Hot and cold water supplies

Sources of water

The source of water varies dependent on which area of the British Isles a supply is required. The types are:

a. Upland catchment (reservoir)

b. Ground water (borehole/artisan)

c. River extraction.

These sources provide water for supply purposes, each with a wide range of physical, and bacterial quality differences, i.e.

i. Hardness

ii. Bacteria count

iii. Minerals.

The quality of water supplied for distribution to, and for use by persons and properties is controlled by an Act of Parliament, the Water Supply (Water Quality) Regulations 1989, and subsequent amendments. The enforcement of the Act is undertaken by the Drinking Water Inspectorate (DWI), who regulate a wide range of key elements to attain and maintain the water supply quality. See Table 1.

The standards cover colour, alkalinity, taste, odour, undesirable and toxic substances, and micro-organisms to specified parameters. The standards are called 'Prescribed Concentrate values' (PCV's) to either maximum, minimum, average or percentage levels.

These standards are imposed on all water supply companies, with relaxation only considered under emergency situations, i.e., extreme drought or flooding, but under no circumstances if there is a risk to public health.

Water supply companies

The water supply companies operate under the requirements of the Water Industry Act 1991, enforced by the Office of Water Services (OFWAT).

Water supply companies are responsible for the catchment or abstraction of raw water; it's conditioning, treatment and distribution to consumers within their region. The characteristics of the water supplied varies, region to region and within regions dependent upon the actual source, single or multiple, and the level of treatment provided in order to attain the prescribed quality at the point of connection to the customer's supply.

Table 1 Drinking water standards

Temperature	25°C
PH	5.5-9.5
Colour	20 Hazen units
Turbidity	4 Formazin units
Qualitative odour	All odour invest
Qualitative taste	All taste invest
Dilution odour	Dilution No
Dilution taste	3 at 25
Conductivity	1500us/cm 20°c
Total hardness	Applies only
Alkalinity	if softened
Free chlorine	Comparison
Total chlorine	against average
Faecal coliforms	0/100 ml
Clostridia	1/20 ml
Faecal streptococci	0/100 ml
Total coliforms	0/100 ml (95%)
Colony count, 2 day	Comparison against
Colony count, 3 day	average
Oxidisability	5 mg/l
Ammonia	0.5 mg/l
Nitrite	0.1 mg/l
Nitrate	50 mg/l
Chloride	400 mg/l
Fluoride	1500 ug/l
Phosphorus	2200 ug/l
Sulphate	250 mg/l
Magnesium	50 mg/l
Iron	200 ug/l
Manganese	50 ug/l
Aluminium	200 ug/l
Calcium	250 mg/l
Potassium	12 mg/l
Sodium	150 mg/l
Copper	3000 ug/l
Zinc	5000 ug/l
Lead	50 ug/l
Silver	10 ug/l
Antimony	10 ug/l
Arsenic	50 ug/l
Barium	1000 ug/l
Boron	2000 ug/l
Cyanide	50 ug/l
Cadmium	5 ug/g
Chromium	50 ug/l
Mercury	1 ug/l
Nickel	50 ug/l
Selenium	10 ug/l
Total organic carbon	Comparisons
Trihalomethanes	100 ug/l
Tetrachloromethane	3 ug/l
Trichloroethene	30 ug/l
Tetrachloroethene	10 ug/l
Benzo 3,4 pyrene	10 ng/l
Fluoranthene, benzo 3, 4, 11, 12, fluoranthene, benzol 12 perylene indeno (123cd) pyrene	Individual testing of these substances to provide total
Total PAH's	0.2 ug/l
Anionic detergents	200 ug/l
Pesticides & Comp'ds	5 ug/l total

From this connection, which generally incorporates a water company meter, the consumer is responsible for all aspects of the supply and distribution of water.

Consumers' rights

Every consumer has the right to be supplied with water for domestic purposes from the water supply company's distribution network. New or modified existing connections can incur a charge by the water company for the following services:

i. New or replacement supply

ii. Meter installation

iii. Supply network reinforcement

iv. Infrastructure charge.

All these charges relate to the anticipated daily demand (m³), peak flow rate (l/s), and number of draw-off fittings being served from the supply.

Water regulations

Consumers water supply installations are required to comply to the Water Supply (Water Fitting) Regulations 1999, and The Water Supply (Water Fitting) (Amendments) Regulations 1999 (2) (the Water Byelaws 2000 (Scotland)). These regulations are enforced by the water company that supplies water to the consumer.

The regulations govern the whole of the consumer's installation from the connection to the water company's communication pipe and meter termination, to all the draw-off fittings, inclusive of any alterations.

The regulations require that no water fitting shall be installed, connected, arranged or used in such a manner, or by reason of being damaged, worn or otherwise faulty that it causes, or is likely to cause:

1. Waste

2. Misuse

3. Undue consumption

4. Contamination

5. Erroneous measurement.

The water supply companies are required to be notified of certain proposed installations, which may be subject to inspection and acceptance prior to receiving the water company's supply connection.

The regulations are a statutory instrument, which is supported by an interpretation of the regulations. The water supply companies have the authority to apply to the Regulator for relaxation of any part of the regulation considered inappropriate to a particular case.

Water regulations guide

The Water Regulations Advisory Scheme (WRAS) publish a guide which provides formal guidance and recommendations on how the regulations should be applied to the actual water installations and include the Water Byelaws 2000 (Scotland).

Water demand

The water demand for a building is dependent on a number of factors.

1. Type of building and its function
2. Number of occupants, permanent or transitional
3. Requirement for fire protection systems.
4. Landscape and water features.

In dwellings the resident's water consumption is divided between the many appliances. A typical percentage break down provided by the Environment Agency is:

1. WC suite   32%
2. Washing machine   12%
3. Kitchen sink   15%
4. Bath   15%
5. Basin   9%
6. Shower   5%
7. Outside supply   3%
8. Miscellaneous   9%

Overall consumption increases by around 10% during warmer months when outdoor usage increases to over 25%. In general, consumption per person decreases with an increase in dwelling size given the shared facilities.

For guidance on the total water demand for typical types of buildings refer to Table 2 for daily water demand. The figures stated have been assembled from a number of sources, including BS 6700, Chartered Institute of Building Services Engineers (CIBSE) and Environmental Agency studies and can be used as a basis for good practice.

Water storage

The storing of water has a number of purposes,

1. Providing for an interruption of supply
2. Accommodation peak demand
3. Providing a pressure (head) for gravity supplies.

Design Codes recommend that storage is provided to cover the interruption of an incoming mains supply, in order to maintain a water supply to the building.

Water supply companies are empowered to insist on specific terms, including the volume or period of storage, within the term of their supply agreement with a consumer. However, many water supply companies only recommend that storage be provided in accordance with the BS 6700, placing the responsibility and decision firmly on the consumers.

Table 2 provides guidance on typical water usage within buildings over a 24-hour period.

In designing storage capacities, account needs to be taken of the building and its location.

1. Period and hours of occupation
2. Pattern of water usage
3. Potential for an interruption of supply
4. Available mains pressure, and any inadequacies during the hours of building use
5. Health & Safety, prevention of bacteria, including legionella.

If a building is occupied 24 hours a day, then an interruption of supply will have a greater impact than that for say an office, which may only be occupied for eight to ten hours. Where a building is occupied by elderly or infirmed people then avoiding any disruption of the water supply is an important consideration as they would be unable to easily leave the building should water become unavailable.

Clients, such as the National Health Service, require their buildings to be provided with storage to safeguard against an interruption of the mains supply. Industrial clients may well require storage to ensure their business and/or production is not interrupted. If water ceases to be available within a building, then the occupiers will eventually leave as toilet facilities will become unusable. It is likely that when an interruption of supply occurs then the water available would be conserved as much as possible, thereby extending the time of occupancy beyond that anticipated under normal usage rates.

Table 2 Daily water demand

Type of Building	Litres	Criteria/Unit
Dwellings		
- 1 bedroom	210	Bedroom
- 2 bedroom	130	Bedroom
- 3+ bedrooms	100	Bedroom
- Student en-suite	100	Bedroom
- Student, communal	90	Bed space
- Nurses Home	120	Bed space
- Children's Home	135	Bed space
- Elderly sheltered	120	Bedroom
- Elderly Care Home	135	Bed space
- Prison	150	Inmate
Hotels		
- Budget	135	Bedroom
- Travel Inn/Lodge	150av	Bedroom
- 4/5 Star Luxury	200	Bedroom
Offices & general workplaces		
- with canteen	45	Person (1)
- without canteen	40	Person (1)
Shops		
with canteen	45	Person
- without canteen	40	Person
Factory		
- with canteen	45	Person
- without canteen	40	Person
Schools		
- Nursery	15	Pupil
- Primary	15	Pupil
- Secondary	20	Pupil
- 6th Form College	20	Pupil
- Boarding	90	Pupil
Hospitals		
- District General	600	Bed
- Surgical ward	250	Bed
- Medical ward	220	Bed
- Paediatric ward	300	Bed
- Geriatric ward	140	Bed
Sports Changing		
- Sports Hall	35	Person
- Swimming Pool	20	Person
- Field Sports	35	Person
- All weather pitch	35	Person
Places of Assembly (excl. staff)		
- Art Gallery	6	Person
- Library	6	Person
- Museum	6	Person
- Theatre	3	Person
- Cinema	3	Person
- Bars	4	Person
- Night Club (3)	4	Person
- Restaurant	7	Cover

SUPPORTING INFORMATION
If the number of building occupants are not accurately known, then as a guide the following criteria can be used. Offices, one person per 14m² of the gross building floor area. Sports hall, four persons per badminton court area per hour open, maximum. Swimming pool, one person per cubical per hour open, with a factor of 0.6 for diversity. Field sports changing, persons per teams per number of pitches, per day.

All Weather Field, persons per teams per hours used.
Museums, Art Galleries, Libraries, One person per 30m² of the gross building floor area.
Restaurants, One person per 1.0m² of the dining area.
Bars, One person per 0.8m² of the public bar/seating area.

When the water supply companies, regulations, or client requirements do not specifically dictate the period to cover an interruption of a mains supply then Table 3 provides recommendations for reasonable periods of storage, expressed as a percentage of the daily water demand.

Table 3 Period of storage

Type of Building	% of the daily demand
Hospitals	50%
Nursing Homes	50%
Dwellings	0 - 50%
Hotels, Hostels	50%
Offices	0 - 50%
Shops	0 - 25%
Library, Museum, Art Galleries	0 - 25%
Cinema, Theatre	0 - 25%
Bars, night-club	0 - 25%
Sports Facilities	0 - 25%
Schools, Colleges, Universities	50%
Boarding Schools	50%

Water distribution

The water distribution installation requires to be able to deliver the correct flow and volume of hot and cold water when and where it is needed. The mains pressure can provide the initial means of delivering water into the building. The water supply companies are required to deliver their water to the boundary with a minimum pressure of 1.0 bar. Often their delivery pressure can be higher, however at times of high demand, the pressure will be closer to the minimum provision.

Type of system
The type and style of water distribution needed for a particular building will depend mainly on the building height and its use.

a. The building height will determine whether pumping will be required to deliver water to the highest level.
b. The building use will determine the amount of storage that will be required.

The type of water system will need to be one or a combination of the following:
a. Direct mains fed
b. High level storage with gravity down feed
c. Pumped from a break cistern or storage provision.

Potentially a one or two storey building in a locality where an interruption of water supply is very infrequent and causing little inconvenience, there is an option for the water supply to be direct from the mains without storage being provided. If the provision of storage is possible at high level, then the system could be enhanced to provide storage coupled with it becoming a gravity down feed system. See Figure 1.
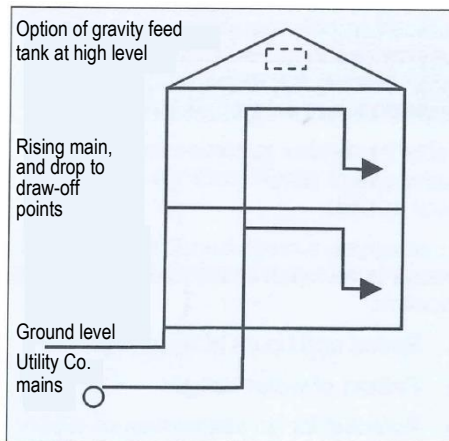

Figure 1 Supply to a two storey building

Storage tanks
A building requiring a large water storage provision may not be able to accommodate it at high level, in which case a low-level location will be needed, in conjunction with a pumped distribution system.

A combination of high and low storage can be considered if a gravity distribution is preferred for all or part of the building. This has an advantage of providing some storage in the event of an interruption of the water supply, or power supply to the pumps. A storage ratio of 2:1 low/high level is a typical arrangement.

Storage can comprise of two compartments or cisterns/tanks in order that maintenance can be carried out without interrupting distribution.

For small storage quantities one-piece cisterns can be used, which generally are of a low height construction. For storage of 2500 litres or more, sectional panel tanks may be considered more appropriate with a centre divide.

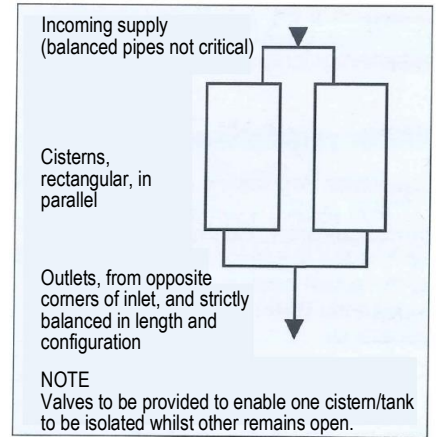Above 4000 litres storage twin cisterns/tanks may be considered appropriate. See Figure 2.

Figure 2 Storage cistern/tank layout

Sectional tanks commonly have flanges, being internal or external. External flanges permit tightening without needing to enter the tank, and on the base permit the tank to be self-draining through a single drain point, without further draining of any entrapped water between flanges. Such a feature reduces maintenance and assists the prevention of water stagnation which can lead to harmful bacteria growth, including legionella.

In calculating the storage capacity, a free board allowance is necessary to accommodate the float valve, overflow installations and any expansion from the hot water system. Depending on pipe sizes, commonly a 250 - 300 mm free board depth is required on cisterns/tanks having a capacity greater than 2500 litres. Raised ball (float) valve housings in conjunction with a weir overflow can provide an increased depth of water stored over the main area of the cistern/tank(s).

The location of the inlet and outlet connections is important. A cross flow through the cistern/tank needs to be achieved to assist the complete regular turnover of water throughout the storage period.

Sub divided, twin and multiple cisterns/tanks ideally should be installed in parallel to each other. The inlets require to be positioned at the same level to ensure they supply the cisterns/tanks in unison, and as far as possible the same flow rate to assist a balanced throughput. The outlet connections and manifold pipe work needs to be arranged with symmetrical and equal lengths, also to provide, as far as is possible a balanced flow from the tanks.

The use of a delayed action float valve may also be considered to ensure a greater turnover of water.

Access to storage cisterns/tanks

Access for installation and maintenance is required. Table 4 is a guide.

For large buildings, accommodation for water storage has a significant impact. Table 5 provides an outline guide to the space that may be required.

Table 4 Access to storage cisterns/tanks

Location	(mm)
Around	750
Between, tanks	750
Above, allowing beams to intrude	1000
Below, between supports	600
For outlet pipe work, incl. access	1500
Tank construction thickness	100
Insulation (may form part of tank)	25
Raised float valve housing	300
Entry to tank	800 dia

Table 5 Water storage plant room area

Storage (Litres)	1.5 metre	Tank Height 2 metre	3 metre
5,000	18 m²	18 m²	-
10,000	31m²	23m²	-
20,000	50m²	40m²	
40,000	72m²	60m²	50m³
60,000	-	80m²	60m²
100,000	-	100m²	80m²

## Gravity supplies

For gravity supplies to be effective, the storage requires to be at a sufficient height to deliver the water to the draw-off point at the required flow rate and pressure. The available head is the dimension between the bottom of the storage cistern/tank(s) and the highest draw-off point or draw-off point with the greatest head/pressure loss. See Figure 3.

The advantages of gravity supplies are:

a. Availability of water in the event of water mains or power failure

Figure 3 Gravity supplies available head
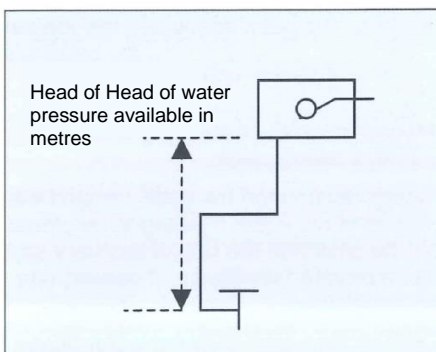
b. No pump running costs.
c. Potentially less noise due to lower pipe flow velocities.

The disadvantages are:

a. Greater structural support
b. Larger pipe sizes due to limited available head, when compared to pumps
c. Lower delivery pressures.

Pumped supplies

The delivery of water by pumping will provide flexibility in the positioning of the storage cisterns/tanks. The delivery flow rate and pressure demanded by the system are met entirely by selecting the correct duty for the pumps. The pump set is required to deliver a constantly varying flow rate as draw-off points are randomly used by the occupants. The use of multistage variable duty and/or inverters is an advantage. See Figure 4.

Generally, a minimum of two pumps are used, each having 100% system duty and controlled to enable them to be a standby to each other. To prevent high pressure overrun when demand is less than the design demand, a pressure limiting, or variable control flow device needs to be fitted on the outlet from the pumps.

For high buildings a combination of pumped and gravity may be appropriate. The advantage of this is to provide a proportion of the daily water usage in a cisterns/tank(s) at roof level, which would provide a gravity down feed service, and continue to provide water in the event of a failure of the pump. See Figure 5. Such a system would comprise of:

a. An incoming main
b. Low level break or storage cistern/tank
c. Pump set
d. High level cistern/tank(s)

Figure 4 Pumped supply layout
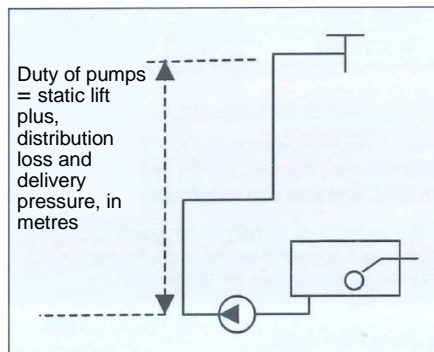
e. Cold water and hot water cold feed gravity distribution.

The low-level pump set can be sized to provide a low volume, more frequent operation and high head to deliver the water to the tanks at roof level.

If a 'mains' water supply is required to be provided specifically for drinking water points or drink making equipment, then either of these can be supplied from the incoming main up to the number of floors that the available mains pressure will reach, and from the pumped rising main above that level; or entirely from the pumped rising main. See Figure 6.

Whilst all water supplied for domestic uses has to be suitable for drinking purposes, supplying drinking water points direct from incoming mains or pumped mains provides a cooler, more oxygenated supply for taste purposes.
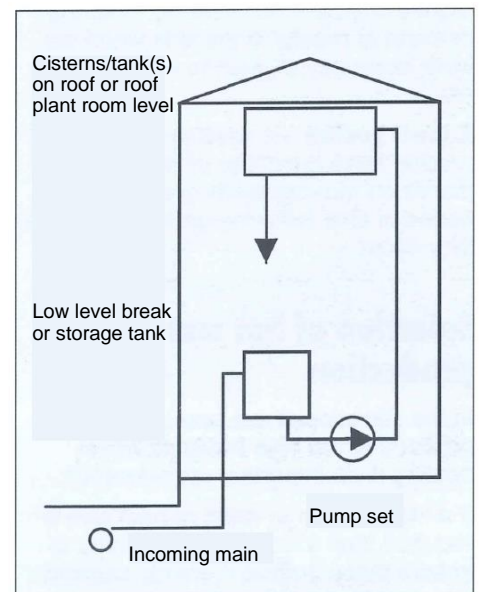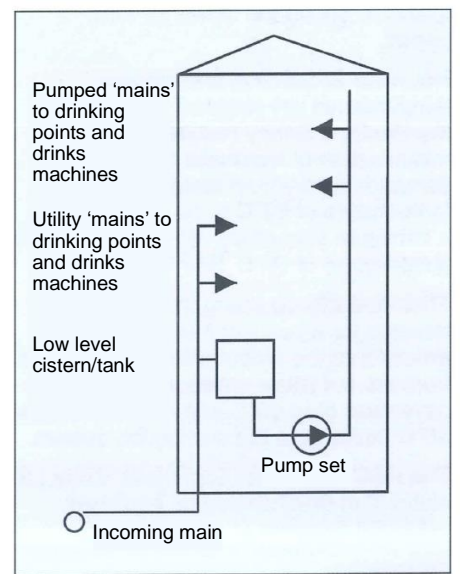

Figure 5 Combined pump and gravity

Figure 6 'Mains' water for drinking

Hot water production

Hot water can be generated by a differing number of methods, and the selection will depend mainly on the quantities of hot water required and the types of energy readily available.

The demand for hot water will vary considerably between types of buildings, governed by their occupants and the activities taking place. For example:

Office buildings will require small quantities frequently and regularly throughout the 'normal' working day, and availability at other times as and when occupant's 'overtime' working hours demand.

A factory with a production line will require sufficient hot water to meet the demand at breaks in the shift when the work force may all wish to wash hands etc.

A sports pavilion will need to be able to provide large quantities of hot water for team's showering needs over a short period of time following games, whenever they occur.

Selection of hot water production

In the selection of the type of hot water production, the time available for reheating is an important consideration.

If a high volume or rapid re-heat rate is required, then it would be necessary to ensure that a sufficient energy capacity is available. If the energy capacity needed is not available, then a greater volume of water storage would have to be provided to ensure hot water is available during the slower re-heat period.

Hot water production and storage temperatures are required to comply to the Health & Safety requirements for the minimisation of legionella bacteria. This demands a minimum storage temperature of 60°C to be attained, with a minimum secondary return (if provided) temperature of 50°C. See Figure 7.

Therefore, in calculating the hot water demand for a building it is necessary to ensure that the output water temperature from the hot water production plant is never less than 60°C, and never less than 50°C throughout the distribution system.

The HSC *'Control of Legionella'* Code L8 states that 50°C should be achieved within 60 seconds at all outlets.

