

Chapter 5

Pipe sizing

Pipes and fittings should be sized so that the flow rates for individual draw-offs are equal to the design flow rates shown in table 5.1. During simultaneous discharges, flows from taps should not be less than the minimum flow rates shown in table 5.1.

BS 6700 recommends that flow velocities should not exceed 3 m/s. BS EN 805 recommends 0.5 m/s to 2 m/s with a maximum of 3.5 m/s in exceptional circumstances. Filling times for cisterns may range from 1 to 4 hours depending on their capacity and the flow rate available from the local water supply. In dwellings the filling time should not exceed 1 hour.

Design flow rates may be calculated by dividing the cistern capacity by the required filling time.

Table 5.1 Design flow rates and loading units

Outlet fitting	Design flow rate l/s	Minimum flow rate l/s	Loading units
WC flushing cistern single or dual flush – to fill in 2 minutes	0.13	0.05	2
WC trough cistern	0.15 per WC	0.10	2
Wash basin tap size $\frac{1}{2}$ – DN 15	0.15 per tap	0.10	1.5 to 3
Spray tap or spray mixer	0.05 per tap	0.03	–
Bidet	0.20 per tap	0.10	1
Bath tap, nominal size $\frac{3}{4}$ – DN 20	0.30	0.20	10
Bath tap, nominal size 1 – DN 25	0.60	0.40	22
Shower head (will vary with type of head)	0.20 hot or cold	0.10	3
Sink tap, nominal size $\frac{1}{2}$ – DN 15	0.20	0.10	3
Sink tap, nominal size $\frac{3}{4}$ – DN 20	0.30	0.20	5
Sink tap, nominal size 1 – DN 20	0.60	0.40	–
Washing machine size – DN 15	0.20 hot or cold	0.15	–
Dishwasher size – DN 15	0.15	0.10	3
Urinal flushing cistern	0.004 per position served	0.002	–
Pressure flushing valve for WC or urinal	1.5	1.2	–

Notes:

- (1) Flushing troughs are advisable where likely use of WCs is more than once per minute.
- (2) Mixer fittings use less water than separate taps, but this can be disregarded in sizing.
- (3) Flow rates to shower mixers vary according to type fitted. Manufacturers should be consulted.
- (4) Manufacturers should be consulted for flow rates to washing machines and dishwashers for other than a single dwelling.
- (5) For cistern fed urinals demand is very low and can usually be ignored. Alternatively, use the continuous flow.
- (6) Loading units should not be used for outlet fittings having high peak demands, e.g. those in industrial installations. In these cases use the continuous flow.
- (7) BS 6700 does not give loading units for sink tap DN 20 or pressure flushing valve for WCs or urinals.

Correct pipe sizes will ensure adequate flow rates at appliances and avoid problems caused by oversizing and undersizing; see figure 5.1.

Oversizing will mean:

- additional and unnecessary installation costs;
- delays in obtaining hot water at outlets;
- increased heat losses from hot water distributing pipes.

Undersizing may lead to:

- inadequate delivery from outlets and possibly no delivery at some outlets during simultaneous use;
- some variation in temperature and pressure at outlets, especially showers and other mixers;
- some increase in noise levels.

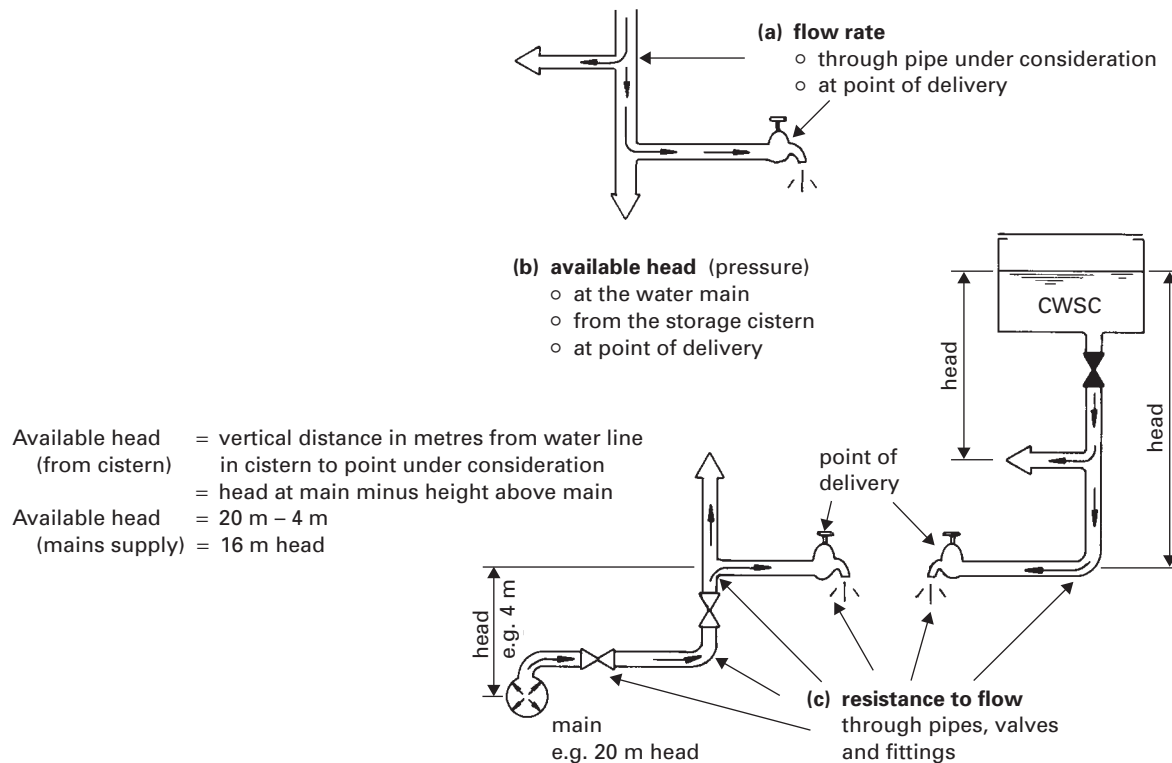


Figure 5.1 Pipe sizing considerations

In smaller, straightforward installations such as single dwellings, pipes are often sized on the basis of experience and convention.

