filled with fluid first (primed). Care is needed to ensure that at the suction of a pump, the absolute pressure of the fluid exceeds the vapour pressure of the fluid. This is particularly important when working with hot fluids. (See Design Watchpoint 2.)

If a pump is drawing water from some point below the centre line of the impellor, the vertical height through which that water is lifted must not be sufficient to cause cavitation.

Cavitation is where small pockets (bubbles) of vapour of the fluid are created due to incorrect pressures. As the bubbles move through the pump, they change in pressure causing them to collapse. This creates noise and can cause damage to the pump in the suction line or to the impellor surface.

## References

Parsloe C J, *Variable speed pumping in heating and cooling circuits*, AG 14/99, BSRIA 1999, ISBN 086022533X
Lawrence Race G, Pennycook K, *Design Checks for HVAC – A Quality Control Framework for Building Services Engineers* – sheet 49, BG 4/2007, BSRIA 2007, ISBN 978 086022 669 7

## See also:

Sheet W1 Pipe sizing - General
Sheet W2 Pipe sizing – Straight lengths
CIBSE Guide B1, *Heating*, Section 5.1.4, 2002,
ISBN 1 903 487 200/Guide B, section 1.5.1.4, 2005,
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CIBSE Guide B2, *Ventilation and Air Conditioning* , Section 5.11, 2001, ISBN 1 903287 16 2/Guide B, section 2.5.11, 2005, ISBN 1 903287 58 8
CIBSE Guide C, *Reference Data*, Section 1, 2007,
ISBN 978 1903287 80 4

**DESIGN WATCHPOINTS**

1. When selecting a pump check the point of operation. If the pump selected is operating on a flat part of the curve, controlling volume flow rate can be difficult as the pressure is fairly constant for a changing volume flow rate.
2. Net positive suction head (NPSH), can be a complex area. If errors are made there can be potential system problems. It is only briefly discussed here as it is advised that a junior engineer should consult a senior engineer.