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Public health and plumbing engineering

CIBSE Guide G



Public health and plumbing engineering

CIBSE Guide G: 2014



The Chartered Institution of Building Services Engineers

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Note from the publisher

This publication is primarily intended to provide guidance to those responsible for the design, installation, commissioning, operation and maintenance of building services. It is not intended to be exhaustive or definitive and it will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

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Foreword

Since the second edition of CIBSE Guide G was published, various amendments to the Building Regulations, British Standards and the introduction of new codes have heavily influenced the content of this new edition. In particular, the emphasis on water conservation and sustainability has had an impact on many chapters, as well as resulted in the Guide being reformatted. The British Standard relating to both building and site drainage and water services has been updated and superseded by a BS EN and this again has affected many chapters. The opportunity has also been taken by chapter authors to carry out general updates and, in the majority of cases, extend the coverage of their chapters. An enormous amount of volunteer time and effort have gone into producing this updated edition, and this foreword provides an opportunity to thank all of the authors and contributors who have been involved for their endeavors during this project. Finally, all those involved in the preparation of this Guide hope that its users, both CIBSE members and non-members, will find it a valuable source of reference and guidance.

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Chair, CIBSE Guide G Steering Committee

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1 Introduction and health and safety considerations

1.1 General	Summary
1.2 Purpose of the Guide	This chapter outlines the scope and contents of each of the chapters of the Guide.
1.3 Contents and scope of the Guide	It also provides guidance on health and safety considerations as they apply to various aspects of public health and plumbing engineering, including a bibliography of the relevant HSE guidance.
1.4 Other sources of information	
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1.1 General

This third edition of CIBSE Guide G has been produced in collaboration with the Chartered Institute of Plumbing and Heating Engineering (CIPHE), and this is reflected in its new title: *Public health and plumbing engineering*. As such, it represents a complete revision of the previous edition plus the addition of new chapters. It has been updated to reflect recent changes to both water and sanitation standards within the UK, including developments in codes overseas.

It also draws attention to health and safety considerations relating to public health engineering, including a bibliography. Clearly, the health and safety guidance is not exhaustive and a full risk assessment should be undertaken for each project on an individual basis.

1.2 Purpose of the Guide

The purpose of CIBSE Guide G: *Public health and plumbing engineering* is to provide guidance to practitioners involved in such systems. In addition to its core readership of public health designers and installers, this Guide should also be of interest to architects and authorities who, while not directly concerned with public health engineering, need to understand the advice offered to them by specialists. The Guide will also be of great value to students embarking on a career or practising engineers and technicians who wish to enhance their knowledge through continuing professional development.

1.3.2 Chapter 2: Water services and utilities

This chapter provides guidance intended to assist the engineer in the design, installation, testing and maintenance of services supplying water for domestic, commercial and industrial uses within buildings and their curtilages.

The Water Supply (Water Fittings) Regulations⁽¹⁻³⁾ replaced the Water Byelaws in England and Wales on 1st July 1999. These introduced new categories of risk for backflow protection and measures to reduce water consumption, which have been incorporated in this edition.

The section on water treatment outlines the principles of water quality analysis and the available treatment processes, and discusses types of water contamination, including organic, inorganic and microbiological contamination. This section has been updated to reflect the latest water treatment techniques and bacteriological issues.

1.3 Contents and scope of the Guide

1.3.1 Chapter 1: Introduction and health and safety considerations

Chapter 1 outlines the purpose and scope of the Guide, and provides an overview of its structure and contents.

This chapter should be read in conjunction with chapters 5, 6, 7, 11 and 12. It should be noted that fire protection services, including sprinklers, are covered in detail in CIBSE Guide E: *Fire engineering*⁽⁴⁾ and are therefore not included in this Guide.

1.3.3 Chapter 3: Sanitary pipework, accommodation and drainage

This chapter covers the design procedures for sanitary accommodation, and foul and surface water drainage within a building and its immediate environs. The chapter includes advice on connections to below-ground drainage systems and sewage systems.

British Standards for both internal and external foul and surface water systems have recently been revised. Revisions to this chapter reflect the changes in these standards along with a new method of calculating discharges from waste appliances introduced in BS EN 12056-2⁽⁵⁾ and BS EN 12056-3⁽⁶⁾.

Chapter 3 covers the flows from sanitary appliances and outlets to an outfall connection and should be read in conjunction with chapter 4.

1.3.4 Chapter 4: Underground drainage and treatment of waste water

This chapter covers many aspects of wastewater and surface water drainage, sewage treatment and pipe design, and includes guidance on sewer connections and access. A guide to the functions and responsibilities of the water companies and drainage authorities is included.

Additional guidance on general hydrology has been included in this edition, along with the necessary revisions to bring the chapter into line with current British/European Standards.

This chapter should be read in conjunction with chapters 3 and 7.

1.3.5 Chapter 5: Conservation and sustainability

Scientific evidence indicates that climate change resulting from carbon dioxide emissions associated with energy use is both real and underway. The way vital water resources are used also plays a critical role in creating a built environment in a sustainable form. The modern day public health design engineer has a significant role to play, not only in reducing the consumption of water and energy but also in looking at the wider environmental impact of the systems designed and materials specified.

There are numerous guidance documents that explore individual topics and therefore this chapter is intended to give a only brief overview of some of the primary areas relating to public health engineering and will refer to other sources for specific design guidance. CIBSE Guide L: *Sustainability*⁽⁷⁾ is a good source of further guidance.

1.3.6 Section 6: Pumps and pumping

This is a completely new chapter, dealing with the pumps and pumping requirements likely to be encountered by public health and plumbing engineers.

It describes the main types of pumps and their application to hot and cold water circulation, sewage and foul water systems, wastewater and rainwater removal, fire protection systems, water features and swimming pools. A short section considers pumping requirements for geothermal and hydrothermal energy systems.

1.3.7 Chapter 7: Waste management systems

This chapter is intended to assist the engineer in providing an appropriate waste management system for the majority of buildings. However, contacting the local councils and commercial waste contractors for further guidance is recommended.

This chapter has been updated to include information on recent trends in the volume and make-up of building waste in the UK.

1.3.8 Chapter 8: Gaseous piped services

This chapter provides guidance on the design of piped systems for gas fuels (including pipe sizing), compressed air, medical gases (including surgical and medical air) and vacuum (medical and non-medical). It takes account of recent changes to legislation and also provides guidance on sustainability issues that need to be incorporated in the design of such systems.

1.3.9 Chapter 9: Steam and condensate

The use of steam in building services is often overlooked on the assumption that there is no place for it in a modern system. It is true that steam as a means of directly heating a building is less common but its unique properties mean that it is very much a fluid for the 21st century.

Steam for humidification in air conditioning systems, sterilisation in healthcare and associated industries, and cooling through absorption chillers are common modern-day applications.

This new chapter seeks to fill a gap in available information by providing an overview of the design and operation of steam systems. The chapter considers boilers and boilerhouse design, steam distribution, flow metering, steam trapping and air venting, control of steam pressure, valves, condensate removal and recovery, and flash steam.

1.3.10 Chapter 10: Swimming pools

Significant changes have taken place recently affecting pool designs. These changes include: development of leisure pool complexes, differing patterns and intensity of use, development of plant and equipment, disinfection options, moves to develop a European standard, changes in public perception with respect to health risks and water quality.

This chapter provides advice on all these aspects of swimming pool design, and includes guidance on filtration, water distribution, chemical water treatment, chemical dosing plant, electrical requirements, plant space and location, hall conditioning and operation and maintenance of pools and associated plant.

Updates to this chapter include consideration of the latest water treatment techniques and sustainability issues relating to backwashing and pool water replenishment. Example design calculations are provided.

1.3.11 Chapter 11: Irrigation

Valuable guidance is given in this chapter on both horticultural and engineering aspects of irrigation system design. It is intended to provide engineers with an overview of the features and techniques employed in designing irrigation systems, including the properties of plants and soil types, drainage, sources of irrigation water, system types and equipment, and system control and maintenance.

This chapter should assist engineers in briefing and working with landscape and equipment specialists. It should be considered in conjunction with chapter 2.

1.3.12 Chapter 12: Corrosion protection

A wide variety of materials, both metallic and nonmetallic, are used in building services. All these materials, under certain environmental conditions, can break down prematurely impairing the function of a component or system.

This chapter provides guidance on the various factors that affect corrosion, including microbiological attack and performance of materials, as well as methods of assessing a corrosive environment and preventing corrosion. Subjects also covered include chemical cleaning and passivation and protecting systems from corrosion when not in use.

1.3.13 Chapter 13: Miscellaneous data

This chapter provide excerpts of data, formulae and quick reference tables and symbols to assist the engineer.

Various miscellaneous data, relevant to public health and hydraulic engineering has been collected for the convenience of the engineer. This section includes a useful reference guide to the conversion of various units from imperial to metric (SI) units. Pipework data have also been collated, including identification of pipework services, comparison of various pipework diameters and conversion data relating to pipework flow and velocities in drainage systems.

In addition, to fulfil a long-felt need, a section has been created providing suggested drawing symbols for water services, drainage, gas services and fire engineering.

Finally, a bibliography containing the key legislation and guidance has been included. It should be noted that mathematical and pipe sizing data are also contained in CIBSE Guide C: *Reference data*.

1.3.14 Chapter 14: Glossary of terms

This chapter provides short descriptions of many of the technical terms used in the Guide and generally in public health and plumbing engineering.

1.4 Other sources of information

CIBSE Guide G: *Public health and plumbing engineering* is intended to provide an essential reference source for those involved in the design of public health installations. However, it does not claim to be exhaustive. It contains many references to other sources of information, particularly British Standards, all of which should be carefully consulted in conjunction with this Guide.

1.5 Health and safety

Within all aspects of engineering, in particular to public health designers, there are three good arguments for good health and safety: moral, legal and financial.

Professionals, and aspiring professionals, have a duty and desire to keep their knowledge up-to-date; this includes the criminal law on health and safety. Punishment for failure to comply includes an unlimited fine or up to two years' imprisonment.

The moral argument for health and safety is clear. The employment activities for the built environment is one of the most dangerous with over 50 deaths a year. Everyone has the right to go home in the same condition in which they arrived at work.

The financial case, is that accidents cost society £10 to £15 billion a year, while only £1 in every £10 loss can be insured against, by a company.

A bibliography of publications by the Health and Safety Executive is included at the end of this chapter.

1.5.1 Duty of care

Designers owe a duty of care to people who will be affected by the risks caused by their designs. Those affected include installers, maintenance operatives, removal operatives and end users. The requirement is defined by Section 3 of the Health and Safety at Work Act 1974⁽⁸⁾:

It shall be the duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety.

The Construction, Design and Management Regulations 2007^(9,10) (CDM Regulations), define the duties of the designer as:

- check client is aware of their duties
- eliminate hazards and reduce risks during design
- provide information about remaining risks.

Where the project is notifiable these additional duties apply:

- Check that a CDM co-ordinator has been appointed.
- Provide any information needed for the H&S file.

1.5.2 Risk assessment

To eliminate hazards and reduced risks through the design, a suitable and sufficient risk assessment, as defined by Regulation 3, of the Management of Health and Safety at Work Regulations 1999⁽¹¹⁾, must be undertaken:

- Identify all the (foreseeable) hazards and evaluate the risks, including legal requirements.
- Record the significant findings.
- Identify any group or individual employees that are specifically at risk.
- Identify anyone else who may be at risk: visitors, members of the public, lone workers etc.
- Evaluate existing controls, stating if they are satisfactory, and if not, then the action needed.
- Evaluate the need for further controls, including information, instruction and training.

1.5.3 Hierarchy of control

After identifying a risk, it is necessary to show preference of the design option, which is as near the top of the hierarchy of control (in order of preference):

- (1) elimination of risk
- (2) substitution of risk
- (3) reducing exposure
- (4) isolation or segregation of risk
- (5) engineering control
- (6) personal protective equipment (PPE) and safe system of work.

The designer needs also to apply the general principles of prevention in the design:

- (a) avoiding risks
- (b) evaluating the risks which cannot be avoided
- (c) combating the risks at source
- (d) adapting the work to the individual (especially regarding design of workplaces, choice of work equipment and choice of working and production methods), with a view to alleviating monotonous work and reducing adverse effects on health
- (e) adapting to technical progress
- (f) replacing the dangerous by the non-dangerous or the less dangerous
- (g) developing a coherent overall prevention policy that covers technology, organisation of work, working conditions, social relationships and the influence of factors relating to the working environment

- (h) giving collective protective measures priority over individual protective measures; and
- (i) giving appropriate instructions to employees.

1.5.4 Risk management

If the risk cannot be eliminated through design then the risk needs to be reduced to 'as low as is reasonably practicable' (ALARP). This can be determined by consulting authoritative sources of good practice such as prescriptive legislation, approved codes of practice and guidance produced by Government and HSE inspectors. The Management of Health and Safety at Work Regulations 1999⁽¹¹⁾ notes that:

Other sources include standards produced by standard-making organisations and guidance agreed by a body representing an industrial or occupational sector, provided the guidance has gained general acceptance...

1.5.5 Health and safety risks in public health engineering

The main health and safety risks in public health engineering are as follows:

- creating confined spaces
- placing equipment that needs to be maintained at height or in difficult to reach places
- inadequate space around pipework for installation and/or replacement
- potential for explosive atmospheres
- water contamination.

1.5.5.1 Water services and utilities

When specifying pipe lengths, ensure they are of such length and weight as to reduce the risks resulting from manual handling, i.e:

- less than 20 kg where practicable
- in lengths that can be carried along the installation and replacement route.

Pipe joints should be located so as to be easily accessible to installers, i.e:

- they should not require working at height, or need specialist access equipment.
- they should not require the demolition or movement of other services.

1.5.5.2 Sanitary pipework, accommodations and drainage

When specifying galvanised steel pipework, ensure that these are not hot-cut on site, as this procedure produces fumes.

Avoid locating system access points or caps within confined spaces. These are areas where there is a risk from:

- fire or explosion

- loss of consciousness due to an increase in body temperature
- loss of consciousness or asphyxiation due to gas, fume, vapour or the lack of oxygen
- drowning, due to an increase in the level of a liquid
- asphyxiation due to a free following solid.

To comply with the Working at Height Regulations 2005⁽¹²⁾, access to gutters and outlets should be in a location where the risk from falls from height are avoided, such as behind a parapet or hand railing.

It may be necessary to co-ordinate access routes along fragile roofs with other members of the design team — a dedicated walkway may be required. Rooftop access routes should be marked if near telecommunications equipment (a source of non-ionising radiation) that is also located on the rooftop.

1.5.5.3 Underground drainage and treatment of waste water

Manholes are potentially a confined space. Prior to entering a manhole, a risk assessment should be undertaken to identify all the potential hazards as well as considering alternatives such as identifying and utilising rodding points for ongoing maintenance.

Ideally, pumps should be located in an area accessible from a level surface. Where this is not possible stair access is preferred over ladder access.

Pumps that cannot be moved by lifting aids, if required by the system design, should be sized so that they can be manhandled for installation and replacement. A manual handling assessment should be undertaken.

Buried pipes of non-metallic material should be tagged to enable detection by cable avoidance tools (CATs).

Septic tanks should be located in a position to provide access by vehicles. Access routes should avoid blind spots, pedestrian routes, and overhead obstructions.

1.5.5.4 Conservation and sustainability

Where green roofs are specified, consideration should be given to low-pollen producing plants, and those that do not contribute to common allergies.

1.5.5.5 Pumps and pumping

All valves and pumps should have an identified replacement route, of sufficient size to enable the equipment ideally to be moved without:

- the need for lifting equipment
- encountering pinch points, steps or level changes, ramps with gradients steeper than 1:12, or floors of insufficient structural load capacity.

Where equipment requires to be lifted, then integrated lifting points should be specified.

1.5.5.6 Waste management systems

Vehicle movements present a major danger to pedestrians. A sufficient site traffic management plan will need to be developed during the design phase to reduce the risk of refuse collection vehicles. This may include the need for a one-way traffic system, mirrors to see around corners and blind spots, designated parking areas of sufficient size, and swept path analysis to determine adequate turning and reversing space (if these cannot be avoided), and separate pedestrian routes.

1.5.5.7 Fire engineering services

Gaseous carbon dioxide (CO₂) systems should be avoided, as they present a real danger to life through asphyxiation due to displacement of oxygen. Where there is a chance of accidental release, the area would be classified as a confined space. Local isolation, with a suitable lockout, should be provided at the point of entry.

Gas bottle stores should be located to provide a step-free maintenance route. The stores should provide a suitable environment to avoid deterioration of the bottles, and provide adequate ventilation to avoid asphyxiation in the event of accidental discharge.

1.5.5.8 Gaseous piped services

Where there is a potential for a gas release leading to a fire or explosion then the designer should undertake a risk assessment in line with the requirements of the Dangerous Substances and Explosive Atmospheres Regulations 2002⁽¹³⁾. This may result in a requirement for equipment and materials being ATEX-rated*.

Where there is a potential for a gas release leading to asphyxiation, then the designer should undertake a confined space risk assessment, and incorporate suitable design mitigation or elimination measures.

1.5.5.9 Steam and condensate

Due respect has to be given to the fact that steam is hot and under pressure. Consequently, specialist knowledge is needed to design, operate and maintain steam and condensate systems Health and Safety Executive (HSE) guide INDG436, *Safe management of industrial steam and hot water boilers*⁽¹⁶⁾, is a good general reference document relating specifically to the boiler. More specific guidance is available in *Guidance on Safe Operation of Boilers*⁽¹⁷⁾, a joint publication from the Safety Assessment Federation and Combustion Engineering Association produced in consultation with HSE.

Safety in the rest of the steam system is equally important, particularly the dangers associated with steam leaks and ineffective water removal (water hammer). Such dangers however are easily avoidable with good design and maintenance regimes. Chapter 9 outlines design principles. Safety in steam systems is covered in the Pressure System Safety Regulations 2000⁽¹⁸⁾ ('PSSR'), where the requirements for regular examination are specified and responsibilities outlined.

* 'ATEX' is the name commonly given to the two European Directives for controlling explosive atmospheres^(14,15).

1.5.5.10 Swimming pools

Where chemicals are specified and there is an occupational disease associated with their use, then an assessment in accordance with the Control of Substances Hazardous to Health Regulations 2002⁽¹⁹⁾ ('COSHH Regulations') will need to be undertaken. These chemicals should be avoided where an alternative is available.

Account should also be taken of workplace exposure levels for specified chemicals, and the system designed to reduce and control exposure to such chemicals.

Chlorine is a potentially dangerous gas and can form an explosive gas when mixed with ammonia and other typical cleaning chemicals. Exposure to chlorine gas can cause difficulty in breathing and pneumonia. Chlorine can also cause burning when in contact with skin or eyes.

A chlorine gas storage room may be considered a confined space (due to the risk of fire and explosion) and would need to be specifically assessed.

1.5.5.11 Irrigation

Where a mechanical system (spray or sprinkler) is specified, then (as with all water systems) there is a risk of Legionnaires' disease. Refer to chapter 2, section 2.8 and CIBSE TM13: *Minimising the risk of Legionnaires' disease*⁽²⁰⁾ for design considerations and requirements.

1.5.5.12 Corrosion and corrosion protection

Where corrosion occurs, this can lead to biological hazards (e.g. Legionnaires' disease etc.) or oxygen depletion in a confined space.

Corrosion or fatigue can also lead to structural failure of the pipework leading to a physical safety risk.

Where liquids leak from pipework, this can create a slip hazard. Therefore it is important that access to dosing points, for the addition of corrosion control chemicals, and testing points are easily accessible.

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2 Water services and utilities

2.1 Cold water supply	Summary
2.2 Water treatment	This chapter provides an overview of water services and utilities systems, covering legal requirements, system types, design considerations and system operation requirements.
2.3 Cold water systems	
2.4 Hot water systems	The public health engineer's role is to ensure that the water (both hot and cold) services distribution system is effectively designed to ensure adequate flow, pressure and volume is fully considered and allowed for, with key emphasis on designing for full peak demand. This requires to be undertaken with a key emphasis on backflow prevention to avoid contamination to the wholesome drinking supply.
2.5 Pipework design	
2.6 Underground pipework	
2.7 Legionnaires' disease	Water usage and conservation is a key element that the public health engineer should consider and be read in conjunction with chapter 5: <i>Conservation and sustainability</i> .
2.8 System maintenance	
2.9 Operation	This Guide does not cover fire protection services, for which reference should be made to CIBSE Guide E: <i>Fire engineering</i> .
References	

2.1 Cold water supply

2.1.1 Introduction

This chapter is intended to assist the engineer in the design, installation, commissioning, testing and maintenance of services supplying water for domestic, commercial and industrial use within buildings and their curtilages. It supports information provided in BS EN 806⁽¹⁾, BS 8558⁽²⁾ and the Water Supply (Water Fittings) Regulations 1999⁽³⁾.

2.1.1.1 Design of water systems

The design of water services is to provide the necessary quantity of water to an area or fixture via the means of a piping system designed, with acceptable water velocities and pressure drops to deliver water at the required flows and pressures to a fixture or appliance.

All water systems should be designed to comply with the minimum requirements of British Standards, and Building Regulations (Building Standards in Scotland) and the Water Supply Regulations 1999⁽³⁾.

It is necessary to provide piping, storage tanks and hot water heating to sufficient capacity to satisfy simultaneous flows extending over the peak demand periods. The designer should ensure the system is not wasteful/inefficient in terms of pipe diameters, equipment capacity, pipework installation or system running costs.

2.1.1.2 Water resources

The source of water varies, depending in which area of the UK the supply is sourced from. The sources in the UK are:

- upland catchments (reservoir)
- ground water (borehole/artesian well)
- water course abstraction.

All these sources can provide water for supply purposes, each with a wide range of physical and bacterial quality differences:

- hardness
- bacteria count
- minerals.

All sources of water, whether groundwater or surface water, will be subject to variations in the quantity available, as a result of variations in rainfall, increases in urbanisation and seasonal demands.

The Water Supply (Water Quality) Regulations 2000⁽⁴⁻⁶⁾, and the World Health Organisation provide guidance covering a maximum range of colour, alkalinity, taste, odour, undesirable and toxic substances, and micro-organisms to specified parameters. The standards are called 'prescribed concentrations or values' (PCVs) and are stated as the maximum, minimum, average or percentage levels. Drinking water quality standards are given in Table 2.1.

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

2.1.1.3 Water examination

The suitability of water for any particular purpose can be assessed only after appropriate chemical and/or microbiological examination using approved sampling and analytical procedures for each individual determinand (or

characteristic) or group of determinands. If required, the analyst will optimise the analytical suite for the relevant determinands to be measured, and provide suitable containers together with detailed sampling instructions. Some determinands are best measured on site and others may require preservative or 'fixing' reagents to be added at the time of sampling. Where requested, supplies must be added to the sample container beforehand and it is important that the analyst's sampling and safety instructions are followed carefully.

Further information on water examination (including water hardness), contamination and treatment is provided within chapter 13: *Corrosion and water treatment*.

2.1.2 Infrastructure supplies

Mains laid for the distribution of water from one district to another, and for the distribution of water within a district, are generally installed by the water supply company.

Supplies must be provided by statute for domestic purposes, in both domestic and non-domestic buildings, or by agreement for industrial uses.

Although no clear definition is given in the Water Acts 1973 and 1989, or the Water Industry Act 1991, mains are generally considered to be divided into three categories:

- (a) *trunk mains*: generally described as those which convey water from a source of supply (reservoir, pumping station etc.) to a district without supplying consumers en route
- (b) *secondary mains*: the distribution mains in any district, usually fed from a trunk main and supplying the consumers' connections in the district
- (c) *service pipes*: the branch supplies from the secondary mains which serve individual consumers or premises (see the Water Supply (Water Fittings) Regulations 1999⁽³⁾).