In larger and more complex buildings, or with supply pipes that are very long, it is necessary to use a recognized method of calculation such as that shown in sections 5.1 and 5.2.

BS EN 806-3 gives an alternative 'simplified method' of pipe sizing that can be used for 'standard installations'.

5.1 Sizing procedure for supply pipes

The procedure below is followed by an explanation of each step with appropriate examples.

- (1) Assume a pipe diameter.
- (2) Determine the flow rate:
 - (a) by using loading units;
 - (b) for continuous flows;
 - (c) obtain the design flow rate by adding (a) and (b).
- (3) Determine the effective pipe length:
 - (d) work out the measured pipe length;
 - (e) work out the equivalent pipe length for fittings;
 - (f) work out the equivalent pipe length for draw-offs;
 - (g) obtain the effective pipe length by adding (d), (e) and (f).
- (4) Calculate the permissible loss of head:
 - (h) determine the available head;
 - (i) determine the head loss per metre run through pipes;
 - (j) determine the head loss through fittings;
 - (k) calculate the permissible head loss.
- (5) Determine the pipe diameter:
 - (l) decide whether the assumed pipe size will give the design flow rate in (c) without exceeding the permissible head loss in (k).

Explanation of the procedure

Assume a pipe diameter (1)

In pipe sizing it is usual to make an assumption of the expected pipe size and then prove whether or not the assumed size will carry the required flow.

Determine the flow rate (2)

In most buildings it is unlikely that all the appliances installed will be used simultaneously. As the number of outlets increases the likelihood of them all being used at the same time decreases. Therefore it is economic sense to design the system for likely peak flows based on probability theory using loading units, rather than using the possible maximum flow rate.

- (a) *Loading units.* A loading unit is a factor or number given to an appliance which relates the flow rate at its terminal fitting to the length of time in use and the frequency of use for a particular type and use of building (probable usage). Loading units for various appliances are given in table 5.1.

By multiplying the number of each type of appliance by its loading unit and adding the results, a figure for the total loading units can be obtained. This is converted to a design flow rate using figure 5.2.

An example using loading units is given in figure 5.3.

(b) *Continuous flows.* For some appliances, such as automatic flushing cisterns, the flow rate must be considered as a continuous flow instead of applying probability theory and using loading units. For such appliances the full design flow rate for the outlet fitting must be used, as given in table 5.1.

However, in the example shown in figure 5.3, the continuous flow for the two urinals of 0.008 l/s (from table 5.1) is negligible and can be ignored for design purposes.

(c) *Design flow rate.* The design flow rate for a pipe is the sum of the flow rate determined from loading units (a) and the continuous flows (b).

Determine the effective pipe length (3)

(d) *Find the measured pipe length.* Figure 5.4 is an example showing how the measured pipe length is found.

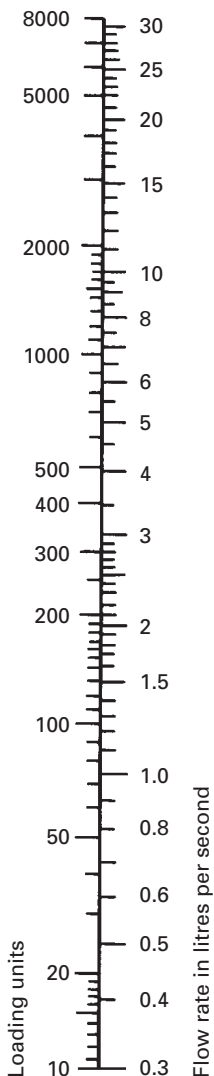
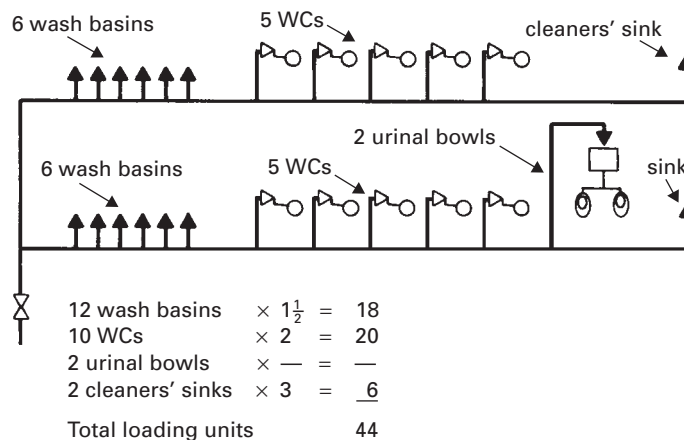
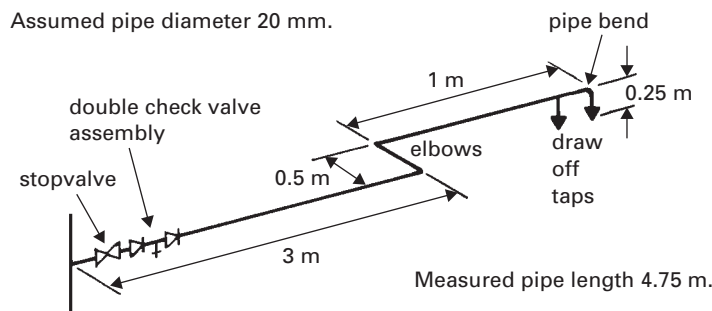


Figure 5.2
Conversion chart - loading units to flow rate



Therefore, from figure 5.2, the required flow rate for the system is 0.7 l/s.

Figure 5.3 Example of use of loading units



Note There is no need to consider both branch pipes to taps.