Table 6 Hot water demand

Type of building	Daily (litres	Stored (litres	Unit
Dwellings			
- 1 bedroom	115	115	Bedroom
- 2 bedroom	75	115	Bedroom
- 3 + bedrooms	55	115	Bedroom
- Student en-suite	70	20	Bedroom
- Student, comm	70	20	Bedspce
- Nurses home	70	20	Bedspce
- Children's home	70	25	Bedspce
- Elderly sheltered	70	25	Bedroom
- Elderly care home	90	25	Bedspace
- Prison			Inmate
Hotels			
- Budget	115	35	Bedroom
- Travel Inn/Lodge	115	35	Bedroom
- 4/5 Star Luxury	135	45	Bedroom
Offices & general work places			
- with canteen	15	5	Person
- without canteen	10	5	Person
Shops			
- with canteen	15	5	Person
- without canteen	10	5	Person
Factory			
- with canteen	15	5	Person
- without canteen	10	5	Person
Schools			
- Nursery	15	5	Pupil
- Primary	15	5	Pupil
- Secondary	15	5	Pupil
- 6th form college	15	5	Pupil
- Boarding	114	25	Pupil
Hospitals			
- District General	200	50	Bed
- Surgical ward	110	50	Bed
- Medical ward	110	50	Bed
- Paediatric ward	125	70	Bed
- Geriatric ward	70	40	Bed
Sports changing			
- Sports Hall	20	20	Person
- Swimming Pool	20	20	Person
- Field Sports	35	35	Person
- All weather pitch	35	35	Person
Places of assembly (excl. staff)			
- Art Gallery	2	1	Person
- Library	2	1	Person
- Museum	1	1	Person
- Theatre	1	1	Person
- Cinema	1	1	Person
- Bars	2	1	Person
- Night Club	1	1	Person
- Restaurant	6	6	Cover

SUPPORTING INFORMATION

The storage figures stated are based on a reheat period of two hours, an inlet temperature of 10°C and a stored temperature of 65°C.

If the number of building occupants are not accurately known, then as a guide the following criteria can be used.

Offices, One person per 14m² of the gross building floor area.

Sports hall, Four persons per badminton court area per hour open, maximum.

Swimming pool, One person per cubical per hour open, with a factor of 0.6 for diversity.

Field sports changing, persons per teams per number of pitches, per day.

All weather field, persons per teams per hours used.

Museums, art galleries, libraries, One person per 30m² of the gross building floor area.

Restaurants, One person per 1.0m² of the dining area.

Bars, One person per 0.8m² of the public bar/seating area.

Figure 7 Hot water temperature protocol

When a conventional bulk hot water vessel is used it is necessary to ensure that the contents of the whole vessel achieves the correct stored water temperature as stratification can occur. To overcome this situation the storage vessel should incorporate the following features:

a. Base inlet hot water cold feed supply

b. Top outlet hot water outlet flow

c. Convex ends to vessel

d. Provide a 'shunt' pump to move the hot water from the top of the vessel to the base to avoid stratification.

Hot water demand

When assessing the hot water production requirements for a building it is necessary to determine the peak demand. The peak demand is the volume of hot water required during the building's period of greatest usage. This may be over an hour, or shorter period dependent on the occupants and activities taking place.

Having determined the peak demand, the volume of hot water needing to be stored can be selected, the rate of recovery and the associated energy input needed can be established.

The buildings total daily hot water usage is relevant to the assessment of the peak demand.

Once the daily usage is determined then the more critical peak demand can be assessed.

Traditionally hot water peak usage was based on a two-hour storage re-heat period and this has generally proved to be a satisfactory benchmark for peak demands for that period.

Table 6 schedules a compilation of figures currently recommended by the water industry's design codes, with additional categories added as considered useful. The recommended storage volumes are based on a 65°C storage temperature and a two hour reheat period, i.e., a bulk storage vessel. This data should be considered as representative of capacities, which have not given rise to complaints of inadequacy.

Two-hour re-heat

The two-hour re-heat storage volume figures can provide a guide to the peak water volume used during a peak two-hour usage period. The same hot water output could also be achieved by the use of low volume/rapid reheat 'semi-storage' types of hot water generators, if the energy input capacity is available.

The 'semi-storage' type of hot water heaters can meet shorter peak demand periods i.e., 1 hour, or less, although detailed secure information about peak period demands during periods of less than 1 hour are not sufficiently available, and therefore a design risk margin will be required.

The established two-hour peak usage figures cannot simply be evenly subdivided into shorter periods without the risk of seriously underestimating the actual hot water volume that will be required during that shorter period. The shorter the period, the greater the disproportion of the two-hour peak storage figure will be required.

For example, the recommended two-hour re-heat period storage volume for a budget hotel is 35 litres per bedroom. For a 50-bedroom hotel the stored volume would need to be 1750 litres, which when supplemented by the re-heated water during the envisaged peak two-hour draw-off period, less the loss (25%) of hot water due to the mixing effect of the incoming cold water feed, is capable of providing a notional 2625 litres, should that demand occur. This is because 1750 litres of 65°C hot water is notionally available at the start of the notional peak draw-off period, and whilst the stored hot water is being drawn off it is also being re-heated at a rate of 1750 litres per two hours, less the loss through the mixing of incoming cold water and the stored hot water (25%).

Therefore, it can be seen that the stored water is there to provide for a peak 1750 litre draw-off occurring over any period from, say ten minutes upwards.

For consideration purposes 1750 litres equates to 35 baths, each using 50 litres of 60°C stored hot water. Dependent on the bath usage ratio of either 1200-, 2400-, or 4800-seconds frequency of use (see simultaneous demand data) the hot water stored could be used up after a 63-minute period. Alternatively, 1750 litres could provide for 73 persons having a shower, each lasting 5 minutes using 24 litres of 60°C of stored hot water (mixed with cold). Dependent on the shower usage rate of 900-, 1800-, or 2700-seconds frequency of use, the hot water stored could be used up after a 45-minute period. These two examples are based on a peak statistical usage which would likely not reoccur during the remaining time of the two-hour re-heat period.

A 'semi-storage' hot water generator requiring to meet the same demand for baths would need to be capable of providing, approximately a 3.3 litre per second flow rate of 65°C continuous hot water output, assuming an initial stored volume capacity of 500 litres.

These potential peak demands could be considered as being extreme examples. However, they clearly demonstrate the demands capable of being put on hot water generation, when taking account of the maximum simultaneous usage that is imposed on draw-off fittings by the building occupants, and accordingly has to be considered for design purposes.

Whatever the building, the likely pattern of hot water usage should be assessed and considered. The hot water usage will be directly related to the building function, its occupancy and the type of

activity that is likely to take place. In determining the pattern of usage, it is important to differentiate between a maximum daily demand and an average daily demand, so that the implications of the system not meeting the buildings hot water requirements can be recognised, and the maximum requirements designed for where necessary.

Measured quantities of hot water consumption should not stand alone as a sizing guide. The rate at which these amounts are drawn off must also be considered. To project the demand pattern over the operating period of the building, an hour-by-hour analysis of likely hot water usage should be made, taking into account the number of occupants, the type and level of activity and any other factors that may affect hot water demand. The projected pattern of demand should be recorded in the form of a histogram profile.

Typical examples of daily demand in various types of buildings are illustrated in Figures 8 and 9.

By establishing a hot water demand histogram, a representative peak demand volume can be established. Typically, the peak hour is between 15-20% of the day's total usage.

When selecting a 'semi-storage' hot water production unit(s) it needs to be recognised that the small stored volume is there to meet the short period peak draw-offs that occur in any water supply system. The shortest of these peak drawoffs is the 'maximum' simultaneous demand litre per second flow rate figure calculated from the sum of the draw off 'demand' or 'loading' units used for pipe sizing. However, periods of time that these flow rates occur are very short, and are based on the period of individual draw- off, i.e., length of time to fill a basin,

Figure 8 *Typical demand pattern histogram*
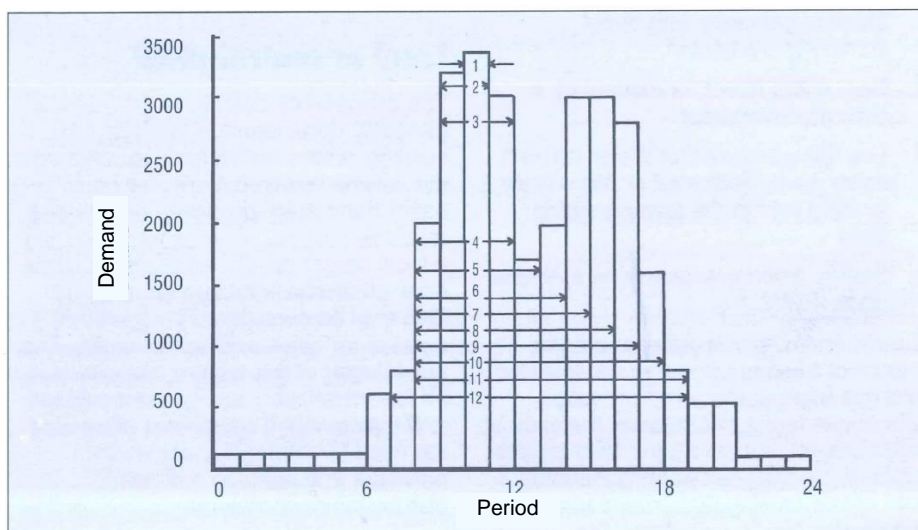
Figure 9 Examples of daily demand patterns for commercial premises   Reproduced from CIBSE Guide G: Public Health Engineering, by permission of the Chartered Institution of Building Services Engineers.

sink, or bath, have a shower, and the number of times the draw-off is used during the peak demand period, i.e., every 5, 10, or 20 minutes, or more. The 'maximum simultaneous demand' must not be applied to periods greater than the period and frequency of 'maximum simultaneous demand'.
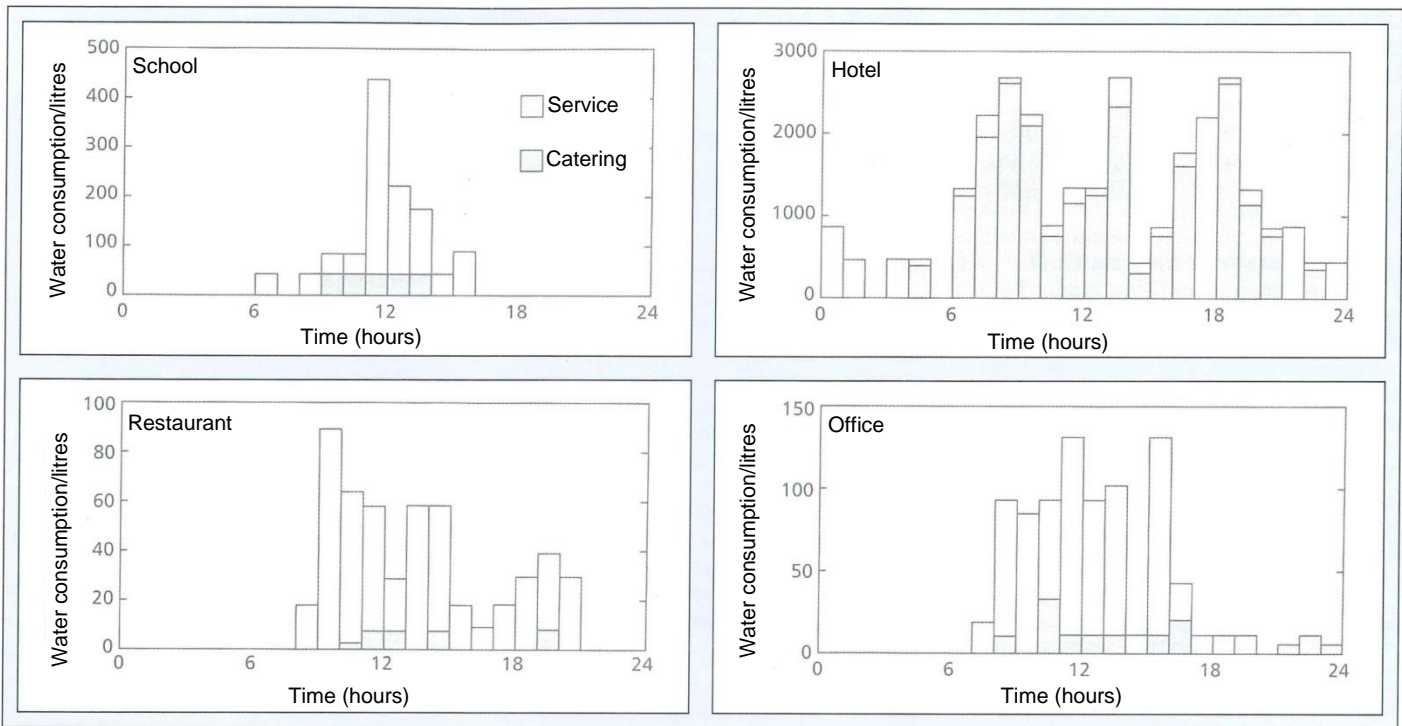
Hot water generators

The production of hot water can be achieved by a varied number of energy sources.

1. Electric, generally with direct immersed elements
2. Gas, either direct, or indirect by a dedicated circulator
3. Low Temperature Hot Water (LTHW) boiler plant, dedicated or more likely forming part of the space heating plant
4. Steam, when available from a central plant facility.

Energy forms, which provide a direct means of heating hot water, i.e., electric and gas in particular, are the most effective in terms of efficiency because of least loss of heat during the heat transfer process. Sharing hot water generation with space heating plant can decrease the energy efficiency through the

additional transfer process and less efficient operation when space heating is not needed.

Solar heating, when available and viable is an excellent supplementary heat source and effective in reducing annual energy tariffs.

Commonly used forms of hot water heating are:

Dwellings and small buildings: Electric, or gas combination (HWS & Heating) boilers.

Offices: Electric, local or 'point of use' water heaters.

Larger premises and sports facilities: Gas direct fired water heaters.

Local or central plant

The adoption of local or central plant is generally dependent on the type of building, where hot water is needed, and the volume required. For toilet wash basin 'hand rinse' purposes only, where relatively little hot water is required then a local heater positioned adjacent to the draw-off fittings would be appropriate. This may be considered particularly suitable for office and school toilets. The advantages of this type of installation can be low installation, energy consumption, and maintenance costs, plus alleviating the need for secondary circulation pipework and pump to maintain distribution temperatures.

Vented or (invented generators

A vented hot water generator is supplied by a gravity hot water down feed and expansion pipe and having an open vent pipe over the feed cistern/tank to provide for pressure relief, in addition to
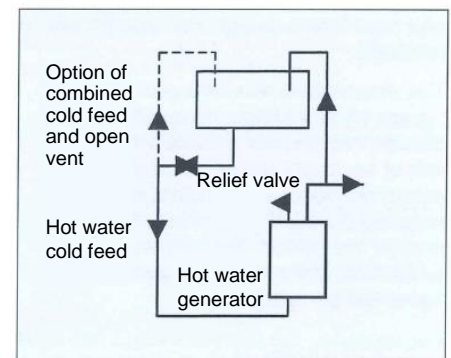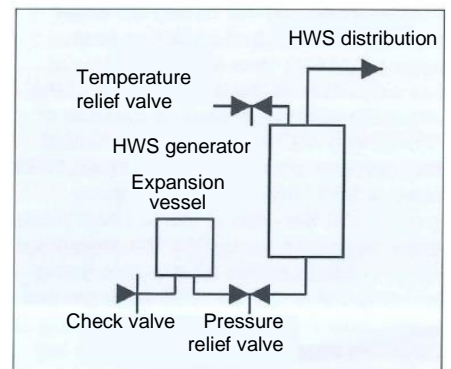

Figure 10 Vented hot water generator

Figure 11 Unvented hot water generator

expansion. These units generally are storage type units rather that semistorage units. As an open vessel the maximum pressure is the static head from the cold-water feed cistern/tank. Individual vessels should be provided with their own open vent. A pressure and/or temperature relief valve can be considered in place of a separate open vent subject to the vent being combined with the cold feed/expansion pipe, and there being no means of closing off the vent.

Unvented hot water generators are generally supplied from Utility Company's mains, or pumped distribution systems. Provision for expansion and pressure/temperature relief is provided by mechanical fittings to provide a safe system. Unvented units are commonly semi-storage types. The pressures that they are subjected to are the operational head of the 'mains' or 'pumped [1] system inclusive of any 'closed head' situation. For unvented units with a capacity of 112 litres or less, the Building Regulations require that the unit is provided complete with all its safety fittings. For larger unvented units the 'Designer' is required to specify the safety fittings in accordance with the Water Regulations.
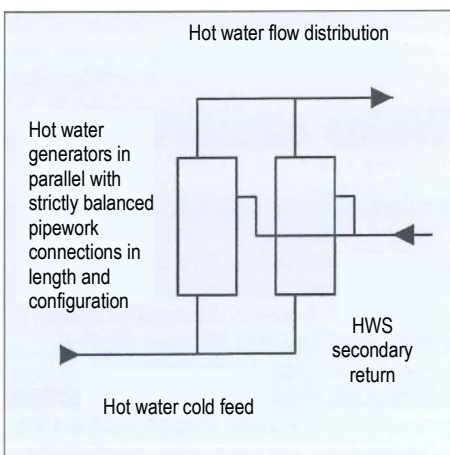
Multiple hot water generators

Figure 12 Multiple hot water heaters

Where multiple hot water generators become necessary for capacity/output, and/or standby/back up purposes care must be taken to ensure that the interconnecting pipework configuration provides a balanced use and flow through the two of more hot water generators.

Secondary circulation and trace heating

Secondary circulation or trace heating needs to be provided when the length of hot water pipework and the volume of water the pipework contains, becomes such that it would take an unreasonable length of time to draw off the cool water. The Water Regulations Guide recommends that un-circulated hot water distribution pipes should be kept as short as possible and if uninsulated not exceed the maximum length stated.

Table 7 Water Regulations Guide

Max. lengths of uninsulated pipes		
Pipe 0D	Length	(Seconds)
< 12 mm	20 m	(11)
< 22 mm	12m	(25)
< 28 mm	8m	(26)
> 28 mm	3m	(>15)

The 'seconds' column illustrates the approximate length of time it would take to draw of the cool water based on the draw off rate of a wash basin tap with an 0.15 l/s flow rate. The Health & Safety Legionella Code L8 states a maximum draw off period for hot water to reach its correct temperature shall be 60 seconds.

Insulating the pipes does not stop the hot water cooling, it only slows down the cooling rate. Once the temperature has dropped below 50°C, then the Health & Safety's '60 seconds' maximum length of time criteria applies. The insulating of pipes is desirable as it delays the cooling rate of the hot water enabling it to be 'useful' for longer, and by that means saves energy and the associated costs.

Once it becomes necessary to provide secondary circulation or trace heating, then it should be extended to serve the whole of the hot water distribution system making un-circulated or trace heated sections of pipework as short as practicably possible, and not the maximum lengths stated in the table.

Local heaters

These generally comprise of small self-contained electrically heated hot water units individually placed near to the position that hot water is required, and serve either a single draw off or a number of draw off's which are adjacent to each other. Gas heaters are available, but not commonly used due to the need to make provision for flues. The purpose of such units provides hot water in a simple manner, in particular where the draw off is remote and only low volumes of hot water is required, such as for hand rinsing. Office toilet accommodation and single showers are

particularly suited for these types of units.

A number of different types of local heaters are available. Most commonly are 'unvented units' supplied directly from the incoming mains or from the main cold water distribution system within the building. Usually, a minimum inlet pressure is required, often being 1.0 bar or above, subject to the manufacturer's instructions.

The Water Regulations govern the requirements for unvented water heaters. Heaters with a capacity of less than 15 litres are classed as being instantaneous and need no temperature or pressure relief valves, or expansion valves or vessels. Units above 15 litres capacity require such devices.

Control of legionella

The means of controlling legionella bacteria is determined by the Health & Safety Approved Code of Guidance L8.

Figure 13 Design temperature and associated risks (CIBSE TM13)

Increasing multiplication of legionella

A. Steam humidification
B. LTHW heating
C. Hot water storage
D. Hot water taps outlets
E. Cold water storage, sprinklers
F. Spray humidification
G. Mains cold water and air cooling coil condensate
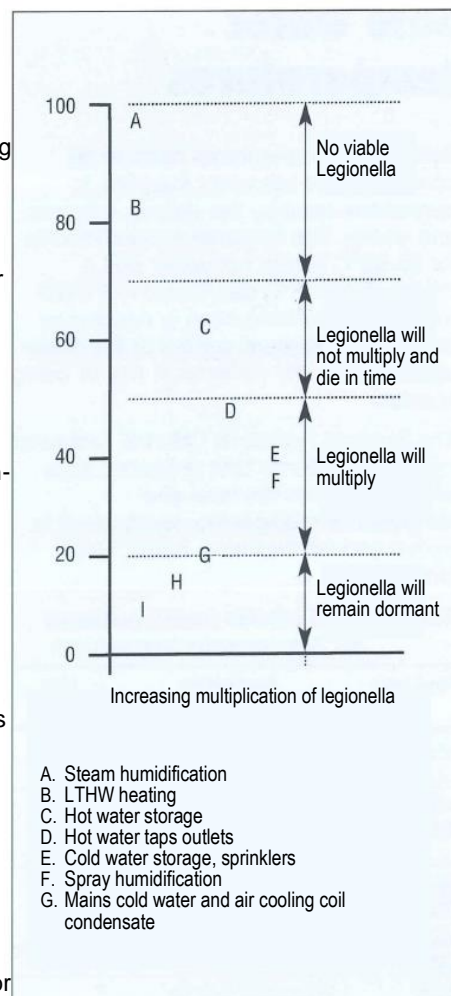
The Code identifies specific practical guidance on how this is to be achieved in water supply systems. The key aims being:

1. Maintain cold water below 25°C

2. Maintain stored hot water between 60-65°C

3. Maintain hot water distribution above 50°C, and preferably at 55°C

4. Insulate all cold and hot water storage vessels and distribution pipework

5. Minimise the length of un-circulated and none trace heated hot water pipes

6. Avoid supplies to little or unused draw-off fittings

7. Maintain balanced use and flows through multiple cold water cisterns/tanks and hot water vessels. See Figure 13.

NOTE:
For further details please see 'legionella section', contained within this guide.