Ensuring compliance with the Water Supply (Water Fittings) Regulations 1999⁽³⁾, hereafter referred to as the

Table 2.1 Drinking water quality standards

Factor	Standard	Factor	Standard
Temperature	25 °C	Calcium	250 mg/l
pH	5.5–9.5	Potassium	12 mg/l
Colour	20 Hazen units	Sodium	150 mg/l
Turbidity	4 Formazin units	Copper	3000 µg/l
Qualitative odour	All odour investigations	Zinc	5000 µg/l
Qualitative taste	All taste investigations	Lead	50 µg/l
Dilution odour } Dilution taste }	Dilution No. 3 at 25 °C	Silver	10 µg/l
Conductivity	1500 µS/cm at 20 °C	Antimony	10 µg/l
Total hardness } Alkalinity }	Applies only if softened	Arsenic	50 µg/l
Free chlorine } Total chlorine }	Comparison against average	Barium	1000 µg/l
Faecal coliforms	0/100 ml	Boron	2000 µg/l
Clostridia	1/20 ml	Cyanide	50 µg/l
Faecal streptococci	0/100 ml	Cadmium	5 µg/g
Total coliforms	0/100 ml (95%)	Chromium	50 µg/l
Colony count, 2-day } Colony count, 3-day }	Comparison against average	Mercury	1 µg/l
Oxidisability	5 mg/l	Nickel	50 µg/l
Ammonia	0.5 mg/l	Selenium	10 µg/l
Nitrite	0.1 mg/l	Total organic carbon	Comparisons
Nitrate	50 mg/l	Trihalomethanes	100 µg/l
Chloride	400 mg/l	Tetrachloromethane	3 µg/l
Fluoride	1500 µg/l	Trichloroethene	30 µg/l
Phosphorus	2200 µg/l	Tetrachloroethene	10 µg/l
Sulphate	250 mg/l	Benzo 3,4 pyrene	10 µg/l
Magnesium	50 mg/l	Fluoranthene 3,4-benzofluoranthene 11,12-benzofluoranthene 1, 12-benzoperylene Indeno(1,2,3-cd)pyrene }	Individual testing of these substances to provide total
Iron	200 µg/l	Total polycyclic aromatic hydrocarbons (PAHs)	0.2 µg/l
Manganese	50 µg/l	Anionic detergents	200 µg/l
Aluminium	200 µg/l	Pesticides and compounds	5 µg/l total

'Water Regulations', is the responsibility of the building or premises owner or occupier.

It is of the utmost importance that a drinking water supply must not be liable to contamination. There must be no interconnection or cross-connection of the supply with any other water supply, e.g. water of uncertain quality or water already used for some other purpose.

Check valves or stop valves are not considered adequate to prevent cross-contamination. The Water Regulations prohibit any cross-contamination connections.

The design of water services must be arranged to prevent the possibility of backflow (or back-siphonage) from any terminal outlet, cistern, or sanitary appliance.

In some overseas countries, especially in the Middle East, authorities maintain separate distribution systems of non-drinking water for industrial and agricultural purposes; they should not be confused with a drinking water system.

2.1.2.1 Mains connections

Connections to a trunk or secondary main are normally only carried out by the water supply company. It is not normal practice to allow a service pipe to be connected to a trunk main. Connections to secondary mains may be made under pressure to connect pipes of 50 mm diameter and below, whereas for larger pipes a shutdown of the main is required.

Service pipes are fitted by the water supply company from the main up to the boundary (curtilage) of the premises to be supplied. At this point a stop valve is provided to enable the premises' water system to be isolated from the mains supply. Responsibility for the supply and installation of this valve and the service pipe should be agreed with the relevant water supply company. From the valve, the service pipe continues inside the boundary to the building, where a second valve is fitted for the use of the consumer. Where a building is divided into separately occupied sections supplied from a common service pipe, a valve should be fixed inside each section to allow the individual user to control the supply. See the Water Regulations.

The size of a service pipe is determined by the water supply company based on discussions and information provided by the building owner or his agent. It should be noted that new connections to all buildings are required to allow a water meter to be fitted.

2.1.2.2 Mains pressures

Subject to the detailed requirements of the Water Act 1989⁽⁷⁾, it is the responsibility of the water supply company to provide water for domestic purposes and fire hydrants 'at such a pressure as will cause the water to reach the top-most storey of every building within the undertaker's area'.

Also, in certain circumstances, detailed in the Water Act 1989, the water undertaker may require the customer to install a cistern with a float-operated valve. The relevant water supply company should be contacted before

designing services, as break tanks and pumps may be required.

Water supply companies may have high and low pressure mains in their area of supply, zoned to avoid interconnection. Schedule 51 of the Water Act 1989 gives 'Duty as respects constant supply and pressure'.

2.1.2.3 Mains pressure fluctuations

Pressure fluctuations in mains will occur during periods of heavy demand, particularly in built-up areas. Night-time and daytime pressures can vary considerably, this being one reason for providing storage. The water supply company can record the pressure fluctuations over a 24-hour period, for a charge.

In some areas of high pressure, the introduction of pressure-reducing valves will enable flow and pressures to be adjusted to balance the system demand. Similarly, pressure-sustaining valves may be fitted to maintain upstream pressures and minimise starvation of supply to higher zones.

In instances where the water supply company's service pipe main cannot provide sufficient pressure to service all of the equipment in a building, pumping equipment with a break tank must be installed for the demand points that are above the level at which the incoming minimum mains pressure can supply.

To ensure that the water utility companies provide water to the prescribed standards, they have the remit to monitor the water companies' performance and report on it as appropriate.

A requirement of the Water Quality Regulations⁽⁴⁾ is that the utility company must take regular samples of the water and monitor that the water being distributed meets the prescribed water quality standard. The intervals for monitoring depend on the parameter being monitored as well as the volume being supplied. The regulations also set out the test methods that should be adopted for certain parameters and sets out the penalties for contravention of the regulations.

As such, it can be accepted generally that the quality of the water provided by each water utility will be within the parameters of the water quality regulations, so it is not necessary to interrogate the quality of a utility water supply for every project.

However, there are conditions when the quality of the water supplied must be modified, even though the water meets the quality regulations standards. These conditions are, for example, total hardness, which has a suggested limit of 200 mg/l (BS EN 806⁽¹⁾) or specific water quality requirements set by a client. In such cases, the water utility will be able to provide details of the water quality in their region or in a specific area within their region either via their website or by telephone.

2.1.2.4 Infrastructure charges

Infrastructure charges come into effect when a site is developed or redeveloped and apply to all water supply company supplies for domestic or non-domestic purposes,

including situations where there is a change in use of a previously developed site.

Normally, the infrastructure charge should be paid before a water supply connection is made. However, by arrangement with the water supply company new supplies can be blanked off so that the supply cannot be used.

Water supply companies publish details of their charges for both infrastructure and other services including measured water supply, unmeasured water supply, standpipe hire (for connection to hydrants), water supplied by tanker, building water, garden sprinkler licences, and swimming pool licences.

2.1.2.5 Metering

Water supply companies usually provide zone meters within their trunk and distribution mains to check consumption within given areas. Mains leaving reservoirs, pumping stations and water towers are metered to record the outflow.

Metered supplies to dwellings are permitted by the Water Act 1989⁽⁷⁾. Supplies to all non-domestic premises are usually metered.

Surface boxes to underground meters should be readily accessible to enable the meter to be read, and the stop valves to be operated. Where the meter has to be fixed inside a building it has to be as close as practicable to the boundary of the premises, with adequate access provided from outside the building to allow for meter reading and maintenance.

The water meter on the incoming water supply company's main is installed by, and remains the responsibility of, the water supply company.

Customers can install check meters on their sites to enable individual buildings or areas to be monitored. It is also possible to connect these meters to a building management system (BMS). Preferred position for meters are shown in Figure 2.1.

2.1.2.6 Fire protection installations

Automatic sprinkler installations require a separate supply, taken from the water supply company's main, and should not be taken from the domestic supply serving the

site. Alternative methods of supplying water to sprinkler installations are given in BS EN 12845⁽⁸⁾. See also BS 5306: Part 1⁽⁹⁾ for information on fire hydrant and hose reel system requirements.

Detailed guidance is provided in CIBSE Guide E: *Fire engineering*⁽¹⁰⁾.

2.1.3 Legislation, standards and codes

In the UK, the quality of the water supplied by the utility companies is strictly regulated. The quality of water supplied for distribution to, and for use by persons and properties is controlled by Statutory Instruments, the most important of which are:

- The Water Supply (Water Quality) Regulations 2000⁽⁴⁾, for England and Wales (amended England 2010, Wales 2010, N Ireland 2010)
- The Water Supply (Water Quality) (Scotland) Regulations 2001⁽⁵⁾
- The Water Supply (Water Quality) Regulations (Northern Ireland) 2007⁽⁶⁾.

All these regulations are based on the EU Drinking Water Directive (98/83/EC)⁽¹¹⁾, which itself is based on advice from the World Health Organization (WHO).

Enforcement of the Regulations is undertaken by:

- The Drinking Water Inspectorate: responsible for England and Wales
- The Drinking Water Quality Regulator: responsible for Scotland
- The Drinking Water Inspectorate Unit, within the Northern Ireland Environment Agency.

The legislation relating to the water utilities in the UK is contained principally in the following Acts and Regulations:

- England and Wales: Water Industry Acts 1991⁽¹²⁾ and 1999⁽¹³⁾, the Water Act 2003⁽¹⁴⁾ and some sections of the Water Resources Act 1991⁽¹⁵⁾.
- In Scotland: Water Industries (Scotland) Act 2002⁽¹⁶⁾ and Water Services etc. (Scotland) Act 2005⁽¹⁷⁾.

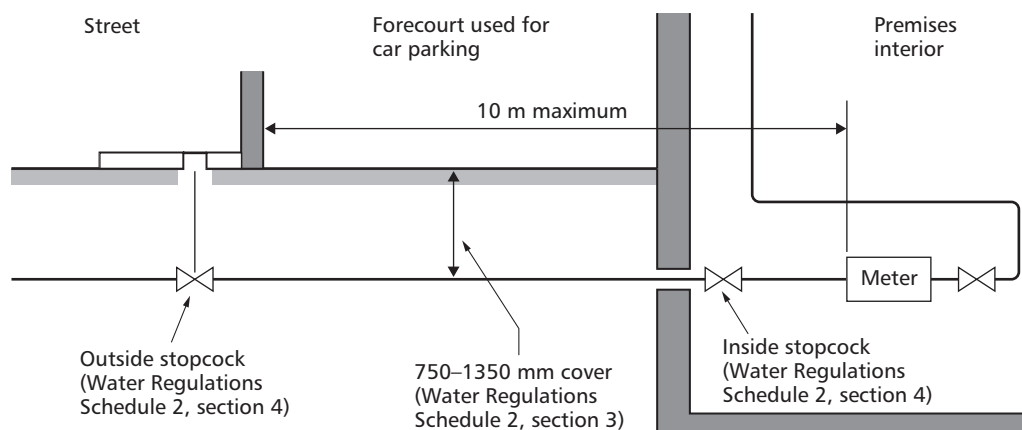


Figure 2.1 Preferred meter position inside premises

- In Northern Ireland: Water and Sewerage Services (Northern Ireland) Order 2006⁽¹⁸⁾.

The water industry legislation is constantly being amended, with the introduction and amendment of other national and European environmental legislation, particularly the Water Framework Directive (2000/60/EC)⁽¹⁹⁾, now being implemented and incorporated into the core Acts.

The above Acts primarily deal with:

- the appointment and economic regulation of water and sewerage companies
- water supply and sewage disposal powers
- drinking water quality obligations of the water utilities and the enforcement of those obligations by the Regulators
- charging powers of the water utilities and the control of charges by the Regulators; protection of customers and consumers by the Regulators
- Retail and common carriage competition.

The operational regulation of the water utilities is via:

- OFWAT in England and Wales
- Northern Ireland Authority for Utility Regulation
- Water Industry Commissioner for Scotland

Each one of these organisations has a remit to promote the interests of water customers by ensuring that the service provided by the utility meets the required standard and that the consumer receives value for money, setting prices, monitoring performance of utilities and promoting competition in the water industry.

However, there is no statutory duty for a water utility to provide water for non-domestic use; in England this includes the external taps. Prior to making a non-domestic water use connection, the utility will have to ensure that all of its domestic water usage is protected and if the new connection exceeds the capacity of the existing infrastructure, then the water utility can charge the developer reasonable costs for upgrading the existing infrastructure plus a rate of return on any capital expense incurred.

2.1.3.1 Water Regulations

Consumers' water supply installations are required to comply to the Water Supply (Water Fitting) Regulations 1999⁽³⁾ and the Water Supply (Water Fitting) (Amendments) Regulations 1999⁽²⁰⁾. (In Northern Ireland, The Water Supply (Water Fittings) Regulations (Northern Ireland) 2009⁽²¹⁾ and, in Scotland, the Water Byelaws 2004⁽²²⁾). 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 supplier's communication pipe to the outlets of all the draw-off fittings, inclusive of any alterations.

In some countries, especially in the Middle East, authorities maintain separate distribution systems of non-

drinking water for industrial, fire and agricultural purposes.

The Regulations require that no water fitting should 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 the following:

- waste
- misuse
- undue consumption
- contamination
- erroneous measurement.

Water suppliers have the duty to enforce the regulations and they do this by granting consent for plumbing installations and by inspecting new and existing premises for compliance of the plumbing systems. Before installation work commences it is a legal requirement to have notified the water supply company of proposed installations and to have its consent to install, which may be granted subject to conditions. For new installations, connection of the water supply may be subject to inspection and compliance with the Water Fittings Regulations^(3,20,21) and the Scottish Water Byelaws⁽²²⁾.

2.1.3.2 Water Regulations Guide

The Water Regulations Advisory Scheme (WRAS) publishes the *Water Regulations Guide*⁽²³⁾, which provides formal interpretations on how the Regulations are applied to the actual water installations, incorporating the government guidance and water industry recommendations.

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

The prevention of contamination is the overall main aim of the Water Regulations. Contamination can occur by:

- *ingress into the system*: for example, bird droppings in uncovered storage cisterns;
- *use of unsuitable materials of construction*: for example, use of lead-based solder in copper pipe joints;
- *cross connection with unwholesome water*: such as recycled greywater or rainwater, and
- *backflow*: contaminated fluids being drawn back into drinking water systems from other pipework or outlets.

2.1.3.3 Backflow prevention

Backflow risks are grouped into five 'fluid categories', see Table 2.2, according to the severity of risk from the contaminants that are present. The Regulations require use of backflow prevention devices of the correct fluid category rating to protect each point of use against backflow.

Table 2.2 Fluid categories and examples

Fluid category	Definition	Example
FC1	Wholesome water supplied by a water undertaker and complying with the drinking water quality standards	Water supplied directly from the water undertaker's main
FC2	Water which would be in FC1 but whose aesthetic quality is impaired owing to a change in temperature or the presence of substances or organisms causing a change in taste, odour or appearance	Water in a hot water distribution system
FC3	Fluid which represents a slight health hazard because of the concentration of substances of low toxicity, including any fluid that contains: (a) ethylene glycol, copper sulphate solution, or similar chemical additives; or (b) sodium hypochlorite (chlorox and common disinfectants)	Water in washbasins, baths or showers in domestic premises (excluding healthcare premises)
FC4	Fluid which represents a significant health hazard due to the concentration of toxic substances, including any fluid that contains: (a) chemical, carcinogenic substances or pesticides (including insecticides and herbicides); or (b) environmental organisms of potential health significance	Water in primary circuits and central heating systems (with output greater than 45 kW·h) other than in a house
FC5	Fluid representing a serious health hazard because of the concentration of pathogenic organisms, radioactive or very toxic substances, including any fluid that contains: (a) faecal material or other human waste; or (b) butchery or other animal waste; or (c) pathogens from any other source	Water in sinks, urinals, WC pans or bidets

2.1.3.4 Notification

In most cases, before work starts on any proposed installation, the installer, owner or occupier must obtain the water supplier's consent by giving notification of the details of the proposed work.

Proposed work that must be notified is summarised in the following list.

The installation of water fittings in connection with:

- (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 the overflow, of more than 230 litres
 - (b) a bidet with an ascending spray or flexible hose*
 - (c) a shower unit of a type specified by the Regulator (none are currently specified)
 - (d) a pump or booster drawing more than 12 litres per minute, connected directly or indirectly to a supply pipe
 - (e) a unit that incorporates reverse osmosis

- (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 (RPZ) valve assembly or other mechanical device for protection against a fluid which is in fluid categories FC4 or 5
- (h) a garden watering system unless designed to be operated by hand
- (i) any water system laid outside a building either less than 750 mm or more than 1350 mm below ground level.

- (5) The construction of a pond or swimming pool over 10 000 litres capacity, designed to be replenished automatically with water supplied by a public water supplier.

In Northern Ireland, in addition to the above, notification is required for:

- grey water, recycled water, reclaimed water and rainwater harvesting systems
- water systems for fire fighting, including domestic sprinklers
- a flexible shower hose or other flexible outlet for use in conjunction with a WC*
- a 'shower toilet' or 'bidet-toilet' where, either as part of the WC itself or as an addition or adaptation of it, a stream of water is provided from below the spillover level of the WC pan (i.e. ascending spray types) for personal cleansing*.

* This requirement does not apply to these fittings where they are installed by an approved contractor.

2.1.4 Alternative water supplies

Increasingly, developments are being built using non-mains water supplies. Such non-utility company water supplies are referred to as private water supplies, e.g. boreholes.

Note: rainwater harvesting and greywater/blackwater supplies are not private supplies unless brought up to drinking water standards. They should be clearly identified and clearly marked 'NOT DRINKING WATER', as should any supply from a storage cistern where it can stagnate and is not designed for a quick turnover.

Where premises with private water supplies or recycled supplies have a back-up supply from the public mains, the plumbing systems come under the scope of the Water Fittings Regulations^(3,20,21) and Scottish Water Byelaws 2004⁽²²⁾, even if the public supply is only used very infrequently. The water fittings must comply with the requirements of the regulations. Both pipework and outlets supplied with private water supplies or alternative sources (recycled water) must be clearly identified to distinguish them from the public supply in order to avoid cross-connection.

Similar to the utility water supplies, private water supplies are subject to water quality standards. These standards are:

- Private Water Supplies Regulations 2009⁽²⁴⁾
- Private Water Supplies (Wales) Regulations 2010⁽²⁵⁾
- Private Water Supplies Regulations (Northern Ireland) 2009⁽²⁶⁾
- Private Water Supplies (Scotland) Regulations 2006⁽²⁷⁾.

All the above regulations set out requirements on private water supplies similar to those applicable to the water utilities; i.e. requirement to meet certain water quality parameter limits, requirement for monitoring of the water, outlining the failure to comply notices and subsequent penalties. The regulations also set out a scale of charges that the regulating authority can apply for the sampling and testing.

The regulations also impose a duty on the regulating authority to carry out a risk assessment on the private water supply, from the source to the tap. The risk assessment looks at not only the water source but also the area around the source to identify any actual or potential contamination risks to health. It must also consider actual or potential risks to health associated with storage tanks, treatment systems and pipework, so that action to make sure the water supply is safe to drink is taken. Where the water is found to be unsafe, the regulating authority must ensure that the owners or, where applicable, managing company etc. undertake the necessary remedial actions to make the water supply safe.

As with the Water Supply Regulations, monitoring is undertaken based on the number of people served but, whereas the water utility undertakes its own sampling and analysis (or may employ an approved third party to undertake this work), private water supplies are monitored, sampled and analysed by the local authority of the area where the supply is located. Northern Ireland is

an exception whereby this duty is carried out by the Drinking Water Inspectorate on behalf of the Northern Ireland Department of the Environment.

The definition of a private water supply is one that is used for more than one house or for commercial purposes in a building, such as food production or as a workplace (employing other people than the building owner) or a public building etc.

Where the house is the only property supplied by the water source and only the occupants consume the water, the local authority will only sample the water if specifically requested to do so. Similarly, a tenant of a building with a private water supply can request a sample to be taken if there is perceived to be a problem with the water.

The suitability of water for any particular purpose can be assessed only after appropriate chemical and/or microbiological examination using approved sampling and analytical procedures for each individual determinand (or characteristic) or group of determinants. The requirements for the tests are laid out in the private water supply legislation.

Water abstractions

From wherever the water is derived, it is important to ensure that the abstraction does not have a detrimental impact on the environment nor cause a risk to health. As such, regulatory authorities for water abstractions in the UK are the Environment Agency in England and Wales, the Scottish Environmental Protection Agency (SEPA) and the Northern Ireland Environment Agency (NIEA).

It must be noted that there are some variations in abstraction requirements for each of the three regulatory authorities; aligning the volume of water to be abstracted, the risk to the environment and the type of consent given, such registration/authorisation for small abstractions to complex licences for large abstraction volumes.

Although consent to abstract may have been given, it does not guarantee that the water will always be available as there may be changes in the natural water levels in the surface water or groundwater that cannot be foreseen or controlled.

Records must be kept of the abstraction, such as the volumes abstracted per hour, day and year, as the consent will limit the volume abstracted within these time limits.

There is a duty on the abstractor to ensure that the abstraction does not cause damage to others.

The penalties for contravention of a licence or damage to others can be a fine, imprisonment or revocation of a licence.

The construction of an abstraction borehole can be costly and is dependent on the type and depth of the aquifer. Prior to proceeding with a borehole, the British Geological Survey (<http://www.bgs.ac.uk>) can provide a desktop borehole prognosis, based on empirical data from existing boreholes in adjacent areas. Although the prognosis cannot give definitive information, it will

provide an indication as to whether an aquifer can yield the volumes of water required.

If the borehole prognosis is favourable and where the abstraction requires a licence (Environment Agency), pumping tests on the underlying aquifer will need to be undertaken. A permit to carry out the pump tests is necessary and, in providing the permit, the regulating authority will set out how the tests are to be carried out and the data required. The pump tests will produce vast quantities of wastewater that will need to be disposed of and consultation with the sewer utility will be essential.

The data from the pump tests have to be submitted to the regulating authority who will analyse it and determine what effect the abstraction will have on the aquifer and, depending on this, the decision as to whether the abstraction will be consented to and under what conditions.

The process of obtaining the licence can take several months, particularly if a complex licence is required, so it is important to contact the regulating authority at the earliest opportunity, as they will be able to give detailed advice on all matters relating to the licence, including the charging regimes applicable.

2.2 Water treatment

2.2.1 Introduction

Water treatment can refer to the treatment of water for drinking purposes, such as in utility mains or private water supplies, or it can refer to the treatment of water within a building prior to its direct use, such as to remove hardness or provide an additional level of disinfection.

Where the treatment is for drinking purposes, the variation in the quality of the raw water (water from its source and with its original water quality characteristics) will be different for every project and the level of treatment can vary from simple filtration and ultraviolet (UV) disinfection to reverse osmosis, chlorine dosing and remineralisation etc. However, the incorrect selection of a treatment process can result in extremely serious consequences and, as such, this aspect of water treatment is outside the scope of this guide and it is recommended that the guidance from a qualified water treatment specialist be sought for the selection of the appropriate treatment process for making drinking water from raw water. Table 2.3 compares the different disinfection technologies currently in use.

The type of water treatment covered in this section will be limited to that used to deal with hardness in water and *Legionella* prevention.

Table 2.3 Comparison of disinfection technologies

Property	Treatment				
	Chlorine	Chlorine dioxide	Ozone	Ultraviolet	Pasteurisation
Disinfection capacity	Medium	Strong	Strongest	Medium	Medium
Time required for operation	Hours	Days (dependant upon dead legs usage)	Minutes	Instant	Hours
Treats the whole system?	No	Yes	No	No	No
pH dependant?	Extreme	None	Medium	Low	No
Corrosive?	Yes	Yes	Yes	No	Yes
By-products	Trihalomethanes (THMs); adsorbable organohalogens	Chlorite; chlorates; halogens	Possible bromate; perchlorate	Possible nitrite	None; possible scalding
Operational temperatures of system	No limitations	No limitations	Not suitable for DHWS systems*	Not suitable for DHWS systems*	No limitations
Maintenance (10-yearly)	Replacement installation	Replacement installation	Replacement installation	Replacement installation	Dependant upon maintenance labour rates and cost of energy
Maximum water pressure	N/A	3 bar	N/A	9.9 bar	N/A
Biofilm removal	Not 100%	100% over time	No	No	No
No					
Smell?	Yes	Yes	Yes	No	No
Water hardness problems?	Yes	Yes	Yes	Yes	Yes

* Can treat cold water system feeding hot water system

2.2.2 Scale in water

Although calcium and magnesium are essential elements, elevated levels of these elements will lead to water becoming 'hard'. When the total hardness is in excess of 200 mg/l, water softening or conditioning should be considered^(1,28).

Scale is caused by the calcium, magnesium or iron salts that naturally occur in water, precipitating when the water is heated to form a hard coating on heating surfaces. There are two ways to control scale in water systems: physical water conditioner systems and water softening. Water softening replaces the hard water ions with soft ions, which do not form scale.

2.2.3 Physical water conditioners

Physical conditioners generally rely on electric or electromagnetic fields acting on the water to modify the structure and size of hard water crystals. As a result, the ability of the crystals to cling to each other or to surface walls of the pipe or equipment is substantially reduced so that limescale can be kept in suspension and discharged with the flow of water from the outlet.

There are five types of physical water conditioners, which use different methods to condition the water:

- *Magnetic*: these use a magnetic field and are suitable for protection of individual appliances but the effect does not last.
- *Electrolytic*: these prevent scale forming by use of dissolved metal (usually zinc or iron).
- *Electrostatic*: in these, an electric field is created by flow of water through the conditioner.
- *Electromagnetic*: a strong magnetic field is generated, which is much stronger than the simple magnetic devices.
- *Electronic*: by generating a low power electrical current, controlled by a microprocessor, a variable electrical field is developed in the water that prevents build-up of scale.