Figure 5.4 Example of measured pipe length

Table 5.2 Equivalent pipe lengths (copper, stainless steel and plastics)

Bore of pipe mm	Equivalent pipe length			
	Elbow m	Tee m	Stopvalve m	Check valve m
12	0.5	0.6	4.0	2.5
20	0.8	1.0	7.0	4.3
25	1.0	1.5	10.0	5.6
32	1.4	2.0	13.0	6.0
40	1.7	2.5	16.0	7.9
50	2.3	3.5	22.0	11.5
65	3.0	4.5	–	–
73	3.4	5.8	34.0	–

Notes:

- (1) For tees consider change of direction only. For gate valves losses are insignificant.
- (2) For fittings not shown, consult manufacturers if significant head losses are expected.
- (3) For galvanized steel pipes in a small installation, pipe sizing calculations may be based on the data in this table for equivalent nominal sizes of smooth bore pipes. For larger installations, data relating specifically to galvanized steel should be used. BS 6700 refers to suitable data in the *Plumbing Engineering Services Design Guide* published by the Institute of Plumbing.

(e, f) *Find the equivalent pipe lengths for fittings and draw-offs.* For convenience the frictional resistances to flow through fittings are expressed in terms of pipe lengths having the same resistance to flow as the fitting. Hence the term ‘equivalent pipe length’ (see table 5.2).

For example, a 20 mm elbow offers the same resistance to flow as a 20 mm pipe 0.8 m long.

Figure 5.5 shows the equivalent pipe lengths for the fittings in the example in figure 5.4.

(g) *Effective pipe length.* The effective pipe length is the sum of the measured pipe length (d) and the equivalent pipe lengths for fittings (e) and draw-offs (f).

Therefore, for the example shown in figure 5.4 the effective pipe length would be:

Measured pipe length		4.75 m
Equivalent pipe lengths		
elbows	2×0.8	= 1.6 m
tee	1×1.0	= 1.0 m
stopvalve	1×7.0	= 7.0 m
taps	2×3.7	= 7.4 m
check valves	2×4.3	= 8.6 m
Effective pipe length		= 30.35 m

Permissible loss of head (pressure) (4)

Pressure can be expressed in the following ways.

- (i) In pascals, the pascal (Pa) being the SI unit for pressure.
- (ii) As force per unit area, N/m^2 .
 $1 \text{ N/m}^2 = 1 \text{ pascal (Pa)}$.

Using the example from figure 5.4:

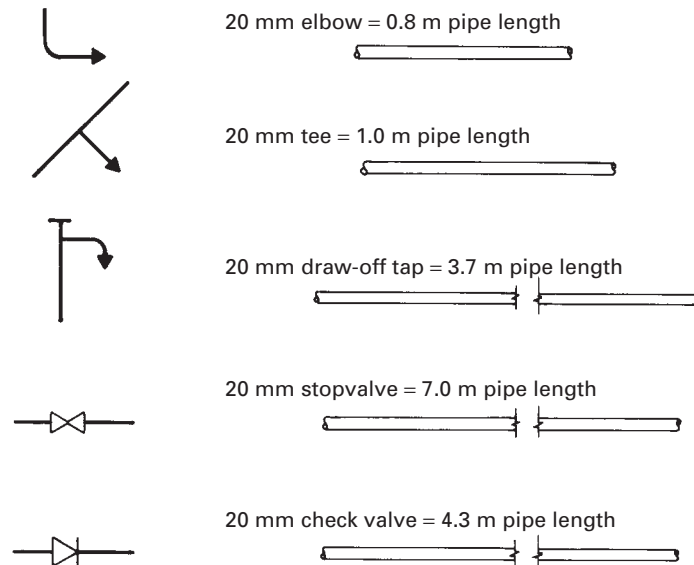


Figure 5.5 Examples of equivalent pipe lengths

- (iii) As a multiple of atmospheric pressure (bar).
Atmospheric pressure = $100 \text{ kN/m}^2 = 100 \text{ kPa} = 1 \text{ bar}$.
- (iv) As metres head, that is, the height of the water column from the water level to the draw-off point.
 $1 \text{ m head} = 9.81 \text{ kN/m}^2 = 9.81 \text{ kPa} = 98.1 \text{ mb}$.

In the sizing of pipes, any of these units can be used. BS 6700 favours the pascal. However, this book retains the use of metres head, giving a more visual indication of pressure that compares readily to the height and position of fittings and storage vessels in the building.

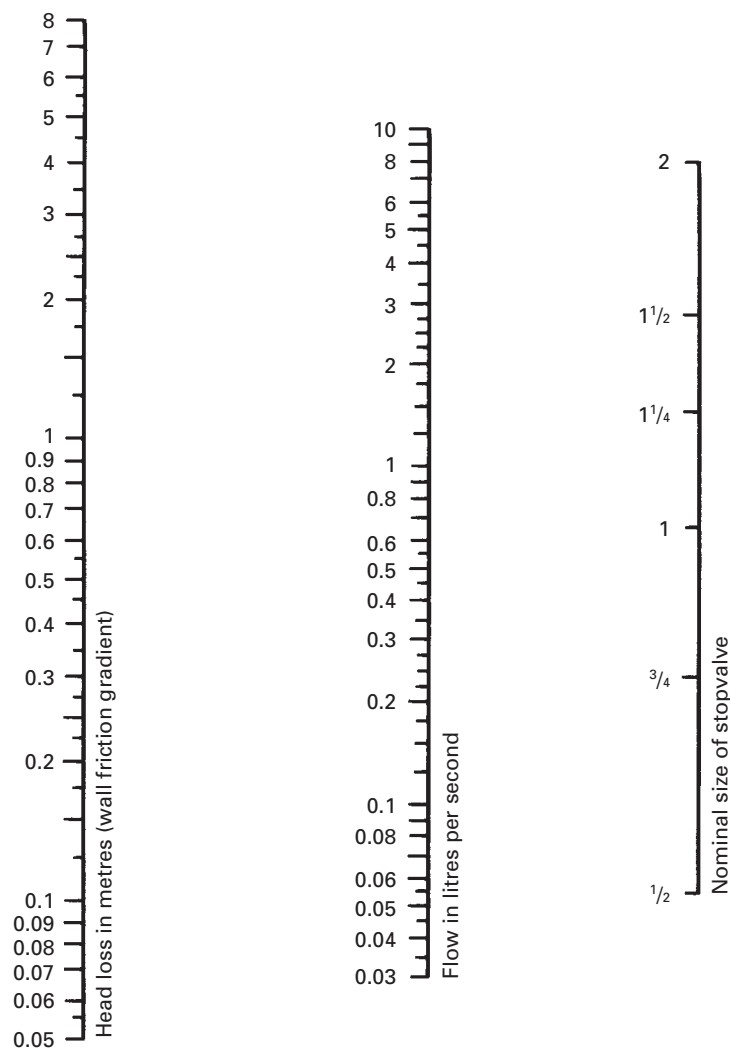
- (h) *Available head.* This is the static head or pressure at the pipe or fitting under consideration, measured in metres head (see figure 5.1).
- (i) *Head loss through pipes.* The loss of head (pressure) through pipes due to frictional resistance to water flow is directly related to the length of the pipe run and the diameter of the pipe. Pipes of different materials will have different head losses, depending on the roughness of the bore of the pipe and on the water temperature. Copper, stainless steel and plastics pipes have smooth bores and only pipes of these materials are considered in this section.
- (j) *Head loss through fittings.* In some cases it is preferable to subtract the likely resistances in fittings (particularly draw-offs) from the available head, rather than using equivalent pipe lengths.