Graph 1 Temperature and duration of exposure, sufficient to cause burns in thin areas of skin
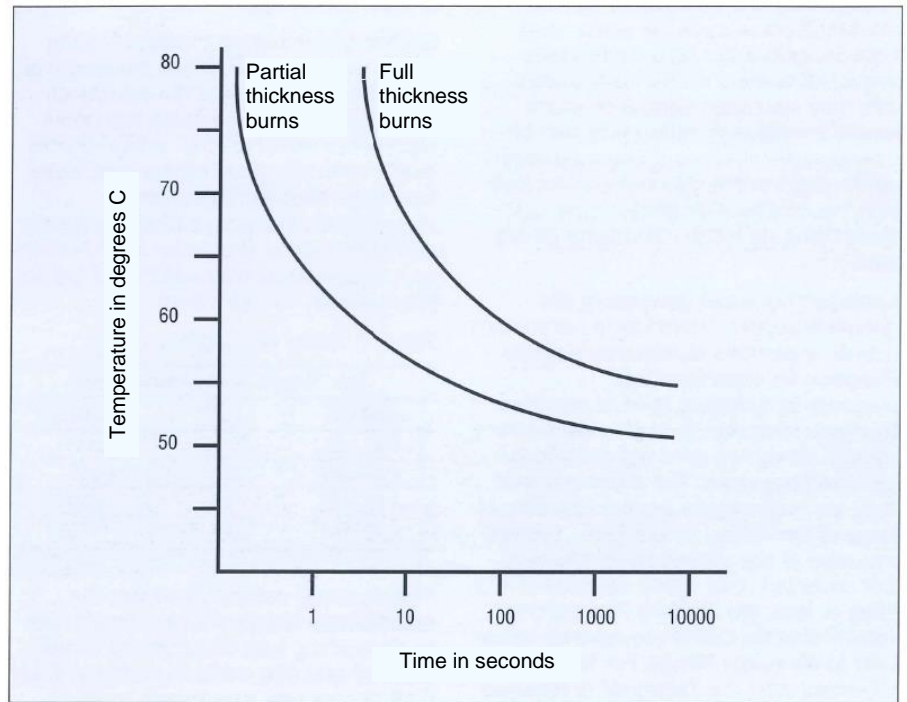
Safe water temperatures

Safe water temperatures need to be considered for hot water supplies to appliances used by the elderly, infirmed and young. The Legionella requirements for 60-65°C stored hot water and a minimum 55-55°C distributed hot water means that consideration is needed to provide temperature control at the drawoff fittings use by persons at risk of being scalded.

The Medical Research Council, Industrial Injuries and Burns Unit produced data which illustrates the time and temperature relationship which result in partial and full thickness burns. See Graph 1.

Table 8 NHS estates health guidance for Safe hot water temperatures

Appliance	Application	Max Temp
Bidet	All	38°C
Shower	All	41°C
Wash basin	Hand rinse only under running water, i.e. toilets	41°C
Wash basin	For an integral part of ablution, i.e., bathroom	43°C
Bath	All	44°C
Bath	Where difficult to attain an adequate bathing temperature	46°C

Design Codes for Health buildings require that all draw-off points that can be used by patients have the temperature of the hot water limited to a safe temperature.

The Health Codes also extends to elderly care homes and sheltered dwellings, which are under the responsibility or licence of the Local Authority. Other buildings that require consideration are nurseries, schools, and anywhere where there is a 'duty of care' by the building owner's landlord, and/or management.

The temperature control is achieved by the deployment of single control mixer taps or valves. The type of valves can vary dependent on their application.

The types of mixing valve, as defined by the Health Guidance Note, are:

Type 1 - a mechanical mixing valve or tap including those complying with BS 1415 part 1, or BS5779 incorporating a maximum temperature control stop device.

Table 9　Recommended application for mixing valves

Application	Type
Bidet	Type 3
Shower	Type 3
Wash basin, hand rinse, for persons not being at risk	Type 1
Wash basins for persons at risk, i.e., elderly, infirmed, young, etc.	Type 3
Bath	Type 3

Type 2 - a thermostatic mixing valve, complying with BS 1415 part 2.

Type 3 - a thermostatic mixing valve with enhanced thermal performance compiling with the NHS Estates Model Engineering Specification D08.

Water conservation

The efficient management of water usage and supplies is necessary to comply with National and International environmental conservation 'best practice' aims and is covered in detail within the Resource Efficient Design section. The Water Regulations incorporate these requirements under their prevention of 'waste, misuse, and undue consumption, and also the specification for reduced capacity of WC flushing cisterns and limit to automatic urinal flushing cisterns.

The key water conservation areas within a water supply installation are:

1. Low volume flush WC's

2. Urinal Controls

3. Draw-off tap controls

4. Clothes and dish washing machines

5. Leak detection

6. Limited need for garden and landscape watering

7. Rainwater reuse

8. Grey water recycling.

The DTER (now DEFRA) Water Conservation in Business document (2000) provides proposals and examples for water savings. An example the document proposes is the potential water savings that could possibly be made in an office building.

Table 10 Office water consumption

Activity	% water used	Anticipated % saving
WC flushing	43%	30% - 60%
Washing	27%	50% - 60%
Urinal flushing	20%	50% - 80%
Miscellaneous	10%	20%

Significant additional water reductions can be made by incorporating leak detection systems, grey water recycling, rainwater collection and water efficient garden and landscape.

The Building Research Establishment provide an assessment method called 'BREEM' which provides a range of performance criteria to assess water economy in buildings. For an office building the BREEM design and procurement performance scoring gives a 'pass' for 200 points, and an 'excellent' for 490 points. Table 11 shows the importance of water conservation design and management, which overall represents 62 points out of the total BREEM score.

Table 11 BREEM 98 for offices water assessment prediction check list

Item	Score
Where predicted water consumption is 10-20m^3 per person per year	6
Where predicted water consumption is 5-9m^3 per person per year	12
Where predicted water consumption is <5m^3 per person per year	18
Where a water meter is installed to all supplies in the building	6
Where a leak detection system is installed covering all mains supplies	6
Where proximity detection shut off is provided to water supplies in WC areas	6
Where there are established and operational maintenance procedures covering all water system, taps, sanitary fittings and major water consuming plant	6
Where water consumption monitoring is carried out at least every quarter using historical data	6
Where storm water run-off is controlled at source	14

The other assessment criteria for the building are Building performance, Design procurement assessments, and management and operational assessments.

Water regulations

The Water Regulations Guide is published by the Water Regulation Advisory Scheme (WRAS), incorporating the Department of the Environment, Transport, and the Regions (DETR, now DEFRA) Guidance and Water Industry recommendations.

The Guide interprets the Regulations and identifies how water supply systems shall be installed to comply with the Statutory Regulations.

The prevention of contamination is the overall main aim of the Water Regulations, and the identification of risks is one of the main changes between the previous Water Bylaws and the Water Regulations. The risks are categorised into five Fluid Category definitions. Refer to Table 13.

The risk of contamination is made present through back pressure and/or back syphonage, termed as Backflow being the source of risk into the water distribution system.

To Protect against Backflow there are a range of mechanical and non-mechanical devices. Reference to the Water Regulations is required for the selection of the appropriate device to match the fluid category risk.

Air gaps are the most effective means of protecting against backflow and the resulting risk of contamination, and a correctly provided air gap protects against all fluid categories from 1 up to 5. All other means of protection will protect between Fluid Categories 1-4.

Notification

The Water Regulations requires that notice shall be given to the water undertaker (company) of work intending to be carried out, which shall not begin without the consent, and shall comply with any conditions set by the water undertaker (company).

Notice of the work shall include details of:

1. Who requires the work

2. Who is to carry the work out

3. Location of premises

4. A description of the work

5. Name of the approved contractor, if an approved contractor is to carry out the works.

Table 12 Notifiable installations

Ref	Installation
1	The erection of a building or other structure, not being a pond or swimming pool
2	The extension or alteration of a water system on any premises other than a house
3	A material change of use of any premises
4	The installation of:
(a)	A bath having a capacity, as measured to the centre line of overflow, of more than 230 litres
(b)	A bidet with an ascending spray or flexible hose
(c)	A single shower unit (which may consist of one or more shower heads within a single unit) not being a drench shower installed for reasons of safety or health, connected directly or indirectly to a supply pipe which is of a type specified by the regulator
(d)	A pump or booster drawing more than 12 litres per minute, connected directly or indirectly to a supply pipe
(e)	A unit which incorporates reverse osmoses
(f)	A water treatment unit which produces a wastewater discharge, or which requires the use of water for regeneration or cleaning
(g)	A reduced pressure zone valve assembly or other mechanical device for protection against a fluid which is in fluid category 4 or 5
(h)	A garden watering system unless designed to be operated by hand, or
(i)	Any water system laid outside a building and either less than 750mm or more than 1350mm below ground level
5	The construction of a pond or a swimming pool with a capacity of more than 10,000 litres which is designed to be replenished by automatic means and is to be filled with water supplied by a water undertaker.

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Backflow prevention

It is necessary to protect against the likelihood of the backflow of contaminated water back into the water supply installation, the contaminated water is any water that has been delivered to the draw off point and has left the water supply system. The degree of contamination is as defined by the Water Regulations Guide, categorised as Fluids 1 to 5. Refer to Table 13.

Table 13 Water regulation fluid categories and examples

Fluid Category 1: Wholesome water supplied by a water undertaker and complying with the requirements of regulations made under section 67 of the Water Industries Act 1991. (The incoming water supply).	Water supplied directly from a water undertaker's main.
Fluid Category 2: Water in fluid category 1 whose aesthetic quality is impaired owing to: a. A change in its temperature, or b. the presence of substances or organisms causing a change in its taste, odour or appearance, including water in a hot water distribution system.	Mixing of hot and cold water supplies. Domestic softening plant. Drink vending machines having no ingredients injected into the distribution pipe. Fire sprinkler systems without anti-freeze. Ice making machines. Water-cooled air-conditioning units (without additives).
Fluid Category 3: Fluid which represents a slight health hazard because of the concentration of substances of low toxicity, including any fluid which contains: a. Ethylene glycol, copper sulphate solution or similar chemical additives; or b. sodium hypochlorite (chloros and common disinfections).	Water in primary circuits and heating systems in a house. Domestic wash basins, baths and showers. Domestic clothes and dishwashing machines. Home dialysing machines. Drink vending machines having ingredients injected. Commercial softening plant. Domestic handheld hoses. Hand held fertilizer sprays. Irrigation systems.
Fluid Category 4: Fluid which represents a significant health hazard because of the concentration of toxic substances, including any fluid which contains: a. Chemicals, carcinogenic substances or pesticides (including insecticides and herbicides), or b. environmental organisms of potential health significance.	**General:** Primary circuits and central heating systems in other than a house. Fire sprinkler systems using anti-freeze solutions. **House and gardens:** Mini-irrigation systems without fertilizer or insecticide application such as pop-up sprinklers or permeable hoses. **Food processing:** Food preparation, dairies, bottle washing apparatus. **Catering:** Commercial dishwashing machines, bottle washing apparatus, refrigeration equipment. **Industrial and commercial installation:** Dyeing equipment. Industrial disinfecting equipment. Printing and photographic equipment. Car washing degreasing plant. Commercial clothes washing plants. Brewery and distillation plant. Water treatment plant or softeners using other than salt. Pressurised firefighting systems.
Fluid Category 5: Fluid represents a serious health hazard because of the concentration of pathogenic organisms, radioactive or very toxic substances, including any fluid which contains: a. Faecal matter or other human waste; b. butchery or other animal waste; or c. pathogens from any other source.	**General:** Industrial cisterns, Non-domestic hose union taps. Sinks, urinals, WC pans and bidets. Permeable pipes in other than domestic gardens laid below or at ground level with or without chemical additives. Grey water recycling systems. **Medical:** Any medical or dental equipment with submerged inlets. Laboratories. Bed pan washers. Mortuary and embalming equipment. Hospital dialyses machines. Commercial clothes washing plant in health care premises. Non-domestic sinks, baths, washbasins and other appliances. **Food processing:** Butchery and meat trades slaughterhouse equipment. Vegetable washing. **Catering:** Dishwashing machines in health care premises. Vegetable washing. **Industrial and commercial installations:** Industrial and chemical plant, etc. Mobile plant, tankers and gully emptiers. Laboratories. Sewage treatment and sewer cleansing. Drain cleaning plant. Water storage for agricultural purposes. Water storage for firefighting purposes. **Commercial agricultural:** Commercial irrigation outlets below ground or at ground level and/or permeable pipes with or without chemical additives. Insecticides or fertiliser applications. Commercial hydroponic systems.

COMMENTS:
1. *The list of examples of applications shown above for each fluid category is not exhaustive, others will present themselves and require to be matched to a Fluid Category, possibly by seeking guidance from the Water Regulations Advisory Scheme.*
2. *The Categories distinguish between domestic use, meaning dwellings; and non-domestic uses, meaning commercial buildings.*
3. *The Fluid Categories define that the water within sinks, baths, basins and showers in domestic premises is a lesser Fluid Category risk, than the water within sinks, baths, basins and showers in medical premises, i.e., hospitals.*

Distribution pipe sizing

The sizing of a water distribution pipe system is achieved by establishing the anticipated flow rates, in litres per second (l/s) taking account of the diversity of use of all the various types and numbers of appliances, and equipment requiring a water supply connection.

In practical terms all the water draw-off points are not in use at the same time. The actual number in use, in relation to the total number capable of being used varies dependent on the occupational use in the various types of building.

Probability theory

The use of probability theory in assessing simultaneous demand is only fully applicable where large numbers of appliances are involved, as probability theory, as the name implies, is based on the likelihood of situations occurring and therefore its predictions may on occasions be at variance with the actual demand.

The criteria for this occurrence is deemed to be reasonable if it is taken as 1 %.

This has been established to be reliable in that it has not led to an under assessment of simultaneous demand calculation.

The probability of a particular number of draw off's occurring at any one time is determined by dividing the time for the appliance to be filled, by the time between successive usage of the appliance to arrive at the probability factor.

P = <u>t - time in seconds of appliance filling</u>
　　T - time in seconds between successive usage of the appliance

Graph 2 Probability graph
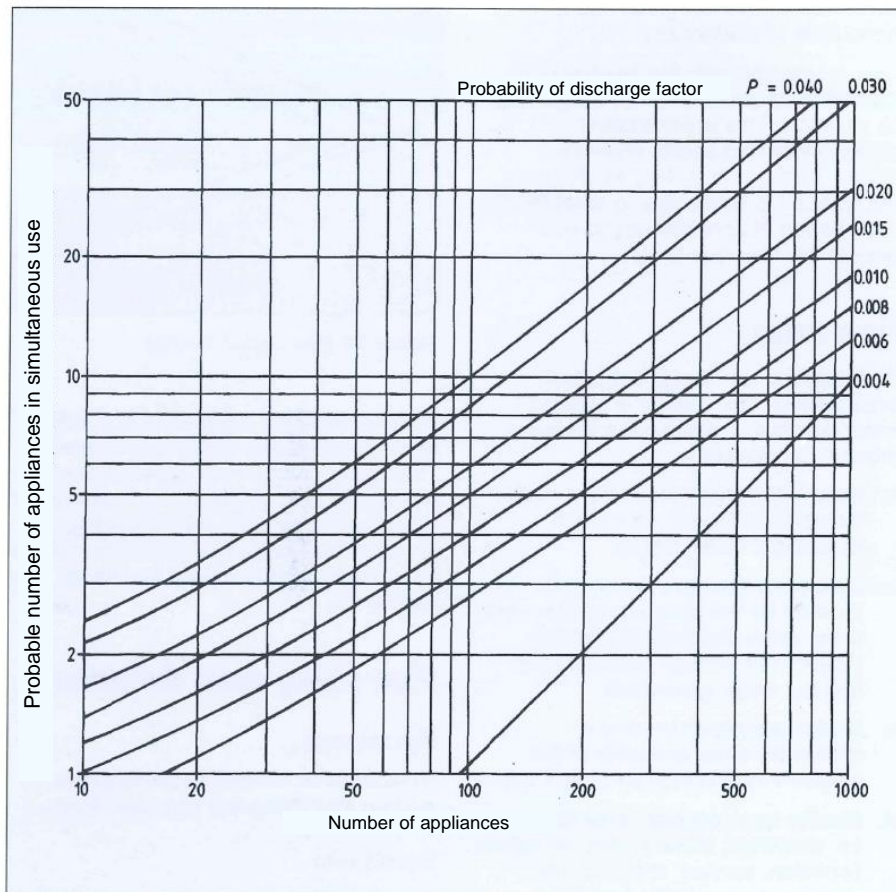
An example of this application which utilises the probability graph is if 100 appliances each take 30 seconds to be filled, and are used at 1200 seconds (20 minutes) frequency intervals, then:

$$P = \frac{t}{T} = \frac{30}{1200} = 0.025 \text{ probability}$$

Using the Probability graph, and the probability factor in this example, then out of the 100 appliances being supplied, only 7 would be in use at any one time.

Simultaneous demand

The number of draw-off points that may be used at any one time can be estimated by the application of probability theory.

The factors, which have to be taken into account, are:

a. Capacity of appliance in litres

b. Draw-off flow rate in litres per second

c. Draw-off period in seconds, i.e. time taken to fill appliance

d. Use frequency in seconds, i.e., time between each use of the appliance.

All of these factors can vary.

The capacity of wash basins, sinks and other appliances all vary in capacity. Draw-off tap sizes and flow rates differ between appliances.

Table 14 Simultaneous demand - base data

Type of appliance	Capacity (litres)	Flow rate (litres/sec)	Demand (seconds)	Frequency (seconds)	Usage ratio	Prop of base appl. ratio	Prop of base appl. flow rate	Demand figure	Demand unit
Basin, 15mm sep. taps	5	0.15	33	1200	0.028	1.00	1.00	1.000	1
	5	0.15	33	600	0.055	2.00	1.00	2.000	2
	5	0.15	33	300	0.110	4.00	1.00	4.000	4
Basin, 2 x 8mm mix tap	5	0.08	33	1200	0.028	1.00	0.53	0.533	1
	5	0.08	33	600	0.055	2.00	0.53	1.067	1
	5	0.08	33	300	0.110	4.00	0.53	2.133	3
Sink, 15mm sep./mix tap	12	0.2	60	1200	0.050	1.82	1.33	2.424	2
	12	0.2	60	600	0.100	3.64	1.33	4.848	5
	12	0.2	60	300	0.200	7.27	1.33	9.697	10
Sink, 20mm sep./mix tap	18	0.3	60	600	0.100	3.64	2.00	7.273	7
Bath, 15mm sep./mix tap	80	0.3	266	4800	0.055	2.02	2.00	4.030	4
	80	0.3	266	2400	0.111	4.03	2.00	8.061	8
	80	0.3	266	1200	0.222	8.06	2.00	16.121	16
Bath, 20mm sep./mix tap	80	0.5	266	3000	0.089	3.22	3.33	10.747	11
WC Suite, 6 litre cistern	4.5	0.1	60	1200	0.050	1.82	0.67	1.212	1
	4.5	0.1	60	600	0.100	3.64	0.67	2.424	2
	4.5	0.1	60	300	0.200	7.27	0.67	4.848	5
Shower, 15mm head	6	0.08	300	2700	0.111	4.04	0.53	2.155	2
	6	0.08	300	1800	0.167	6.06	0.53	3.232	3
	6	0.08	300	900	0.333	12.12	0.53	6.465	6
Urinal, single bowl/stall	0	0.003	1500	1500	1.000	36.36	0.02	0.727	1
Bidet, 15mm mix tap	0	0.08	33	1200	0.028	1.00	0.53	0.533	1
	0	0.08	33	600	0.055	2.00	0.53	1.067	1
Hand spray, 15mm	0	0.08	75	1200	0.067	2.27	0.53	1.212	1
Bucket sink, 15mm taps	0	0.15	60	3600	0.017	0.61	1.00	0.606	1
Slop hopper, cistern only	7.5	0.1	75	600	0.125	4.55	0.67	3.030	3
Slop hopper, cistern/taps	7.5	0.2	60	600	0.100	3.64	1.33	4.848	5
Clothes washing m/c, dom.	5	0.2	25	600	0.042	1.52	1.33	2.020	2

The frequency of the use of the appliances are different in varying locations, both within a building, and within different buildings.

Frequency of use

This is the time between each use of the appliance. Refer to Tables 14 and 15.

Low use is deemed to have 1200 seconds (20 minutes) between each use, and is appropriate for dwellings, and in other buildings where appliances are dedicated for use by a single person, or a small group of people, as a private facility.

Medium use is deemed to have 600 seconds (10 minutes) between use, being appliances that are available to be used by a larger group of people, as and when they require on a random basis with no set time constraint, typically associated with 'public use' toilets.

High use is deemed to have 300 seconds (5 Minutes) between each use for appliances to be used by large numbers of persons over a short period, as would be the case within buildings such as theatres, concert halls and fixed period sports events.

Loading units

To account for these variations, a 'loading unit' system has been devised which takes account of the appliance type, it's capacity, flow rate, period of use, and frequency of use characteristics, to establish a calculation method which satisfactorily reflects a 'maximum simultaneous design flow rate,' in litres for any part of a pipework distribution system.

Table 15 Loading units

Type of appliance	Frequency of use		
	Low	Med	High
Basin, 15mm sep. taps	1	2	4
Basin, 2 x 8mm mix. tap	1	1	2
Sink, 15mm sep/mix tap	2	5	10
Sink, 20mm sep/mix tap	-	7	-
Bath, 15mm sep/mix/tap	4	8	16
Bath, 20mm sep/mix tap	-	11	-
WC Suite, 6. litre cistern	1	2	5
Shower, 15mm head	2	3	6
Urinal, single bowl/stall	-	1	-
Bidet, 15mm mix tap	1	1	-
Hand Spray, 15mm	-	1	-
Bucket sink, 15mm taps	-	1	-
Slop Hopper, cistern only	-	3	-
Slop Hopper, cistern/taps	-	5	-
Clothes washing m/c, dom.	2	-	-
Dishwasher m/c domestic	2	-	-

This method of calculation should be considered as representative of flow rates, which have not given rise to complaints of inadequacy.

Care is required with the 'loading unit' method of calculation where usage may be intensive. This is particularly applicable to field sports showers, theatre toilets, and factory washrooms, etc. where it is necessary to establish the likely period of constant usage and provide the flow rate to suit.