An important point to note is that because the limescale is held in suspension and discharged via the outlet, there will still be evidence of limescale on any evaporative surface, such as shower heads and screens and stainless steel sinks.

2.2.4 Water softening

Water softening is a technique that removes the ions that cause the water to be hard; in most cases these ions are calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, which are positively charged.

A water softener consists of a pressure vessel filled with resin with a control valve at the top. As water is passed through the control valve and down into the vessel, the water passes across the resin and the calcium and magnesium attach to the resin so that the water leaving the unit has significantly reduced Ca^{2+} and Mg^{2+} .

The softened water will have elevated levels of sodium. The general consensus is that, although softened water is safe to drink as it still contains all the natural minerals needed by the human body, the elevated sodium content.

2.2.5 Removal of organisms

There are generally four accepted methods of treating water to remove organisms, described below.

2.2.5.1 Chemical

Various chemical treatments disinfect the system, but may not kill or remove biofilms that already exist in the system, typically in some parts of a system that form a pocket in which sediment can collect. The chemical treatment circulates through the whole system but once flushed through correctly leaves little residue. If a continuous dosing system is used this must be monitored to prevent trihalomethane levels (THMs) greater than 100 µg/litre, which is the maximum allowable. THMs are formed in the reaction between chlorine and organic materials and greater amounts are known to be carcinogenic. The storage and handling of chemicals prior to the point of input need to be taken into account on the risk assessment. Chlorine-based systems, if not monitored regularly, could lead to inherent corrosive actions of the system, leading to taste and turbidity problems as well as accelerated degradation of the pipework system. Re-infection could occur on a dosing and flushing system but a constant dosing system should prevent this.

2.2.5.2 Pasteurisation

Temperature control of the whole system kills the *Legionella* bacteria not protected by biofilm etc., but does not kill or remove biofilms that already exist in the system or those parts of a system that form a pocket in which sediment can collect. The pasteurised water circulates through the whole system but once the temperature drops and newly infected water is brought into the system, *Legionella* will start breeding again. Thus, to prevent re-colonisation, the whole of the system should be brought up to correct temperature daily. This method has a higher energy cost but requires little or no maintenance and can be monitored via a control system. There is also a shortening of the life of the plant.

2.2.5.3 Ionisation

Ionisation involves the electrolytic dissolution of metals, which is continually distributed throughout the system. Research indicates that it kills biofilms and bacteria but needs regular maintenance, monitoring and sampling to operate at the optimum level in order to stop the pH rising above 7.6 and to control the hardness of the water (with too many totally dissolved solids), which can cause scaling of the electrodes. This system needs additional plantroom space (a small amount) and spares as compared with traditional systems.

2.2.5.4 Irradiation

Ultraviolet light does not circulate its effects throughout a system or treat the entire installation, but it does kill

bacteria effectively on entry to the system or at the point of application. It is not recommended to be installed on the entry point of an existing system (which already may be infected) without initial cleaning and disinfection of the existing system. It needs regular but simple maintenance. Again, a small amount of plant room space and spares are required. *Of the four methods outlined above, this is the only one suitable for use as part of the pre-treatment of water for kidney dialysis.*

2.3 Cold water systems

2.3.1 Introduction

2.3.1.1 Water systems

The water supply installation is required 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 0.7 bar⁽²⁹⁾. Often their delivery pressure can be higher. However at times of high demand, or during evenings and overnight, the pressure will be closer to the minimum provision.

2.3.1.2 Water demand

The water efficiency of new buildings has significantly improved following amendments to the Building Regulations. For dwellings, Part G^(30,31) (Regulation G2) of the Building Regulations for England and Wales* requires that 'the potential consumption of wholesome water ... must not exceed 125 litres per person per day'. The *Code for sustainable homes*⁽³²⁾ suggests various performance levels and standards.

2.3.1.3 Type of system

The type and style of water distribution required for a particular building will depend mainly on the building height and its use:

- The building height will determine whether pumping will be required to deliver water to the highest level.
- 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 distribution
 - (c) pumped from a break or storage cistern.

Potentially, for a low-rise building in a locality where an interruption of water supply is infrequent and would cause little inconvenience, then a water supply direct from the mains, without storage is an option. If the provision of storage is possible at high level then the system could be

* Requirements may differ in Scotland and Northern Ireland.

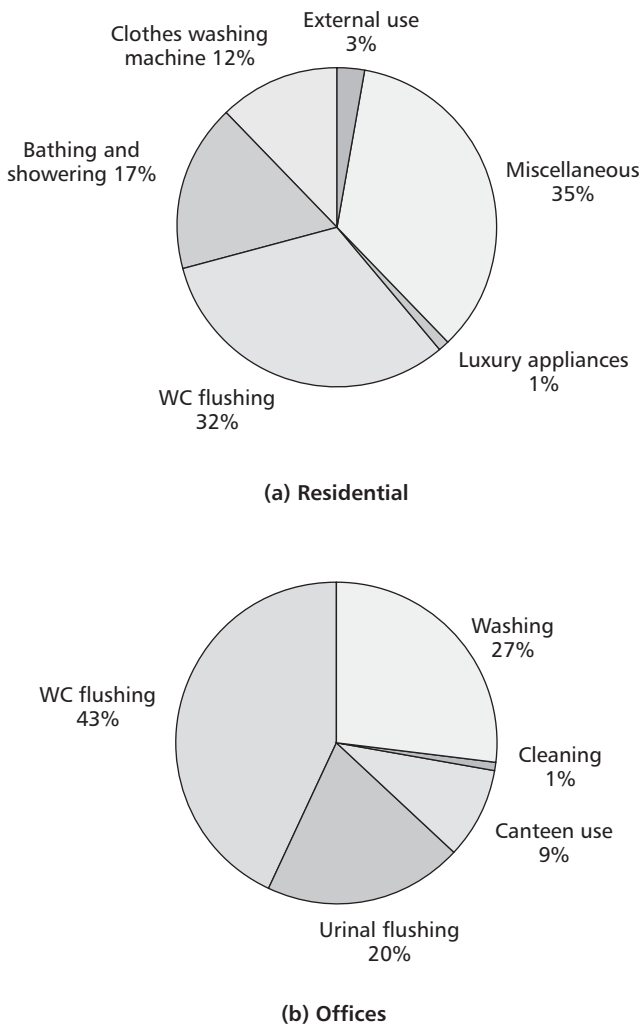


Figure 2.2 Typical water usage for dwellings and offices⁽³³⁾

enhanced to provide storage coupled with a gravity distribution system.

In dwellings, the occupants' water consumption is divided between the many appliances. A typical percentage breakdown is shown in Figure 2.2⁽³³⁾.

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 cold water usage refer to Table 2.4.

Refer to chapter 5 for further guidance on water conservation measures.

2.3.2 Cold water storage

2.3.2.1 General

Design codes recommend that storage be 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 storage provision, including the volume or period of storage, within the terms of their supply agreement with a consumer. However, many water supply companies recommend only that storage be provided in accordance

Table 2.4 Typical cold water usage for fixtures and appliances (source: BREEAM⁽³⁴⁾)

Fitting/appliance	Cold water usage
WC	6 litres (effective flush volume)
Handwash basin taps	12 litre/min
Bath	200 litres (volume)
Urinal:	
— single	10 litre/h
— 2 or more	7.5 litre/h per bowl
Kitchen tap:	
— kitchenette	12 litre/min
— restaurant (pre-rinse nozzels only)	10.3 litre/min
Dishwasher:	
— domestic	17 litres per cycle
— commercial	8 litres per rack
Domestic washing machine	50 litres per use

with BS EN 806⁽¹⁾, placing the responsibility and decision firmly on the designer.

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

- period and hours of occupation
- pattern of water usage
- potential for an interruption of supply
- available mains pressure and any inadequacies during the hours the building is in use
- health and safety considerations, including prevention of bacterial contamination such as *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 be occupied for only eight to ten hours. Where a building is occupied by elderly or infirm people then avoiding any disruption of the water supply is an important consideration as they would be unable to leave the building easily should water become unavailable.

Healthcare and custodial establishments require their buildings to be provided with storage to safeguard against an interruption of the mains supply. Industrial clients may 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, the water available would be conserved as much as possible, thereby extending the time of occupancy beyond that anticipated under normal usage rates.

Where the period of storage to cover an interruption of the mains supply is not specified by the water supply companies, regulations, or client requirements, then Table 2.5 provides recommendations for storage volumes expressed as a percentage of the daily water demand.

Before starting the design, the water supply company with responsibility for the local supply where the project is located should be consulted regarding available water

Table 2.5 Period of storage (source: *Plumbing engineering services design guide*⁽³⁵⁾)

Type of building	Percentage of daily demand (%)
Hospitals	50%
Nursing homes	50%
Dwellings	0–50%
Hotels, hostels,	50%
Offices	0–50%
Shops	0–25%
Libraries, museums, art galleries	0–25%
Cinemas, theatres	0–25%
Bars, night clubs	0–25%
Sports facilities	0–25%
Schools, colleges, universities	50%
Boarding schools	50%

quantities and pressure. In some areas the water supply company will recommend water storage for the following reasons:

- To provide against interruptions of the supply caused by repairs to mains, etc. and to provide storage up to a 24-hour period dependent upon building occupation time. Excessive storage should be avoided in order to minimise stagnation.
- To reduce the maximum rate of demand on the water reticulation mains.
- To enable the water supply company to limit the pressure in the distribution system, thereby reducing waste of water resulting from leaking reticulation mains, and reduce their mechanical water pressurising operational costs.
- To enable water to be pumped to a height not available from the water supply company mains.

The storage cistern should be located and protected from frost and heat gain to keep the water below 20 °C and designed to maintain the water quality. It should not be in the same plant room as heat raising or rejecting plant.

If the storage cistern is supplying water to a vented domestic hot water system then it should be sized to accommodate the expansion and contraction of that system without wasting water, i.e. not expelling water via the overflow when the water heats up and expands.

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, in conjunction with a pumped supply system, will be needed.

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.

Ideally all storage should comprise two compartments or cisterns in order that maintenance can be carried without interrupting the water supply.

For small storage quantities one-piece tanks can be used as these are generally of a low-height construction. For storage of 1000 litres or more, sectional panel cisterns may be considered more appropriate with a central divider, thus half the supply is available while the other half is emptied to enable maintenance to be carried out.

Above 4000 litres storage, twin cisterns may be considered appropriate. Sectional tanks commonly have flanges, either internal or external. External flanges permit tightening without maintenance personnel needing to enter the cistern and, on the base, permit the tank to drain through a single drain point, thereby avoiding entrapment of water between the flanges. This feature reduces the possibility of water stagnation, which can lead to the growth of harmful bacteria such as *Legionella*.

In calculating the size of storage cisterns, a freeboard allowance is necessary to accommodate the float valve and overflow installations. Depending on pipe sizes, a freeboard depth of a 250–300 mm is commonly required on 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(s). An allowance for the 'dead zone' at the base of the cistern should also be made, e.g. where a low water level cut-out switch protects a pump set.

The location of the inlet and outlet connections is important. A crossflow through the cistern needs to be achieved in order to assist with the complete and regular turnover of water throughout the storage period.

2.3.2.2 Overflows and warning pipes

The arrangement of water storage facilities including overflows and warning pipes must comply with the Water Supply (Water Fittings) Regulations^(3,20,21).

Every overflow and warning pipe termination should be clearly visible and should not discharge to another cistern.

Cisterns with a capacity less than 1000 litres should be fitted with a warning pipe only, while every cistern or tank with a capacity of 1000 litres or more should be fitted with both an overflow pipe and a warning pipe, or other approved device as indicated below.

For a cistern with a capacity of between 5000 litres and 10 000 litres, only one overflow pipe needs to be provided, as long as the cistern is fitted with a level indicator to clearly show when the water level is not less than 25 mm below the overflowing level of the lowest overflow pipe. Where storage capacity exceeds 10 000 litres and the cistern is fitted with an audible or visual alarm operating independently of the valve or device which controls the inflow of water, indicating when the water in the cistern is about to overflow, then only one overflow need be fitted.

Each warning pipe and overflow pipe should be installed so as to discharge water immediately the water in the cistern reaches the overflow level.

The overflow should be at least one pipe size larger than the incoming water main supplying the cistern or tank. All overflows should be hydraulically capable of convey-

ing the full water inflow rate that could occur if the level control fails and the valve remains fully open.

The warning pipes and overflow pipes must be constructed of rigid pipework only. Where two or more cisterns have a common warning pipe that pipe should be installed so that the source of any overflow may be readily identified.

The overflow and/or warning pipe must comply with the requirement that the ingress of foreign bodies and contamination of the stored water are prevented. A screened air inlet and overflow and/or warning pipe must be provided.

2.3.2.3 Space requirements

Table 2.6 provides a guide to the plantroom area required by storage cisterns of various sizes.

For large commercial and industrial buildings, additional space will be required to enable installation and maintenance. Table 2.7 provides a guide to the minimum dimensions required for access, but the actual requirements should be obtained from the cistern manufacturer.

2.3.2.4 Cold water storage design

Water storage cisterns should be designed and sized to provide an adequate water supply to a building or a development to:

- (a) avoid excessive cutting-in and cutting-out of pumps

Table 2.6 Space requirements for water storage tanks (source: *Plumbing engineering services design guide*⁽³⁵⁾)

Capacity (litre)	Tank height (m)		
	1.5	2	3
5000	18	18	—
10 000	31	23	—
20 000	50	40	—
40 000	72	60	50
60 000	—	80	60
100 000	—	100	80

Table 2.7 Access distances for water storage tanks (source: *Plumbing engineering services design guide*⁽³⁵⁾)

Location	Distance (mm)
Around tank	750
Between tanks	750
Above tank	1000
Below tank	600
Outlet pipework	1500
Tank thickness	100
Insulation	Up to 100
Float valve housing	300
Service entry to tank	800

- (b) to provide a buffer supply in the event of failure of power or water supply.

Sizing of storage cisterns should be sensible and reasonable for the type of development. It is important to keep records of the assumptions made during design and of how the cistern size was selected.

Consideration should be provided to the following when designing cold water storage cisterns:

- estimated number of people being served
- average water usage per person
- fixed connected loads
- estimated peak duration period
- estimated maximum demand (litre/s)
- use of building
- space requirements for cistern(s)
- air break and overflow arrangement.

2.3.2.5 Occupancy

If the expected occupancy of the building is not known, the requirements of Health and Safety at Work etc. Act 1974⁽³⁶⁾ may be used to estimate the likely building occupancy, whereby a general allowance is given of 10 m² per person of actual working floor space excluding the floor area occupied by such items as toilet facilities, staircases, passages etc. The estimated occupancy can then be used to calculate the number and type of sanitary fittings requiring water services.

2.3.2.6 Calculating water storage requirements

Table 2.8 gives recommended water quantities for various building types. Note that these figures are for congested use, and those listed in Table 2.9 are more typical.

The following is proposed as a general guideline only. Water storage should be assessed on a project-by-project basis. The same principle for calculating water storage

Table 2.8 Recommended minimum storage of cold water for hot and cold water services

Type of building/occupation	Minimum storage
Hostel	90 litres/bed space
Hotel	200 litres/bed space†
Office premises:	
— with canteen facilities	45 litres/employee
— without canteen facilities	40 litres/employee
Restaurant	7 litres/meal
Day school:	
— nursery	15 litres/pupil
— primary	15 litres/pupil
— secondary	20 litres/pupil
— technical	20 litres/pupil
Boarding school	90 litres/pupil
Children's home or residential nursery	135 litres/bed space
Nurse's home	120 litres/bed space
Nursing or convalescent home	135 litres/bed space

† There will be significantly greater demand in a luxury hotel than in a budget hotel.

Table 2.9 Recommended water storage

Type of building	Demand (litre)	Basis of demand	Type of building	Demand (litre)	Basis of demand
Residential:			Hospitals:		
— 1 bedroom	210	Bedroom	— district general	600	Bed
— 2 bedroom	130	Bedroom	— surgical ward	250	Bed
— 3 or more bedrooms	100	Bedroom	— medical ward	220	Bed
Student accommodation:			— paediatric ward	300	Bed
— en-suite	100	Bedroom	— geriatric ward	140	Bed
— communal	90	Bed space	Sports changing rooms:		
Nurses home	120	Bed space	— sports hall	35	Person
Children's home	135	Bed space	— swimming pool	20	Person
Elderly persons' accommodation:			— field sports	35	Person
— sheltered	120	Bedroom	— all-weather pitch	35	Person
— care home	135	Bed space	Art gallery	6	Person
Prison	150	In mate	Library	6	Person
Hotels:			Museum	6	Person
— budget	135	Bedroom	Theatre	3	Person
— Travel Inn/Lodge	150 (average)	Bedroom	Cinema	3	Person
— 4/5-star luxury	200	Bedroom	Bars	4	Person
Offices:			Night club	4	Person
— with canteen	45	Person	Restaurant	7	Cover
— without canteen	40	Person	Airports	15	passenger
Schools:			Railway terminals	6	passenger
— nursery	15	Pupil	Laundries	45	kg dry clothes
— primary	15	Pupil			
— secondary	20	Pupil			
— 6th form college	20	Pupil			
— boarding	90	Pupil			

may be used in all cases, with the period of storage differing according to the nature of the project and any specific requirements requested by the client.

Sizing should be based on the average water consumption per person per day. These figures and statistics can be obtained from various sources, including local water supply companies. The following figures may be used as guidance. It should be noted that to comply with water efficiency regulations, the design water usage should not exceed 125 litres per person per day. For luxury apartments, where there is potentially high usage, the designer will most likely need to incorporate rainwater harvesting or greywater re-use systems to reduce the consumption of wholesome water.

- (a) *Office buildings*: 55 litres/person per day (includes nominal air conditioning loads)
- (b) *Apartments/residential*:
 - Low budget housing (one bathroom): 190 litres/person per day
 - Three bedroom dwelling (two bathrooms): 280 litres/person per day
 - Luxury apartment (two or more bathrooms): 400 litres/person per day
- (c) *Hotels*:
 - Guests: 140 litres/person per day (includes meals and laundry)
 - Staff: 55 litres/person per day

The above figures do not apply to 'high-end' luxury hotels.

An allowance for air conditioning should be added to the storage capacity for hotels.

Note: most international hotel chains have their own guidelines for water storage, which should be always followed.
- (d) *Restaurants*: 8 litres/person per meal
- (e) *Schools*: 30 litres/student per day.

Supply or initial storage

The required storage is obtained from:

$$\text{Storage volume} = \left(\frac{\text{number of persons}}{\text{persons}} \right) \times \left(\frac{\text{litres per person}}{\text{person}} \right) \times \left(\frac{\text{number of days' storage}}{\text{storage}} \right)$$

Elevated roof or gravity supply tanks should have a minimum storage capacity of one hour's peak use. The following formulae should be used only as a guide:

- *Office buildings*: allow for 1½ hours supply:
1½ hours supply = no. of persons × 55 litres
- *Apartments/residential*: assume 75% of total daily demand will be used during a 2-hour peak period (morning and evening peak periods):
Capacity required for peak period =
no. of persons × litres × 0.75 × 0.5
- *Hotels*: assume 40% used over a peak period of 3 hours:

$$\begin{aligned} \text{Capacity required for peak period} = & \\ & [(\text{no. of guests} \times 140 \text{ litres}) \\ & + (\text{no. of staff} \times 55 \text{ litres})] \times 0.4 \\ & + \text{air conditioning requirements for 3 hours} \end{aligned}$$

Note that Table 2.9 gives the combined design demand for both hot and cold water supply; these data are intended to aid in estimating how much water is used and where.

2.3.3 Water delivery systems

2.3.3.1 Gravity distribution

For gravity distribution 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(s) and the highest draw-off point, or draw-off point with the greatest head/pressure loss.

The advantages of gravity supplies are:

- availability of water in the event of water mains or power failure
- no pump running costs
- potentially less noise due to lower pipe flow velocities.

The disadvantages are:

- greater structural support
- larger pipe sizes due to limited available head, when compared to pumps
- lower delivery pressures.

2.3.3.2 Pumped supplies

The delivery of water by pumping will provide flexibility in the positioning of the storage 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 multi-stage variable duty and/or inverters is an advantage.

Generally, two pumps are used as a minimum, each having 100% system duty and controlled to enable them to act as a stand-by for 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 feeds may be appropriate. The advantage of this is to provide a proportion of the daily water usage in a tank(s) at roof level which would provide a gravity-down feed service and would continue to provide water in the event of a failure of the pump. Such a system would comprise:

- an incoming main
- low level break or storage tank
- pump set
- high level tank(s)

- 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.

Pumped supply selection

Careful consideration should be given when selecting the most suitable system for a project. The following examples are for information, and may be used as a guide on projects of a similar nature.

- *High rise, apartments or office block*: water should be pumped by means of a booster pump to an elevated storage tank at roof plant level. The storage tank then supplies taps and outlets by gravitational means while the top four floors are served by a pressure pump.
- *Low rise hotel or apartments (6 floors or fewer)*: an automatic variable speed pumping system provides water from the supply to each tap and outlet, over the variable water flows at the required design pressures.
- *Dwelling*: an automatic pressurised pumping system, supplying water from the water supply, direct to all taps and outlets.

Detailed guidance on pump selection is provided in chapter 6.

2.4 Hot water systems

2.4.1 Introduction

Hot water services should be designed to provide the necessary quantity of hot water to a fixture or appliance by means of a piping system designed with suitable water velocities, pressure drops and thermal losses to deliver hot water at the required flows, pressures and temperature.

Hot water production and storage temperatures must comply with Health and Safety Executive requirements⁽³⁷⁾ in order to minimise the growth of *Legionella* bacteria. This demands a minimum storage temperature of 60 °C with a minimum secondary return (if provided) temperature of 50 °C.

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

2.4.2 Hot water demand and storage

2.4.2.1 Pattern of hot water usage

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 building's hot water requirements can be recognised and the maximum requirements designed for where necessary.

Measured hot water consumption alone is not sufficient 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, (see Figure 2.3).

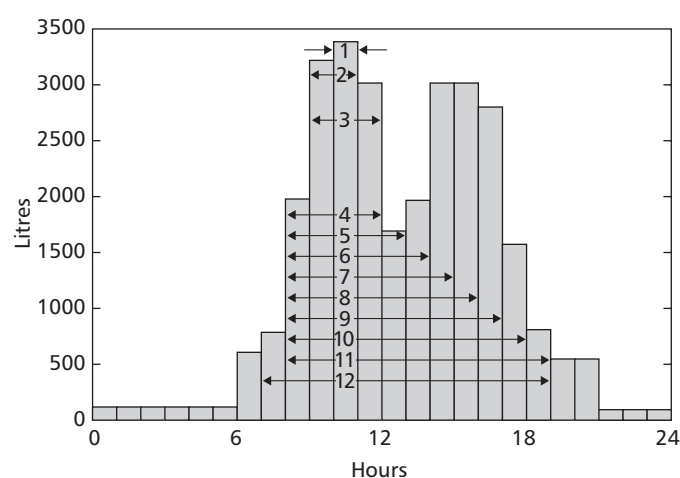


Figure 2.3 Example of a demand pattern histogram (reproduced from the *Plumbing Engineering Services Design Guide*⁽³⁵⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

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

The size of plant required is determined by the draw-off rate and pattern of consumption in each day. The hot water storage capacity should be related to both the design consumption and recovery rate. In most instances hot water is not required continuously but at specific periods throughout the day, see Figure 2.3. The hot water peak usage can be calculated to determine the hourly hot water output required. Examples of daily demand patterns for various types of building are shown in Figure 2.4.

Peak hot water demand periods for some specific applications are shown in Table 2.10.

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 dependant on the occupants and activities taking place, see section 2.4.2.1.