Table 5.3 gives typical head losses in taps for average flows compared with equivalent pipe lengths. Figures 5.6 and 5.7 provide a method for determining head losses through stopvalves and float-operated valves respectively.

Note Where meters are installed in a pipeline the loss of head through the meter should be deducted from the available head.

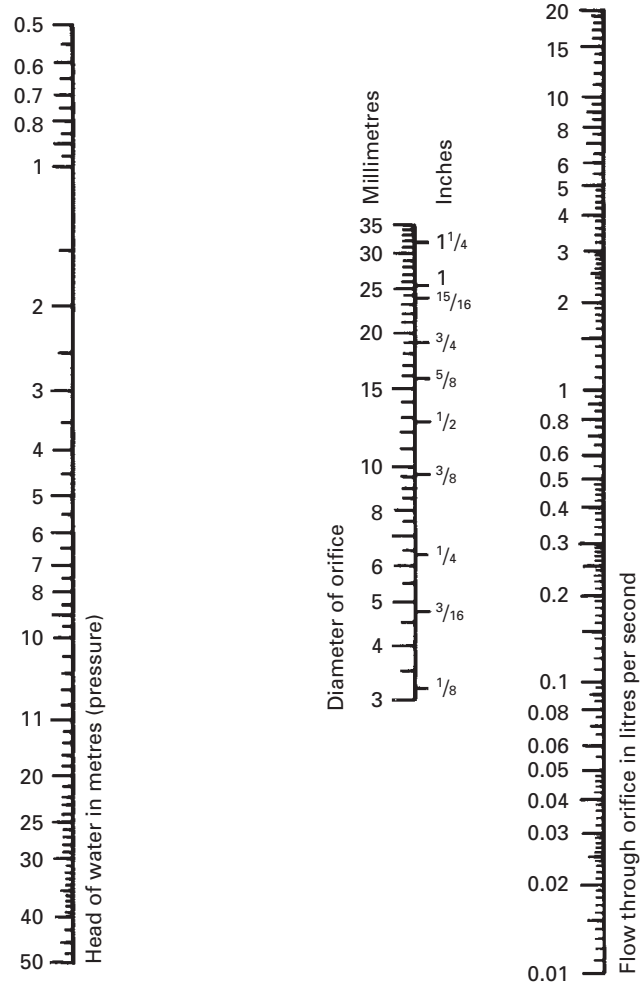
Table 5.3 Typical head losses and equivalent pipe lengths for taps

Nominal size of tap	Flow rate l/s	Head loss m	Equivalent pipe length m
G $\frac{1}{2}$ -DN 15	0.15	0.5	3.7
G $\frac{1}{2}$ -DN 15	0.20	0.8	3.7
G $\frac{3}{4}$ -DN 20	0.30	0.8	11.8
G 1-DN 25	0.60	1.5	22.0



Note Gate valves and spherical plug valves offer little or no resistance to flow provided they are fully open.

Figure 5.6 Head loss through stopvalves



Based on $Q = AV0.75$
 $V = \sqrt{2gH}$

where Q is flow (l/s)
 A is cross sectional area of pipe (m²)
 V is velocity (m/s)
 g is acceleration due to gravity (m/s²)
 H is head of water (m)

Figure 5.7 Head loss through float-operated valves

- (k) *Permissible head loss*. This relates the available head to the frictional resistances in the pipeline. The relationship is given by the formula:

$$\text{Permissible head loss (m/m run)} = \frac{\text{Available head (m)}}{\text{Effective pipe length (m)}}$$

This formula is used to determine whether the frictional resistance in a pipe will permit the required flow rate without too much loss of head or pressure. Figure 5.8 illustrates the permissible head loss for the example in figure 5.4.