Flow rates

To determine the design maximum simultaneous flow rate for a specific water distribution system the following process is necessary:

a. Identify the type and position of all the appliances and equipment requiring a water supply.

b. Determine the pipe routes and location for the incoming mains, cold & hot water distribution, and the locations of storage cisterns/tanks and hot water generators.

c. Sketch a scaled plan and a schematic or an isometric of the pipework distribution and plant layout.

d. Identify type, position of all fittings, i.e., couplings, elbows, tees; all valves, (isolation, service, check, double check, pressure reducing) all cisterns/tanks and vessel entry and exit arrangements.

e. Identify all types of draw-off fitting attached to appliances and equipment.

f. Establish the mains pressure available, in metres, and the cistern/tank head available in metres.

g. Identify the index run, i.e.. the furthest and/or highest outlet, and greatest draw-off volume.

Having established items a-g, proceed to add the sanitary and appliance loading units, loading each section of pipe with the number of loading units that it is required to carry.

This is best achieved on either a plan or isometric of the system. A useful technique is to use a four-quarter frame. See Figure 14.

The pipe size at this initial stage is provisional in order to enable the calculation to proceed. The provisional pipe size can be established by calculating the available head or pressure, in metres head and dividing it by the overall length of the index circuit, i.e., the longest pipe route with the greatest duty and least head or pressure, plus a 30% factor for, at this stage an assumed loss through fittings. The result

Figure 14 Pipe section loading

of the provisional calculation is a 'head loss in metres, per metre run of pipe.' This figure can be used with the pipe sizing charts to establish the assumed or provisional pipe size. As the loading unit for each pipe section is established enter the figures into the calculation sheet. See Figure 15.

Pipe sizing chart definitions

Pipe reference

Numbered or lettered sections of the system identifying the start and finish.

Loading units

Simultaneous maximum demand figure being carried by that section of pipe.

Flow rate (l/s)

Litres per second derived from the loading unit figure.

Assumed pipe diameter (mm)

Nominal internal diameter established from the available head divided by the index circuit length plus 30% for loss through fittings.

Length (m)

Length of pipe, in metres of the pipe section being sized, measuring its total route length.

Pipe losses (mh/m)

In metres head per metre of pipe, taken from the pipe sizing charts.

Velocity (m/s)

Velocity, in metres per second of the water flowing through the pipe being sized, taken from the pipe sizing charts.

Pipe loss (mh)

In metres head, being the multiplication of the pipe length and the metres head loss per metre run of pipe length.

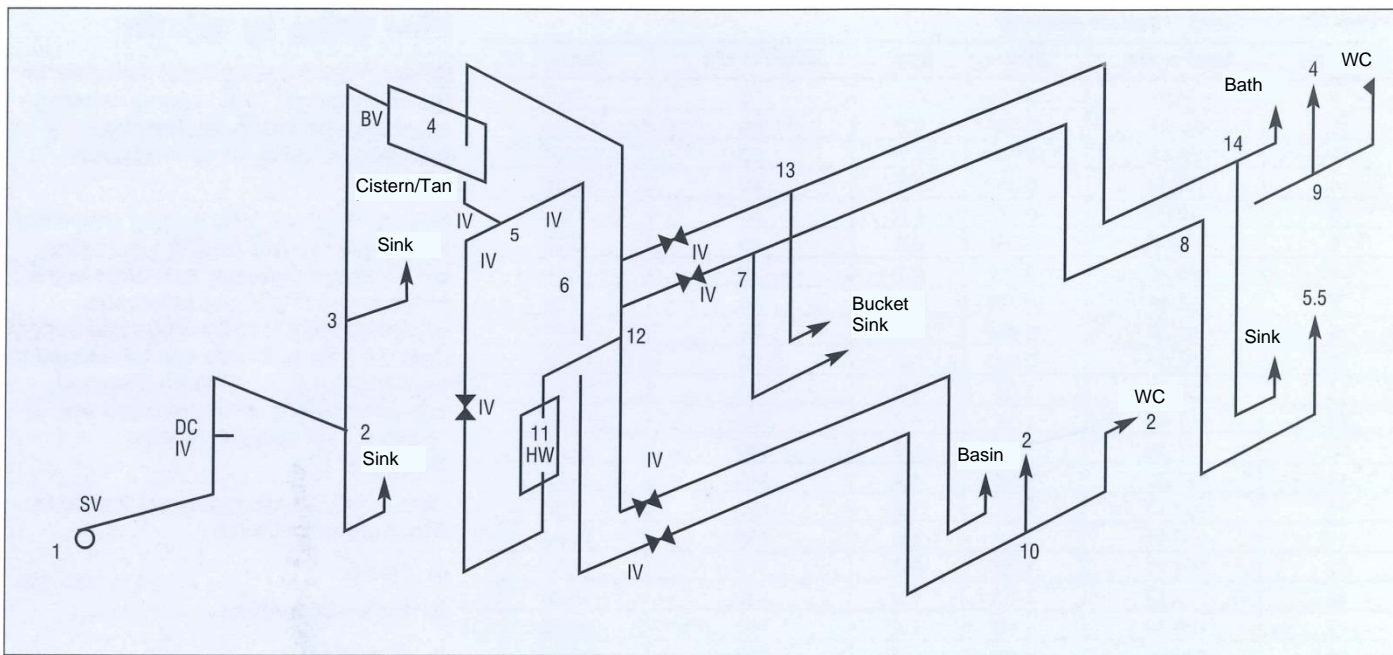| Pipe Ref	Loading units	Flow rate (l/s)	Assumed pipe dia.	Length (m)	Pipe loss (mm/h)	Velocity (m/s)	Pipe loss (mh)	Fittings head loss (m/h)							Total head loss (mh)	System head loss (mh)	Total head available (mh)	Final pipe size (mm)
								E	T	SV	IV	BV	DO	Other				
1-2	10 + tank	.45	20	10	.15	1.3	.5	.2	.15	0.75					2.6		15.0	20
2-3	5 + tank	.35	20	2	.09	1.1	.18		.08						.26		Less static	20
3-4	Tank	.15	15	3	.17	1.0	.51	.01			.02	.16			.7	3.56		15
4-5	29	.56	25	2	.06	1.0	.12	.07	.08		.015			.07	.355			25
5-6	16	.42	25	3	.035	.75	.105								.155			25
6-7	12	.32	20	2	.07	.9	.14	.09	.065						.295			20
7-8	10	.3	20	4	.066	.85	.264	.12	.065						.449			20
8-9	5	.2	20	2	.32	.65	.064			.02					.084			20
9-wc	1	.15	15	1	.16	1.0	.16	.04			.02	.16			.38	1.718	2.0	15
5-11	13	.35	25	3	.25	.6	.075	.06			.005			.03	.17			25
11-12	13	.35	25	1	.025	.6	.025	.04							.065			25
12-13	11	.32	20	2	.07	.9	.14				.03				.17			20
13-14	9 (inc. bath)	.3	20	4	.07	.9	.28	.07							.35			20
14-bath	Bath	.3	20	1	.07	.9	.07							.5	.507	1.262	2.0	20
6-10																		
10-basin																		

Continue for the remainder of the system

Figure 15 *Pipework isometric and calculation sheet*

Fittings head loss (mh)

In metres head, for each pipe fitting and valve on the section of pipe being sized.

Total head loss (mh)

In metres head, being the total sum of the pipe head loss and the fittings head loss.

System head loss (mh)

In metres head, being the total sum of all the sections of pipe relevant to the source of head available.

Total head available (mh)

In metres head, being either the mains or pump pressure and/or the height of the gravity feed cistern/tank. See Table 16.

Final pipe size (mm)

In mm, nominal internal diameter, confirming the pipe size for that section of pipe.

Loss of head through fittings

Refer to Table 19 loss of head, in metres through various pipeline fittings and terminal outlets, against a range of flow rates and sizes.

Loss of head through Tees should be assumed to occur at the changes of direction only.

For fittings not identified reference shall be made to the respective manufacturer's literature.

Where the flow rate falls between the stated figures then the proportional flow rate difference between the higher and lower figure shall be equally applied to the higher and lower head loss figure.

Table 16 Head and pressure of water

Metres	kNm² or kPa	Bars	Bars	kN/m²/ or kPa	Metres
1	9.81	0.098	0.1	10	1.02
2	19.61	0.196	0.2	20	2.04
3	29.42	0.294	0.3	30	3.06
4	39.23	0.392	0.4	40	4.08
5	49.03	0.490	0.5	50	5.10
6	58.84	0.588	0.6	60	6.12
7	68.65	0.686	0.7	70	7.14
8	78.45	0.785	0.8	80	8.16
9	88.26	0.883	0.9	90	9.18
10	98.07	0.981	1.0	100	10.20
11	107.87	1.08	1.1	110	11.22
12	117.68	1.18	1.2	120	12.24
13	127.49	1.27	1.3	130	13.26
14	137.29	1.37	1.4	140	14.28
15	147.10	1.47	1.5	150	15.30
16	156.91	1.57	1.6	160	16.32
17	166.71	1.67	1.7	170	17.34
18	176.52	1.77	1.8	180	18.36
19	186.33	1.86	1.9	190	19.38
20	196.13	1.96	2.0	200	20.40
25	245.17	2.45	2.5	250	25.49
30	294.20	2.94	3.0	300	30.59
35	343.23	3.43	3.5	350	35.69
40	392.37	3.92	4.0	400	40.79
45	441.30	4.41	4.5	450	45.89
50	490.33	4.90	5.0	500	50.99
60	588.40	5.88	6.0	600	61.18
70	686.47	6.86	7.0	700	71.38
80	784.53	7.85	8.0	800	81.58
90	882.60	8.83	9.0	900	91.77
100	980.66	9.81	10.0	1000	101.97

The use of various units to describe pressure can cause confusion. The calculation of 'Head loss' n this Guide Section is declared in 'Metres head' as a readily usable means of measurement. Metres head can be easily converted to Bar, kN/m² and/or Pascals pressure figures as there is a close correlation between all of them. The table above provides the comparative figures for ease of reference.
1 litre of water weighs 1 kilogram, or 1000 grams.
1 cubic metre of water = 1000 litres.
1 metre head of water = 9810 Pa or kN/m², or 9.81 Pa or kN/m², or 0.1 bar.

Table 17 Pipework velocities

Location	Noise rating NR	Pipe material	
		Metal: copper, stainless steel, galvanised (m/s)	Plastic UPVC, ABS, CPV, Pb (m/s)
Service duct, riser, shaft, plant room	50	2.0	2.5
Service enclosure, ceiling void	40	1.5	1.5
Circulation area, entrance corridor	35	1.5	1.5
Seating area, lecture/meeting room	30	1.25	1.25
Bedroom	25	1.0	1.0
Theatre, cinema	20	0.75	0.75
Recording studio	<20	0.5	0.5

Other factors than velocity need to be considered with regard to noise generated by water flows in pipework. The pipe support and brackets required to secure the pipework sufficient to restrain it and prevent contact with other elements. Where pipework passes through a hollow structure i.e., wall or floor, then it needs to be separated or sleeved so as not to be in contact with the structure, to avoid resonance, and resulting amplified noise to occur.

Pipe sizing by velocity

Where there is ample head available, or the water supply is by a pump or pump set, then pipe sizing can best be achieved by using an optimum pipe velocity.

In a gravity down feed system where the head available is a limiting factor, pipe velocities are generally low, often in the range of 0.4 to 0.8 metres/second. Where delivery is to be a pumped supply then the pipe velocities can be allowed to increase to 1.0 to 1.5 metres/second, and possibly higher where pipes are routed in non-occupied areas. See Table 17.

Pipe velocities, ultimately are limited by either of the following:

a. Noise

b. Erosion/corrosion

c. Cavitation.

Noise is a major consideration, and velocities above 1.5 metres/second in pipework passing through occupied areas, in particular bedrooms should be avoided.

Erosion and corrosion are less of an issue. If velocities are being set to limit noise, then erosion and corrosion will not generally be a problem. Where velocities exceed 2.5 metres/second erosion and/o corrosion can result from the abrasive action of particles in the water. This type of water would normally be associated with a 'raw' water rather than a water supply for domestic use purposes where filtration has taken place as part of the treatment process by the Water Companies who have a duty to provide a 'wholesome' supply for domestic purposes.

Cavitation caused by velocity is not considered an issue with water supply systems as velocities should always be below the 7.0 to 10.0 metres/second where velocity cavitation can occur.

Having determined the appropriate velocity for the location of the distribution pipes, using the pipe sizing charts you can determine the pipe size by cross reference to the design flow rate, and record the pipe head loss per metre. From thereon the pipe sizing schedule for the whole system can be completed.

Table 18a Heat emission from insulated pipes (40°C temperature difference)

	Value of pipework insulation thermal conductivity W/mK											
	0.040				0.055				0.070			
	Thickness of pipework insulation (mm)											
	12.5	19	25	38	12.5	19	25	38	12.5	19	25	38
10	9	7	6	4	12	10	8	7	14	12	10	9
15	11	9	8	6	14	12	10	9	16	14	12	11
20	12	10	9	7	16	13	12	10	19	16	14	12
25	14	11	10	8	19	15	13	11	22	18	16	14
32	17	13	12	9	22	18	5	12	26	22	19	15
40	19	15	13	10	24	20	17	13	29	24	21	17
50	23	18	15	12	30	23	20	16	34	28	24	19
65	27	21	18	14	35	28	23	18	42	33	28	22
75	31	24	20	15	40	31	26	20	48	38	32	25

Table 18b Heat emission from uninsulated pipes (W/m run)

Pipe size	Copper/stainless steel	Plastic	Steel
10	22		
15	31		42
20	43	Refer	51
25	53	to	62
32	64	manufacturers	75
40	75	data	84
50	93		102
65	112		125
75	125		143

Pipework taken to be shiny surface, individual, with zero air movement, and a 40°C temperature difference between the pipe content and surrounding air temperature.

Figure 16 Secondary circulation pipework isometric and calculation sheet
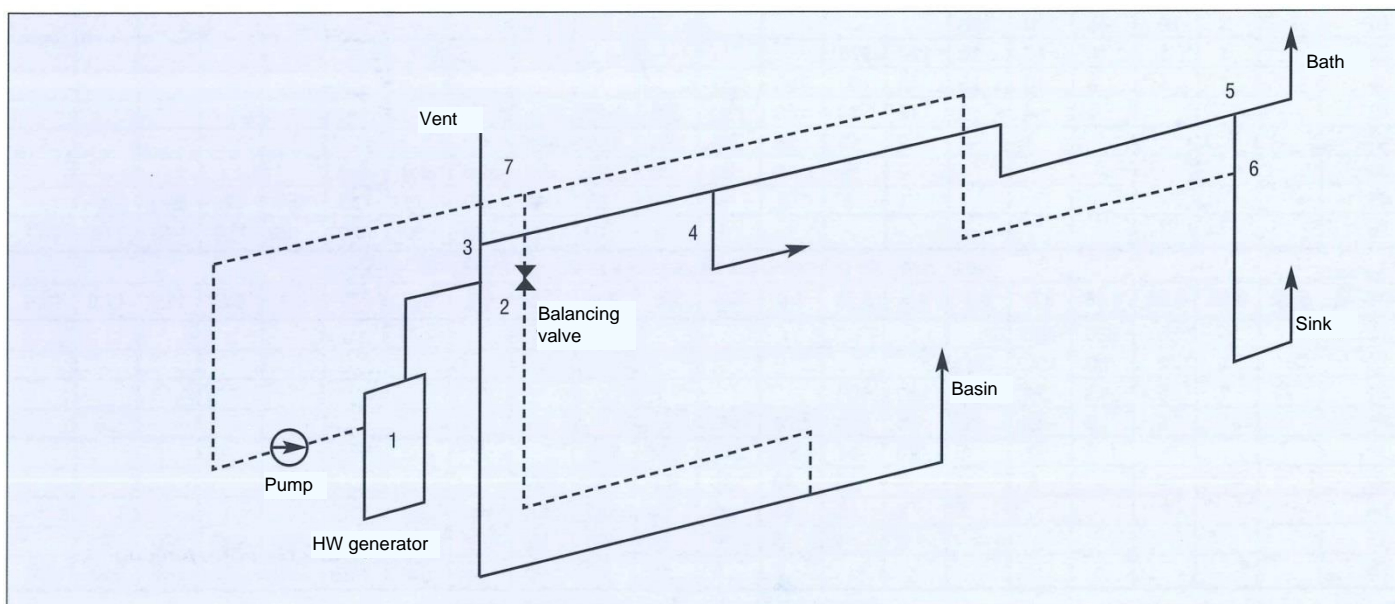
| Pipe Ref | Heat loss load (W) | Flow rate (l/s) | Assumed pipe dia. | Length (m) | Pipe loss (m/mh) | Velocity (m/s) | Pipe loss (m/h) | Fittings head loss (m/h) | | | | | | | Total head loss (m) | System head loss (m) | Total head available (m) | Final pipe size (m) |
								E	T	SV	IV	BV	DO	Other				
1-2 (flow)	400	.09	25	1	.0025	<.5	.0025	.002						.02	.0045			25
2-3 (flow)	200	.05	20	2	.003	<.5	.006				.001				.007			20
3-4 (flow)	200	.05	20	4	.003	<.5	.012	.001							.013			20
4-5 (flow)	200	.05	20	1	.003	<.5	.003	.002							.005			20
5-6 (flow)	200	.05	15	1	.02	<.5	.02	.001							.021			15
6-1 (return)	200	.05	15	7	.02	<.5	.14	.045							.0185			15
7-1 (return)	400	.09	15	3	.05	0.6	.15	.045						.02	.195	.264		15

Hot water secondary circulation

In order to maintain the correct temperature of hot water within the hot water distribution system, provision of a 'return' pipe to enable the water to be circulated back to the hot water generator is required.

Hot water circulation can be achieved by gravity or pump circulation means, although in nearly all instances a pumped system is provided.

Secondary circulation pipe sizing

The formal method of sizing the secondary circulation pipework is to calculate the heat loss from all of the 'flow' and 'return' pipe circuits throughout the system. Calculating the heat loss allows a comparable flow rate to be established, and thereafter the head loss throughout the system is determined, and the duty of the circulating pump.

The total heat loss from each section of pipe is converted to a flow rate necessary to replace the lost heat.

$$kg/s = \frac{Watts}{4.187 \ (shc \ of \ water) \times 1000 \times \Delta t}$$

The pipework heat loss is that which is emitted through the pipe wall and insulation material. See Tables18a and 18b for pipes with and without insulation.

A 'Rule of Thumb' method of sizing pumped HWS secondary circuits is to initially select a return pipe size two sizes lower than the flow. As a guide select smaller sizes over larger pipe sizes and maintain a check on the HWS return pipe velocities.

Pipe circuit balancing valves will be needed where the HWS return has a number of branches and loops to serve the various parts of the circulation system. These valves restrict the flow to the circuits nearest the pump where there is greater pump pressure, forcing the HWS return to circulate to the furthest circuit.

Commonly the circuit valves are a double regulating pattern which permit an accurate 'low flow' setting to be achieved and retained when the valve may be shut off and re-opened during maintenance of the system. The use of ordinary isolation valves can achieve a crude form of restricting the flow for balancing purposes, but these rarely remain effective, or return to their initial setting after being shut off.

The over-riding purpose of the balancing valve is to maintain the correct temperature within the pipework distribution system to minimise the potential for bacterial growth, in particular legionella. The Health & Safety Approved Code of Practice Guidance L8 should be applied (see earlier).