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

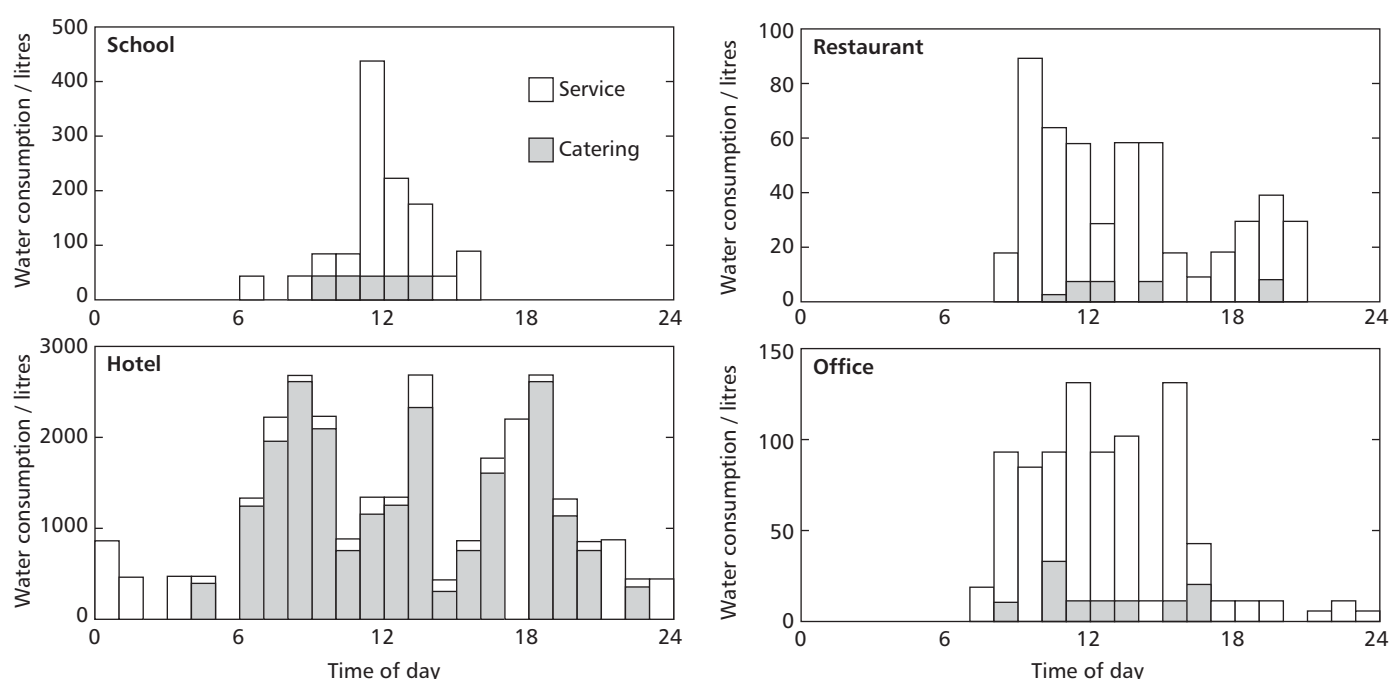


Figure 2.4 Peak demand histograms (reproduced from the *Plumbing Engineering Services Design Guide*⁽³⁴⁵⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

Table 2.10 Peak hot water demand periods for specific applications

Application	Suggested peak period	Hot water requirements (at supply temperature of 60 °C unless stated otherwise)
Snack bars; takeaway food outlets	1–2 hours (12 to 1 pm or 12 to 2 pm)	Allow 3.1 litres per meal; this allows for cooking and washing-up (e.g. 200 meals over 2 hours requires 620 litres). <i>Note:</i> water is required at 77 °C for sanitising (usually heated to this temperature within the dishwasher).
Canteens, cafes, hotel kitchens, restaurants	1–2 hours (12 to 1 pm or 12 to 2 pm)	Allow 5.5 litres for each 3-course meal; this allows for cooking and washing-up (e.g. 200 meals over 2 hours requires 1100 litres). <i>Note:</i> water is required at 77 °C for sanitising (usually heated to this temperature within the dishwasher).
Holiday flats, hotels, motels, guest houses	1 hour (7:30 to 8:30 am)	Allow 20–25 litres per head over the peak hour (e.g. 40 guests require 1000 litres over 1-hour. For 4-star and 5-star accommodation allow 35–50 litres per head.
Apartments	1 hour (7 to 8 am)	Allow for each type of apartment within the building: studio 25 litres, 1-bed apartment 40 litres, 2-bed apartment 70 litres, 3-bedroom apartment 90 litres, 4-bedroom apartment 110 litres, penthouse 150 litres.
Caravan parks, camping areas	Spread over 2 hours	Allow 20 litres per person; average 4 persons per van (e.g. 30 vans = 120 persons require 2400 litres over 2 hours). In long-term or residential parks, the peak may extend over a much longer time; the actual usage pattern should be ascertained.
Hairdressing salons	3–4 hours	Each installation needs to be evaluated individually but 10 litres per customer may be taken as a guide
Squash courts	Spread over 4 hours	Allow 20 litres per player; average 16 players per court over 4 hours (e.g. 4 courts require $4 \times 16 \times 20 = 1280$ litres over 4 hours).
Offices	Spread over 8 hours	Allow 3–4 litres per person per day (showers seldom used) or 1.5 litres per person over a 1-hour peak. (The increasing popularity of cycling to work will increase the requirement for showers in office buildings.)
Factory changing rooms (light industry)	1 hour (4 to 5 pm)	Average 30% use showers; allow 20 litres per head; average 70% use hand basins, allow 3 litres per head (equivalent to 8–9 litres per person)
Factory changing rooms (heavy/dirty industry)	1 hour (4 to 5 pm)	Allow 30 litres per head; in some industries, such as mining, allow up to 50 litres per head.
Coin-operated laundries	Spread over 8 hours	Allow 70 litres per machine per hour (e.g. 6 machines $\times$ 70 litres $\times$ 8 hours = 3360 litres over 8 hours. For large commercial laundries allow 10 litres per kilogram of washing.
Glass-washing machines	Usually over 2 hours	Determine quantity of glasses to be washed over peak period. Allow 3 glasses per litre of beverage sold. Most machines require 7 litres of hot water per wash of 25 glasses, and can perform one wash per minute (e.g. 1000 litres of beverage over 2 hours requires $1000 \times 7 \times 3/25 = 840$ litres of hot water). Alternatively, allow 3 glasses per person, taking the licensed capacity of the premises as a guide. <i>Notes:</i> (1) temperature required by regulations is 82 °C, (2) where beverage quantity is known in gallons, multiply by 4.55 to convert to litres, (3) the equipment manufacturer should be contacted to determine whether a hot water supply is required.

The building's 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 has been based on a 2-hour storage re-heat period and this has generally proved to be a satisfactory benchmark for peak demands for that period.

2.4.2.2 Hot water demand

Table 2.11 offers a compilation of figures currently recommended by the water industry's design codes, with additional categories added where considered useful. The recommended storage volumes are based on a 65 °C storage temperature and a 2-hour re-heat period (i.e. assumes a bulk storage vessel). The data should be considered as representative of capacities that have not given rise to complaints of inadequacy. The storage capacity can be reduced by using high heat input and high recovery systems.

Additional hot water appliances must be considered in commercial and industrial applications associated with dishwashing and laundries. Commercial dishwashing and washing machines can be divided into two basic types:

- batch operation
- continuous operation.

The hot water requirements depend upon the appliances selected and it is advisable to check with the manufacturer regarding the quantity of hot water used per cycle and the pressure required. Hot water availability should cover continuous use of all machines over the period during which they are likely to be in use. Many dishwashers are supplied with cold water only and are equipped with their own water heating and heat recovery arrangements.

Typical hot water requirements for dwellings are shown in Table 2.12.

2.4.2.3 Hot water storage

Efficient hot water storage may depend on stratification within the vessel, so that the lower density hot water remains at the top of the vessel ready for use, whilst the cold replenishment water enters and remains at lower levels. This is particularly relevant where the water

Table 2.11 Daily hot water demands (adapted from data contained in the *Plumbing Engineering Services Design Guide*⁽³⁵⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

Type of building	Daily demand / (l/person)	Storage per 24-h demand / 1	Recovery period / h
Colleges and schools:			
— boarding	115	23	2.0
— day	15	4.5	2.0
Dwelling houses:			
— economic, local authority	115	115	4.0
— medium, privately owned	115	45	2.0
— luxury, privately owned	125	45	2.0
Flats*:			
— economic, local authority	68	23	4.0
— medium, privately owned	115	32	2.0
— luxury, privately owned	125	32	2.0
Factories	15	4.5	2.0
Hospitals†:			
— general	136	27	1.0
— infectious	225	45	1.0
— infirmaries	68	23	1.5
— infirmaries with laundry	90	27	1.0
— maternity	225	32	2.0
— mental	90	23	2.0
— nursing staff accommodation	136	45	2.0
Hostels	115	32	2.0
Hotels:			
— 5 star rating	136	45	1.0
— 2 star rating	114	36	1.5
Offices	14	4.5	2.0
Sports pavilions	40	40	1.0
Restaurants (per meal)	—	6	2.0

* Based on indirect systems; storage volumes may be reduced where high input, high recovery systems are installed.

† For hospital design refer to HTM 04-01⁽⁴⁷⁾.

heating system uses off-peak electricity and is taken into account in the plant sizing curves given in section 2.4.6.

Without proper design, even short bursts of draw-off at high flow rates may produce sufficient turbulence to cause mixing. Mixing will tend to be less in larger, especially taller, vessels. Thus the traditional cylinder with height at least twice the diameter is highly suitable.

Table 2.12 Hot water requirements for typical domestic installations

Use	Temp / °C	Quantity of mixed water	User's requirements
Wash basin in bathroom	43 °C	2.5 litres	Minimum wait and minimum waste
Normal bath	44 °C	45–145 litres	Minimum wait to fill bath to required level and ability to top-up with hot water as bath water cools
Spa bath	44 °C	200–350 litres	As above with emphasis on quick filling over increased volume; a spa bath holding 300 litre of mixed would take 20 minutes to fill at a flow rate of 15 litre/min
Shower	41 °C	25–70 litres	Ability to adjust flow rate from 7 to 30 litre/min and to adjust temperature from 40 °C down to 'chill-off' temperature at will; freedom from temperature fluctuations due to other draw-offs
Kitchen	50–60 °C	About 4–5 litres	Minimum waste before obtaining hot water; water hot enough to clean greasy utensils

When calculating hot water storage volumes, a diversity factor should be applied, assuming stratification of 80% unless otherwise stated or known. This implies that 80% of the storage capacity will provide usable hot water.

Suitably constructed bunds should be considered for individual hot water units located in areas where water spillage or a burst hot water unit may cause damage. These areas include under sinks, in cupboards etc. The location of bunds or safe trays should comply with the requirements of BS EN 806⁽¹⁾.

Where heaters are located on drained floor surfaces, a floor waste adjacent to the hot water units should be provided.

Recommended hot water storage volumes for dwellings are given in Table 2.13.

Table 2.13 Hot water storage for domestic properties (reproduced from BS 8558⁽²⁾ by permission of the British Standards Institution)

Heat input to water / kW	Minimum storage capacity	
	With stratification / litre	With mixing / litre
<i>(a) Dwellings with one bath</i>		
3	109	122
6	88	88
10	70	70
15	70	70
<i>(b) Dwellings with two baths</i>		
3	165	260
6	140	200
10	130	130
15	120	130

2.4.3 System selection

There are many types of hot water systems suitable for differing applications. Selection depends on the application, the client's requests and the required performance of the system.

The different systems include:

- individual hot water systems
- centralised hot water systems
- solar and heat pump hot water systems.

The production of hot water can be achieved by various means, e.g:

- *Electricity*: generally with direct immersed elements (*Note*: except where the hot water demand is low, the use of electricity for hot water production is not recommended due to the relatively high CO₂ emissions associated with electricity production).
- *Gas*: generally directly fired through a heat exchanger inside the tank, but may heat the water in a separate heat exchanger module external to the tank.
- *Low temperature hot water boiler plant*: either dedicated or, more likely, forming part of the space heating plant.

- *Steam*: when available from a central plant facility.

Sharing hot water generation with space heating plant can reduce energy efficiency as a result of the additional transfer process and less efficient operation when space heating is not needed.

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

Commonly used forms of hot water heating are:

- *Dwellings and small buildings*: electricity, or gas combination (i.e. HWS plus heating) boiler.
- *Offices*: electrical local ('point of use') water heater.
- *Larger premises and sports facilities*: oil or direct fired gas water heater.

A decision tree for selecting hot water supply systems is shown in Figure 2.5.

2.4.3.1 Individual hot water systems

Individual hot water systems are designed to serve a dwelling or group of fixtures. Hot water units, whether storage type or instantaneous, should be located as close as possible to all outlets being served.

Storage hot water units should be sized to provide adequate hot water for the maximum peak period. This size will depend totally on the type of fuel/energy source being used to heat the water, i.e:

- *Electricity*: storage systems using off-peak electricity should be sized for the full 24-hour daily load. Storage systems utilising continuous tariff electricity should be sized for the peak period.
- *Gas or oil*: the required amount of storage combined with the capacity of the burner should be sized for the peak load.
- *Indirect*: the storage volume should be sufficient to cover the peak hour load plus the recovery period; high recovery indirect systems may reduce the storage by taking into account the heat input during the peak period. Recommended storage volumes for dwellings are given in Table 2.13 above.

Instantaneous, continuous flow hot water units should be sized so that the water is raised to the required temperature, i.e. 60 °C, in order to provide adequate hot water at the maximum calculated flow rate.

2.4.3.2 Centralised hot water systems

A centralised hot water system consists of a hot water heating plant, flow and return piping, and circulation pump.

The hot water heating plant can either be:

- a bank of storage hot water units (either gas or electric)
- copper fin-type boiler plant (gas) with storage

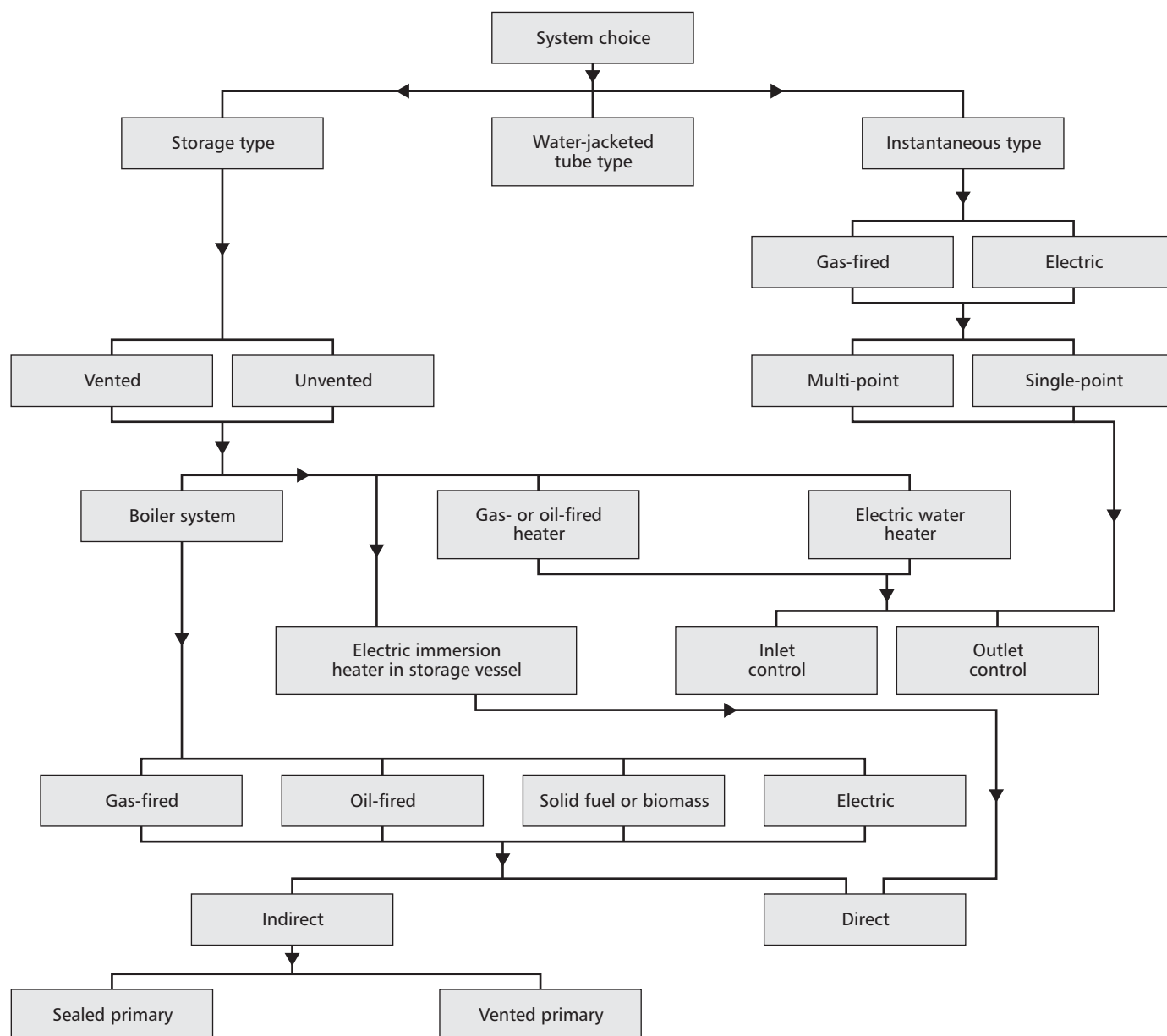


Figure 2.5 Decision tree for hot water supply selection

- calorifiers with boiler (gas, oil)
- boilers with heat exchangers.

The last two may be combined with the mechanical services boiler plant, utilising the boiler plant as required for the mechanical services and as a heat energy source, heating the domestic water via a calorifier or heat exchanger.

2.4.3.3 Solar hot water systems

Detailed guidance on the use of solar energy for domestic hot water is provided in *Solar heating: design and installation guide*⁽³⁸⁾.

2.4.3.4 Unvented hot water systems

In England and Wales*, installation must be carried out by competent persons in compliance with Part G3 of the

* Requirements may differ in Scotland and Northern Ireland.

Building Regulations 2010⁽³⁰⁾. Part G3 of Building Regulations Approved Document G⁽³¹⁾ provides guidance and defines domestic hot water as:

‘...water that has been heated for cooking, food preparation, personal washing or cleaning purposes. The term is used irrespective of the type of building in which the hot water system is installed.’

There are three categories of unvented storage system:

- systems with a capacity of 15 litres or less
- systems up to 500 litres and 45 kW power input
- systems over 500 litres or over 45 kW power input.

Approved Document G3 states that water heaters with a capacity of 15 litres or less that have appropriate safety devices for temperature and pressure will generally satisfy the requirement set out in G3(3). Approved Document G3 does not apply to systems providing space heating only or systems that heat or store water for the purposes of an industrial process.

For systems of up to 500 litres and 45 kW power input, any unvented hot water system should be in the form of a proprietary unit or package that complies with Part G3 and is installed by a 'competent person'.

Systems of over 500 litres or over 45 kW power input will generally be individual designs for specific projects and not proprietary units or packages. The system should be designed to the same safety requirements as cited in Approved Document G3⁽³¹⁾ and BS EN 806⁽¹⁾ and be designed by competent engineers. The system should be installed by a competent person. Due to the potential dangers in designing an unvented system, it must only be undertaken by a competent engineer experienced in this specialism. Note that the Water Regulations^(3,20,21) also apply.

Since the hot water supply is provided by the same incoming main as the cold water, the incoming main should be sized on the maximum simultaneous demand for both hot and cold water requirements.

Direct mains water supply systems are limited in pressure to the available water pressure from the water supply company. For this reason it is recommended that flow or pressure tests over a 24-hour demand period are taken to ensure sufficient pressure is available to correctly operate both the hot and cold water systems simultaneously.

Building Regulations 2010 Part G3⁽³⁰⁾ covers combination boilers and water jacketed tube heaters. The unvented discharge pipe from the combined temperature and pressure relief valve, or temperature relief valve device, must be of metal and the diameter must conform to Table 1 in Building Regulations Approved Document G⁽³¹⁾. This pipe must discharge into a purpose-made tundish so that there is a clear, visible air gap. The pipe from the tundish must be metal with a diameter and a continuous fall conforming to the recommendations in the Approved Document.

Hot water expansion

The expansion tank/vessel has the potential to become a place for *Legionella* bacteria to develop, so correct installation is paramount. The expansion tank should be:

- positioned so as to accommodate the expansion and contraction
- positioned to allow constant change of water and to drain freely
- kept cool (i.e. below 20 °C), e.g. positioned on the cold water supply to the hot water system, and not be subjected to temperature fluctuations
- positioned to prevent debris from collecting in it
- constructed using materials that will not encourage microbiological growth
- correctly sized to accommodate the expansion of the water in the system, but not oversized since this could lead to stagnation
- fitted with filters on the incoming supply to prevent debris entering the system
- checked regularly to ensure that the air charge is maintained.

Adequate provision for expansion and contraction should be made in every section of pipework, especially where a pipe passes through a wall, floor, slab, beam etc.

Expansion loops as outlined in BS EN 806⁽¹⁾ should be used in preference to mechanical devices. They should be produced from continuously bent tubing and not made-up from a combination of fittings.

Automatic air release valves should be installed in all centralised hot water systems.

2.4.4 Design considerations

2.4.4.1 General

In the selection of the type of hot water production, the time available for re-heating 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 that hot water is available during the slower re-heat period.

The selection and capacity of hot water systems requires careful planning and consideration. Design parameters should also be assessed to ensure the load profile of the building matches the end user's requirements.

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 required by occupants working outside the normal working hours.
- A factory with a production line will require sufficient hot water to meet the demand at breaks in the shift when the workforce may all wish to wash hands etc.
- A sports pavilion will need to be able to provide large quantities of hot water for teams' showering needs over a short time following games, whenever they occur.

The following points should be considered during the design of hot water supply systems and selection of components:

- building function and number of occupants
- hot water capacity required, dependent upon the occupancy profile
- fuel type: availability and reliability of the chosen fuel, i.e. gas, solar, steam, off-peak electricity etc.
- client's requirements for hot water storage
- special requirements such as commercial kitchens, need to cater for large functions etc.
- environmental considerations
- maintenance and running costs of the system

- need for water treatment to avoid scaling heat exchangers (see chapter 13).

The hot water supply for public or commercial food preparation areas and kitchens, and for all kitchen sinks, should be at 60 °C. The temperature will be raised to 80 °C internally within dishwashers and glass washers for rinsing and sanitising.

Hot water for ablution is normally used at approximately 40 °C, being delivered to the outlet via a thermostatic mixing valve.

Hot water for laundries is usually required at 60 °C, with consideration given to multiple washing machines being used to evaluate demand at peak periods.

Within factories, shower facilities for shift workers may have one or two peak periods per day of approx. 30–60 minutes, with minimal draw-off in between. This is due to the shift patterns of 7–8 hours in between periods of peak demand. In these circumstances, consideration should be given to providing high storage capacity but with slow recovery.

To reduce energy costs, consideration should be given to the use of renewable energy sources for heating domestic hot water, such as solar heating and heat pump preheating etc.

Hot water systems for commercial purposes may consist of a natural gas, solid fuel, biomass, or oil-fired boiler in conjunction with a separate hot water storage vessel heated indirectly by a heat exchanger within the vessel, or a plate heat exchanger. The sizing of the hot water generator and heat exchanger not only influences the recovery rate of the storage, but also affects the system efficiency. Heat exchangers that can transfer only a small fraction of the boiler output can lead to excessive cycling of the boiler, particularly when space heating is not required. The full benefit of high-transfer heat exchangers requires the correct applications of controls. Where an indirect tank is used, consideration should be given to employing a coil with a high temperature drop in order to give a return temperature of 50 °C, but this may increase the recovery time.

Where only a few outlets are required, or outlets are widely separated, consideration should be given to the production of hot water locally either by electric or gas-fired water heaters. Where a large number of appliances are required to operate simultaneously, such as a sports centre where a large amount of hot water is necessary, the use of buffer vessel and heat exchangers should be considered.

Centralised hot water generation is typically used in large buildings or complexes. The procedure for designing a centralised hot water system may be summarised as follows:

- determination of hot water demand (quantity and temperature)
- selection of type of hot water system
- selection of storage capacity
- selection of hot water generator capacity

- design of pipe scheme and determination of pipe diameters.

In addition, the designer needs to consider the risk from bacteriological contamination, particularly *Legionella*, since the *Legionella* bacteria multiply actively at temperatures between 20 °C and 45 °C^(37,39).

Devices such as baffles within calorifier or cold water inlets are available to reduce turbulence and mixing where supplies to two or more appliances with high demands are required simultaneously.

2.4.4.2 Recovery

Hot water recovery is dependent upon the unit rating, and the peak demand, as well as the end users' requirements. For example, a hotel will have a number of peaks throughout the day, which may differ in terms of usage and time requirements, e.g. showering in the morning and kitchen/laundry usage in the afternoon.

The design engineer should also take into account the thermal efficiency and heat losses of the water heater, as well as consider stratification. Semi-storage hot water heaters can meet shorter demand peak periods, i.e. less than one hour. Recovery periods of between 1 and 2 hours are considered the industry norm, although consideration should be given to the peak periods throughout the day.

The approximate amount of hot water available from the available stored volume can be calculated using:

$$\begin{aligned} \text{Hot water available} = \\ \text{stored HW volume} + (\text{recovery rate} \times \text{time}) \end{aligned} \quad (2.1)$$

For example, consider a storage vessel of capacity 80 litres installed with a 3.6 kW element. It is required to raise the water temperature by 50 °C. Assuming 80% stratification, see section 2.4.3.2, an 80-litre hot water vessel can provide 64 litres of hot water.