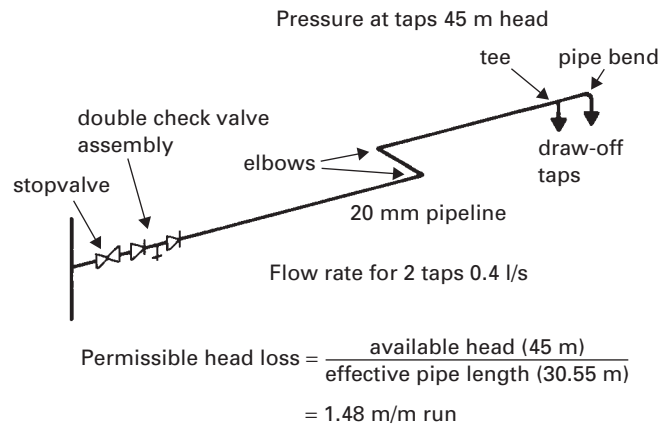


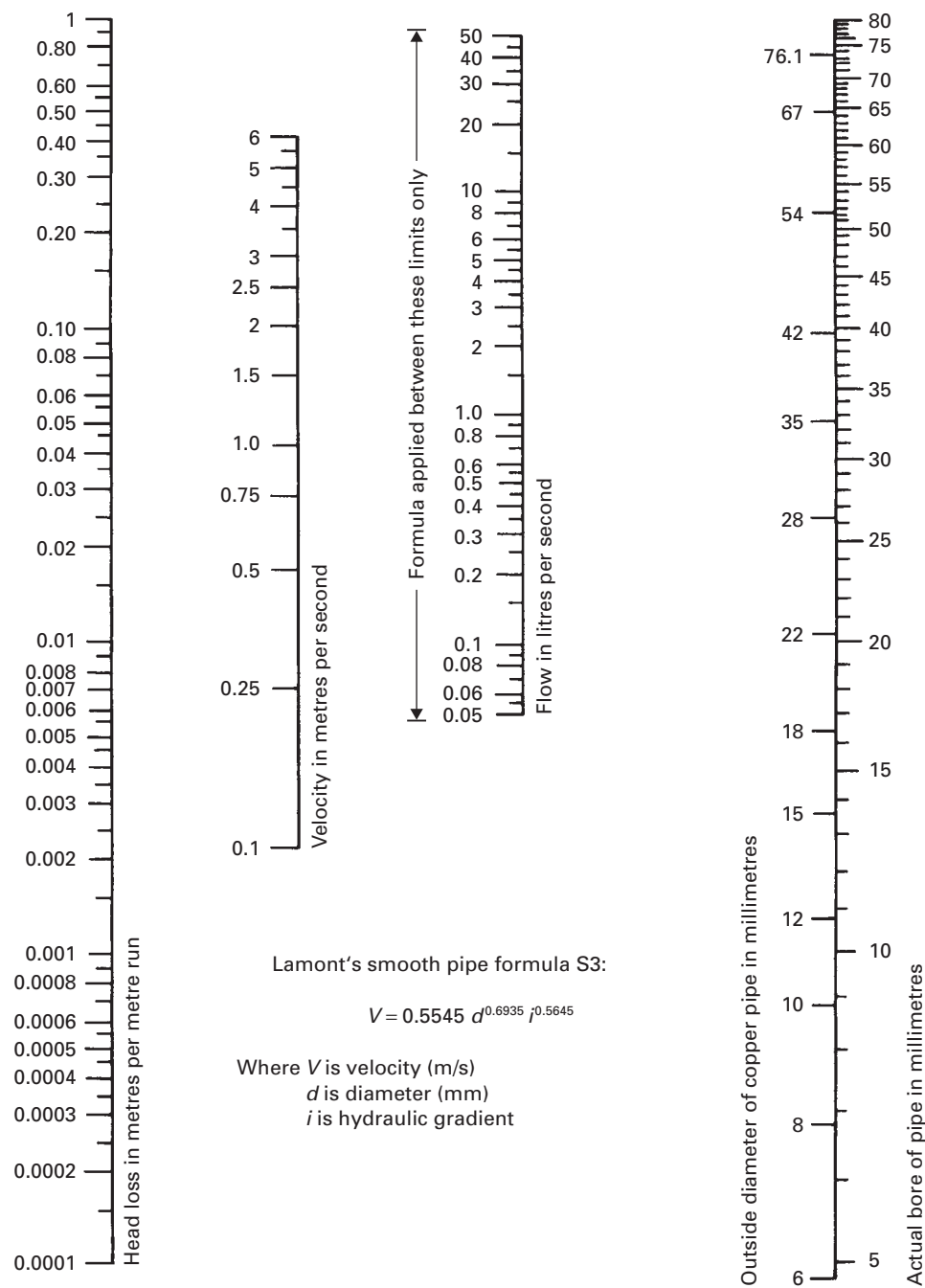
Figure 5.8 Example of permissible head loss

Determine the pipe diameter (5)

In the example in figure 5.4 a pipe size of 20 mm has been assumed. This pipe size must give the design flow rate without the permissible head loss being exceeded. If it does not, a fresh pipe size must be assumed and the procedure worked through again.

Figure 5.9 relates pipe size to flow rate, flow velocity and head loss. Knowing the assumed pipe size and the calculated design flow rate, the flow velocity and the head loss can be found from the figure as follows.

- (1) Draw a line joining the assumed pipe size (20 mm) and the design flow rate (0.4 l/s).
- (2) Continue this line across the velocity and head loss scales.
- (3) Check that the loss of head (0.12 m/m run) does not exceed the calculated permissible head loss of 1.48 m/m run.
- (4) Check that the flow velocity (1.4 m/s) is not too high by referring to table 5.4.



Notes Figures shown are for cold water at 12°C.
 Hot water will show slightly more favourable head loss results.
 BS 6700 gives head loss in kPa.
 1 m head = 9.81 kPa.

Figure 5.9 Determination of pipe diameter

Table 5.4 Maximum recommended flow velocities

Water temperature °C	Flow velocity	
	Pipes readily accessible m/s	Pipes not readily accessible m/s
10	3.0	2.0
50	3.0	1.5
70	2.5	1.3
90	2.0	1.0

Note Flow velocities should be limited to reduce system noise.

5.2 Tabular method of pipe sizing

Pipe sizing in larger and more complicated buildings is perhaps best done by using a simplified tabular procedure. BS 6700 gives examples of this but for more detailed data readers should refer to the Institute of Plumbing's *Plumbing Engineering Services Design Guide*.

The data used in the tabular method that follows are taken from BS 6700 but the author has simplified the method compared with that given in the standard.

The tabular method uses a work sheet which can be completed as each of the steps is followed in the pipe sizing procedure. An example of the method follows with some explanation of each step.