Table 19 *Loss of head through pipe fittings (expressed in millimetres, i.e., 1mm = 0.001 m unless otherwise stated)*

Pipe size nom. ID	Elbows - flow rate in litres/second																				
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10	2	10	35	150	300																
15	1	3	15	45	100	190															
20		1	5	10	15	45	120	270													
25			1	5	10	15	45	100	180	420											
32				1	3	5	15	30	60	130	230	540									
40					1	2	5	15	25	60	100	250	440								
50						1	2	5	10	20	35	85	150	220	320	450					
65							1	2	3	5	10	20	40	60	85	115	150	190	240	290	
75									1	3	5	10	20	35	50	70	90	110	140	170	200

Pipe size nom. ID	Tees - flow rate in litres/second (applicable to change of direction only)																				
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10	3	15	50	220	450																
15	2	5	20	60	150	280															
20		1	5	15	20	65	180	400													
25			1	5	15	20	65	150	270	600											
32				1	3	5	20	45	95	210	370	870									
40					1	2	5	20	40	100	160	400	700								
50						1	2	5	15	30	50	135	240	350	520	720					
65							2	4	5	10	20	40	80	120	170	230	300	380	480	580	
75									2	5	10	20	40	70	100	140	180	220	230	340	400

Pipe size nom. ID	Globe valve/Stop tap - Flow rate in litres/second																				
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10	30	135	430	1800																	
15	20	45	190	570	1200	2400															
20		10	20	80	125	290	840	1890													
25			25	50	110	315	690	1340	2950												
32				15	45	125	290	530	1150	201 Oj	4720										
40					20	40	90	180	380	660	1570	2750	4020								
50						30	60	130	230	530	940	1400	2030	2850							
65							50	90	220	400	570	870	1170	1570	1900	2530	2920				
75								50	100	180	280	420	560	730	920	1120	1400	1710			

Table 19 *Loss of head through pipe fittings - continued (expressed in millimetres, i.e., 1mm = 0.001 m unless otherwise stated)*
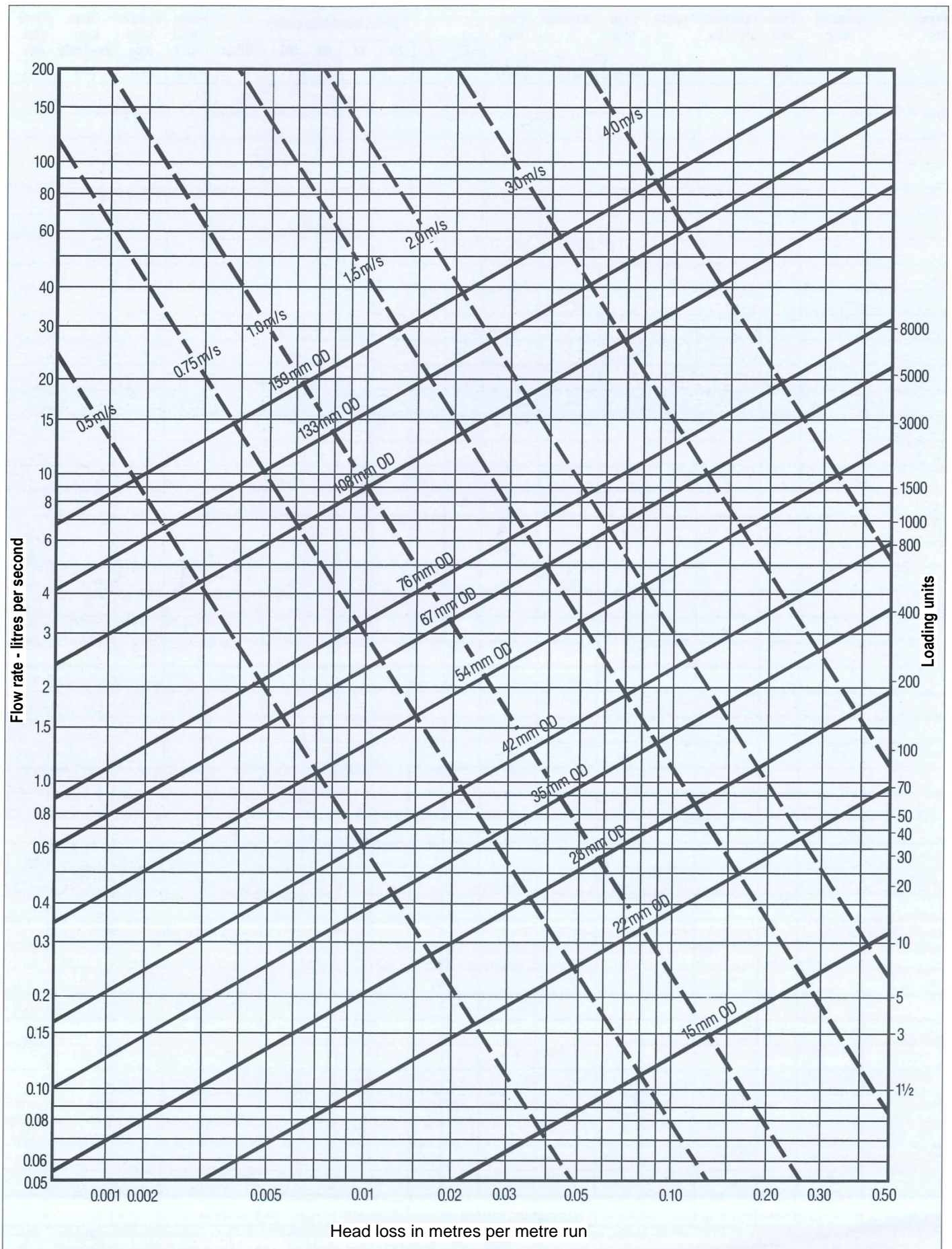
Gate valves/Service valves - Flow rate in litres/second

Pipe size nom. ID	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10	2	5	15	75																	
15	1	1	5	20	50	100															
20			1	5	10	20	60	135													
25				1	2	5	10	30	90	125											
32						1	5	10	20	50	85	200									
40							1	5	10	20	40	90	165	250							
50								2	5	10	20	35	55	80	110	150					
65								1	3	10	15	25	35	45	60	75	95	115			
75												2	5	7	10	15	18	20	25	35	40

Check valve - Flow rate in litres/second

Pipe size nom. ID	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10	5	20	70	300																	
15	3	5	30	95	200	400															
20			5	20	45	80	240	540													
25				5	15	30	85	200	360	840											
32						10	35	80	150	330	570	1350									
40							15	35	70	150	260	630	1100	1720							
50								25	50	90	210	370	610	810	1140	1500					
65									40	90	160	250	350	460	620	830	1010	1170			
75											50	90	140	210	280	360	460	580	700	850	

Double check valve

Pipe size nom. ID	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10																					
15				750	850	1400	3000														
20				450	500	550	900	1800	3000												
25				300	450	500	600	800	1100	2400											
32																					
40																					
50																					
65																					
75																					

RPZ valves (reduced pressure zone valve) excluding filters (expressed in metres

Pipe size nom. ID	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10																					
15			8.2	8.8	8.9	9.2	10.0	11.2	14.0												
20			8.1	8.5	8.7	8.8	9.3	9.7	10.2	11.8	16.0										
25				8.3	8.4	8.6	8.9	9.2	9.5	10.2	11.0	13.8									
32				8.2	8.3	8.4	8.6	8.8	9.0	9.3	9.7	10.8	12.0	15.0							
40				8.1	8.2	8.3	8.6	8.8	9.0	9.1	9.2	9.7	10.0	11.3	11.9	13.0					
50				8.0	8.1	8.2	8.4	8.5	8.7	8.8	8.9	9.1	9.3	9.7	10.0	10.3					
65									8.0	8.05	8.1	8.18	8.3	8.35	8.5	8.7	8.9	9.2			
75											8.0	8.15	8.23	8.35	8.5	8.6	8.9	9.0	9.1		

Ball float valves - Flow rate in litres/second

Pipe size nom. ID	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10																					
15			120	160	350	700															
20				40	80	145	420														
25				10	25	55	155	340	670	1470											
32						20	65	140	250	540	950	2220									
40							30	60	115	250	430	1030	1810	2840							
50									40	85	150	350	620	1010	1330	1880					

Table 19 Loss of head through pipe fittings - continued

Pipe size nom. ID	Vessel entry										Vessel exit									
	0.2	0.3	0.5	0.75	1.0	2.0	4.0	6.0	8.0	10.0	0.2	0.3	0.5	0.75	1.0	2.0	4.0	6.0	8.0	10.0
20		20	40	120	270						10	15	50	100						
25			20	40	100	180						10	15	40	70					
32			5	20	40	80	280				1	5	15	30	110					
40				10	20	35	130	550					5	10	15	50	220			
50					10	50	190	400	770	1200					5	20	70	160	300	480
65						20	80	175	315	500						10	30	70	120	200
75																				

Pipe size nom. ID	Vessel inlet - tank (not ball valve)																				
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10																					
15																					
20																					
25																					
32							Additional example tables if required														
40																					
50																					
65																					
75																					

Pipe size nom. ID	Reducers, individual or combination with tee																				
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
10																					
15																					
20																					
25																					
32							Additional example tables if required														
40																					
50																					
65																					
75																					

Pipe size nom. ID	Pillar tap draw-off fitting												Bib tap draw-off fitting								
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0
10																					
15			240	520	700								185	520	750	1800					
20				240	300	500								210	330	750	1500				
25																450	1000				

Pipe size nom. ID	Manual mixer valve (only) (metres)												Thermostatic mixer valve (only) (metres)								
	0.02	0.04	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	0.08	0.15	0.2	0.3	0.5	0.75	1.0	1.5	2.0
15			0.8	1.5	3.0	10.0	30.0						0.7	1.2	2.0	4.0	10.0				
20																1.5	4.3	10.0	16.0		
25																		2.0	4.0	9.0	12.0

Table 20 Water supply system - pipe sizing table

Pipe Ref	Loading units	Flow rate (l/s)	Assumed pipe dia.	Length (m)	Pipe loss (m/mh)	Velocity (m/s)	Pipe loss (m/h)	Fittings head loss (m/h)							Total head loss (m)	System head loss (m)	Total head available (m)	Final pipe size (m)
								E	T	SV	IV	BV	DO	Other				

Graph 3 Pipe sizing chart - copper and stainless steel.

Graph 4 Pipe sizing chart - plastic
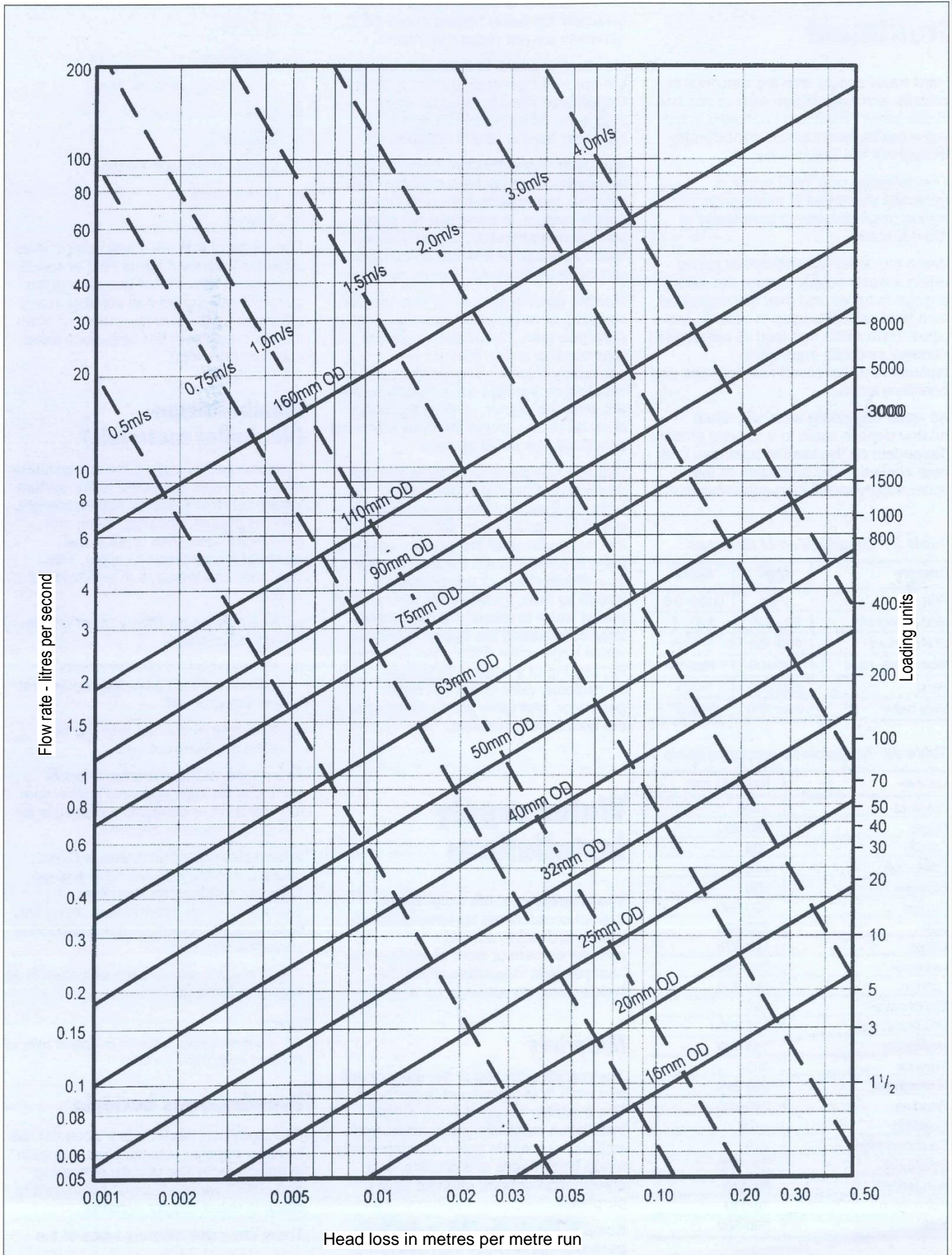
Hard water treatment

Hard water occurs with the presence of calcium and magnesium salts in solution in the water. This occurs naturally in the water, but its extent varies considerably throughout the British Isles.

The definition or a 'hard water' is generally measured in either parts per million (mg/l as calcium carbonate) or 'Clarks' scale.

When the water temperature is raised within a water supply system the salts change to solids and they are deposited as a hard rock-like scale in vessels and pipes. Hard water can lead to widespread damage incurring expensive replacement, increased maintenance and operating costs.

All water containing salts will, when heated deposit scale to a varying amount dependent on the level of hardness and heat applied.

Table 21 Classification of hardness

Category	Mg/l	Clarks
Soft	0-50	under 3.5
Moderately soft	50 -100	3.5-7
Slightly hard	100-150	7-10.5
Moderately hard	150-200	10.5-14
Hard	200-300	14-21
Very hard	Over 300	Over 21

Table 22 *Typical water hardness levels*

Location	Hardness ppm
Bradford	<100
Bristol	250-350
Cardiff	100
Edinburgh	<50
Glasgow	<50
Hartlepool	400-580
Hull	250-400
Leeds	120-220
Leicester	250-320
London	250-320
Manchester	<60
Middlesbrough	145-165
Newcastle	150-165
Norwich	300+
Nottingham	220-300
Reading	260-300
Sheffield	<100
Southampton	280
Southport	220-300
Sunderland	80-420
Warrington	70-250
York	200-300

If the protection of the water supply installation apparatus is the prime concern, then waters having a hardness level of below 150ppm, and generally not being heated above 65°C, generally will not require treatment.

However, to assist in extending the life of the hot water generating plant a 'Water Conditioner' fitted to the cold water supply would be beneficial where the hardness level is above 100ppm.

For water above 150ppm treatment will be needed to protect the condition and maintain the expected life of the water supply system, in particular hot water plant and thermostatic valves. Either a 'water softener' or a 'water conditioner' can be used for protecting the system.

If softer water is desired by the user for washing, or manufacturing production purposes then a base exchange 'salt regeneration' water softener will be necessary. It will be required to be installed on the cold water supply to the hot water generator, or to all the water draw off points except the draw offs used specifically for drinking water.

Water conditioners are effective for the protection of the hot water system because they alter the mineral crystals, reducing their ability to adhere to the internal surfaces of the system, enabling them to pass through the water system. The effectiveness of this process is limited by time, therefore the shorter the period water is retained in the system after conditioning the better. Therefore, within large water distribution systems the placing of a water conditioner immediately prior to the hot water generator, and other plant, will provide the best results possible.

Water supply installations

The installation of the water supply system components requires planning and co-ordination prior to commencement of work to achieve the best possible integration within the building and the areas to be served.

Materials

The correct selection of the component materials is of paramount importance. The available range of water supply installation materials is extensive and includes numerous types of components made from metals and plastics, or a combination of both, often for similar purposes.

Some materials are more suited to particular applications than others.

For the selection of components and materials the main considerations are:

a. Suitability

b. Availability

c. Appearance (if to be seen)

d. Cost

e. Durability

f. Compatibility with existing

g. User choice

h. Spares.

The range of materials and components available from merchants held or readily available stocks are an excellent guide as to the most used and suitable in any particular regional area, and more often than not represent the best discounted cost component(s).

Plumbosolvent (dissimilar materials)

Plumbosolvency covers the compatibility of the materials within the water system. Where there is a mix of metal materials, such as copper, stainless steel, and galvanised steel then there is the potential for corrosion to occur. This 'potential' can increase to a 'likelihood' where:

a. The metals are widely apart on the 'galvanic' scale

b. the water has a greater acidity or alkalinity above or below the neutral pH value of 7.5

c. the water in contact with the two metals is warm or hot.

To prevent, or minimise the effect of corrosion through 'Galvanic' action then the selection of compatible materials for the type of water is required.

Where dissimilar metals are in direct contact, and they do not have a close Galvanic relationship, then the installation of an intermediate metal link is appropriate to reduce the likelihood of corrosion occurring.

The 'Galvanic' relationship of metals is as shown in Table 30.

NOTE:
For a greater appreciation of corrosion refer to the later part of this section.

Pseudomonas bacteria

Pseudomonas bacteria is a potential risk to water supply systems. More common in the closed water circuits of heating and chilled water systems, but known to occur in water supply systems.

Table 23 Commonly used materials

Component	Options			
Underground mains	Soft copper	Polyethylene	UPVC	Ductile iron, lined
Storage tanks	Polypropylene	Glass reinforced plastic	Steel, lined	
Pipework	Copper	Stainless steel	Polybutylene	CPVC
Hot water vessels	Copper	Steel, copper or glass lined	Stainless steel	
Draw off fittings	Chromed brass	Brass, brass alloy	Plastic	
Valves	Chromed brass	Brass, brass alloy	Plastic	

There are many different types of the Pseudomonas bacteria that once in a water system can be difficult to eradicate. If not completely destroyed the bacteria can reappear and grow at a fast rate to form a biofilm within the system.

Problems occur due to a greasy brown slime or biofilm that coats strainers, pipework, tanks etc. creating corrosive conditions which can discolour the water and can exude a noxious smell.

Pseudomonas Bacteria can grow more when it has access to a higher level of oxygen and temperatures between 20°C and 40°C, although it can grow outside this range if the water has a pH value of 7-8.5.

Pseudomonas has greater chance of occurring under the following circumstances.

a. Water used for temporary works and filling/testing of pipework coming from dirty cisterns/tanks or temporary mains with dead legs and areas of low use.

b. Non-disinfected hoses used for filling systems.

c. Systems that are filled and then left for long periods with stagnant untreated water or are partially or fully drained down and then left for long periods with wetted surfaces.

d. Pipework installed on site where there is substantial amounts of debris.

e. If ambient temperatures are high.

Avoiding the above circumstances will greatly reduce the likelihood of pseudomonas bacteria becoming prevalent within the water supply installation.

Infected systems must be disinfected and flushed. Any excessive growth may require repeated disinfecting and flushing to effect a reduction. Ultra-violet water treatment is an effective method of killing the widest range of micro-organisms. However, both ultra-violet and disinfection will only provide a temporary respite unless the causes are identified and removed.

Frost protection

Precautions are required to be taken to prevent the water contained within the water supply distribution system freezing, as this will likely cause components to fail, or burst due to the increase in the internal pressure by the expanding volume as the water turns to ice.

To minimise the risk of 'bursts' pipework and associated components should always be located within areas where the ambient temperature will remain above freezing. In practical terms this would be 3°C and above.

Locations to avoid are:

a. All external locations, unless a minimum of 750mm below ground

b. Roof spaces, unless part of the building's accommodation

c. Under floor voids, unless part of the building's accommodation

d. Outhouses, enclosures, sheds, and garages etc.

e. Adjacent to ventilators, air bricks, or anywhere subject to external drafts of air.

If the above, and similar locations cannot be avoided then protection will need to be provided by insulating the pipework and components, and possibly providing heating to the spaces that contain water supply installations.

Insulation alone will not ultimately prevent freezing, but only slow down the lowering of the temperature of the water. However, if a suitable type and thickness of insulation is used, and it is protected from damage or moisture, then it is a worthwhile method of protection.

Reference should also be made to the guidance provided within the Water Regulation Guide.

An enhanced and very effective method of frost protection is the provision of trace heating.

Table 25 Thermal conductivity of insulating materials

Material	Thickness, mm, W (m.K)
Rigid phenolic foam	< 0.020
Polisocyanurate foam Rigid polyurethane foam	0.020 to 0.025
PVC foam	0.025 to 0.03
Expanded polystyrene. Extruded polystyrene. Cross linked polyethylene foam. Expanded nitrile rubber. Improved polyethylene foam.	0.03 to 0.035
Standard polyethylene foam Expanded synthetic rubber Cellular glass	0.035 to 0.040
Cork board	0.04 to 0.055
Exfoliated vermiculite (loose fill)	0.055 to 0.07

Table 24 Minimum thickness of insulating material to delay freezing

Nominal outside diameter of pipe	Thermal conductivity (W/mK)							
	0.035	0.04	0.055	0.07	0.035	0.04	0.055	0.07
	Indoor installations (mm)				Outdoor installations (mm)			
Up to and including 15	22	32	50	89	27	38	63	100
Over 15, up to and including 22	22	32	50	75	27	38	63	100
Over 22, up to and including 42	22	32	50	75	27	38	63	89
Over 42, up to and including 54	16	25	44	63	19	32	50	75
Over 54, up to and including 76	13	25	32	50	16	25	44	63
Over 76, and flat surfaces	13	19	25	38	16	25	32	50

This table is reproduced from BS 6700, and lists the thermal conductivity value with an air temperature of 0°C, and the minimum thickness of insulating material that will afford worthwhile protection against freezing during the normal occupation of buildings.
Storage cistern and pipework in roof spaces are considered as indoor installations in this context.
Pipes in the air space beneath a suspended ground floor or in a detached garage should be protected as outdoor installations.
All insulation requires to be vapour sealed to remain effective.

Table 26 General pipe insulation

Pipe size (mm) od	Insulation material and thickness		
	Glass fibre 0.040W/mK	Phenolic foam 0.018W/mK	Nitril rubber 0.035W/mK
15	25	15	13
22	25	15	19
25	32	20	25
32	32	20	32
40	32	20	32
50	32	20	32
65	32	20	32
75	32	20	32
100	38	20	32

Where the insulation material is located in areas requiring fire protection in accordance with the Building Regulations then it shall have a 'Class 0' classification.

This comprises of self-regulating electrical heating elements in a tape form, capable of being wrapped around pipework and components. By the selection of the appropriate type and rating of heating tape the water within pipework and components can be kept above the freezing temperature. Trace heating is used in conjunction with insulation and weathering protection.

General insulation

Pipework and plant components throughout the distribution system should be provided to keep hot water hot and cold water cold. Without insulation a hot water distribution system would lose heat wasting energy, requiring a larger generating plant, and increasing the opportunity for bacteria growth and potentially failing to comply with the Legionella Codes. The impact on the cold water system would be to unnecessarily gain heat from the warmer ambient temperature and any adjacent heat sources making the water less palatable for drinking, and again increasing the opportunity for bacteria growth and a failure to comply to the Legionella Codes.

The insulation for cold water components requires them to be vapour sealed to prevent condensation forming on the cooler surfaces within the higher ambient areas.

Recommended types and thicknesses of insulation are scheduled in Table 26.

Pipework and plant supports

Water supply pipework, plant and components require to be adequately supported to be functional and prevent noise, vibration and general movement, which would become a nuisance and/or lead to damage to itself and other elements of the building.

For the support of plant and components, the respective manufactures requirements and recommendations should be fully adhered to.

Pipework requires supporting throughout its length at regular and specific positions to maintain its stability, avoid movement which could result in noise or vibration, whilst enabling sufficient movement for pipework expansion and contraction. See Table 27.

Underground pipework

The Water Supply Company mains are located below ground, and therefore the incoming mains connection to the building will also be below ground until it can enter into the building in its desired location.