The time required to raise the temperature of a given mass of water is given by:

$$\Phi = m c_p \Delta T \quad (2.2)$$

where Φ is the rate of heat supplied (kW), m is the mass of water (kg), c_p is the specific heat capacity of water (= 4.187) (kJ/kg·K) and ΔT is the temperature rise (K).

Rearranging equation 2.2:

$$\begin{aligned} \text{Heat-up time} &= m c_p \Delta T / (\Phi \times 60) \\ &= 80 \times 4.187 \times (60 - 10) / (3.6 \times 60) \\ &= 77 \text{ minutes} \end{aligned}$$

Therefore, the hot water vessel can heat up 62 litres of water in one hour or 124 litres in a 2-hour recovery period.

Therefore, using equation 2.1:

$$\text{Hot water available} = 80 + (62 \times 2) = 204 \text{ litres}$$

2.4.4.3 Secondary circulation

Secondary circulation (or trace heating, see below) needs to be provided when the length of hot water pipework and the volume of water the pipework contains become such that it would take an unreasonable length of time to draw off the cool water.

The secondary return pipework needs to carry only enough hot water to overcome the total heat loss from the flow pipework, which will have been sized to deal with the maximum demand on that circuit, plus the heat loss from the return pipework.

The recirculation flow rate must be set to ensure that an adequate temperature (rather than flow rate) is maintained throughout the system. The required flow rate is obtained by calculating the total heat emission from the pipework, including both the flow and return lines.

The calculated water flow and the resistance head of the circulation system are then used to select a suitable circulating pump.

The design procedure is as follows:

- (1) Determine the length of all hot water flow and return piping.
- (2) Multiply the heat loss for each pipe size in accordance with the relevant Building Regulations Compliance Guide^(28,40), using the corresponding heat loss per metre run of pipe for the insulating material selected.
- (3) For a maximum temperature difference ('delta-t') of 5 °C, the following formula may be used to calculate the required flow rate:

$$v_f = \frac{\phi \times 10^{-3}}{c_p \Delta\theta} \quad (2.3)$$

where v_f is the flow rate (litre/s), ϕ is the heat loss per metre run of pipework per hour (W), c_p is the specific heat of water (= 4.187) (kJ/kg·K) and $\Delta\theta$ is the temperature difference between the flow and return piping (= 5) (K). (Water at 4 °C has a density of 1000 kg/m³.)

For example, where the total heat emission from the combined flow and return pipes is 750 W in one hour, the flow rate from a hot water return pump is:

$$P = \frac{750 \times 10^{-3}}{4.187 \times 5} = 0.036 \text{ litre/s}$$

Therefore the hot water return pump would be required to move approx. 0.04 litre/s of water at 55 °C, against a head that must be calculated.

- (4) Select a circulating pump to provide the total required flow rate against the calculated head losses in the system at the required flow. A variable speed circulating pump system should be used for larger projects where the temperature drop in the system is critical, e.g. an international hotel.
- (5) Determine the required flow rate (litre/s) for each return leg and check the return pipe size, based on head loss and allowable velocity.

- (6) Locate balancing valves in the system where return pipes join together.

The system should be designed to limit the number of balancing valves, which should be located in readily accessible positions.

Balancing valves should be sized appropriately for the flow passing through them, so as to allow scope for adjustment during balancing and commissioning of the system. Balancing valves are often not the same bore as the pipe in which they are located.

For flow and return systems:

- Pipework should be installed on a gradient, rising to the furthest outlet, regardless of whether circulating pumps are to be installed or not.
- Circulating pumps should be located at the end of the flow line to ensure adequate head is available to avoid cavitation. Circulating pumps installed in gravitational systems should be installed where the maximum water pressure is available during flow conditions.
- Install automatic air release valves at all high points in the system.

2.4.4.4 Electrical trace heating

A flow-pipe-only system, incorporating trace heating, can be used as an alternative to the circulation of domestic hot water to the various points of use. In this type of system the heating cable automatically regulates its heat output according to the pipe temperature. As fresh hot water flows into the system, the cable reduces its heat output along those sections, and when the water becomes static and the temperature falls, the cable increases its heat output. Thus, the quantity of heat is provided according to the hot water demand.

It is also possible to use the trace heating to adjust the temperature to thermally disinfect the system for *Legionella* see section 2.7. This requires a temperature of 70 °C for not less than 1 hour.

The trace-heating cable is attached directly to the hot water pipe before applying thermal insulation. The main advantages of a trace-heated system over a conventional domestic hot water system include:

- less pipework and insulation
- less space required
- no pumps or balancing valves required
- reduced maintenance
- installation may be cheaper (but this would need to be assessed for the individual case).

Any savings in installation and maintenance costs must be balanced against the cost of on-peak electricity.

2.4.4.5 Safe water temperatures

Safe water temperatures needed to be considered for hot water supplies to appliances used by elderly, infirm and young persons. The requirements of 60–65 °C for stored

hot water and a minimum 50–55 °C for distributed hot water, in order to minimise the risk of *Legionella*, mean that temperature control will need to be provided at draw-off fittings used by persons at risk of being scalded. NHS document D08⁽⁴¹⁾ limits the temperature to taps in all NHS-type buildings (i.e. hospitals, care homes etc.) and Building Regulation G3(4)⁽³⁰⁾ limits bath temperatures in new dwellings and dwellings created by a change of use. Note that requirements may differ in Scotland and Northern Ireland.

Thermostatic mixing valves

To avoid scalding thermostatic mixing valves (TMVs) should be of the fail-safe pattern, closing down completely in the event of the cold water supply being shut off.

Avoid long (dead leg) branch pipes, keeping pipework from the valve to a minimum.

When selecting TMVs consideration should be given to:

- type of operation
- fail-safe characteristics
- recommended maintenance period
- ease of maintenance
- cost.

Design codes for health buildings require that all draw-off points that can be used by patients limit the temperature of the hot water to 43 °C.

The codes also extend to care homes for elderly persons 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, landlord and/or managing agent.

Temperature control is achieved by the deployment of single control mixer taps or valves. The type of valves can vary depending on the application. The types of mixing valve, as defined by NHS Health Guidance Note: *Safe hot water and surface temperatures*⁽⁴²⁾ are as follows:

- Type 1: a mechanical mixing valve, or tap including those complying with BS EN 1286⁽⁴³⁾ or BS 5779⁽⁴⁴⁾ incorporating a maximum temperature control stop device.
- Type 2: a thermostatic mixing valve, complying with BS EN 1287⁽⁴⁵⁾.
- Type 3: a thermostatic mixing valve with enhanced thermal performance complying with the NHS Estates Model Engineering Specification (MES) D08: *Thermostatic mixing valves (healthcare premises)*⁽⁴¹⁾.

The temperatures recommended by NHS Estates are shown in Table 2.14.

2.4.4.6 Thermal balancing valves

The introduction of automatic thermal balancing may require the designer to take a different view on the design

Table 2.14 Safe hot water temperatures (source: NHS Estates)

Appliance	Application	Max. temp. (°C)	Mixing valve type
Bidet	All	38	3
Shower	All	41	3
Wash basin	Hand rinse only under running water, i.e. toilets)	41	1
	For an integral part of ablution, i.e. bathroom	43	3
Bath	All	44	3
	Where difficult to attain an adequate bathing temperature	46	3

principles when applying these products within a domestic hot water (DHW) secondary circulation system.

The concept of thermal balancing introduces a dynamic balancing valve that will control the circulation volume within the system based on achieving a set temperature. The valve is often pre-set to ensure that the DHW secondary circulation return pipework, as close as possible to the draw-off points, is maintained at 55 °C or above. During initial commissioning, the valve will adjust the volume flow based on the temperature being sensed by the thermal element contained within the valve. As the temperature increases towards the set point, the valve will throttle down, which in turn increases the resistance in that particular pipework circuit and forces higher temperature water to other areas of the system, eventually leading to a successful thermal balance across the entire system.

It is important that once the set temperature has been achieved, a residual flow through the valve is maintained to prevent the introduction of dead legs into the system and to also allow the valve to maintain dynamic control on the system by constantly monitoring system temperatures. If the valve senses a decrease in water temperature, the valve will open gradually to encourage a higher volume of water through the circuit to try to maintain the pre-set temperature on the valve.

During an elevated water temperature pasteurisation process, many of the thermal balancing valves available will also assist the designer to implement a dynamic control of the flows with increased flow at higher temperatures. The thermal balancing valve will sense that there is an increase in temperature and will start to open past the residual flow position, this encourages higher temperature water to circulate around a subcircuit thus pasteurising that particular area of the system.

Once pasteurisation temperature has been achieved in a particular area, the thermal balancing valve should throttle back to residual flow, ensuring that a balance on the system is maintained during pasteurisation and forcing higher temperature water to other areas of the system to successfully achieve pasteurisation throughout the entire system.

The logical locating of thermal balancing valves within the HWS return circulation allows the designer to calculate

a volume flow based on the data for the thermal balancing valve against the available pump pressure within the system, as opposed to calculating heat losses through varying lengths of pipework.

The designer should consider that for the majority of the time the system will be trying to reduce volume flow as the temperature set points are achieved at the thermal balancing valves. The only time the system will require an increase in volume flow is when the system is cold or during part of the pasteurisation process. The designer should also consider that when a pasteurisation temperature is activated in the system, not all the thermal balancing valves will see the elevated temperature at the same time and thereby a ‘cascading effect’ of increased flows will occur across the system.

The thermal balancing valves closest to the plant room will sense the elevated temperature first, which will encourage higher volume flow through those pipework circuits. When the required pasteurisation temperature for the valve is reached, the valve will throttle back to residual flow and force higher temperature water to other areas of the system.

In most cases, the resultant diversity applicable to maximum flow requirements would be 1/3rd of valves at pasteurisation volume and 2/3rds of the valves at residual flow.

The performance characteristics of thermal balancing valves is shown in Figure 2.6.

In order to establish pump duties, the total number of thermal balancing valves within the circuit would need to be determined, together with the pressure drop through the index valve and the difference in the available pump pressure within the system between the favoured valve and the index valve.

To calculate the difference in the available pressure between the favoured valve and the index valve, the designer can simply measure the pipework length between the two valves and apply a rule of thumb of 200 Pa/m. The pressure drop though the index valve should be in the order of 5 kPa. By adding these two figures together, the

available pressure drop through the most favoured valve is calculated. Using the reference data available from the thermal balancing valve manufacturer (see example, Figure 2.7), the total flow rate requirement for the pump can be established, as follows:

$$\begin{aligned}
 P = & \{[(P_i + P_f)/2] \times \tfrac{1}{3} N_v\} \\
 & + \{[(R_i + R_f)/2] \times \tfrac{2}{3} N_v\}
 \end{aligned}
 \tag{2.4}$$

where P is the required total flow rate (litre/s), P_i is the pasteurisation volume flow for the index valve (litre/s), P_f is the pasteurisation volume flow for the favoured valve (litre/s), R_i is the residual volume flow for the index valve (litre/s), R_f is the residual volume flow for the favoured valve (litre/s) and N_v is the number of valves.

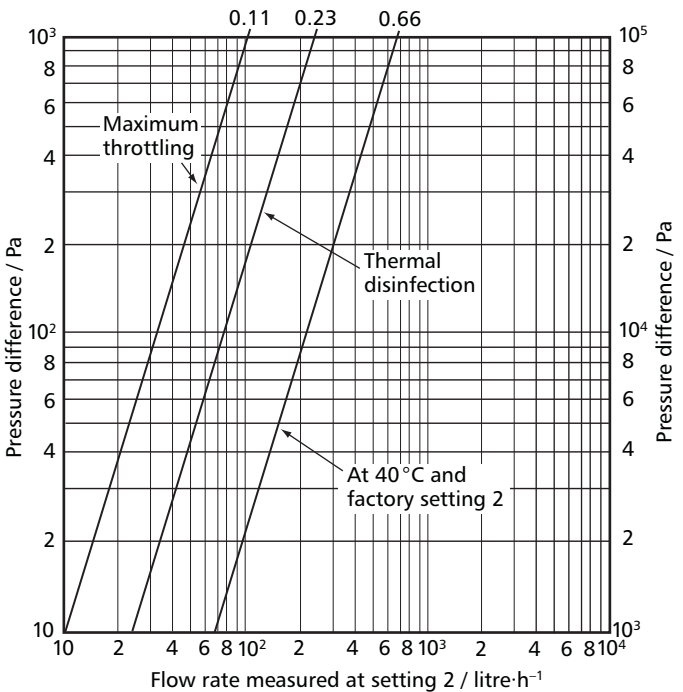


Figure 2.7 Typical manufacturer’s data sheet for thermostatic balancing valves (courtesy of Oventrop (UK) Ltd.)

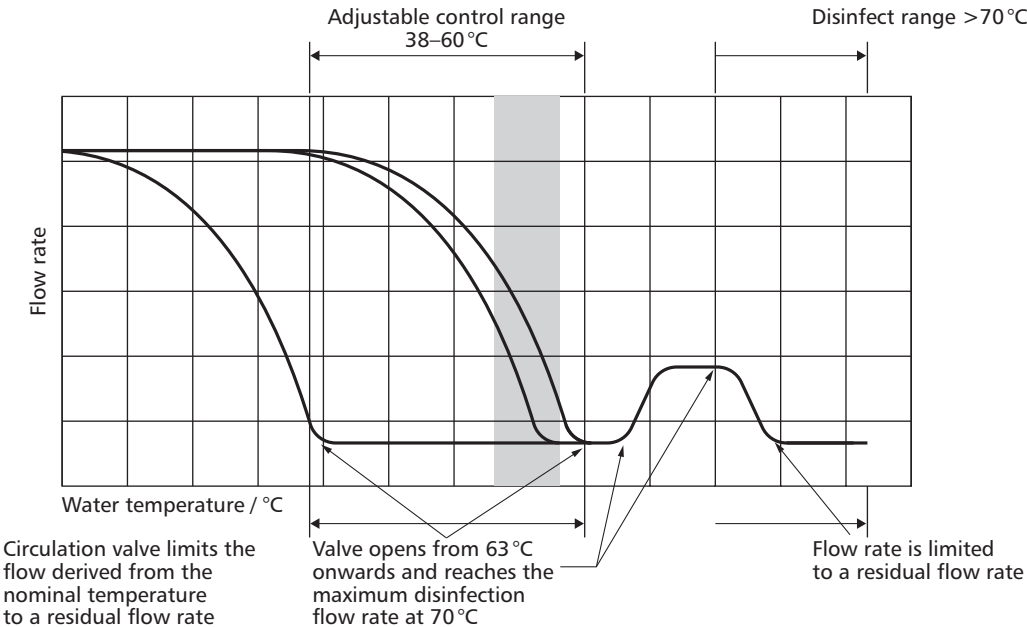


Figure 2.6 performance characteristics for thermostatic balancing valves (courtesy of Oventrop (UK) Ltd.)

Example

An HWS return circulation system contains 50 thermal balancing valves and the distance between the index and most favoured valve is 175 metres. It follows that the available pressure for the index valve is 5 kPa.

Using the ‘200 Pa/m’ rule of thumb, the available pressure drop for the most favoured valve is:

$$(175 \times 0.2) + 5 = 40 \text{ kPa}$$

From manufacturers’ data:

- residual flow at 5 kPa (index): $R_i = 0.0068 \text{ l/s}$
- residual flow at 40 kPa (favoured): $R_f = 0.0193 \text{ l/s}$
- pasteurisation flow at 5 kPa (index): $P_i = 0.0143 \text{ l/s}$
- pasteurisation flow at 40 kPa (favoured):
 $P_f = 0.0404 \text{ l/s}$

Pump flow calculation, using equation 2.4:

$$\begin{aligned} P &= \{[(0.0143 + 0.0404)/2] \times 1/3 \times 50\} \\ &\quad + \{[(0.0068 + 0.0193)/2] \times 2/3 \times 50\} \\ &= 0.4504 + 0.4455 = 0.8959 \text{ litre/s} \end{aligned}$$

2.4.4.7 Subcircuit balancing

Typically the system would be installed as detailed in Figure 2.8. Subcircuits 1, 2 and 3 would not require additional balancing valves as the way that the pipework has been installed would ensure circulation within those subcircuits. The question often arises about the requirement to install additional balancing valves downstream of a thermal balancing valve on subcircuit 4, as it appears that there is a favoured circuit and an index circuit contained within that subcircuit.

The designer needs to consider the relative pressure difference between the favoured circuit and the index circuit. Having established the flow rate previously, it can now be used to confirm that there is no requirement for additional balancing within this subcircuit.

Example

Subcircuit 4 has four sinks contained within it and the distance from the favoured sub-branch to the index is 9 m. From the previous example, the residual flow rate through the index thermal balancing valve is calculated as 0.0068 l/s, so the volume flow requirement for each sink unit = $0.0068/4 = 0.0017$.

Using pressure loss tables, the pressure losses for the index and favoured circuit can be calculated as follows:

- Favoured circuit: for 5 m of 15 mm copper pipe, pressure loss/metre at 0.00017 l/s = 0.75 Pa/m; total pipe loss = $0.75 \times 5 = 3.75 \text{ Pa}$

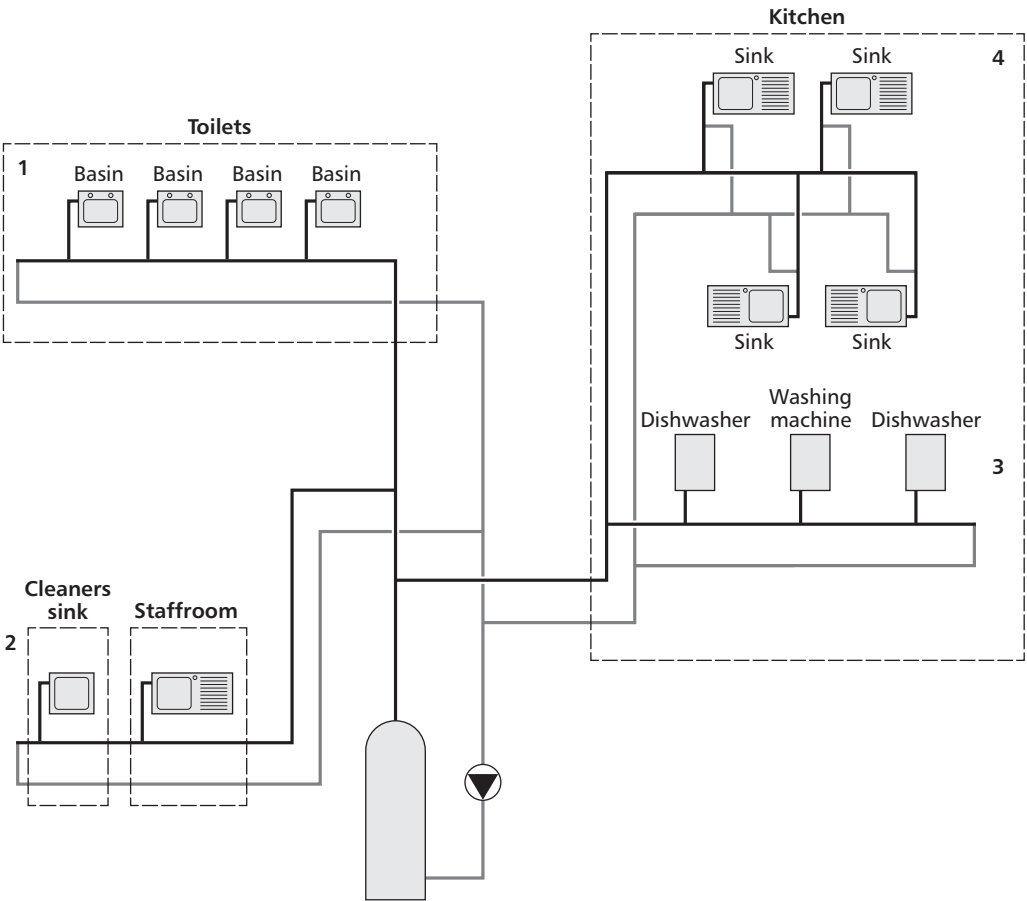


Figure 2.8 Schematic of thermostatic balancing valve arrangement (courtesy of Oventrop (UK) Ltd.)

- Index circuit: for 2 m of 15 mm copper pipe, pressure loss/metre at 0.00051 l/s = 2.25 Pa/m; total pipe loss = $2.25 \times 2 = 4.5$ Pa

For 2 m of 15 mm copper pipe, pressure loss/metre at 0.00034 l/s = 1.5 Pa/m; total pipe loss = $1.5 \times 2 = 3$ Pa

For 5 m of 15 mm copper pipe, pressure loss/metre at 0.00017 l/s = 0.75 Pa/m; total pipe loss = 3.75 Pa

Total pipe loss for index circuit = $4.5 + 3 + 3.75 = 11.25$ Pa

Therefore residual pressure loss to balance is:

$$11.25 - 3.75 = 7.5 \text{ Pa}$$

A residual pressure loss of 7.5 Pa is so small that the downstream subcircuits will 'self-balance' after the thermal balancing valves as there is effectively no difference to balance between the two circuits. A contributory factor in this assessment is the common practice of sizing the secondary circulation return pipe no smaller than 15 mm. It should also be borne in mind that no balancing device will control correctly against such low flow rates and pressure drops.

2.4.4.8 Water quality

Certain water supplies can cause major problems to the equipment and distribution pipework in a hot water system.

The concentration of total dissolved solids (TDS) will affect the conductivity of the water and this will influence the choice of sacrificial anode.

Scaling can occur when calcium carbonate is precipitated out of the water as it is heated; this can eventually lead to the blockage of valves and pipes. Water heaters should not be exposed to water with a pH less than 6 or greater than 9.5.

Note: water analysis should be performed by an accredited analytical laboratory.

2.4.4.9 System maintenance

In the design of hot water systems consideration should be given to future maintenance of the completed installation. This may influence the selection of components and equipment; factors to be considered include:

- proven reliability of selected plant and equipment, i.e. boilers, water heaters, heat exchangers etc.
- manufacturers' warranties and guarantees
- technical and service support
- availability and cost of parts
- speed of response to service call-outs
- extent of recommended periodic maintenance of equipment.

2.4.5 Design process

The hot water requirements may be calculated, as follows:

- (1) Determine the number of end users and hot water appliances. The hot water vessel should be selected according to the peak occupancy pattern potential of the building and not necessarily the total number of occupants. Appliances that use hot water (e.g. a washing machine and or dishwasher) must be considered.
- (2) Evaluate a basic peak demand. This step is relevant for hot water storage vessels on a continuous fuel supply. The availability consists of the peak delivery volume plus the recovery over one hour.
- (3) Consider the potential hot water usage in detail. An adequate supply of hot water must be available at temperatures, flow rates and quantities to suit the building requirements. In addition to the number of occupants, consideration must be given to the specific requirements of certain appliances. For example, a batch-type dishwasher has a maximum of 60 racks and a peak usage period of one hour. The manufacturer's literature for the machine indicates that the machine can perform 60 cycles per hour and requires 4.5 litres per cycle. The machine has a 14 litre rinse tank and a 32 litre wash tank. Therefore, hot water required during peak = $(60 \times 4.5) + 14 + 32 = 316$ litres.
- (4) Redundancy: depending upon the building usage, careful consideration is required to determine if two or more smaller vessels would provide a better solution than a single vessel. This is highly recommended and considered essential in buildings such as hospitals, hotels and nursing homes to provide cover if one hot water vessel is inoperable.
- (5) Storage and load capacity: an assessment of the peak demand needs to be carried out to determine the amount of storage in relation to the recovery period required. For most applications, allowing 10% of first-hour peak consumption will provide a good balance between storage and recovery. More storage will be required for applications such as sports centres where the peak demand is large but of short duration. The hot water generator will be required to meet the necessary hot water output.
- (6) Pipe size and circulator selection: correct specification of primary flow/return and pump size is required to obtain optimum performance from the water vessel.
- (7) Storage capacity: some installations, such as shower facilities for custodial establishments, are characterised by one or two high peaks per day of around 30–60 minutes each, with minimal draw-off in between. These requirements are most cost effectively served by providing high storage capacity but slow recovery. Since there is often seven to eight hours between usages, a slow recovery is acceptable, with the advantage that smaller gas piping or electrical cabling can be used, thus saving installation costs. The system needs to be designed so that the system achieves full recovery in time for each peak. However, standing losses for large storage volumes, therefore

- installation costs and long term running costs should be considered at the design stage.
- (8) Ensure adequate space is available in the building for the installation. This is very important, particularly where a number of water heaters are connected in parallel. When allocating space, observe the installation regulations, particularly in respect of flueing for gas fired water heaters. In allocating space for the installation, consider the possible expansion of the system should the hot water demand increase, and allow room for access for maintenance.
- (9) Ensure that the pipe diameters are calculated correctly, particularly for commercial and industrial installations at mains pressure.