Explanation of the tabular method

Pipework diagram

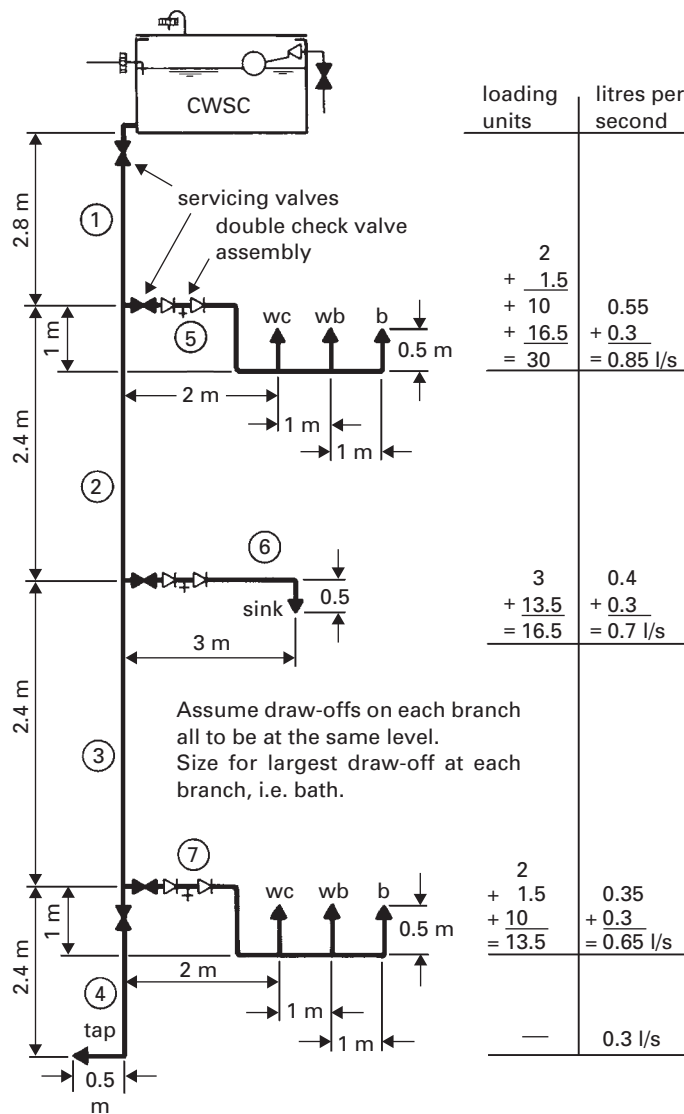
- (1) Make a diagram of the pipeline or system to be considered (see figure 5.10).
- (2) Number the pipes beginning at the point of least head, numbering the main pipe run first, then the branch pipes.
- (3) Make a table to show the loading units and flow rates for each stage of the main run. Calculate and enter loading units and flow rates; see figure 5.10.

Calculate flow demand

- (1) Calculate maximum demand (see figure 5.10):
 - add up loading units for each stage (each floor level);
 - convert loading units to flow rates;
 - add up flow rates for each stage.
- (2) Calculate probable demand (see figure 5.10):
 - add up loading units for all stages;
 - convert total loading units to flow rate.
- (3) Calculate percentage demand (number of stages for which frictional resistances need be allowed). See figure 5.12.

Work through the calculation sheet

See figure 5.11, using the data shown in figures 5.10 and 5.12.



Assume draw-offs on each branch all to be at the same level. Size for largest draw-off at each branch, i.e. bath.

Bib tap at 0.3 l/s in frequent use.

Note Figure is not to scale for convenience, water level in cistern taken to be at base of cistern. Servicing valves assumed to be full-flow gate valves having no head losses.

Refer also to figure 5.12.

Figure 5.10 Pipe sizing diagram

This is an example of a suitable calculation sheet with explanatory notes.

Calculation sheet

Enter pipe reference on calculation sheet													
Determine loading unit (table 5.1)													
Convert loading units to flow rate (figure 5.2)													
Make assumption as to pipe size (inside diameter)													
Work out frictional resistance per metre (figure 5.9)													
Determine velocity of flow (figure 5.9)													
Measure length of pipe under consideration													
Consider frictional resistances in fittings (table 5.2 and figures 5.6 and 5.7)													
Add totals in columns 7 and 8													
Head consumed – multiply column 5 by column 9													
Add head consumed in column 10 to progressive head in previous row of column 11													
Record available head at point of delivery													
Compare progressive head with available head to confirm pipe diameter or not													
Notes													

Note If, for any pipe or series of pipes, it is found that the assumed pipe size gives a progressive head that is in excess of the available head, or is noticeably low, it will be necessary to repeat the sizing operation using a revised assumed pipe diameter.

Figure 5.11 Calculation sheet – explanation of use

Estimated maximum demand = 1.4 l/s

Probable demand = 0.85 l/s

$$\text{Percentage demand} = \frac{\text{probable demand}}{\text{estimated maximum demand}} \times \frac{100}{1}$$

$$= \frac{0.85}{1.4} \times \frac{100}{1} = 60\%$$

Therefore only 60% of the installation need be considered.

For example, if we were designing for a multi-storey building 20 storeys high, only the first 12 storeys need to be calculated.

However, in the example followed here, the whole system has been sized because the last fitting on the run has a high flow rate in continuous use.

For branches only the pipes to the largest draw-off, i.e. the bath tap, need be sized.

Calculation sheet

(1) Pipe reference	(2) Loading units	(3) Flow rate (l/s)	(4) Pipe size (mm diameter)	(5) Loss of head (m/m run)	(6) Flow velocity (m/s)	(7) Measured pipe run (m)	(8) Equivalent pipe length (m)	(9) Effective pipe length (m)	(10) Head consumed (m)	(11) Progressive head (m)	(12) Available head (m)	(13) Final pipe size (mm)	(14) Remarks
1	30	0.85	32	0.05	1.2	2.8	1.4	4.2	0.21	0.21	2.8	32	
5	13.5	0.35	20	0.095	1.25	5.5	12.0	17.5	1.66	1.87	3.3	20	
2	16.5	0.7	25	0.12	1.5	2.4	—	2.4	0.29	2.16	5.2	25	
6	3	0.3	20	0.07	1.0	3.5	10.4	13.9	0.97	3.13	5.7	20	
3	13.5	0.65	25	0.1	1.4	2.4	—	2.4	0.24	3.37	7.6	25	
7	13.5	0.35	20	0.095	1.25	5.5	12.0	17.5	1.66	5.03	8.1	20	
4	—	0.3	20	0.07	1.0	2.9	1.6	4.5	0.31	5.34	10.0	20	

Refer also to figure 5.10.