Table 27 Pipe supports - maximum spacing

Pipe size nominal id (mm)	Pipe material - spacing of supports in metres							
	Copper		Stainless steel		Polybutylene		CPVC	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
15	1.8	2.4	1.8	2.4	0.3	0.5	0.5	1.0
20	2.4	3.0	2.4	3.0	0.5	0.8	0.5	1.0
25	2.4	3.0	2.4	3.0	0.5	0.8	0.5	1.0
32	2.7	3.0	2.7	3.0	0.9	1.2	0.8	1.4
40	3.0	3.6	3.0	3.6	0.9	1.2	0.8	2.0
50	3.0	3.6	3.0	3.6	1.2	1.5	1.2	2.2
65	3.0	3.6	3.0	3.6	1.5	2.0	1.5	2.2
75	3.6	4.5	3.6	4.5	1.8	2.2	1.8	2.2

Intermediate supports will be required at changes of direction, branches, and connections to plant. Polybutylene and CPVC pipe supports can benefit from being provided with a continuous tray, rigid bar or rail spanning between support brackets at centres similar to copper, with straps to secure the pipe to the bar.

Table 28 Thrust per bar internal pressure (kN)

Nominal internal diameter of pipe	End thrust	Radial thrust on bends of angle			
		90 deg	45 deg	22.5 deg	11.25 deg
50	0.38	0.53	0.29	0.15	0.07
75	0.72	1.02	0.55	0.28	0.15
100	1.17	1.66	0.9	0.46	0.24
125	1.76	2.49	1.35	0.69	0.35
150	2.47	3.50	1.89	0.96	0.49

The kN thrust figures stated are the force exerted by the pipe on its end or radial area.

Pipes laid below ground require to be of a suitable material. The most commonly used is polyethylene, certainly for sizes up to 50mm ID (65mm MDPE OD).

The depth of pipes required to comply with the Water Regulations is a minimum of 750mm from ground level to the top of the pipe barrel, and a maximum of 1350mm, unless in a duct. Where pipes are located below a road the depth should increase to 900mm and be ducted. Where water pipes are laid in a service strip close to other services, the National Joint Utilities guidance documents recommends that the depth of the water service is at 900mm throughout to coordinate with the depth of the other services, and enable services to cross each other. The minimum distance between the water pipework and other services is recommended as being 350mm.

The pipe trenches should be kept to the minimum width that is practicable and retain the trench wall to minimise ground loadings transferring onto the pipe. The trench bottom requires to be firm, level and to the correct depth. A bedding of sand is appropriate having a minimum depth of 50mm, to provide a suitable means of bedding the barrel and joints of the pipe. The trench back filling should be of a suitable material such as selected excavated or imported material, consolidated to resist subsequent movement of the pipes.
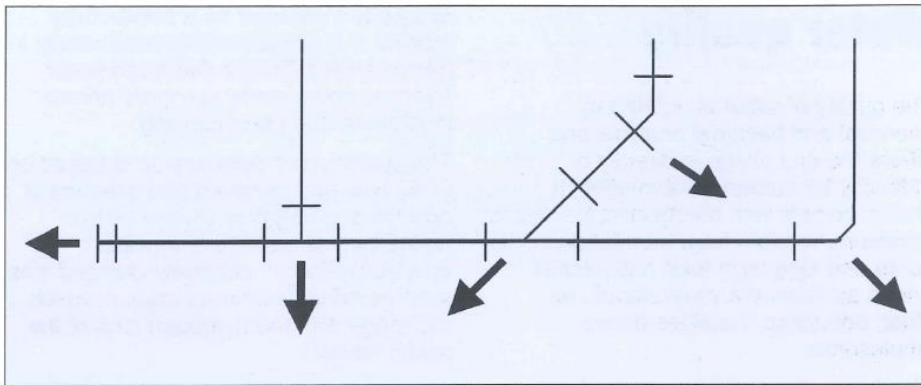
Figure 17 Direction of thrusts developed in a pipeline due to internal pressure

No large stones or sharp objects shall be allowed to be in contact or near the pipe material.

Below ground pipework requires to be restrained throughout its length. To combat the thrust of the internal pressure and flows. For the greater part of the pipework this should be achieved by the weight of the backfill material but at bends, tee's, blank ends, and valves the provision of thrust blocks will be required and must be placed in a position that is in the line of the thrust developed in the pipeline due to internal pressures.

For standard fittings, the thrust can be calculated by multiplying the values given in the Table 28 for thrust in kN for a one bar internal pressure. The internal pressure can be deemed to be the maximum working pressure of the below ground pipe system.

Thrust blocks for the restraint of below ground pipework will require an adequate bearing area to resist the thrust. Refer to Table 29 for the bearing capacity of soils for horizontal thrust.

Entry to buildings

Pipe entries to buildings may be made by a number of methods. If entry can be made into a basement or under floor area then the pipe can pass through a pipe sleeve constructed into the section of wall below ground, into the building.

Table 29 Bearing capacity of soils kN/m^2

Soil type	Safe bearing load
Soft Clay	24
Sand	48
Sandstone & Gravel	72
Sand & Gravel Bonded with Clay	96
Shale	240

For a building having no basement or under floor void then a pipe duct incorporating a 90° bend. If the incoming pipe size is larger than can be passed through a pipe sleeve bend, then a pit, or reduced section of floor will be required to pass the pipe into the building in a manner similar to a basement arrangement, but then rising vertically to the building ground floor level. Once the pipework is installed then the openings between the external and internal parts of the building require to be sealed. The pit can be filled with sand and topped off with a floor screed.

Disinfection

The process of disinfection is sometimes misunderstood and described as 'sterilisation' or 'chlorination'. It is important that the terminology is understood and used correctly.

Disinfection describes the process of killing reducing or inactivating microorganisms, especially by chemical means.

Sterilisation is to render sterile, defined as completely free of living microorganisms.

Chlorination refers to the use of chlorine, in particular sodium hypochlorite, as a disinfectant.

Disinfection and control methods

Disinfection is carried out whilst the system is not in use, or 'off-line'.

Control methods are used to kill bacteria and prevent their growth while the system is in use, or 'on-line'.

Chemical disinfection – off line

The use of oxidising disinfectants is still the most commonly used method of disinfecting both new and existing domestic hot and cold water systems and is highly effective when carried out correctly. The most common oxidising disinfectant used is sodium hypochlorite (often referred to as 'chlorination') but stabilised chlorine dioxide is rapidly gaining in popularity as an alternative without the problems associated with hypochlorite's use. Other oxidising disinfectants like bromine and ozone, and non-oxidising disinfectants are commonly used for disinfecting industrial process and cooling water systems. Water containing disinfectant at concentrations greater than that approved for drinking water is classed as fluid category 3 under the Water Regulations so suitable backflow prevention is required. It is also a hazardous waste so suitable disposal procedures for used disinfectant solution must be followed and if necessary, consent to discharge must be obtained from the Environment Agency.

Thermal disinfection - off line

This method, often referred to as pasteurisation, involves raising the water temperature in the calorifier and circulating through the entire system for at least an hour, running each tap and outlet for 5 minutes, with a temperature between 60-70°C being maintained at all times in all parts of the system. Good insulation is vital, as It may be difficult to maintain a high temperature in all parts of the system for the time required. Scalding may be a significant risk, due to the high temperatures and risk control methods need to be in place. Thermal disinfection does not address the need to disinfect the cold-water storage and feed system to the calorifiers.

Chemical dosing - on line

The most commonly used methods are the continuous dosing of chlorine or chlorine dioxide, or the release of copper and silver ions from electrodes. All can be equally effective if delivered and managed correctly and if the water conditions required for them to operate effectively are maintained. Temperature, hardness/alkalinity, pH, dissolved solids - these may all have an effect on the efficacy of some of these systems. It is therefore essential that the system is properly assessed, designed and maintained as part of an overall risk control strategy. Chemicals continuously dosed to domestic water systems will require approval for use in drinking water.

Temperature control - on line

This requires the storage of hot water at 60°C and distribution so that a temperature of at least 50°C is attainable at all outlets within 30-60 seconds of running. Cold water storage and distribution is recommended to be at 20°C or below. For hot water systems these temperatures present a risk from scalding. Where a significant scalding risk has been identified the use of thermostatic mixing valves at the point of use to appliances should be considered.

The NHS Estates Health Guidance note on safe hot water temperatures, recommends maximum outlet temperatures for different appliances.

Other methods

Other disinfection methods for domestic systems are available, for example ultraviolet light (UV) or ozone, but these are considered to be non-dispersive, i.e., their effect is close to the point of application, not to the system as a whole and as a consequence are not always as effective.

Please Note

Schedule 2 paragraph 13 of the Water Supply (Water Fittings) Regulations 1999 requires that 'Every water system shall be tested, flushed and where necessary disinfected before it is first used'.

However, there are a number of factors to be considered before attempting the disinfection of any water system and approved training is required before undertaking either risk assessment or the disinfection of water systems within buildings. It is also essential to remember that disinfection and control methods are not a substitute for maintaining a high degree of water system cleanliness and carrying out good plumbing and engineering practices.

Water quality

The quality of water is defined by chemical and bacterial analysis and where the end usage is directly or indirectly for human consumption. It should comply with recognised standards to ensure freedom from harmful bacteria, acute and long-term toxic substances and in addition, the water should be clear, odourless, tasteless and wholesome.

The *International Standards for Drinking* Water produced by the World Health Organisation define the toxic limits for substances frequently found in water supplies.

Waters that satisfy the quality standards for human consumption are not always suitable for certain medical, industrial and commercial uses. They may contain levels of trace elements, high total dissolved solids contents, non-pathogenic bacteria, gases and suspended matter which necessitate some form of treatment before water can be used in activities such as food and pharmaceutical preparation, brewing, research, medicine and in many areas where heat generation and transfer take place.

Pure water exists of an equilibrium between the acid species, the hydrogen ion (H^+) and the hydroxyl ion (OH). In neutral water the acid concentration equals the hydroxyl concentration, and at room temperature they are both present at 10^{-7} gram equivalents (or moles) per litre. The purest water contains no ions at all.

Water that has 10^{-7} gram equivalents per litre of hydrogen ions is said to have a pH of 7.

pH is a numerical indication of the intensity of acidity or alkalinity of a solution. It is defined as - log 10 (H^+), where (H^+) is the hydrogen ion concentration. The scale is logarithmic and runs from 0-14. Low numbers are acidic and high numbers are alkaline. A neutral solution exhibits pH of 7. The logarithmic nature of pH can be confusing, e.g., as the acid concentration increases, the pH value decreases. A solution of pH5 is 10 times more acidic than one of pH6 and 100 times more acidic than one of pH7.

Deionised water

Where water is required to a higher biological and chemical purity than that supplied by the local water company, single or mixed bed deionisers are capable of producing pure and ultra-pure water approaching theoretical H_2O.

Purity is usually measured by a conductivity monitor that measures the conductivity in microsiemens. Totally deionised water has zero conductivity (as there are no ions present to carry current).

The operation of deionisation is based on using twin bed or mixed bed columns of positive and negative charge ionised resins so that the incoming water disassociates into positively charged ions such as magnesium and calcium which exchange with the hydrogen ions of the acidic resins.

Likewise, the negative ions of sulphate and bicarbonates are exchanged with the hydroxyl ions of the alkaline resins, the resultant hydrogen and hydroxyl ions combining to form theoretical H_2O. The exhausted resins are periodically replaced or regenerated with acid and alkaline regenerates.

As the name of the process implies, only ionisable dissolved solids and gases can be removed and the treated water is not necessarily pure or sterile. Centralised recirculating systems, local units, and both in combination where terminal polishing is required, can produce water up to the megohms at 25°C which is close to theoretical maximum.

Figure 18 shows a two-bed recirculation system suitable for providing 3m³/hr of deionised water up to 1 microsiemen centimetre quality.

Softened water

Water softening in large quantities for commercial use and distribution is usually carried out using one or more of the lime or lime/soda processes. For domestic application however, the base exchange system of softening is more commonly used and only this method is described. Base exchange softening operates on a similar principle to the ion exchange described in the ionised water and functions by the process of exchanging sodium salts for those of calcium.

The action of softening can be expressed chemically as follows:

SODIUM CALCIUM CALCIUM SODIUM

+ exchanges to +

ZEOLITE CARBONATE ZEOLITE CARBONATE

And that of re-generation:

CALCIUM SODIUM SODIUM CALCIUM

+ exchanges to +

ZEOLITE CHLORIDE ZEOLITE CHLORIDE

Because the base exchange system produces water of zero hardness, it is often only necessary to soften part of the total water requirement and blend the raw and softened water together.
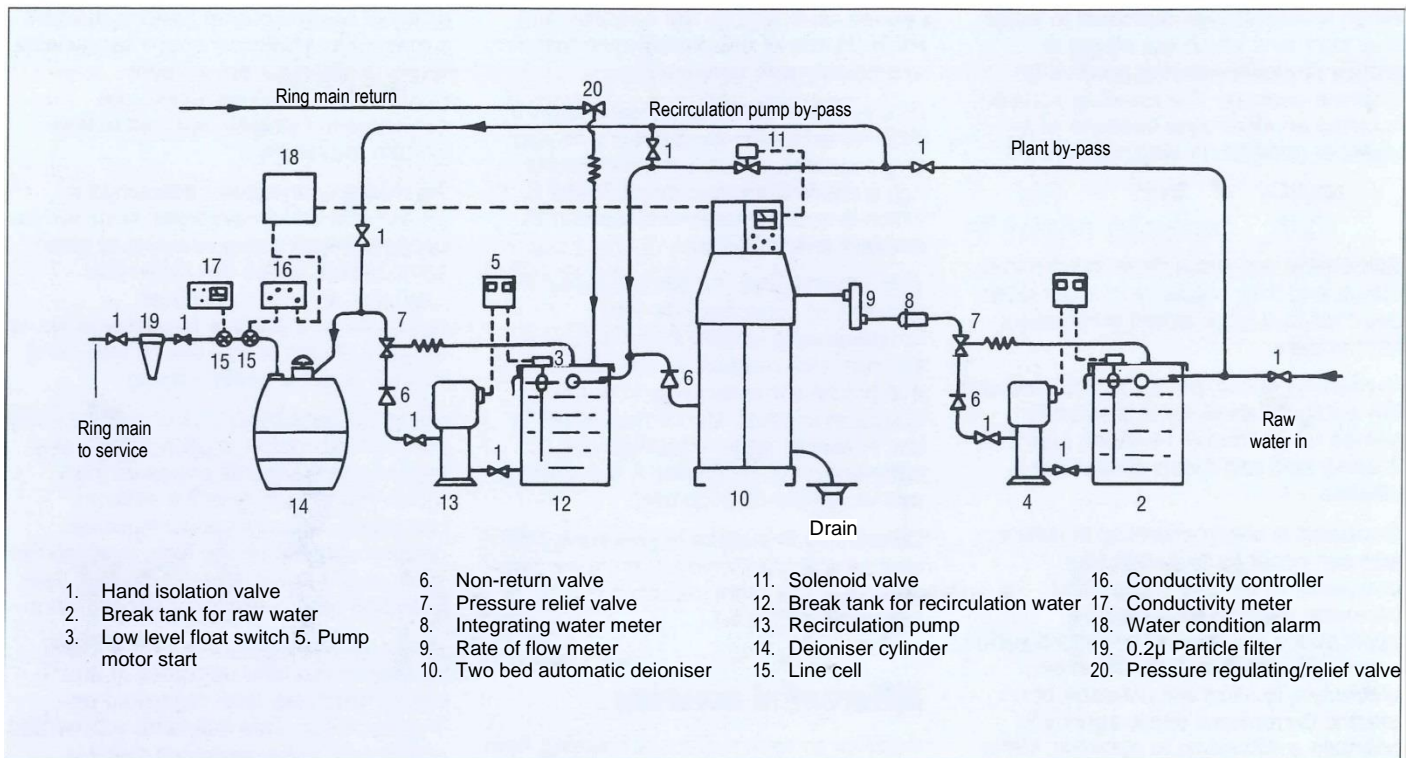
Figure 18 Recirculation deionisation system

1. Hand isolation valve
2. Break tank for raw water
3. Low level float switch 5. Pump motor start
6. Non-return valve
7. Pressure relief valve
8. Integrating water meter
9. Rate of flow meter
10. Two bed automatic deioniser
11. Solenoid valve
12. Break tank for recirculation water
13. Recirculation pump
14. Deioniser cylinder
15. Line cell
16. Conductivity controller
17. Conductivity meter
18. Water condition alarm
19. 0.2µ Particle filter
20. Pressure regulating/relief valve

Operation of a base exchange water softener

The raw/hard water supply is connected into the top of the softener tank and flows downwards under pressure through the bed of softening material (zeolite) where the hardness is removed by the process of 'ion exchange'. At the same time, sediment in the water is filtered out and retained by the mineral bed. Clear soft water leaves the bottom of the tank into the water distribution system.

The softening mineral eventually becomes saturated with hardness and no longer softens the water. Regeneration of the softening material is then necessary and the three-stage process is as follows:

Backwash

Reverse the water flow through the mineral bed to remove accumulated sediment and wash to drain. A backwash controller is necessary to limit the water flow and thus prevent washing out the mineral bed.

Brine rinse

Ordinary salt (sodium chlorine) has the ability to fully restore the softening capacity of the mineral. A measured amount of salt brine is drawn from the brine tank through the brine injector and rinsed slowly down through the mineral bed to remove the hardness, which is rinsed to drain.

Flushing

The water flow is again reversed to repack the mineral bed and any trace of sediment not removed by the backwash is flushed to drain. The softener can now be returned to normal service.

Corrosion

Corrosion is one of the major causes of premature failures in plumbing services. Not only is it responsible for increased maintenance cost but losses in efficiency, particularly in heating systems, can increase running costs.

Corrosion may be defined as the reaction of a metal with its environment resulting in damage that impairs the function of a component or system. Whilst the mechanisms of corrosion are common to different plumbing applications, methods of control and/or prevention have to be tailored to suit that particular environment.

Causes of corrosion - basic theory

Before discussing the causes of corrosion in detail it is useful to define and clarify in simple terms some of the nomenclature used in the text.

A salt (not to be confused with common salt, NaCl) is formed by the replacement of acidic hydrogen in an acid by a metal or basic group.

$$2Na + H_2SO_4 \rightarrow Na_2SO_4 + H_2I$$
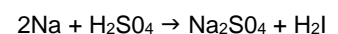
Metal   acid   a salt   hydrogen

When most salts are dissolved in water, they form ions which are atoms or groups of atoms carrying positive or negative charges. The resulting solution is called an electrolyte because of its ability to conduct an electrical current.

$$Na_2SO_4 \rightarrow 2Na^+ + SO_4$$

a salt   positive ion   negative ion
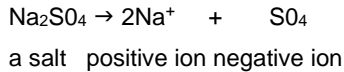
Some salts are much more soluble than others and their solubility in water often depends to a large extent on solution temperature.

In practical terms, pH is used to measure the acidity or alkalinity of a solution. Values range from 0-14, those less than 7 being acid and those greater are alkaline.

Corrosion is electrochemical in nature and can occur by oxidation (dry corrosion) or wet corrosion. Most corrosion problems in plumbing applications are caused by wet corrosion which requires the presence of an electrolyte to allow the passage of an electric current and some agency to maintain a difference in potential. Many corrosion processes also require the presence of oxygen. Natural and supply waters contain dissolved salts that make them into electrolytes and therefore capable of carrying an electric current. The factors which may cause and will affect the rate of corrosion are as follows:

Solution potential

If a metal is placed in an electrolyte, corrosion in the form of a chemical reaction may occur accompanied by the passage of an electric current. That part of a metal system where current, i.e., positive charges in the form of metal ions, leaves and enters the solution is called the anode while the resulting electrons (negative charges) migrate to an area of higher potential, the cathode, where they react with other ions or oxygen.

In the corrosion process it is always the anode that is dissolved. The difference in potential between the anode and the cathode at equilibrium is termed the solution potential. This potential has different values for different metals and conditions, e.g., temperature, electrolyte concentration and the surface or metallurgical condition of the metal, has a profound effect on corrosion.

Temperature

In general, rates of chemical reaction and therefore corrosion, increase with a rise in temperature. However, some corrosion reactions, for example the corrosion of steel in aerated solution, may be controlled by the solubility and diffusion rate of dissolved gases that vary appreciably with temperature.

As the rate of corrosion of steel is partly determined by the availability of oxygen at the surface, it is found that this rate has a maximum in the range 75-85°C, which is approximately 4 times that at ambient temperatures.

With other metals, for example zinc, the variation of corrosion rate with temperature is related to the nature of the corrosion product. At temperatures that produce a continuous/adherent corrosion product, the corrosion rate is low. However, when a granular, nonadherent product is formed, the corrosion rate increases considerably.

Differences in surface temperature on the same metal component can create areas differing in potential, resulting in increased corrosion.

Differential aeration

If part of a metal surface is shielded from air, the natural oxide film can break down. Where the oxygen availability is low, these areas become anodic to those areas to which there is greater supply. This results in localised corrosion, which can occur particularly in crevices and also underneath surface deposits, for example mill scale. This type of corrosion is called differential aeration.

Dissolved salts

The influence on corrosion of salts dissolved in natural or supply waters is determined both by their concentration and more importantly, by the type of ion produced in solution. In general, a high dissolved solids content would be expected to exacerbate corrosion, due to the increase in conductivity, if conditions favour it. Some ions, however, for example carbonates, can be protective due to their scale forming ability on metal surfaces. Other ions, in particular chloride and sulphate, are aggressive as they interfere with the development of protective films and also allow passive films to be broken down more readily. Both ions occur naturally in source waters, with additional sources of chloride being fluxes, washing up liquids (sometimes misguidedly used to quieten noisy boilers), and malfunctioning water softeners. Sulphate ions also support the growth of anaerobic bacteria.

Although in certain conditions the overall rate of corrosion may not be increased, the attack may be more localised and therefore corrosion pits tend to be deeper.

In the absence of aggressive ions, the corrosion rate of steel at different oxygen concentrations reaches a maximum, however, where appreciable levels of chlorides are present (>200mg/litre), the corrosion rate continues to increase with increasing oxygen availability.

Two indices have been developed to predict whether a carbonate scale will be deposited from a supply water of given composition. These are called the Langelier and Ryznar indices respectively; a positive Langelier index or a Ryznar index of less than 6 indicating that the water is scale forming.

Since the deposition of a carbonate scale can stifle corrosion, it often follows that these waters are less corrosive than those that tend to dissolve calcium carbonate. Their behaviour however, depends greatly on the form in which the scale is laid down, a discontinuous layer providing relatively little protective value.