2.4.6 Plant sizing curves

For smaller installations the methods given in Annex C of BS EN 806⁽¹⁾ should be adopted, but for larger systems the following may be more appropriate.

Figures 2.9 to 2.19⁽⁴⁶⁾, see pages 2-29 to 2-34, have been prepared to provide guidance on the total hot water requirements of specific building types, within the stated limits. Separate curves are provided for catering and service (i.e. uses other than catering).

Different methods of using the curves apply for constant tariff fuels (e.g. gas) compared with those fuels incorporating off-peak tariffs (e.g. electricity).

On selection of a recovery period, the curves provide the basis to calculate (for a storage temperature of 65 °C):

- (a) system heat input (excluding system heat losses)
- (b) hot water storage capacity.

2.4.6.1 Procedure for constant tariff fuel systems

- (a) Select a recovery period (a recovery period of less than half an hour can seldom be achieved with indirectly heated systems).
- (b) Apply selected recovery period to curve (a) for building type and area of demand (i.e. catering or service).
Read off:
 - (i) boiler output, q , in kW per person or per meal
 - (ii) hot water storage capacity, v , in litres per person or per meal.
- (c) Adjust the boiler output if the required hot water temperature differs from 65 °C:

$$q' = q \frac{(\theta_s - \theta_c)}{(65 - \theta_c)} \quad (2.5)$$

where q' is the adjusted boiler output rating (kW/person or meal), θ_s is the hot water storage temperature required (°C) and θ_c is the cold feed temperature (°C) (if unknown assume 10 °C)

- (d) (i) Calculate boiler output rating, Q (kW) and total storage capacity, V (litre), using numbers of people or meals applicable. Where one central plant is provided for both catering and service demands, the ratings and capacities should be added.
- (ii) Add rate of system heat loss to Q to give an adjusted rate, Q' .
- (e) It is assumed in the above stages that the design of the vessel incorporates devices to inhibit mixing of incoming cold water with hot water (see HTM 04-01⁽⁴⁷⁾ for recommendations on stratification). If the vessel does not have such a device then an increase in the storage volume is necessary to allow for mixing.

Example 1: Constant tariff fuels

It is required to size the hot water plant for a school which has 500 pupils and staff and with catering for 400 meals per day. The required hot water temperatures are 55 °C for service and 65 °C for catering. The kitchens are in a separate building and therefore require separate plant.

- (a) A recovery period is chosen to suit the type of building. For the purposes of this example the recovery time will be taken as two hours for service and one hour for catering.

- (b) From the schools curve (a) in Figure 2.9:

$$q = 0.035 \text{ kW/person}$$

$$v = 1.1 \text{ litre/person}$$

From the schools curve (a) in Figure 2.10:

$$q = 0.1 \text{ kW/meal}$$

$$v = 1.6 \text{ litre/meal}$$

- (c) Adjust boiler output for hot water temperature:

$$q' = 0.035 \frac{(55 - 10)}{(65 - 10)} = 0.029 \text{ kW/person}$$

- (d) (i) For the service requirement:

$$Q = 0.029 \times 500 = 14.5 \text{ kW}$$

$$V = 1.1 \times 500 = 550 \text{ litres}$$

For the catering requirement:

$$Q = 0.1 \times 400 = 40 \text{ kW}$$

$$V = 1.6 \times 400 = 640 \text{ litres}$$

- (ii) System heat losses would be calculated for the pipework involved. For the purpose of this example the following are assumed:

$$\text{Service system heat loss} = 4.0 \text{ kW}$$

$$\text{Catering system heat loss} = 2.5 \text{ kW}$$

Adjusted boiler output ratings:

$$\text{— service system: } Q' = 14.5 + 4 = 18.5 \text{ kW}$$

$$\text{— catering system: } Q' = 40 + 2.5 = 42.5 \text{ kW}$$

- (e) Add 25% allowance for mixing of incoming water with hot water, following consultation with vessel manufacturer. Final hot water storage capacities are:

- service system: $550 + 137 = 687$ litres
- catering system: $640 + 160 = 800$ litres

2.4.6.2 Procedure for fuel tariff systems incorporating off-peak periods

- (a) Select a recovery period.
- (b) Apply selected recovery period to curve (a) for building type and area of demand (i.e. catering or service).

Read off:

- (i) upper element rating, q_u , in kW per person or per meal
- (ii) hot water storage capacity above the upper element, v_u , in litres per person or per meal.

Adjust upper element rating where temperature of hot water is required to differ from that of the curves.

$$q_u' = q_u (\theta_s - \theta_c) \quad (2.6)$$

where q_u' is the adjusted upper element rating (kW/person or meal), θ_s is the hot water storage temperature required ($^{\circ}\text{C}$), θ_c is the cold feed temperature ($^{\circ}\text{C}$) (if unknown, use 10°C).

- (d) Apply v_u to curves (b) and project horizontally. This horizontal line intersects sloping lines to represent values of percentage of annual consumption taken at on-peak rate. Each intersect represents an option which can be selected after a comparison of associated capital costs, operating costs and spatial considerations.

For the selected on-peak energy percentage value, project upwards and downwards from the intersect and read off:

- (i) lower element rating, q_l , in kW per person or per meal
- (ii) hot water storage capacity above lower element, v_l , in litres per person or per meal. This volume of stored water includes that stored above the upper element, v_u .
- (e) Calculate the following, in each case using the number of people or meals applicable:
- (i) storage capacity above lower element, V_l (litres)
- (ii) storage capacity above upper element, V_u (litres)
- (iii) lower element rating, Q_l (kW)
- (iv) upper element rating, Q_u (kW).

Record the percentage annual consumption taken at on-peak rate from which these values derive.

- (f) Add rate of system heat loss, L , to Q_u to give an adjusted upper element rating, Q_u' .
- (g) Express system heat loss in terms of 'equivalent volume', E , where:

$$E = \frac{L n 3600}{4.186 (\theta_s - \theta_c)} \quad (2.7)$$

where E is the equivalent volume (litre), L is the rate of system heat loss (kW) and n is the period of operation of system (h).

(4.186 is the specific heat of water in kJ/kg·K, 3600 is the number of seconds in an hour.)

- (h) Calculate the increase in V_l , to allow for system heat losses:

$$I = \frac{(100 - P) \times E}{100} \quad (2.8)$$

where I is the increase in hot water storage capacity (litre) and P is the annual on-peak proportion selected (%).

Add I to V_l , to give the adjusted capacity above lower element, V_l' .

- (i) Calculate the adjustment necessary to Q_l :

$$Q_l' = Q_l + \left(\frac{1}{V_l'} \times Q_l \right) \quad (2.9)$$

where Q_l' is the adjusted lower element rating (kW).

- (j) It is assumed in the above stages that the design of the vessel incorporates devices to inhibit mixing of incoming cold water with hot water (see HTM 04-01⁽⁴⁷⁾). If the vessel does not have such a device then an increase in the storage volume is necessary to allow for mixing. Previous practice included a 25% allowance to take account of this effect, but this may be larger than necessary.

Example 2: Off-peak tariff

An office with 120 staff requires a hot water heater to supply water at 55°C to wash basins. It is estimated that of 20% annual consumption will be taken at on-peak rate.

- (a) A two-hour recovery period is selected.
- (b) From the office curve (a) in Figure 2.15:

$$q_u = 0.04 \text{ kW/person}$$

$$v_u = 1.2 \text{ litre/person}$$

- (c) Adjust the upper element rating:

$$q_u' = 0.04 \frac{(55 - 10)}{(65 - 10)} = 0.033 \text{ kW/person}$$

- (d) From the office curve (b) in Figure 2.15 and for 20% on-peak rate:

$$q_l = 0.042 \text{ kW/person}$$

$$v_l = 4.2 \text{ litre/person}$$

- (e) Using the number of people applicable:

$$V_l = 4.2 \times 120 = 504 \text{ litres}$$

$$V_u = 1.2 \times 120 = 144 \text{ litres}$$

$$Q_l = 0.042 \times 120 = 5.04 \text{ kW}$$

$$Q_u = 0.033 \times 120 = 3.96 \text{ kW}$$

- (f) Assume system heat loss, L , has been calculated as 0.8 kW:

$$Q_u' - 3.96 + 0.8 = 4.76 \text{ kW}$$

- (g) For a 10-hour day:

$$E = \frac{0.8 \times 10 \times 3600}{4.178 \times (55 - 10)} = 152 \text{ litres}$$

- (h) Calculating the increase in V

$$I = \left(\frac{100 - 20}{100} \right) \times 152 = 122 \text{ litres}$$

$$V_1' = 504 + 122 = 626 \text{ litres}$$

- (i) Calculating the adjustment to Q_1 :

$$Q_1' = 5.04 + \left(\frac{122}{504} \times 5.04 \right) = 6.26 \text{ kW}$$

- (j) Add 25% allowance for mixing of incoming cold water with hot water. Final hot water storage capacity is:

$$626 + 152 = 778 \text{ litres.}$$

2.4.7 Primary flow and return requirements

2.4.7.1 Water flow from primary hot water circulating pumps

The flow from primary hot water pumps is obtained by calculating the required heat emission from the hot water heating battery and primary flow and return pipelines.

The flow of primary hot water is obtained from equation 2.3:

$$v_f = \frac{\phi \times 10^{-3}}{c_p \Delta\theta}$$

where v_f is the flow rate (litre/s), ϕ is the heat loss per metre run of pipework per hour (W), c_p is the specific heat of water (= 4.186) (kJ/kg·K) and $\Delta\theta$ is the temperature difference between the flow and return piping (typically 10–20) (K). (Water at 4 °C has a density of 1000 kg/m³.)

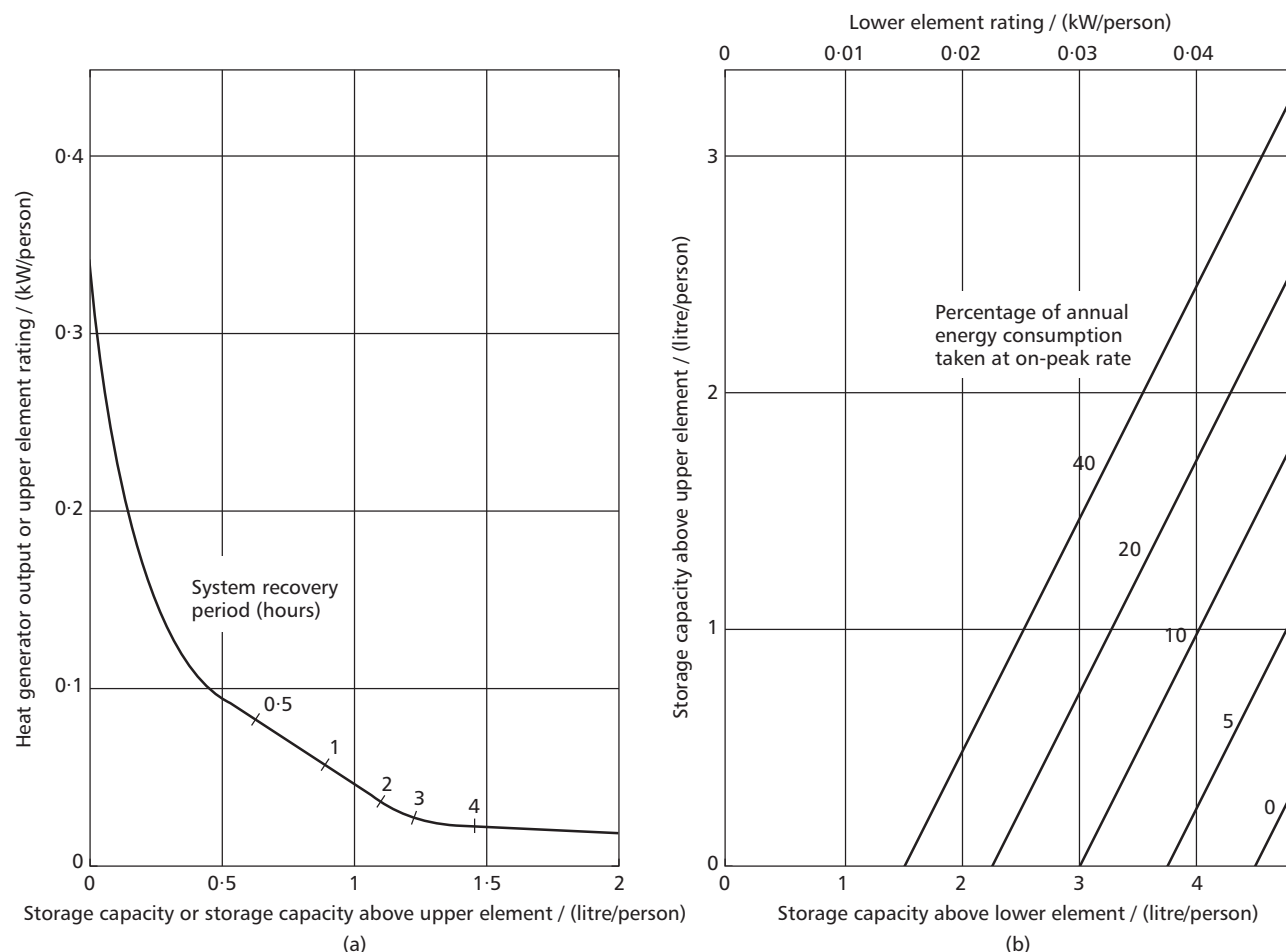


Figure 2.9 Plant sizing guide for schools — service; use for schools with between 380 and 1600 persons/day⁽⁴⁶⁾

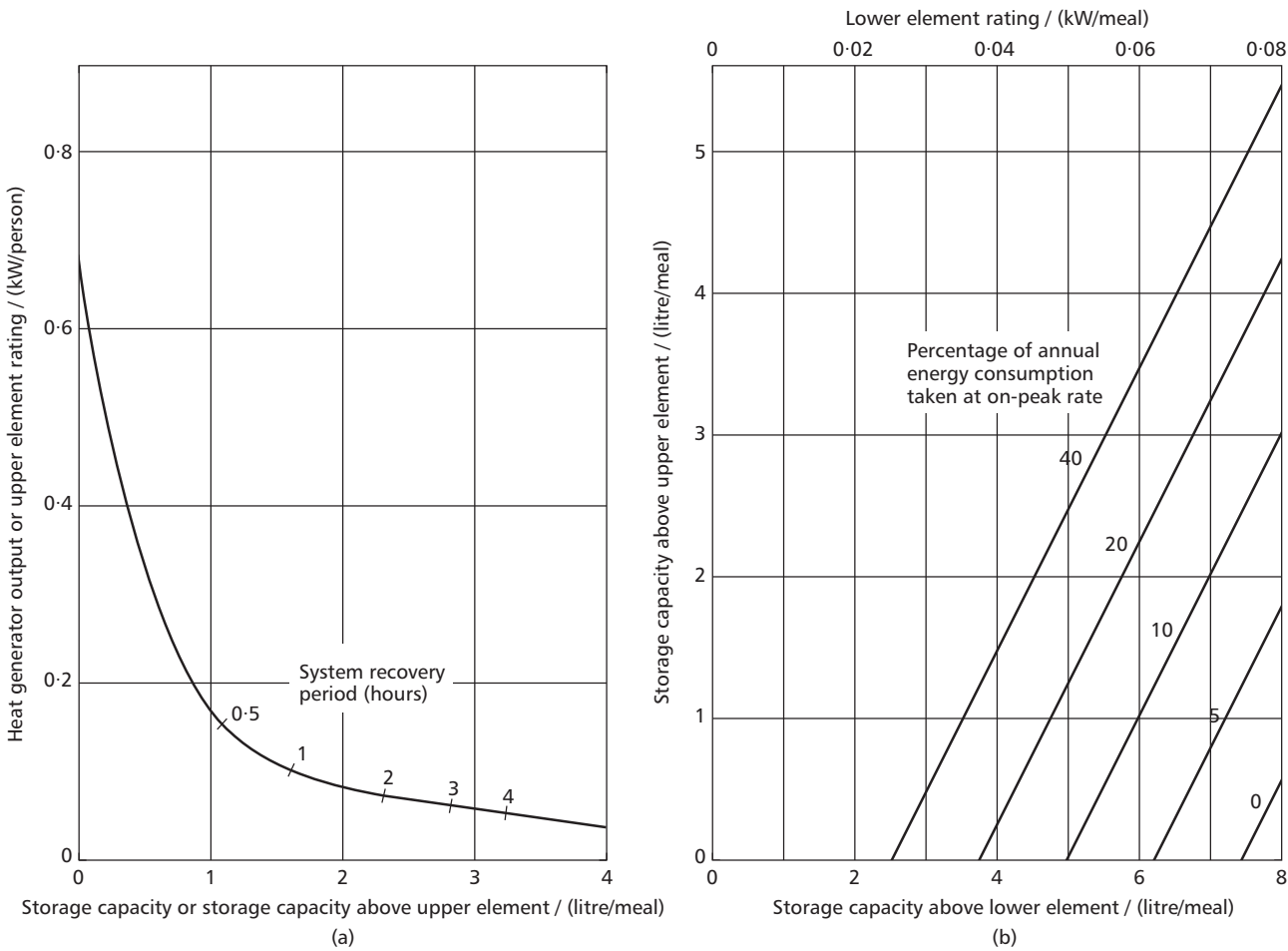


Figure 2.10 Plant sizing guide for schools — catering; use for schools serving between 240 and 1200 meals /day⁽⁴⁶⁾

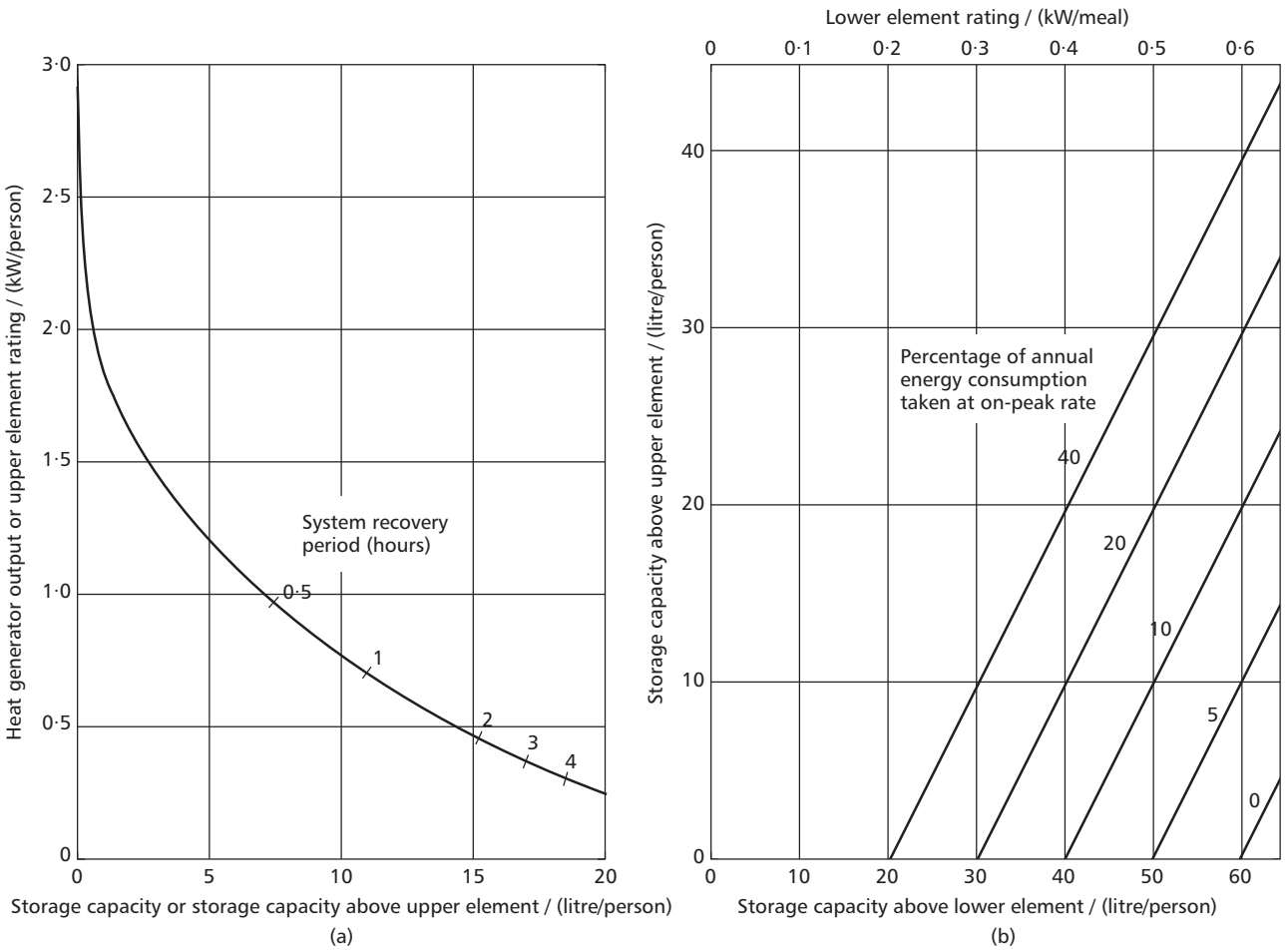


Figure 2.11 Plant sizing guide for hotels — service; use for hotels with between 80 and 320 persons/day⁽⁴⁶⁾

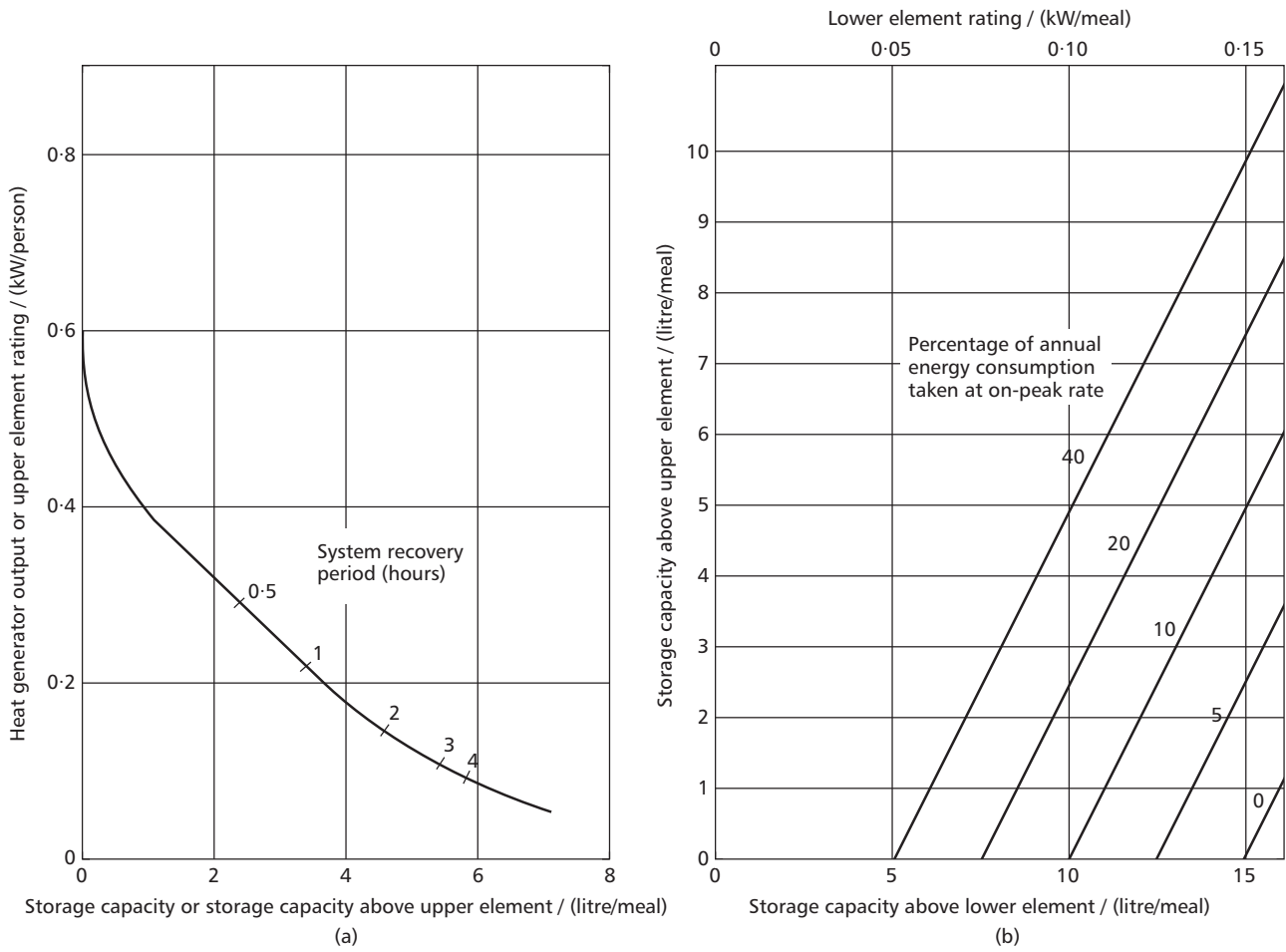


Figure 2.12 Plant sizing guide for hotels — catering; use for hotels serving between 140 and 840 meals/day⁽⁴⁶⁾