Figure 5.12 Calculation sheet – example of use

5.3 Sizing cold water storage

In Britain, cold water has traditionally been stored in both domestic and non-domestic buildings, to provide a reserve of water in case of mains failure. However, in recent years we have seen an increase in the use of 'direct' pressure systems, particularly for hot water services where many combination boilers and unvented hot water storage vessels are now being installed.

BS 6700 no longer gives storage capacities for houses. The following figures are based on the 1997 edition.

Smaller houses	cistern supplying cold water only	– 100 l to 150 l
	cistern supplying hot and cold outlets	– 200 l to 300 l
Larger houses	per person where cistern fills only	– 80 l
	at night per person	– 130 l

However, in clause 5.3.9.4 it recommends a minimum storage capacity of 230 l where the cistern supplies both cold water outlets and hot water apparatus, which was a requirement of byelaws in the past. The author still favours the old byelaw requirements, which are more specific and which still seem to be the normal capacity installed.

Cold water storage cistern	– 115 l minimum
Feed cistern	– No minimum but should be equal to the capacity of the hot store vessel supplied
Combined feed and storage cistern	– 230 l minimum

For larger buildings the capacity of the cold water storage cistern depends on:

- type and use of buildings;
- number of occupants;
- type and number of fittings;
- frequency and pattern of use;
- likelihood and frequency of breakdown of supply.

These factors have been taken into account in table 5.5, which sets out minimum storage capacities in various types of building to provide a 24-hour reserve capacity in case of mains failure.

Calculation of minimum cold water storage capacity

Determine the amount of cold water storage required to cover 24 hours interruption of supply in a combined hotel and restaurant. Number of hotel guests 75, number of restaurant guests 350.

Storage capacity = number of guests × storage per person from table 5.5	
Hotel storage capacity	= 75 × 200 = 15 000 l
Restaurant storage capacity	= 350 × 7 = 2450 l
Therefore total storage capacity required is	15 000 l + 2450 l = 17 450 l

Assuming 12-hour fill time, the design flow rate to the cistern would be:

$$\begin{aligned}\text{Design flow rate} &= 17\,450 \text{ l cistern capacity} \div 12 \text{ hours} \\ &= 17\,450 \div (12 \times 3600 \text{ seconds}) \\ &= 0.4 \text{ l/s}\end{aligned}$$

Table 5.5 Recommended minimum storage of hot and cold water for domestic purposes

Type of building	Minimum cold water storage litres (l)	Minimum hot water storage litres (l)
Hostel	90 per bed space	32 per bed space
Hotel	200 per bed space	45 per bed space
Office premises:		
with canteen facilities	45 per employee	4.5 per employee
without canteen facilities	40 per employee	4.0 per employee
Restaurant	7 per meal	3.5 per meal
Day school:		
nursery }	15 per pupil	4.5 per pupil
primary }		
secondary }	20 per pupil	5.0 per pupil
technical }		
Boarding school	90 per pupil	23 per pupil
Children's home or residential nursery	135 per bed space	25 per bed space
Nurses' home	120 per bed space	45 per bed space
Nursing or convalescent home	135 per bed space	45 per bed space

Note Minimum cold water storage shown includes that used to supply hot water outlets.

5.4 Sizing hot water storage

Minimum hot water storage capacities for dwellings, from BS 6700, are:

- 35 l to 45 l per occupant, unless the heat source provides a quick recovery rate;
- 100 l for systems heated by solid fuel boilers;
- 200 l for systems heated by off-peak electricity.

The feed cistern should have a capacity at least equal to that of the hot storage vessel.

Information on storage capacities for larger buildings is given in table 5.5 using data based on the Institute of Plumbing's *Plumbing Engineering Services Design Guide*. The calculations are similar to those in section 5.3 for the minimum cold water storage capacity in larger buildings, and require the number of people to be multiplied by the storage per person, shown in table 5.5.

BS 6700 takes a different approach to the sizing of hot water storage and suggests that when sizing hot water storage for any installation, account must be taken of the following:

- pattern of use;
- rate of heat input to the stored water (see table 5.6);

- recovery period for the hot store vessel;
- any stratification of the stored water.

Table 5.6 Typical heat input values

Appliance	Heat input kW
Electric immersion heater	3
Gas-fired circulator	3
Small boiler and direct cylinder	6
Medium boiler and indirect cylinder	10
Directly gas-fired storage hot water heater (domestic type)	10
Large domestic boiler and indirect cylinder	15

Stratification (see figure 3.41) means that the hot water in the storage vessel floats on a layer of cold feed water. This enables hot water to be drawn from the storage vessel without the incoming cold feed water mixing appreciably with the remaining hot water. In turn, this allows a later draw-off of water at a temperature close to the design storage temperature, with less frequent reheating of the contents of the storage vessel and savings in heating costs and energy.

Stratification is most effective when cylinders and tanks are installed vertically rather than horizontally, with a ratio of height to width or diameter of at least 2:1.

The cold feed inlet should be arranged to minimize agitation and hence mixing, by being of ample size and, if necessary, fitted with a baffle to spread the incoming water.

Stratification is used to good effect in off-peak electric water heaters (see figure 5.13). In this case no heat is normally added to the water during the daytime use and consequently very little mixing of hot and cold water takes place. In other arrangements the heating of the water will induce some mixing.