When natural water runs over a metal surface, it can take up traces of that metal, which are later deposited on another metal. This may form a bimetallic couple and if the deposited metal is cathodic to the substrate, rapid corrosion will ensue. Typical examples are copper pipework upstream from galvanized cisterns and run-off from copper roofs into aluminium gutters. The high acidity of rainfall in certain areas, due to the dissolved sulphur and nitrogen oxide pollutants has generally resulted in reduced service life of exposed metal surfaces.
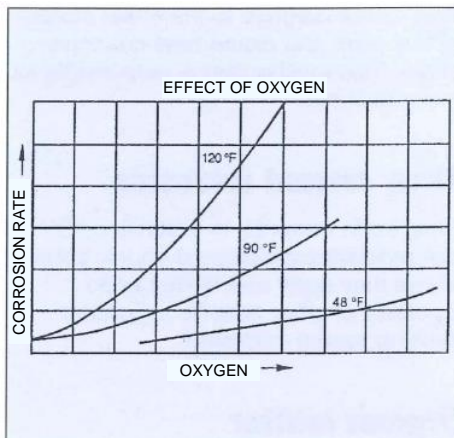
Surface effects

Certain surface films are cathodic to steel and under wet conditions where there are breaks in the film, the underlying steel surface becomes the anode and will corrode preferentially.

Ion concentration

As discussed above, the solution potential is affected by the concentration of ions in the electrolyte. The higher the concentration, the more cathodic the metal becomes. If therefore, a metal surface is in contact with an electrolyte that varies in concentration, those areas of metal in contact with dilute solution will become anodic to those areas in contact with the more concentrated solution and corrosion will be accelerated.
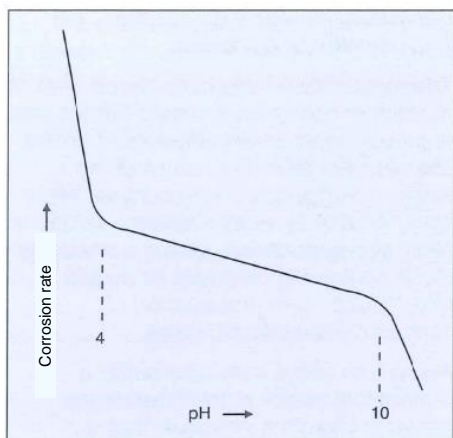
Graph 5 *The effect of pH on mild steel corrosion rate in an open recirculating cooling system*

Graph 6 *Effect of oxygen concentration on corrosion at different temperatures*

Table 30 *Galvanic series of metals and alloys in natural waters*

Metal	Normal electrode potential (vs standard hydrogen electrode, mV) 'Noble' or cathodic, i.e., protected end
Graphite (carbon)	+200
Titanium	
Silver	
Nickel	
Monel	
Austenitic stainless steel (types 304/316)	
Copper	
Ferritic stainless steel (type 416)	
67/33 Nickel copper	
Martensitic stainless steel (type 431)	
Aluminium bronze	
70/30 Brass	0
Gunmetals, phosphor bronzes and tin bronzes 60/40 brass	
Chromium	-100
Tin	-200
Tin-lead solder	
Lead	-300
Steel	-400
Cast iron	
Cadmium	-500
Aluminium and aluminium alloys	-700
Galvanised iron Zinc	-800
Magnesium and magnesium	-1300
'Base' or anodic, i.e., corroded end	

pH

Waters with a pH below 7 will dissolve most metals to an appreciable extent. This will not necessarily cause serious deterioration of the metal structure concerned, but it can produce undesirable amounts of dissolved metal in the water.

Graph 5 shows the effect of pH on the corrosion of iron. Within the acid range (pH<4), the iron oxide film is continually dissolved. The increased potential for calcium carbonate deposition with higher pH causes the corrosion rate to decrease slightly from 4-10. Above pH 10, iron becomes increasingly passive.

Dissolved gases

The significant gases are oxygen and carbon dioxide. Oxygen is the main driving force for corrosion of steel in water. The increase in corrosion with temperature for a given oxygen concentration is due to more rapid oxygen diffusion occurring at higher temperatures.

Carbon dioxide is present in some supply waters, particularly those derived from deep wells and has the effect of lowering the pH. This will cause any protective scales to dissolve.

It must be borne in mind that plastic materials, unlike metals, are permeable to gases. This can exacerbate oxidative corrosion of iron/steel components in closed systems where plastic pipework is used for distribution or under floor heating.

Contact with dissimilar materials

Metals

If different metals are immersed in an electrolyte, after a period of time each will attain a characteristic potential. In this way it is possible to arrange metals in what is termed a galvanic series; however, the precise order may differ slightly depending on the particular metal/alloy composition and the nature of the electrolyte.

Table 30 gives the galvanic series for metals and alloys when in contact with natural waters.

Corrosion occurring when two differing metals/alloys are in electrical contact is termed bimetallic corrosion. There are three other factors that can influence corrosion at a bimetallic junction.

The first is the relative areas of the two metals in contact. If the area of the cathodic metal is large compared with that of the anodic (corroding) metal, corrosion would be concentrated resulting in rapid attack. Conversely with a large anode connected to a small area of cathodic metal, although some corrosion will be localised adjacent to the contact area, most corrosion will be distributed over the remaining area and the relative thickness loss will be less.

The second is the conductivity of the electrolyte. In an electrolyte of low conductivity, attack will be confined adjacent to the joint area and may be relatively intense. Where the electrolyte conductivity is high, the attack will spread out more and the level of general corrosion will be greater.

The third factor concerns electrical contact between the dissimilar metals. Some metals, in particular aluminium and stainless steel, form coherent oxide films in air which are non-conductive.

If they prevent a current flow between the metals, then bimetallic corrosion will be prevented. In the absence of dissolved oxygen, bimetallic contact will not cause iron and steel surfaces to corrode.

Other materials

Many non-metallic materials found in or around buildings can be responsible for corrosive attack on metals. Some woods are acidic and under damp conditions can cause attack on steel, cadmium, zinc and lead. If the wood has been treated with a copper/chrome arsenate preservative, corrosion can be accelerated and in particular aluminium alloys and zinc are attacked.

Fresh concrete is very alkaline (pH12.6-13.5) and while this is responsible for protecting steel reinforcement against corrosion, other metals, for example zinc, aluminium and lead will be attacked. Some concrete also contains chlorides, which will increase the risk of corrosion.

Bleach and some soldering fluxes contain high level of chloride ions, which will cause rapid attack on many metals including copper and stainless steel.

Furthermore, some plastics on heating or degradation also give off acids and/or chlorides, which in the presence of moisture will cause corrosive attack.

Soils are complex in nature and therefore are extremely variable in corrosive activity. The most widespread form of corrosion is due to sulphate reducing bacteria. Other problems are caused by acidic conditions due to natural constituents or contamination by industrial waste, for example ashes and clinker.

Although not strictly corrosion, it is worth mentioning that other industrial wastes, for example, tar, oils, can cause failures in buried plastic pipework due to environmental stress cracking. They may also attack protection on metal pipework, thus exposing the underlying surfaces to corrosive attack.

Bacteria

In the absence of oxygen, corrosion may continue by the cathodic reduction of sulphate, which is present in most soils and natural waters. This is facilitated by anaerobic bacteria (called sulphate- reducing bacteria, disulpho-vibrio disulphoricans) that are able to use cathodic hydrogen in their living process and convert sulphate to sulphide. This type of corrosion is responsible for the smell of 'bad eggs' (hydrogen sulphide) sometimes observed when venting radiators.

Flow, erosion, impingement and cavitation

Corrosion can be aggravated by the nature of water flow across a metal surface. The overall rate will be controlled both by the rate of reaction and how quickly reactants and products can approach and leave the metal surface. These are termed chemical and diffusion control respectively. Flow may be stagnant, laminar or turbulent which will affect the rates of diffusion.

Where the flow is turbulent, the impingement of gas, liquid or solids or a combination of any three can cause mechanical damage, which removes or prevents formation of a protective film. If the metal or alloy is corrodible in that environment, localised attack of the surface will occur.

Cavitation is a particular type of attack that occurs when a metal surface is exposed to a high velocity, low-pressure liquid.

In areas where the pressure is sufficiently low, pockets of vapour form, which may suddenly collapse when they pass to an area of higher pressure.

The shock generated is sufficient to cause mechanical damage to the metal surface at that point and exacerbate corrosive attack. This mechanism is responsible for water hammer.

Stray current corrosion

Stray earth currents, in particular DC, can produce cathodic and anodic areas where they enter and leave buried pipelines or other metallic structures causing severe corrosion.

Organic matter

Organic matter, derived from their natural or industrial sources, may lower the pH and increase corrosion rates as well as preventing scale deposition. Bacteria are also often present in organic matter and these may be responsible for fouling and increased corrosive attack under both aerobic and anaerobic conditions.

It can be seen from the forgoing that corrosion phenomena are very complex in nature and are affected by many factors. Most of these factors can have a profound effect on corrosion rates and highlight the difficulties in predicting corrosion behaviour and time to first maintenance or failure. However, many techniques are now available for identifying, monitoring and controlling corrosion to acceptable limits.

Effects of corrosive environments

Corrosion can manifest itself in numerous ways, depending on the metal or alloy and particular environment in which it is in contact. It is convenient to look back at the various metals likely to be encountered in plumbing applications and the environments that can be detrimental to their service life.

Some of these metals are also used as protective coatings and their performance together with that of the substrate is also considered.

Aluminium and aluminium alloys

Although aluminium is a very reactive metal, it has a high resistance to corrosion because of the tenacious, inert oxide film that forms on the surface. Pure aluminium is generally stable in the pH range 4.5-8.7 but outside this range, attack can be rapid.

Aluminium alloys, particularly those containing copper in significant quantities (Duralumin), are less resistant to corrosion.

The most commonly encountered form of aluminium corrosion is pitting but the rate of propagation is very dependent on the alloy composition and nature of the solution with which it is in contact. While many neutral or weakly alkaline solutions allow self-passivation, others particularly those containing chlorides or copper ions, cause rapid propagation of corrosion pits in some alloys.

Aluminium alloys may also suffer a preferential attack at the boundaries between the grain structure that is termed intercrystalline corrosion.

Aluminium and its alloys have very good resistance to atmospheric corrosion providing the surfaces are regularly washed by rain etc. Where deposits of, for example acidic sulphates are allowed to build up on sheltered surfaces, moisture from condensation is sufficient to give an increased rate of attack.

In all environments, aluminium is very sensitive to bimetallic corrosion. Contacts with copper and copper alloys, and to a lesser extent, iron and iron alloys, should be avoided.

Cadmium

The main application of cadmium is as a protective coating on steel. It is particularly useful as a plated finish on high strength steels where zinc finishes can heighten the risk of cracking due to hydrogen embrittlement. Its corrosion behaviour is similar to zinc and although it is less protective to steel, unlike zinc, it is stable in alkali solution.

Cast iron

Cast irons are ferrous alloys containing generally 2-4% carbon and frequently have high silicon contents. A wide variety of compositions are available, and additions of silicon, chromium and nickel can be used to improve corrosion resistance. Typical applications include boiler sections, pump housings and pipe fittings (malleable iron). Although corrosion rates are similar to those of steel, above ground corrosion is not normally a problem due to the thick sections used for cast iron components.

When in contact with some natural waters, particularly those that are slightly acidic or contain chlorides (salt), cast iron may suffer a form of attack called graphitisation. The iron corrodes leaving weak, porous structure composed of graphite and iron oxides. This can result in catastrophic failures in underground pipes where soil or ground movement causes large sections where graphitisation has occurred to crust without warning.

Although not directly associated with corrosion, it is worthwhile mentioning a common cause of premature failure in gas-fired sectional boilers. If hard-water scale is allowed to build up inside the cast iron sections, and flame impingement occurs on the outside, overheating can cause a change in the cast iron structure to a weaker 'undercooled' form. Subsequent thermal stress can result in fracture and consequent leakage from the boiler.

Copper and copper alloys

Copper and its alloys comprise a versatile range of materials, which are used in a wide variety of plumbing applications.

Copper is used extensively for pipework and heat exchanges due to its excellent ductility and thermal conductivity. A wide range of copper alloys are available and in addition to the aforementioned applications, they are used for valve and pump components, pipe fittings, etc.

Most problems occur when these materials are in contact with water or steam containing dissolved oxygen or carbon dioxide and/or acids or chlorides, although corrosion can also result from contact with aggressive atmosphere e.g., flue gases or certain bacteria.

These environments cause a breakdown in the protective oxide film formed on the surface by contact with oxygen and water, thus allowing corrosion to proceed. Not only will this eventually result in failure of the component, but also dissolved copper can cause accelerated corrosion if it is deposited on other metals that are more anodic.

Copper

Copper is used extensively in the form of tube for pipework and the manufacture of hot water cylinders. When in contact with natural waters corrosion can occur by a variety of mechanisms.

A major factor in the corrosion of copper is dissolved oxygen. The higher the temperature of the water the less dissolved oxygen it can contain, consequently cold water is more corrosive to copper than hot water. Typically, when copper is first exposed to a water, a significant increase in the copper concentration will occur, however, within a short period of time the corrosion rate will fall to an acceptable level due to the formation of protective films or scales on a metal surface.

Waters given rise to the highest rates of corrosion are those drawn from wells and springs (usually privately owned) which are often soft and contain dissolved carbon dioxide. Such waters are called cuprosolvent. Here the role of dissolved oxygen is less significant, and corrosion is most marked when the water has been heated.

Pitting corrosion of copper is divided into three categories:

Type 1

Type 1 pitting is characterised by broad/shallow pits. Temperature is a significant factor with corrosion more likely to occur in cold and lukewarm water than in hot water. It is most usually associated with borehole waters or waters that have been treated by flocculation. Often the total hardness of the water is greater than 100mg/l and is usually greater than 150mg/l, but corrosion can occur in soft waters. It is thought that in surface derived waters, the presence of extremely low levels of organics such as polyphenols acts to inhibit this form of attack. Type 1 pitting needs initiation and used to be caused by carbon film in copper tube remaining after the drawing process. The modern use of abrasive cleaning of the tube minimises the problem.

Type 2

Type 2 pitting is characterised by narrow/deep pits. It occurs in soft waters at temperatures above 60°C. The bicarbonate/sulphate ratio is often less than 1 with the pH less than 7.6. In the United Kingdom it is thought that the presence of manganese is contributory.

Type 3

Type 3 pitting is characterised by pepper pot holes under a crust. This form of corrosion remains a major area of research. It is virtually unknown in England but is prevalent in Scotland where it is associated with moorland waters. The cause is uncertain; however, it appears that the standard of tubing is not important. Research is concentrating on finding methods of analysis for the detection of microscopic quantities of organic acids, which it is thought, might be contributory.

Copper cylinders can be prone to pitting attack, particularly in the base sections where near stagnant conditions exist in crevices or underneath debris. In an attempt to control the problem, the incorporation of aluminium anodes, which corrode preferentially whilst a uniformly thick protective film builds up on the surface of the copper, was included in a British Standard and soon became commonplace. In most cases it was necessary only for the anode to remain intact for approximately 3 months to fulfil its purpose.

Problems, which have been generally confined to cylinders not fully complying with BS1566 (for indirect) or BS699 (for directs), were found to arise in two ways from one cause. Poor insulation of the connection point resulted in early detachment of the anode, whereupon it fell to the base of the cylinder, causing a massive buildup of oxide sludge. Normally such oxide debris would form around the extremities of the anode and be carried away by the water flowing through the vessel, however, where sludge built up, under-deposit corrosion of the base of the cylinder was initiated due to differential oxygenation. Rapid failure could occur. If failure didn't occur in this way, the absence of the anode from its proper position allowed corrosion by the mechanisms it was originally installed to prevent.

Rosette corrosion is another form of copper corrosion. The phenomenon is so named because the corroded copper has the characteristic appearance of petal shapes etched on to its surface. There are no reported instances of copper other than that associated with cylinders being affected. Research into the causes continues, but factors known to contribute to its occurrence include nitrate and the presence of an aluminium anode. There is also evidence that rosette corrosion is favoured when a copper vessel fitted with an aluminium anode has been allowed to stand full of water for an extended period.

In some parts of the country, the concentration of nitrate has risen significantly over the last few years, probably due to the permeation of nitrate based fertilisers down to the aquifers providing all or part of the mains supply water. However, it remains unproved that this is the main factor responsible for the apparent increase in rosette corrosion.

Changes to the design of cylinders to inhibit the formation of stable areas of colder water (less than 30°C) will prevent many early failures, whether they are due to Type 1 pitting, or by elimination of the aluminium anode, rosette corrosion. Standards include a test to ensure that water in the base of the cylinder is heated appropriately.

Specifiers and installers can also take sensible steps to help themselves, by installing only units correctly sized for the job, so eliminating large volumes of unused water from residing in the vessel. In regions of the country where pitting failure is known to be a problem, end users should be encouraged to periodically drain their cylinder completely. This might well be applied to cylinders filled and left in non-use situations, e.g., new unoccupied properties.

Compared with its alloys, copper generally has a lower resistance to impingement attack in waters containing oxygen and/or carbon dioxide. Where dissolved gases are absent, for example in closed heating systems, this type of attack is not a problem. Table 31 gives recommended maximum water velocities for copper pipework carrying fresh aerated water of pH not less than 7.

Table 31   *Maximum recommended water velocities for copper tube at different temperatures (metres/second)*

Temperature °C	10	50	70	90
Pipes that can be replaced	4.0	3.0	2.5	2.0
Pipes that cannot be replaced	2.0	1.5	1.3	1.0
For short connections which are used intermittently, e.g., taps	16.0	12.0	10.0	8.0

Impingement attack has a distinctive appearance, the pits formed having a water swept appearance, sometimes in the shape of horseshoes and being free from corrosion products. In closed heating systems where the oxygen content is low, this type of attack does occur.

Copper can fail by stress corrosion cracking (the combination of constant stress together with a specific corrodent, (see brasses) and corrosion fatigue results from the conjoint action of fluctuating stresses, which may be caused by expansion and contraction in restrained pipework, vibration of equipment, poorly supported tubes, or pressure variations and a corrosive environment.

Occasionally, corrosion can result in copper calorifiers where large temperature differences exist. This may be between a coil carrying steam, high temperature water under pressure or immersion heater sheath and the calorifier shell. The large differences in temperature are sufficient to generate a potential difference and cause preferential attack on the hotter surface. This may be prevented by electrically insulating the shell and heater.

Brasses

The common brasses consist of a range of copper alloys containing from 10-50% zinc and other minor alloying elements. Alloys containing up to 39% zinc from a single-phase alloy with copper is termed a brass and in the range 47-50% zinc is another single-phase alloy termed (3 brass.

Alloys containing 39-47% zinc content, both phases are termed a + (3 or duplex brasses. The latter alloys are more suitable for hot pressing or diecasting small components.

An alloy has been developed having a controlled composition so that it is suitable for processing as a duplex brass, but heat treated to attain the dezincification resistance of inhibited brass (see below). This material is termed DZR (dezincification resistant) brass and fittings are marked by the Water Research Centre recognised symbol CR. It should be noted that brazing alloys containing zinc can suffer from similar forms or attack to brasses.

Brasses can suffer a form of selective corrosion called dezincification. Zinc is preferentially removed from the alloy leaving a porous mass of copper having little strength. Where the zinc corrosion products are not washed away, they may form bulky hollow shells which readily block waterways. This is termed 'meringue' dezincification. In the single-phase brasses the whole of the metal is corroded either uniformly over the surface or more commonly on the form of a 'plug'. With duplex brasses the phase which contains a higher proportion of zinc is preferentially attacked.

In general, the risk and/or rate of dezincification is increased by higher proportions of zinc in the alloy, high temperature, high chloride content of the water, low pH, low temporary hardness, low water speed and the presence of surface deposits or crevices.

Where leakage or breakage of a fitting has occurred, dezincification may be suspected if the defective areas have a dull, coppery appearance.

Brasses may be inhibited against dezincificaiton by small additions of arsenic. Duplex brasses cannot be inhibited in this way and where there is a risk of dezincification, either DZR brass or gunmetal must be used.

Where brasses have a high degree of internal stress, which may be induced during manufacture, in particular those containing ammonia or ammonium compounds (in-organic or organic) can cause failure by a mechanism called stress corrosion cracking (season cracking). The corrosive environment is normally external and may result from an ammoniacal compounds used as light weight concrete foaming agents, in rubber lattices used as cement additives or for bonding floor tiles, and from fertilisers either as residues in aggregate or airborne pollution.

In common with copper, brasses can suffer attack by impingement or cavitation. This may cause particular problems down stream from valves that when properly open, cause a pressure drop sufficient to create air bubbles from dissolved gasses and initiate attack. It is important therefore that valves are carefully positioned in plant so that possible damage from this type of attack is minimised.

Bronzes (gunmetals, phosphor bronzes and tin bronzes)

Technically the term 'bronze' should refer to copper-tin alloys, but in practice a variety of copper alloys are termed bronzes, irrespective of whether they contain tin.

This wide variation in composition makes corrosion behaviour of a component difficult to predict unless the specific composition is known.

In general, copper-tin alloys have a good resistance to corrosion when in contact with both water (natural and sea) and steam and rarely suffer from the selective attack (dezincification) that brasses do.

Aluminium bronze

These materials generally have a high resistance to corrosion, impingement attack and cavitation erosion. They are however, surprisingly prone to pitting corrosion in natural waters and can suffer selective corrosion analogous to dezincification.

Cupro nickel alloys

Alloys containing copper and nickel have excellent resistance to corrosion and many environments, including those containing chlorides. They are more stable than brasses under flow conditions, less susceptible to stress corrosion and are used in heat exchanger applications.

Lead

Lead and lead alloys have a good corrosion resistance due to the formation of insoluble adherent carbonate or sulphate corrosion products. These films are protected and may be formed over a wide range of pH values (3-11) in most natural and treated waters. However, in soft waters with a low carbon dioxide content, a less protective oxide film is formed which allows corrosion to proceed slowly.

Lead is generally resistant to atmospheric corrosion but may be attacked by organic acids or free alkali. Run off from roofs bearing organic growths, acetic acid derived from wood and fresh cement, can all cause corrosive attack.

In its pure form, lead has poor mechanical properties and without small alloying additions, is susceptible to creep and fatigue failures induced by thermal movement.

Magnesium

The only plumbing application in which magnesium is likely to be met is that of cathodic protection. The greater negative potential in relation to steel and compared to zinc or aluminium makes magnesium alloys efficient for protecting the interior of steel (either unprotected, painted or galvanised) water cisterns or the exterior of buried steel structures and pipelines.