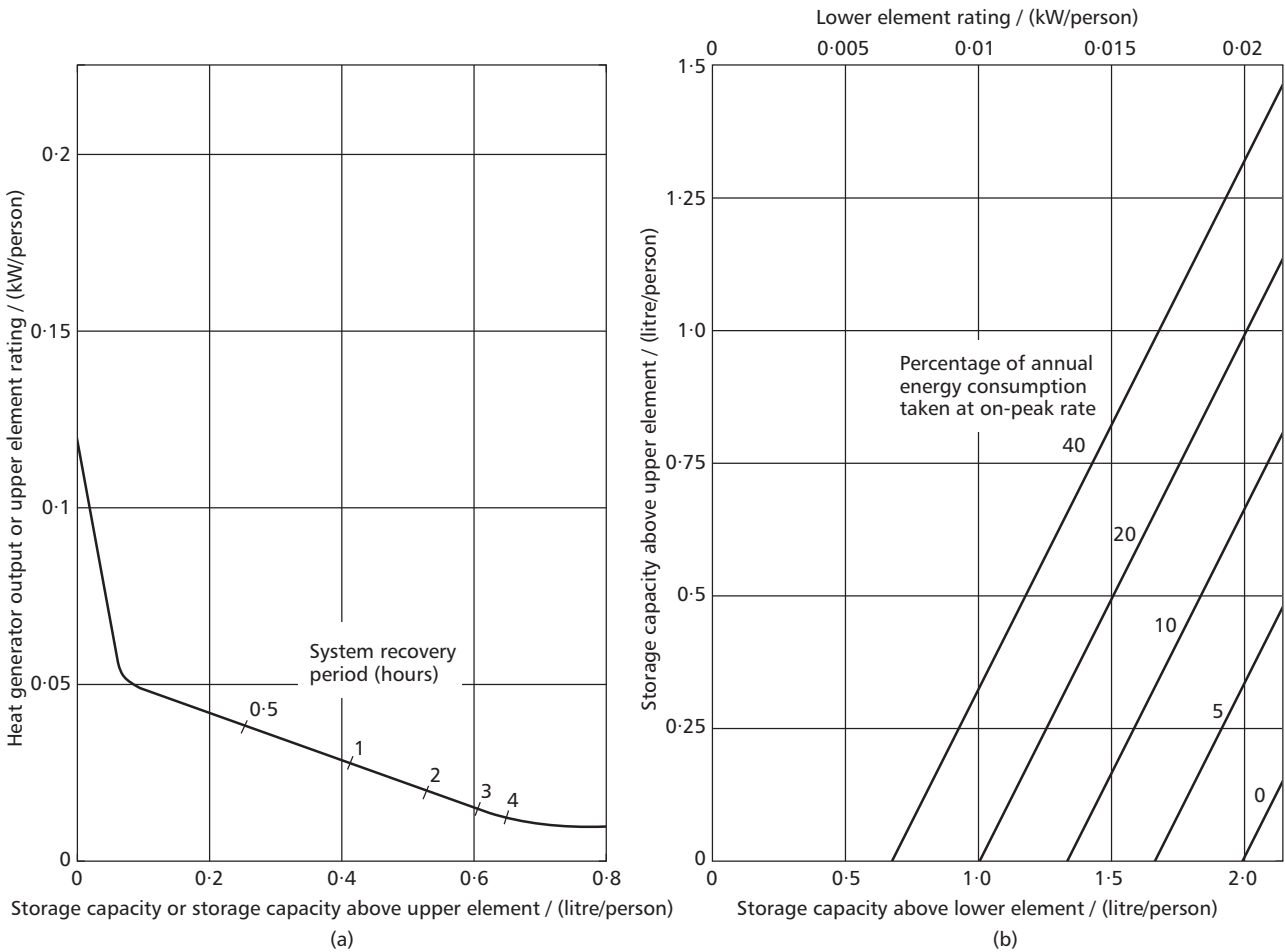


Figure 2.13 Plant sizing guide for restaurants — service; use for restaurants with between 100 and 1010 diners/day⁽⁴⁶⁾

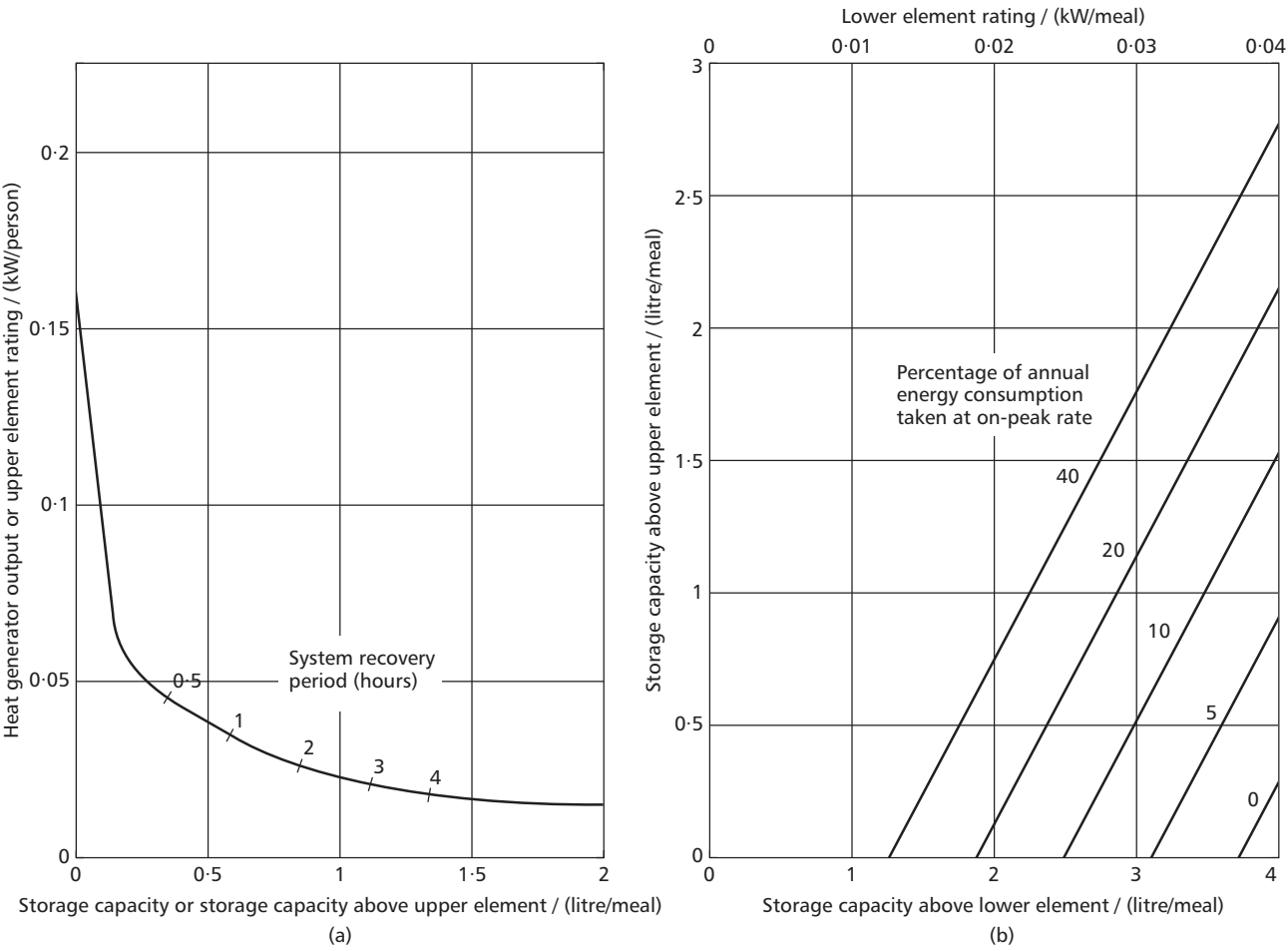


Figure 2.14 Plant sizing guide for restaurants — catering; use for restaurants serving between 100 and 1010 meals/day⁽⁴⁶⁾

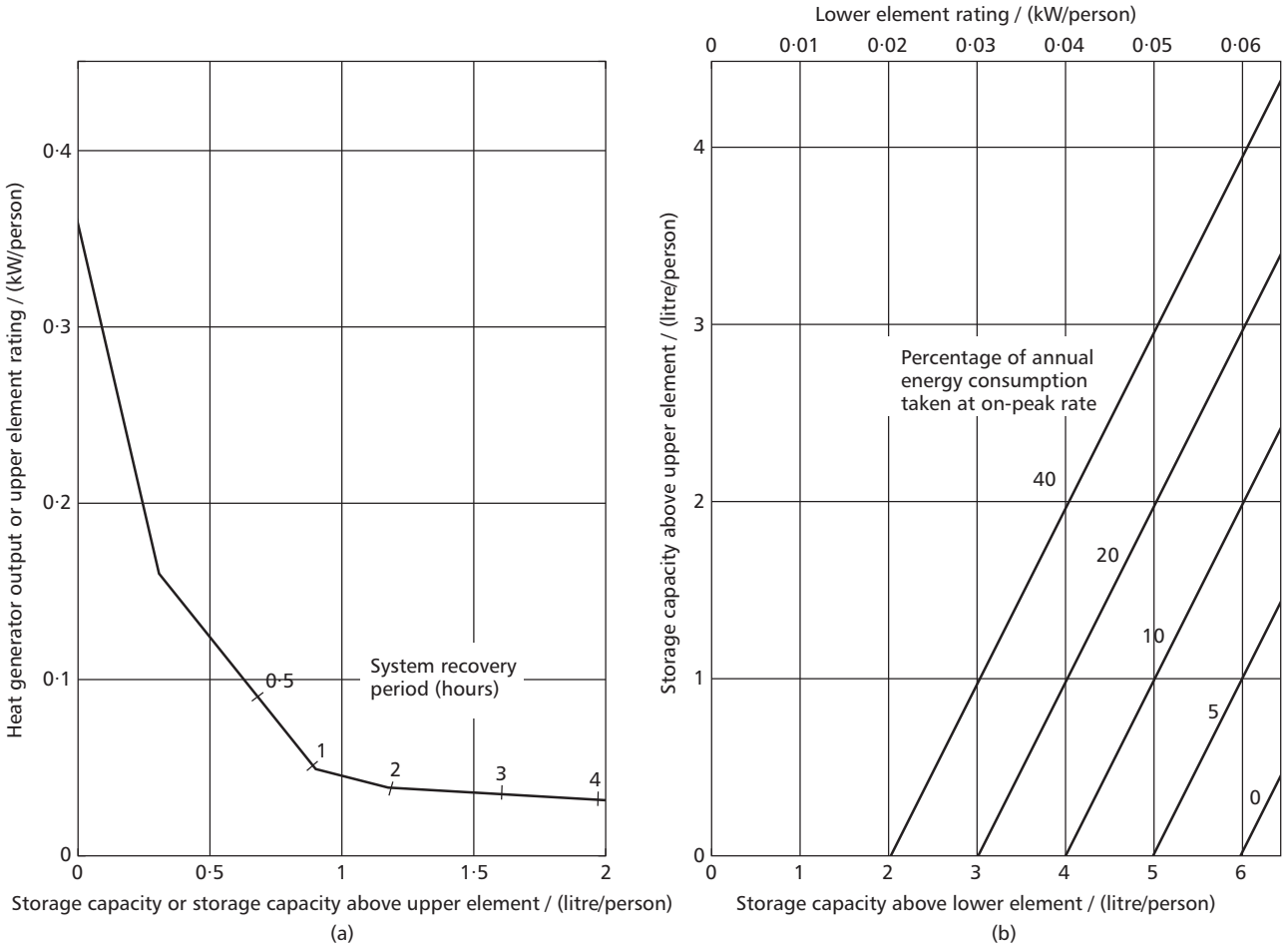


Figure 2.15 Plant sizing guide for offices — service; use for offices with between 110 and 660 persons/day⁽⁴⁶⁾

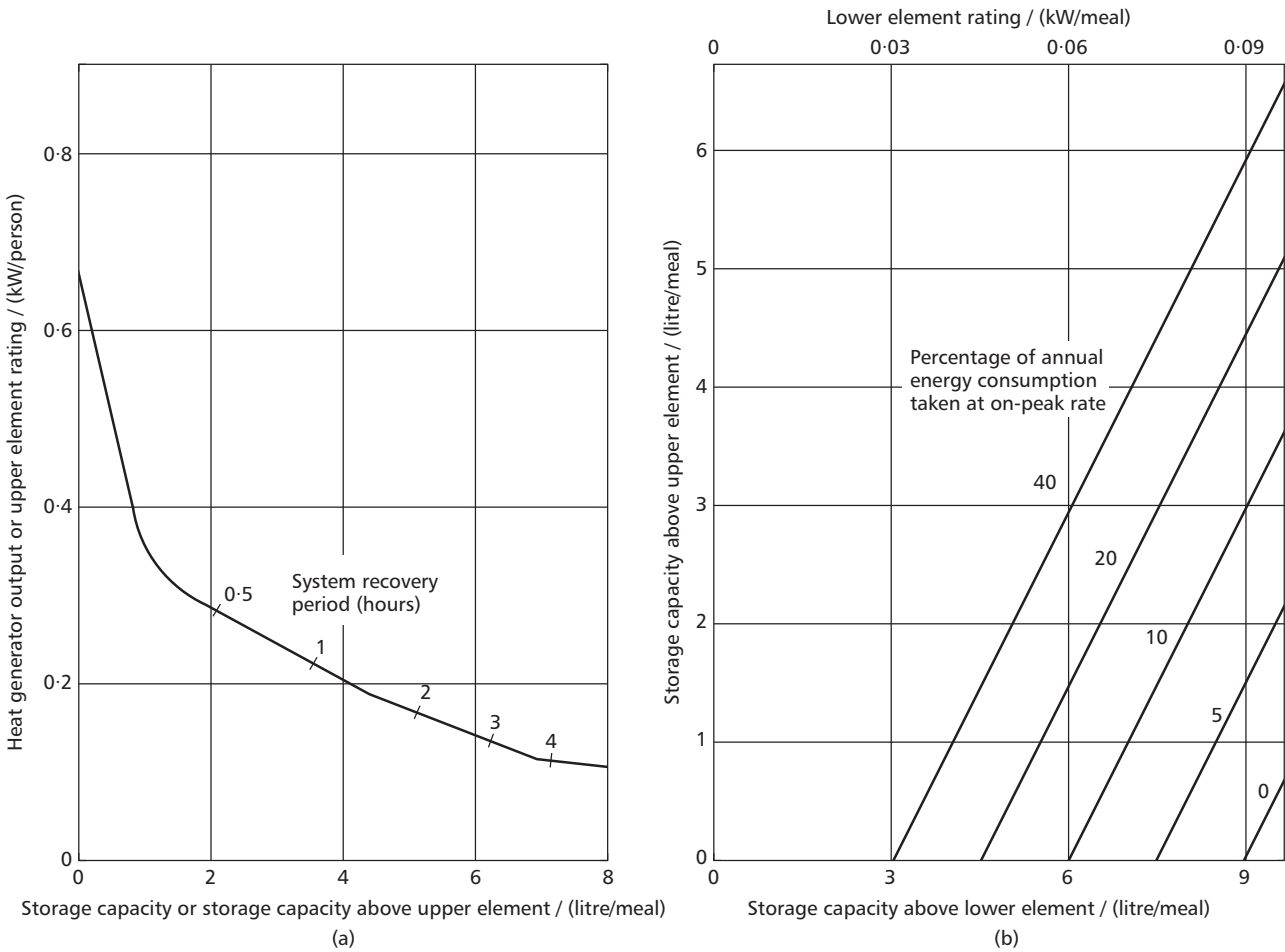


Figure 2.16 Plant sizing guide for offices — catering; use for offices with restaurant serving between 40 and 370 meals/day⁽⁴⁶⁾

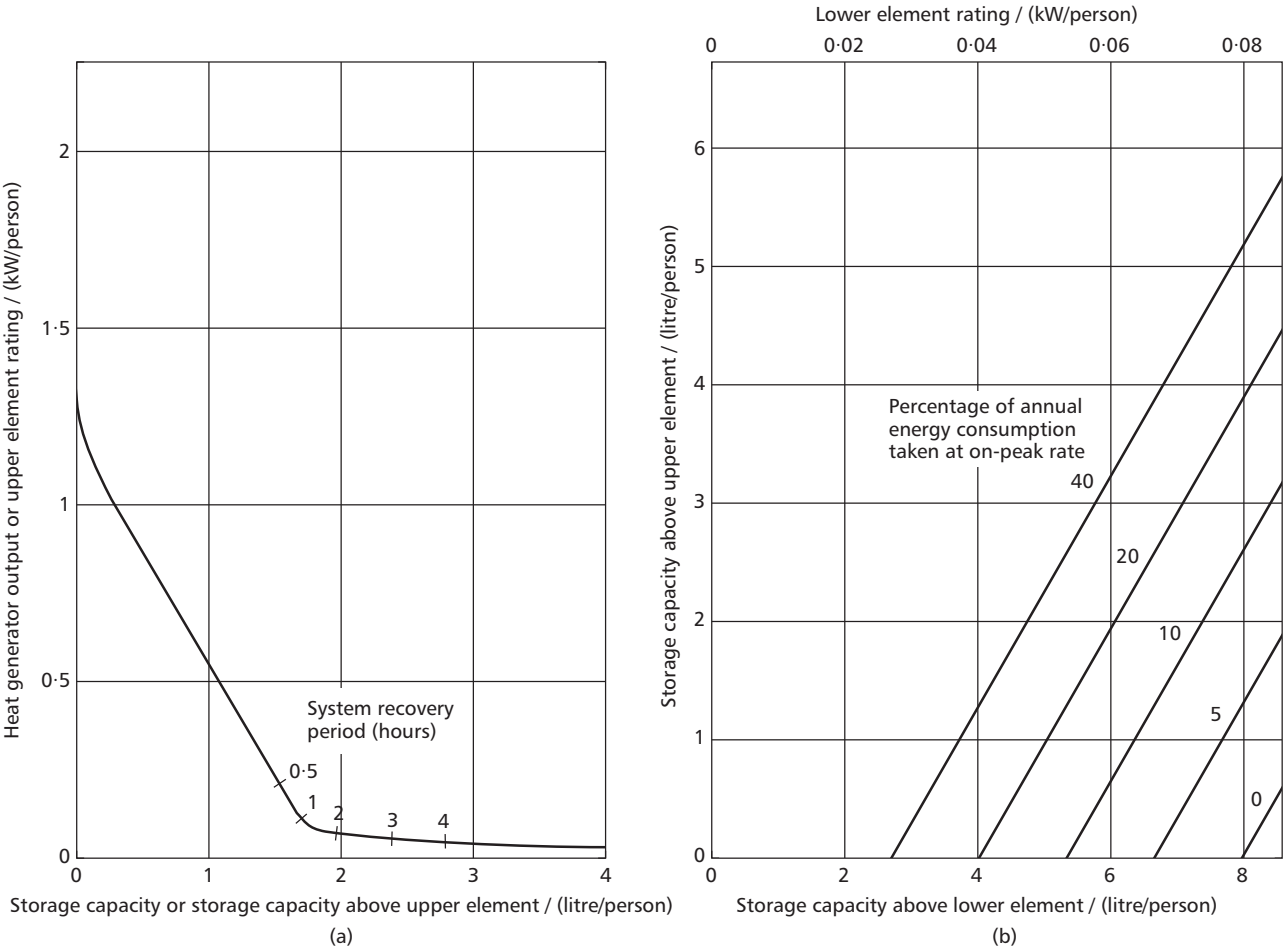


Figure 2.17 Plant sizing guide for large shops — service; use for shops with between 50 and 220 staff/day⁽⁴⁶⁾

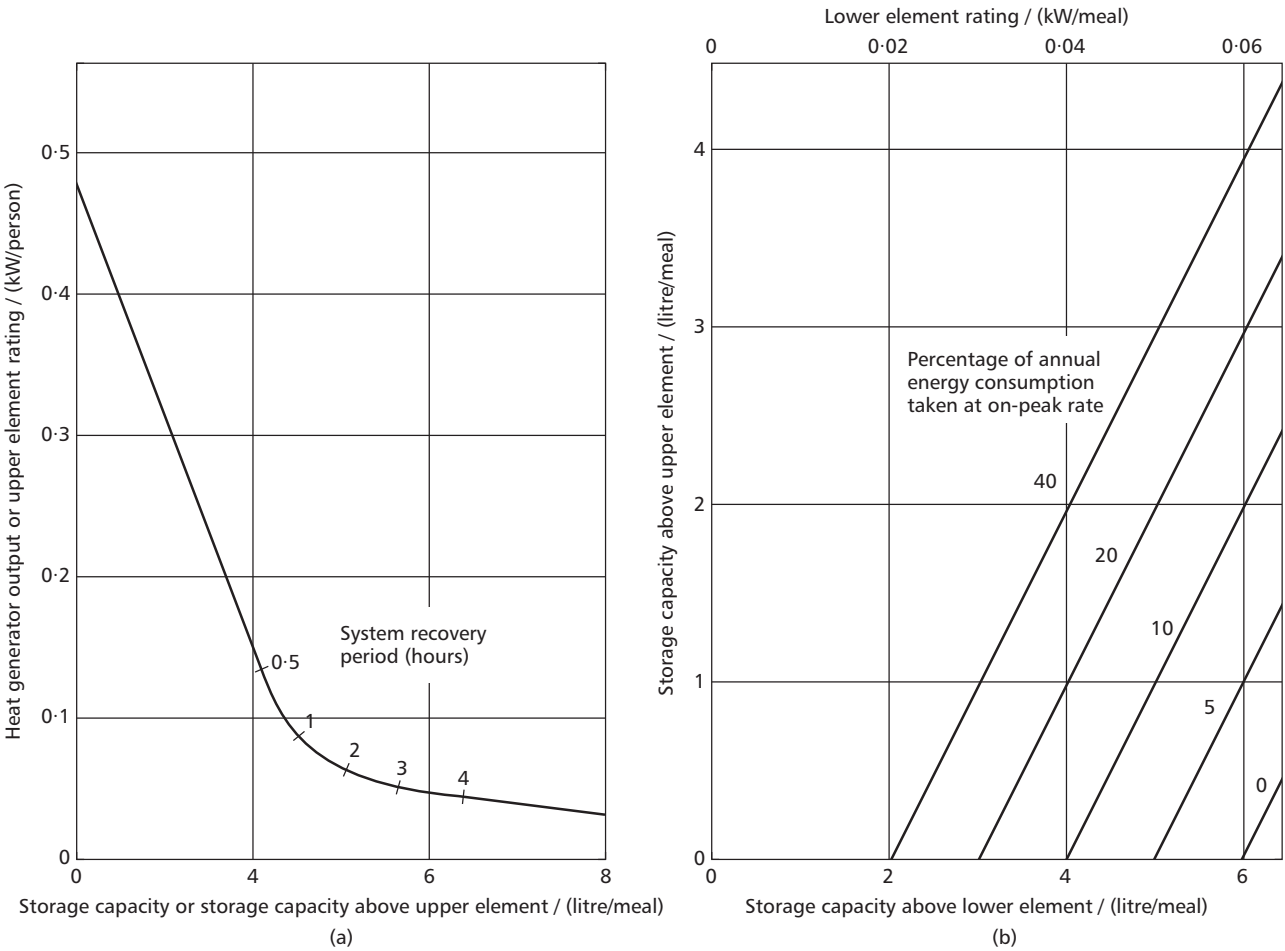


Figure 2.18 Plant sizing guide for large shops — catering; use for shops with restaurant serving 60 and 540 meals/day⁽⁴⁶⁾

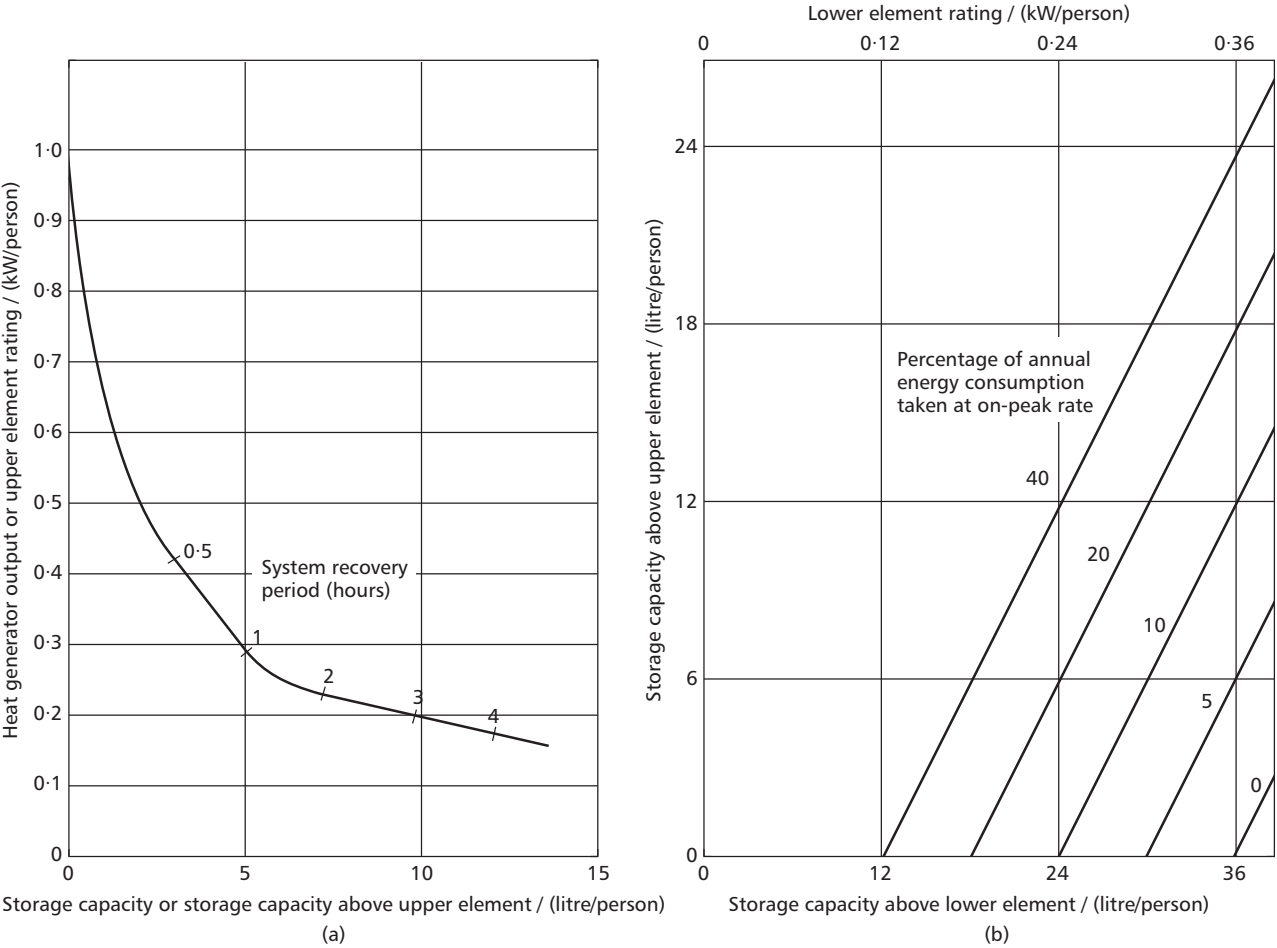


Figure 2.19 Plant sizing guide for student hostels — service; with between 80 and 320 persons/day⁽⁴⁶⁾

2.5 Pipework design

2.5.1 Introduction

The guidance that follows applies to both hot and cold water pipework system design. Information on pipe sizing is contained within this section.