Calculation of hot water storage capacity

As noted above, the storage capacity required in any situation depends on the rate of heat input to the stored hot water and on the pattern of use. For calculating the required storage capacity BS 6700 provides a formula for the time M (in min) taken to heat a quantity of water through a specified temperature rise:

$$M = VT/(14.3P)$$

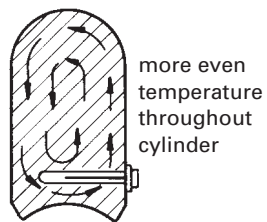
where

V is the volume of water heated (in l);

T is the temperature rise (in °C);

P is the rate of heat input to the water (in kW).

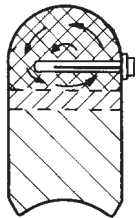
This formula can be applied to any pattern of use and whether stratification of the stored water takes place or not. It ignores heat losses from the hot water storage vessel, since over the relatively short times involved in reheating water after a draw-off has taken place, their effect is usually small.



more even
temperature
throughout
cylinder

(a) Bottom entry heater

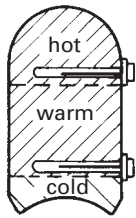
With a bottom entry immersion heater mixing will occur when the water is being heated.



hot at top
warm
cold at bottom

(b) Top entry heater

With top entry immersion heater stratification will prevent mixing.



(c) Twin entry immersion heater

With a twin entry immersion heater the top entry element can provide economical energy consumption for normal use with the bottom entry element operating when large quantities of water are needed, for example, for bathing and washing.

With off-peak heaters the top element can be brought into use during on-peak periods when needed to top up hot water, and stratification will ensure that on-peak electricity is not used to excess.

Figure 5.13 Effects of stratification

The application of this formula to the sizing of hot water cylinders is best illustrated by the following examples, in which figures have been rounded.

In these examples a small dwelling with one bath installed has been assumed. Maximum requirement: 1 bath (60 l at 60°C plus 40 l cold water) plus 10 l hot water at 60°C for kitchen use, followed by a second bath fill after 25 min.

Thus a draw-off of 70 l at 60°C is required, followed after 25 min by 100 l at 40°C, which may be achieved by mixing hot at 60°C with cold at 10°C.

Example 1 Assuming good stratification

Good stratification could be obtained, for example, by heating with a top entry immersion heater. With a rate of heat input of 3 kW, the time to heat the 60 l for the second bath from 10°C to 60°C is:

$$M = VT / (14.3P)$$

$$M = (60 \times 50) / (14.3 \times 3)$$

$$M = 70 \text{ min}$$

Since the second bath is required after 25 min, it has to be provided from storage. But in the 25 min the volume of water heated to 60°C is:

$$\begin{aligned} V &= M(14.3)/T \\ V &= (25 \times 14.3 \times 3)/50 \\ V &= 21 \text{ l} \end{aligned}$$

Therefore the minimum required storage capacity is:

$$70 + 6 - 21 = 109 \text{ l}$$

Example 2 Assuming good mixing of the stored water

Good mixing of the stored water would occur, for example, with heating by a primary coil in an indirect cylinder.

Immediately after drawing off 70 l at 60°C for the first bath and kitchen use, the heat energy in the remaining water plus the heat energy in the 70 l replacement at 10°C equals the heat energy of the water in the full cylinder.

The heat energy of a quantity of water is the product of its volume and temperature. Then, if V is the minimum size of the storage cylinder and T is the water temperature in the cylinder after refilling with 70 l at 10°C:

$$\begin{aligned} (V - 70) \times 60 + (70 \times 10) &= VT \\ T &= (60V - 4200 + 700)/V \\ T &= (60V - 3500)/V \\ T &= 60 - 3500/V \end{aligned}$$

The second bath is required after 25 min. Hence, with a rate of heat input of 3 kW:

$$\begin{aligned} 25 &= VT/(14.3 \times 3) \\ \text{and the temperature rise } T &= (25 \times 14.3 \times 3)/V \\ \text{and } T &= 1072.5/V \end{aligned}$$

A temperature of at least 40°C is required to run the second bath. Therefore the water temperature of the refilled cylinder after the first draw-off of 70 l, plus the temperature rise after 25 min, must be at least 40°C, or:

$$\begin{aligned} (60 - 3500/V) + (1072.5/V) &= 40 \text{ (or more)} \\ 60 - 2427.5/V &= 40 \\ 20 &= 2427.5/V \\ V &= 122 \text{ l} \end{aligned}$$

These calculations, which may be carried out for any situation, show the value of promoting stratification wherever possible. They also show the savings in storage capacity that can be made, without affecting the quality of service to the user, by increasing the rate of heat input to the water. Results of similar calculations are shown in table 5.7 and are taken from BS 6700.

Table 5.7 Hot water storage vessels – minimum capacities

Heat input to water kW	Dwelling with 1 bath		Dwelling with 2 baths*	
	With stratification litres (l)	With mixing litres (l)	With stratification litres (l)	With mixing litres (l)
3	109	122	165	260
6	88	88	140	200
10	70	70	130	130
15	70	70	120	130

Note * Maximum requirement of 130 l drawn off at 60°C (2 baths plus 10 l for kitchen use) followed by a further bath (100 l at 40°C) after 30 min.

5.5 Legionella – implications in sizing storage

It has been common practice in the past for water suppliers to recommend cold water storage capacities to provide for 24 hours of interruption in supply. Table 5.5 in this book and Table 1 of BS 6700 reflect this practice.

Recent investigations into the cause and prevention of *Legionella* contamination suggest that hot and cold water storage should be sized to cope with peak demand only, and that in the past, storage vessels have often been over-sized.

Reduced storage capacities would mean quicker turnover of water and less opportunity for *Legionella* and other organisms to flourish.

Stratification in hot water can lead to ideal conditions for bacteria to multiply, as the base of some cylinders often remains within the 20°C temperature range. The base of the cylinder may also contain sediment and hard water scale which provide an ideal breeding ground for bacteria.

Where, however, good mixing occurs, higher temperatures can be obtained at the cylinder base during heating up periods. This is helpful because *Legionella* will not thrive for more than 5 minutes at 60°C and are killed instantly at temperatures of 70°C or more.