Soft solders (tin alloys)

Soft solders (i.e., tin alloyed with lead, antimony, silver and/or copper) are anodic to copper and therefore corrosion of solder used in capillary joints could be expected. However, due to the nature of the protective film formed, corrosion often occurs in waters of high conductivity, for example those containing chlorides. Most problems with capillary joints may be attributed to the use of soldering fluxes which leave aggressive residues at, or adjacent to the joint area.

Stainless steels

The term 'stainless steel' covers a variety of alloys which may be simply and conveniently divided into the following three categories:

Martensitic stainless steels

These alloys generally contain 12-14% chromium and from 0.1-2 % carbon, which confers hardenability and controls the mechanical properties. They are used for applications requiring high strength and wear resistance combined with considerable corrosion resistance.

Ferritic stainless steels

Alloys containing 16-18% chromium and having a low carbon content are termed ferritic stainless steels. They are not hardenable and are used for flue and sink components.

Austenitic stainless steels

Often termed 18/8 stainless steels, the common austenitic alloys contain 15-22% chromium, 6-11% nickel and 0.05-0.15% carbon and have the highest resistance to corrosion (grades 302, 304). The addition of molybdenum (2-4%) confers even greater corrosion resistance (grade 316). They are non-magnetic and not hardenable unless heavily cold worked.

The main applications in plumbing services are for pipework, boiler flues, sinks and urinals.

Stainless steels owe their high corrosion resistance to the presence of self-healing oxide films on the metal surface. However, certain environments may cause these films to break down and allow corrosion rates comparable to those of mild steel. The most common environments to cause attack are those containing chlorides and in crevices or underneath surface debris where the absence of oxygen prevents repair of the protective oxide film.

Corrosion of stainless steels is often localised. The presence of chlorides can cause rapid pitting, particularly at grain boundaries and can initiate intergranular attack and stress corrosion cracking.

Steels (low alloy)

Low alloy steels, due to their ease of fabrication and the range of mechanical properties attainable by alloying additions, are used in a wide variety of plumbing applications. When compared with other metals in most environments, they are found to have a much lower corrosion resistance. Under certain conditions, small additions of copper, chromium and nickel improve corrosion resistance, but the overall effect is often small and variable.

Steel can exhibit two entirely different types of corrosion behaviour depending on the nature of the environment with which it is in contact. In the passive state, for example when in contact with neutral or alkaline natural water free from bacteria and oxygen, the corrosion rate is negligible. However, in the active state widely differing rates of corrosion, either general or localised, can occur depending on the many factors that have been discussed earlier.

The most common cause of corrosion is exposure to water containing dissolved oxygen. The rate of attack is greatest when the water is soft and/or acidic and the corrosion products often form bulky mounds in the surface called tubercles. These overlie areas where localised attack is occurring and can seriously reduce the carrying capacity of pipes. In severe cases, iron oxides can cause contamination leading to complaints of 'red water'.

In hard, neutral or slightly alkaline waters, calcium carbonate (lime scale) can deposit on steel surfaces and provide a protective coating.

Although carbon dioxide has no specific influence on the corrosion of steel, it will increase the corrosion rate by lowering the pH and also preventing the formation of protective calcium carbonate films.

In the absence of oxygen, corrosion can occur in waters where sulphate-reducing bacteria are active.

The effect of dissolved gases and calcium carbonate in fresh waters has already been discussed. Water may also contain a variety of other dissolved material present in the supply or as a result of subsequent contamination. Ions such as chloride and sulphate can interfere with the development of protective films and lead to more localised attack whereas other ions such as calcium and bicarbonate have inhibitive properties. Small concentrations of organic matter can improve the protective qualities of carbonate films; however, organic acids resulting from decomposition of vegetation can increase corrosion rates by lowering the pH. Where the pH is reduced to values below 4 as a result of acid contamination, then the corrosion rate will progressively increase with a further decrease in pH. Other surface contaminants such as oil, mill scale or deposits may not increase the overall rate of corrosion but can localise the attack causing pitting and pinhole corrosion.

Steel pipes are not normally suitable for use in wet soils unless protected against external corrosion.

Zinc

Zinc is used almost exclusively in plumbing applications as a protective coating on steel. It may be applied by a variety of methods, which give widely varying coating weights and consequent degrees of protection. Both zinc and zinc alloys have good resistance to corrosion under conditions of exterior exposure and when in contact with most natural waters. This resistance is due to the protective layers of zinc oxide and hydroxide, or other basic salts depending on the nature of the environment, which are formed on the metal surface.

Under atmospheric conditions, the rate of corrosion depends on the degree of pollution. Heavily polluted industrial areas containing sulphur dioxide can increase the rate of corrosion by a factor of up to 10 as compared with rural areas. Where new zinc surfaces are stored under damp conditions, an unsightly white corrosion product may be formed.

This is termed 'white rust' and can be prevented by oiling or a chromate treatment.

In natural waters, the rate of corrosion is governed by the presence of dissolved salts and gases. The presence of carbon dioxide together with calcium and magnesium salts will form a basic carbonate film that is protective to the base metal. Zinc is anodic to steel and will provide protection in the form of a coating even if small areas of substrate are exposed due to damage or in fabrication.

Temperature has a marked effect on the corrosion of zinc in natural waters. Due to a change in the nature of the protective films, the corrosion rate increases in the range of 55°C to 95°C, giving a maximum increase of some 100 times at 70°C. In some natural waters where zinc is used as a protective coating on steel, a reversal of potential occurs above 65°C. The zinc then becomes cathodic to steel, stimulating attack which results in localised (pitting) corrosion and subsequent perforation.

In general zinc and copper or copper alloys are not compatible when used in natural water systems. Where waters which are cupro-solvent (e.g., those containing free carbon dioxide) flow through copper pipework, traces of copper are dissolved which can subsequently deposit as metallic copper on zinc surfaces and stimulate attack due to bimetallic corrosion. Brass fittings on galvanised steel tanks and cisterns, however, rarely cause problems due to the relatively small area of brass to zinc.

Where unprotected galvanised pipes are used below ground the most severe attack occurs in soils which are poorly aerated and/or have high acid and soluble salt contents.

In conclusion, galvanised tanks/cisterns, calorifiers and pipes should not be used at temperatures above 65°C or downstream from copper pipework. Below ground, galvanised pipework is best protected using proprietary tape wrap systems.

Plastic and rubber components

Although polymeric materials do not corrode in the accepted sense, they may degrade when exposed to certain environments. These environments include ultraviolet light, heat, organic compounds and inorganic and metallic ions, but the wide range of materials and compositions available make specific guidance impossible.

Prevention of corrosion

Before deciding on the most suitable course of action required, if any, to control or prevent corrosion, it is often beneficial to assess the nature of the environment to which the metal will be exposed or the rate at which corrosion will occur. In certain cases, metal loss due to corrosion may be economically acceptable providing the required service life or life to first maintenance is exceeded. Furthermore, where corrosion has occurred, there are now several nondestructive techniques that may be used to quantify the extent of the attack and metal loss.

Assessing the corrosivity of the local environment

External surfaces

The external surfaces of pipework, etc. may suffer attack if buried in soil, located in ductwork subject to condensation or flooding, or where exposed to rain, spray, etc.

The aggressiveness of soils to buried metals, particularly ferrous, may be assessed using resistivity data to measure the likelihood of oxidative corrosion and redox-potentials to indicate the risk of bacterial corrosion. Soils may be considered aggressive if the resistivity is less than 200Ωcm at the specified depth or the mean redox-potential is less than +0.400 volts (standard hydrogen scale) when corrected to pH = 7 (+0.430 volts if the soil is predominantly clay).

Accelerated corrosion may also be caused by the presence of stray electrical earth currents from for example, DC railway systems or rectified induced AC from high voltage transmission systems, and these may be identified from the measurement of voltage differences in the soil.

Where metal surfaces may be exposed to natural waters, either due to immersion, condensation or rainfall, corrosion can be severe particularly if salts or other pollutants are present. The likely corrosivity of these environments can be assessed using a variety of electrical and electrochemical techniques.

Internal surfaces

The nature of the water in contact with the metal surfaces may be most conveniently assessed or monitored by chemical analysis of representative samples.

The analysis required depends to a certain extent on the particular situation in which the supply or circulating water is being used.

It must be stressed that conclusions from analytical results should be drawn very carefully and expert consideration needs to be given to the many factors involved. It is only then possible to formulate the most appropriate treatment to control corrosion and also scale deposition, which may affect the efficient operation of a system.

The data given should only be used as a guide and no indications have been given as to the relative importance of the different factors.

Wholesome (supply), hot and cold domestic waters

The ability of these waters to deposit a protective film of calcium carbonate scale on internal metal surfaces can play an important part in controlling corrosion. As described earlier, the Langelier and Ryznar indices indicate whether a particular water will dissolve or deposit a protective scale.

A negative Langelier index indicates that the water will tend to dissolve scale and promote corrosion while a positive index indicates that a protective film will be deposited.

The Ryznar index is a modified form of the Langelier index that is claimed to be more reliable. Using this index, a water is considered to be corrosive when the index exceeds approximately 6 and scale forming when it is less than 6. Where the water is used to feed heating plant, then the hardness value will determine the need for chemical treatment/softening to minimise scale deposition.

Primary and secondary heating waters - chilled water systems

These systems, whether open vented or sealed, should use little or no make-up. Problems can arise when there are excessive water losses, air ingress, and aggressive residues from fabrication or cleaning operations. Flushing will be necessary to reduce the risk of corrosion. Guidance on system cleansing is given in BS 7593: 1992, *'Treatment of water in domestic hot water central heating systems'* (the advice is equally suited to chilled systems). Analytical data can be used to assess the waterside condition.

pH - Aluminium

A pH less than 5.0 or greater than 8.5 is liable to be detrimental to aluminium. A pH outside these limits is unlikely to have occurred naturally.

If the pH is lower than 5.0, an acid is present. If higher than 8.5, the water is alkaline, either due to the presence of an alkaline treatment, e.g., caustic soda, or in some circumstances due to alkali generated within the system naturally.

Conductivity

If the system water has a higher conductivity than the supply water, this indicates that the water has been treated with an inhibitor or contaminated. The levels of concentration to be expected in the other analyses can be estimated from this comparison, e.g., a high conductivity is likely to be associated with high levels on the other tests.

Chloride

Chloride is naturally present in all supply waters. A high level may indicate the presence of residues from acid descaling or chloride-based fluxes. It should be noted that the chloride concentration in a towns mains supply water is liable to fluctuate, however, a level more than 25 mg/l greater or 50% greater in the system, is strongly suggestive of flux contamination.

Sulphate

Sulphate is naturally present in all supply waters. A low level (<10 mg/l) in the system may indicate the presence of sulphate reducing bacteria.

Hardness

Towns mains supplies are categorised in Table 22

Generally speaking, hard water is present in 60% of the country (especially in the Eastern, Central and Southern areas of England) and to varying degrees in the rest of the United Kingdom and Northern Ireland. The water for some northern cities is supplied from naturally soft water reservoirs in Wales and the Lake District.

Most calcium salts form a scale when heated. Comparison with the system water will indicate if scale has been formed. If a high level of hardness is present in the system water after it has been heated, it may be because of water loss and subsequent make-up.

Iron

As a heating system corrodes, iron will dissolve or form corrosion debris and hydrogen gas will be generated. The amount of any debris present (visible as suspended solids) is a factor in determining the seriousness of a corrosion problem. In terms of dissolved iron, an increase of 0.5mg/l over that in the supply water is significant, with an increase of more than 3mg/l very high.

If the test sample contains rust particles, they will be dissolved when the test is carried out. The iron reading will then be the dissolved iron plus the iron due to the particles. Care should be taken to ensure that the suspended solids are representative of the overall system conditions.

Copper

A dissolved copper concentration of 0.2mg/l more in the system than in the supply water is significant.

Aluminium

Where aluminium components are present, an aluminium concentration of 0.3mg/l or more in the system water than in the supply water indicates that some corrosion has taken place. If the pH lies between 5.0 and 8.5, the aluminium surfaces will be passive and further corrosion will not be occurring. Any given concentration of aluminium is not a problem in itself, but an increase over a period should be noted and would require corrective action.

More significance should be attached to the aluminium concentration when an aluminium heat exchanger is fitted. Where aluminium radiators are concerned, concentrations above 0.5 mg/l do not present any special problem, provided there is no deterioration.

Steam boilers and water heaters

BS 2486: 1997 *'Treatment of water for steam boilers and water heaters'* gives recommendations for the control of waterside conditions of steam boilers and water heaters and also for the preparation of feed water for such plant. Categories covered are:

a. Hot water systems i.e. water above 120°C (HTHW), water below 100°C (LTHW), water at 100-120°C inclusive (MTHW)

b. Electrode boilers

c. Shell (fire tube) boilers operating at pressures up to 30 bar

d. Water tube boilers operating up to critical pressure

e. Once through boilers, including 'coil' and 'hairpin' types, operating up to critical pressure.

Cooling waters

Cooling for air conditioning systems is most commonly achieved by evaporation of water, normally 1-1.5% of the circulation rate being used to cause a

temperature drop of 5-8°C. This evaporation leaves behind both dissolved solids that build up until deposition occurs and aggressive ions, for example chlorides, which will exacerbate corrosion. In addition, the cooling water may become contaminated by atmospheric pollution resulting in acid corrosion due to the reduced pH.

Corrosion control and prevention

External surfaces

A variety of methods are available for protecting pipework etc. When their external surfaces are exposed to a corrosive environment.

Organic coatings such as paints, plastic coatings or tape wrap systems may be applied to the metal surface which has been prepared by grit blasting and/or the application of a suitable primer. In general, the more severe the conditions of service, the thicker and more resistant the coating needs to be. These types of coatings can be very susceptible to mechanical damage and this should be borne in mind during installation.

Both tanks and pipes can be repaired and protected using either glass reinforced plastic (GRP) or specially formulated concrete linings.

Metal coatings, for example zinc and aluminium, may be applied to steel surfaces by hot dipping or spraying, which gives the thickest coating, diffusion or in the case of zinc, electro-deposition. These metals will corrode, albeit at a rate much slower than steel and therefore the coating thickness required depends on the aggressiveness of the environment. In severe cases, an additional paint coating may be applied.

Another method of protecting underground pipelines is that of cathodic protection. Two methods are available each of which produce a counter current sufficiently large to neutralise the currents responsible for corrosion. The first uses a more electro-negative metal, the most common being either magnesium, aluminium or zinc, in the form of sacrificial anodes which are connected electronically to the metal requiring protection. The second uses an impressed current from a generator in conjunction with auxiliary anodes of iron, steel, graphite, lead or platinised titanium.

Infernal surfaces

All internal surfaces that store or carry water, for example pipes, tanks, calorifiers, heat exchangers, radiators etc. may be subject to corrosive attack.

There are many different possible approaches to preventing corrosion and it is of utmost importance that the correct method is chosen to suit each particular situation. In most cases, proprietary blends of chemicals are available which fulfil some or all of the required preventative treatment.

Other factors may also need to be considered for example toxicity when treating wholesome waters or if there is a risk of crossover between primary heating and domestic supplies.

Both polyphosphates and sodium silicates may be used as a non-toxic, tasteless, odourless and colourless treatment for domestic waters. They both prevent iron corrosion discolouring the supply water (commonly known as 'red water') and inhibit the deposition of scale by forming a thin film on the metal surfaces, which acts as a barrier. They are dosed either in liquid form using a proportional dosing pump or as slowly dissolving crystals from a suitable dispenser.

Storage tanks/cisterns may be protected internally using cathodic protection. Sacrificial anodes, normally magnesium for steel or aluminium for copper, are connected to and suspended in the tank. While aluminium anodes in copper tanks only have to last for sufficient time to form a permanent protective film, magnesium anodes in steel tanks need to be replaced when consumed.

Primary and secondary heating waters - chilled water systems

These systems, because they are essentially closed recirculating systems, may be treated with either oxygen scavengers, which act by the removal of oxygen responsible for the corrosion process, or inhibitors which slow down the corrosion reactions to acceptable levels, sometimes in conjunction with pH control.

Inhibitors need to be chosen carefully to suit the system under consideration. Some inhibitors may reduce corrosion in one environment while increasing it in another, while others only work effectively in a certain concentration range, actually intensifying corrosion outside this range. Sulphate reducing bacteria may be controlled by maintaining a specified level of biocide in the system.

With the current trend towards very low content boilers, it is also advisable to use sludge conditioners to prevent scale deposition inside boiler sections and tubes. These materials should be used with caution in older systems as they may dislodge scale and corrosion products highlighting weaknesses at joints and causing leaks.

Where larger systems suffer continuous water loses due to the presence of leaks, it can be beneficial to use softened water for make-up to reduce the need for frequent scale removal.

Cooling waters

Corrosion may be controlled by dosing the system with a suitable inhibitor. This needs to be carried out continuously at a rate proportional to the bleed-off required to prevent scale deposition and excessive levels of aggressive ions building up. The treatment should also include sludge conditioners to prevent localised scale deposition and biocides to control bacteria and algae (slime) growth.

In hard water areas, the cost of water and treatment chemicals can be high and therefore consideration should be given to using a softened make-up supply. Disposal of bleed-off water also needs to be considered as some treatment chemicals are toxic and cannot be drained into local sewerage systems.

Steam rising plant

Steam boilers are treated by ensuring that the boiler water is alkaline at all times and by removing dissolved oxygen to maintain a protective film of magnetite (magnetic iron oxide) on steel surfaces. In addition, treatment may also be necessary to prevent corrosion in condensate lines, which is most commonly caused by the presence of dissolved oxygen and carbon dioxide gases.

Dissolved oxygen in boiler water may be removed by means of a physical deaerator or oxygen scavenger, the chemicals most commonly used being catalysed sodium sulphite, certain selected tannins or hydrazine. Condensate corrosion may be controlled by the addition of volatile amines which either neutralise the acidity caused by the presence of carbon dioxide or form a protective film on the metal surfaces.

Caustic cracking, which used to be a fairly common phenomenon particularly in riveted boilers, can occur if concentrations of sodium hydroxide greater than 5% exist. This may be prevented by either:

i. maintaining the ratio of sodium nitrate to total alkalinity (in terms of calcium carbonate) at a minimum value of 0.32 at all times

ii. maintaining the ratio of sodium sulphate to caustic alkalinity (in terms of calcium carbonate) at a minimum value of 2.0 at all times.

In high-pressure boilers, the level of chloride ions needs to be limited to minimise corrosion.

In addition to treatment for the prevention of corrosion, sludge and scale deposition also needs to be carefully controlled to maintain efficiently and steam purity, particularly as the trend in modern boilers is towards a lower water content and higher heat transfer rates. In brief, the concentration of solids in the boiler water may be controlled by the following methods depending on the quality of supply water:

i. Softening and filtration of the feed water to remove dissolved and suspended solids.

ii. Precipitation of hardness salts as a mobile sludge in the boiler by maintaining a controlled reserve of either carbonate or phosphate in solution in the boiler water. In addition, organic sludge conditioners may be added to ensure that the precipitated salts are non-adherent and mobile.

iii. Maintaining the total dissolved solids below the maximum level applicable to the particular boiler and operating conditions (usually below 3500mg/l) by 'blowing down'. Blowdown may be either intermittent or continuous.

iv. Cleaning the boiler when shut down.

Cleaning and descaling of boilers and associated plant

In newly installed systems, it is often necessary to remove internal contaminants, for example flux residues, metal filings and other builder's debris by flushing. Even if carried out in accordance with recommended procedures, it is unlikely that all will be removed due to either their insolubility or the internal geometry of the system. This highlights the need to adopt working procedures that negate the need for flushing, for example using non- aggressive fluxes and cutting rather than sawing copper tubes.

In older systems, particularly where there has been water losses or air ingress; scale and sludge may have deposited, which will affect the efficiency. In the worst case, particularly where low water content boilers are used, overheating will lead to eventual failure of sections or splitting of tubes.

If inspection indicates that de-scaling is necessary, the nature of the deposits should be determined to ascertain the best method of removal.

Loose deposits may be removed manually or mechanically but hard deposits will normally require chemical removal. Table 32 indicates chemicals that may be used to remove the most common types of deposit.

Table 32 *Cleaning and descaling treatments*

Treatment	Deposit x indicates effective treatment								
	Carbonate	Phosphate	Sulphate	Silicate	Copper & oxide	Millscale	Magnetite	Oil	Grease
Hydrochloric acid (inhibited)	X	X				X	X		
Hydrochloric/hydrofluoric acids (inhibited)	X	X	X			X	X		
Sulphuric acid (inhibited)	X					X	X		
Sulphamic acid	X								
Citric acid						X	X		
Ammonium citrate with oxidising agent (pH 9.5)					X				
Formic acid	X	X				X	X		
Tetra sodium salt of EDTA (ethylene diamine-tetra acetic acid)	X	X	X						
Tetra-ammonium salt of EDTA	X	X	X	X	X	X			
Sodium hydroxide/sodiuim phosphate								X	X

If scaling is present in a confined part of the system, for example the boiler, then treatment should be isolated to that part of the system. Progress of the cleaning should be strictly monitored; care being taken to ensure that all aggressive chemical residues are removed after completion of the de-scaling operation. Throughout the treatment, adequate safety precautions need to be observed and the effluent disposed of in accordance with statutory and other requirements.

Plant shutdown

When plant and associated equipment is taken out of service for any length of time, steps need to be taken to prevent damage due to internal corrosion.

In the case of heating and chilled water systems, they should be left completely filled with water containing oxygen scavengers or corrosion inhibitors and a biocide maintained at a high pH. In this situation, precautions may also need to be taken to prevent frost damage. Plant should only remain in a drained down condition if left and maintained completely dry internally, otherwise rapid localised attack, particularly in for example steel panel radiators, can occur resulting in premature failure.

Cooling towers need to be drained and where necessary dismantled to prevent seizure of pumps etc. When they are brought back on line, treatment with suitable biocides is recommended to control bacteria.

References

Water Regulations Guide, including the Water Byelaws 2000 (Scotland), ISBN 0-9539708-0-9; Water Regulations Advisory Scheme, Fern Close, Pen-y-Fan Industrial Estate, Oakdale, Newport, NP11 3EH.

The HSE's ACOP and Guidance document - L8 2001.

The Department of Health's code of practice HTM2040 - *the control of legionella in healthcare premises.*

BS6700:1997 - *Specification for the design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilages.*

The Institute of Plumbing - *Legionnaire's Disease - good practice guide for plumbers.*