2.5.2 Estimating demands

This section contains a summary of the general background and some practical guidance to the use of loading units for assessing water supply demand.

In order to determine the size of pipework required in water supply systems it is necessary to determine the rate of flow for each pipe and the diameter of the pipework.

The first problem in assessing flow rates is the fact that most sanitary fittings are used only at irregular intervals, which may vary over the day depending on the type of building and its occupancy. Because sanitary fittings are generally operating for only very short periods, it is uncommon (and uneconomic) to size pipework on continuous maximum demand.

In order to utilise probability theory it is usual to start by assuming that the sanitary fittings in a building have purely random usage. This is obviously not true but provides a basis from which variations from random usage can be considered.

A second step is to determine the maximum frequencies of use of the sanitary fittings based on observations at periods of peak usage for various types of buildings. Finally, the average water usage rates of each type of sanitary fitting and the time taken for a single usage are measured.

It should be noted that the use of probability theory in assessing simultaneous demand is only applicable where large numbers of sanitary fittings are involved, as probability theory is based on the likelihood of situations occurring and therefore its predictions will occasionally be exceeded. It is a requirement of this method of calculation that a limit is set on the time for which a calculated value is expected to be exceeded. This has often been taken as 1%, which has proved to be reliable in that it has not led to under-design of pipework. It is however likely that a higher value would also provide adequate results, but this could only be demonstrated by observing the effect in practice on a large number of buildings designed to the higher figure.

It is also important to consider the effect where design flow is exceeded. In practice, in buildings with large numbers of sanitary fittings, a small increase in demand over the design level will cause a slight reduction in pressure and flow at the fittings in use and unless this becomes excessive, it is unlikely to be noticed by the users.

When using published loading units it is important to consider sanitary fittings such as cleaners' sinks, which are unlikely to be used at normal peak usage times. Therefore fittings of this type should be ignored except for local groups of fittings where their use would significantly

affect the small number of adjacent fittings. Also, urinal flushing cisterns have a small constant flow rate and, depending on the numbers involved, can usually be ignored or a constant flow be added to the calculations. A constant flow may also be required for any significant process uses in buildings such as factories.

Consideration also needs to be given to the maximum frequencies of use in various types of building. For example, showers in team changing rooms at sports clubs will have a very different usage pattern compared with showers in domestic dwellings. Some publications have indicated an increase in loading units per fitting by a factor of 3 or more, for congested situations.

Simultaneous demand calculations are based on variations of one or more of the following factors, and will therefore give results that differ to some extent from the BS EN 806⁽¹⁾ data:

- average flow duration for each outlet when discharging, each time it is used
- average time between usages.

It is also common today to use computer simulation for estimating pipe sizes.

2.5.3 Water pressures

Having established the design flow rates, the required water pressure may be established before proceeding to calculate the pipe diameter. The pressure is divided into the following:

- (a) required pressure to operate the fitting including terminal outlet pressure
- (b) vertical static head pressure from the point of supply to the fitting
- (c) hydraulic dynamic head loss due to pipe length and number or type of valves and fittings, the resistance of which increases with velocity
- (d) available pressure at water main.

The resultant system pressure is given by:

$$\begin{aligned} \text{System pressure} &= \text{static head} \\ &\quad - (\text{terminal fittings head requirements} \\ &\quad \quad + \text{dynamic pipe loss}) \end{aligned}$$

2.5.3.1 Vertical static head pressures from point of supply to fitting

The static head pressure from the point of supply to the fitting is measured vertically in metres. For an elevated cistern/tank it is the distance from the bottom of the storage vessel to the point of supply demand. Do not measure from the water level in the cistern/tank as this is constantly changing due to fluctuations in demand and supply. For elevated cisterns/tanks this vertical measurement will be positive head in metres. Where the static head is being provided from an external water main or low level pumping system, the vertical distance from the water main or pump set outlet to the points of supply will be a negative head; this negative head will have to be overcome by the external water main or pumping system in order to

ensure discharge at the point of supply. Should the termination supply point be below the pumps or water main then the vertical distance measured will be positive head pressure in metres.

2.5.3.2 Terminal fitting pressures

All terminal fittings (including taps, float valves in flushing or storage cisterns, and industrial and commercial appliances) require a residual pressure to operate efficiently. For commercial and industrial applications these pressures requirements can be obtained from the specialist manufacturers.

The different types of taps can also create problems for the designer as some are designed to operate at high pressures and others at low pressures. Always check with the manufacturer. Valve manufacturers will also supply graphs showing the head pressure against head loss for varying flow rates.

2.5.3.3 Dynamic head loss

Dynamic head loss (due to pipe, valves and fittings resistance) increases with water velocity; it is the loss in pressure due to friction as the water travels along the pipe.

An additional point to note is that unacceptable noise levels can be produced with high velocity. Once the internal pipe velocity exceeds approximately $3.0 \text{ m}\cdot\text{s}^{-1}$ significant noise levels can be transmitted from the pipe. For valves, this critical velocity can be lower due to turbulence of the water passing over the valve seat and washer. Noise transmission from water supply systems can be very loud and disturbing to the occupants or users. The designer has also to consider temperature; as water temperature increases its density decreases, thus increasing the velocity noise.

Table 2.15 lists maximum recommended water velocities, and Table 2.16 lists typical head losses through taps and equivalent pipe lengths.

Table 2.15 Maximum water velocities in pipework (source: *Plumbing Engineering Services Design Guide*⁽³⁵⁾)

Location	Noise rating (NR)	Recommended max. water velocity for stated pipe materials / $\text{m}\cdot\text{s}^{-1}$	
		Metal (copper, stainless steel, galvanised)	Plastic (uPVC, ABS, CPV); lead
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 or 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

Table 2.16 Typical discharge rates through taps and equivalent pipe lengths (source: *Plumbing Engineering Services Design Guide*⁽³⁵⁾)

Fitting	Discharge rate with tap fully open / $\text{litre}\cdot\text{s}^{-1}$	Equivalent length of pipe of same diameter as tap / m	
		Copper	Galvanised mild steel
15 mm ($\frac{1}{2}$ inch) bibtap or pillar tap	0.20	2.70	4.0
20 mm ($\frac{3}{4}$ inch) bibtap or pillar tap	0.30	8.50	5.75
25 mm (1 inch) bibtap or pillar tap	0.60	20.0	13.0

Note: Head losses for stated flow rates are typical only and tap flow rates and head losses should be confirmed by the fitting manufacturer.

2.5.3.4 Available water main pressure

Variations in the available pressure at the water main can cause the designer problems if the correct procedure is not followed. The pressure the design engineer requires is the minimum available. In general, the pressure in the main reduces with demand. The pressure the water supply company can provide is the maximum. To obtain the actual minimum pressure the design engineer requires a 24-hour or 7-day read-out of the main pressure, recorded adjacent to the point of demand. Point-of-use pressure should not be used as this will give the pressure at one particular time of day only. The water supply company should be able to advise on the likely minimum pressure in any particular area.

2.5.3.5 Length of pipework and fittings

The length of pipework and fittings will create head losses due to friction between the pipe wall and the velocity of the water passing through it. For fittings with changes of direction there are hydraulic losses due to both the flow friction and the change of direction. An elbow joint will have a greater loss than a bend, and a swept joint tee less than a plain tee branch.

Simple equivalent length charts have been calculated for pipe fittings (see Table 2.17), so that the designer can add the equivalent length for the fittings to the actual pipe length of the system, giving an overall design pipe length. It should be noted that these values are not relevant for proprietary pipe fittings that incorporate a nozzle for insertion into multi-layer pipe. These type of joints often have a significantly reduced bore, which generates increased frictional losses. In such cases head loss data should be obtained from the manufacturer.

Table 2.17 Equivalent pipe lengths (copper, plastics and stainless steel) (source: BS EN 806⁽¹⁾, Table D3)

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

2.5.4 Theory of probability

The objective in designing the water supply systems for a project is to ensure an adequate supply of water at adequate pressure to all fixtures and equipment at all times and to achieve the most economical sizing of the piping.

The basic requirements for estimating demand call for a method that:

- produces estimates that are greater than the average demand for all fixtures, otherwise the supply will be inadequate during periods of peak demand
- produces an accurate estimate of the peak demand to avoid oversizing
- produces estimates for demand of groups of the same type of fixtures, as well as for mixed groups of fixtures.

Problems involving demand on draw-off points fall into three categories:

- those where a known amount of processes or equipment will be used on a timed basis
- those where it is known that all fittings will operate at once, e.g. sports centre showers
- those where no special co-ordination is known other than the probable ratio between the duration of the flow and the frequency of usage, e.g. a basin is filled with water in 1 minute but is not used for another hour (or again in the same day).

Two methods have evolved that, when used where applicable, have proven to give satisfactory results. They are (1) the method of probability, and (2) the empirical method. The latter method is based upon arbitrary decisions derived from experience and judgment of fixtures usage and is not described here.

A standard method for estimating the water demand for a building has evolved through the years and has been accepted almost unanimously by plumbing designers. It is a system based on 'weighting' fixtures in accordance with their load-producing effects on the water distribution system.

In developing the application of the theory of probability to determine design loads on a domestic water distribution system, it is assumed that the operation of the fixtures in a system could be viewed as purely random events.

The 'theory of probability' is based on the likelihood of situations occurring and therefore its predictions may on occasions be at variance with actual demand. The theory of probability can assess simultaneous demand but is only fully applicable where large numbers of appliances are involved. The criterion for this occurrence of variance is deemed to be reasonable if it is taken as 1%.

The probability of a particular number of draw-offs discharging simultaneously is determined by dividing the time for the appliance to be filled by the time between successive usage of the appliances to arrive at the probability factor:

$$P = \frac{t}{T} \quad (2.14)$$

where P is the probability factor, t is the time for appliance to fill (s) and T is the time between successive usages' of the appliance (s).

Having calculated the probability factor, the probability graph (Figure 2.20) may be used to determine the likely number of appliances in simultaneous use for a given total number of appliances.

Example

Using equation 2.14, the probability factor for a group of appliances, each taking 24 seconds to fill and used at 20 minute (i.e. 1200 second) intervals is:

$$P = \frac{24}{1200} = 0.02$$

By using the probability graph (Figure 2.20), for a group of 100 appliances and a probability factor of 0.02, out of 100 appliances being supplied only six would be in use at any one time.

2.5.5 Simultaneous demand

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

The factors that have to be taken into account are:

- (a) capacity of appliance (litre)
- (b) draw-off flow rates (litre/s)
- (c) draw-off period (time to fill the appliance) (s)
- (d) usage frequency (time between uses of each appliance) (s).

The capacity of wash basins, sinks and other appliances varies. Draw-off tap sizes and flow rates differ between appliances. The frequency of use of appliances are different in different locations, both within and between buildings.

This time between each use can be obtained from Table 2.18, in which:

- 'low use' is deemed to represent 1200 seconds between each use and is appropriate to private facilities used by a single person or small group of persons
- 'medium use' is deemed to represent 600 seconds between each use, e.g. public toilets
- 'high use' is deemed to represent 300 seconds, e.g. toilets in theatres, cinemas etc.

To account for these many variations a 'loading unit' system has been devised, which takes account of the appliance type, its capacity, flow rate, period of use and frequency of use. Values for loading units are given in Table 2.18.

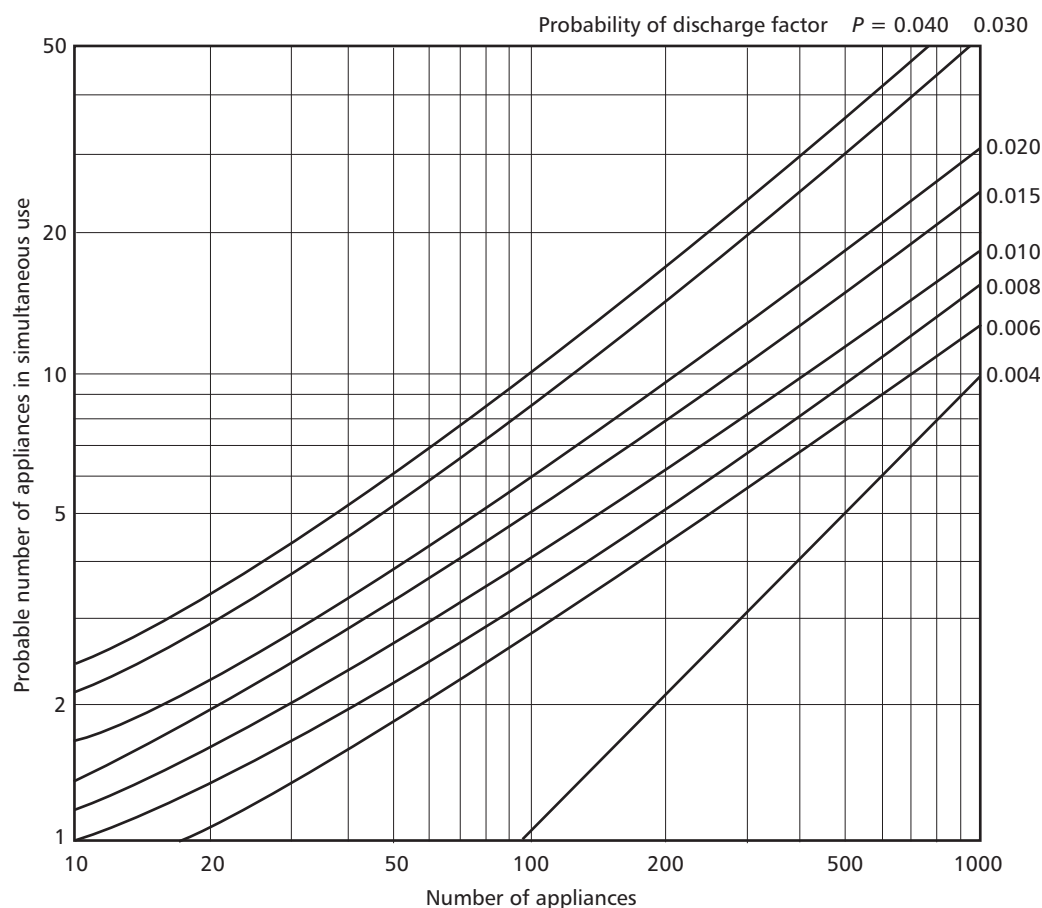


Figure 2.20 Probability graph (reproduced from the *Plumbing Engineering Services Design Guide* by permission of the CIHPE)

Table 2.18 Loading units (reproduced from the *Plumbing Engineering Services Design Guide* by permission of the CIHPE)

Type of appliance	Loading units for stated frequency of use		
	Low	Medium	High
Basin (15 mm, separate taps)	1	2	4
Basin (2 × 8 mm mixer tap)	1	1	3
Sink:			
— 15 mm separate/mixer tap	2	5	10
— 20 mm separate/mixer tap	—	11	—
Bath:			
— 15 mm separate/mixer tap	4	8	16
— 20 mm separate/mixer tap	—	11	—
WC suite (6 litre cistern)	1	2	5
Shower (15 mm head)	2	3	6
Urinal (single bowl/stall)	—	1	—
Bidet (15 mm mixer tap)	1	1	—
Hand spray (15 mm)	—	1	—
Bucket sink (15 mm taps)	—	1	—
Slop hopper:			
— cistern only	—	3	—
— cistern and taps	—	5	—
Washing machine (domestic)	2	—	—
Dishwasher (domestic)	2	—	—

2.5.6

Pipework design considerations

2.5.6.1

Flow definitions

‘Maximum flow’ (or maximum possible flow) is the flow that will occur if the outlets on all fixtures are opened simultaneously and is the maximum flow that will occur under peak conditions. It is also called ‘peak demand’ or ‘peak flow’.

It is essential that the term ‘flow pressure’ (or dynamic pressure) be thoroughly understood and not confused with static pressure. Flow pressure is that pressure that exists at a point in the system when water is flowing at that point. It is always less than the static pressure. To have flow, some of the potential energy is converted to kinetic energy and additional energy is used in overcoming friction. This results in a flow pressure that is less than the static pressure.

When a manufacturer lists the minimum pressure required for the proper operation of a fitting (e.g. ‘2 bar’), it is the flow pressure requirement that is being indicated, that is the pressure remaining with the fitting and the rest of the system operating at the same time. The fitting will not function at peak efficiency (if at all) if the system has been designed such that only a static pressure of 2 bar exists at the inlet to the fitting prior to operation.

2.5.6.2

Flow at an outlet

There are many occasions when the engineer must determine how many litres per second are being delivered at an outlet. This can be determined by installing a

pressure gauge in the line adjacent to the outlet and reading the gauge while flow is occurring. With the flow pressure known, the following formula can be used:

$$v = 1.5 d^2 p_f^{1/2} \quad (2.10)$$

where v is the rate of flow at the outlet (litre/s), d is the inside diameter (ID) of the outlet (mm) and p_f is the flow pressure (bar).

Alternatively, the flow rate may be determined by timing the discharge into a calibrated vessel or proprietary flow measuring funnel.

2.5.6.3 Constant flow

Pressures in the various parts of the piping system are constantly fluctuating depending upon the flow required to meet the demands of the system at any moment. However, some industrial or commercial situations (e.g. laboratories) may require a constant flow. To prevent the rate of flow from an outlet varying with the change of pressure, an automatic flow-control orifice should be incorporated.

2.5.6.4 Materials selection

Before the type of material for the piping of a water distribution system can be selected, the following must be considered:

- (1) *Characteristics of the water supply*: What is the degree of alkalinity or acidity? pH7 represents neutral; a pH above 7 is alkaline and below 7 is acidic. Consider the air, carbon dioxide, and mineral content? The water supply company can usually furnish all this information. If it is not available, a water analysis should be carried out by a qualified laboratory.
- (2) *Relative cost of materials*: Consider the relative costs of the various suitable materials, e.g. bracketing.
- (3) *Ease of replacement*: Can the material be obtained in a reasonable time or must it be shipped from localities that might delay arrival for months?
- (4) *Inside dimensions*: Although of the same nominal size, the actual inside dimensions of pipes and fittings of different materials may differ. This can have a significant effect on sizing because of the variation in rates of flow for the same design velocity.
- (5) *Coefficient of friction of materials*: The roughness or smoothness (coefficient of friction) of the pipe will have a marked effect on pipe sizes.

When selecting a pipe material the following should be considered:

- allowable working/design pressure
- proven durability
- purchase cost
- ease of installation
- method of jointing
- impact from environment, e.g. industrial area

- proposed lifespan of building/development
- maintenance
- skill level required for installation, e.g. brazing of copper pipes
- maximum design/working velocities.
- pressure losses
- acoustics/water hammer.

Materials generally available for pipework are:

- copper (Cu)
- ductile iron, cement lined (DICL)
- cross link polyethylene (PE-X)
- thermoplastic (ABS)
- stainless steel (SS)
- medium-density polyethylene (MDPE)
- barrier MDPE
- polybutylene
- multi-layer (e.g. PE-X/aluminium/PE-X).

2.5.6.5 Demand type

In hot and cold water systems it is rare that all the appliances installed are in simultaneous use. The sizing of a water distribution pipe system, whether it is serving a single building or multiple buildings, is always less than total flow. This is achieved by establishing the anticipated flow rate taking into account the diversity of use/operation of the various types and numbers of appliances requiring a water supply connection.

The actual number of appliances in use, in relation to the total number capable of being used, varies depending on the occupational use and the number of appliances in the various areas of the building(s).

Usually, the appliances within a building do not all operate simultaneously except, for example, changing rooms associated with playing fields where all the teams come off the playing fields and go to the showers at the same time. Some outlets impose what is called a continuous demand on the system, e.g. lawn irrigation, air-conditioning make-up, water cooling etc. These and similar flow requirements are considered to be continuous demands and occur over an extended period.

Appliances draw water for a relatively short periods and are considered as imposing an intermittent demand. Each appliance has its own singular loading effect on the system, which is determined by the rate of water supply required, the duration of each use, and the frequency of use.

The water demand is related to the number of appliances and probable extent of simultaneous use.

2.5.6.6 Water flow in pipes

There are two types of steady flow: laminar flow and turbulent flow.

Different laws govern the two flow types. Each is characterised by the Reynolds number, which is determined by the physical characteristics of the water, the velocity of flow and the internal diameter of the pipe:

$$Re = \frac{c \times d \times \rho}{\eta} \quad (2.11)$$

where Re is the Reynolds number, c is the velocity (m/s), d is the internal diameter of the pipe (m) and η is the dynamic viscosity ($\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$).

Reynolds numbers are used to obtain friction co-efficients, which are used in expressions to determine pressure losses.

Flows having Reynolds numbers greater than 4000 are turbulent, in which the particles of the fluid move in a haphazard fashion in all directions. Water flows for almost all plumbing applications are turbulent.

Viscosity is the property that determines the resistance of a fluid to a shearing force. Viscosity is due primarily to interaction between fluid molecules. Viscosities of liquids decrease with temperature increases but are not affected appreciably by pressure changes. Cold water is more viscous than hot water. Therefore, a greater pressure drop results with cold water compared to hot water for a given velocity through pipes of the same diameter.

The amount of water that a pipe can convey in a given time depends upon:

- the cross-sectional area of the pipe
- the velocity of the water.

Therefore the flow rate is given by:

$$Q = A \times V \quad (2.12)$$

where Q is the flow rate (m^3/s), A is the cross-sectional area of the pipe (m^2) and V is the flow velocity (m/s). The cross-sectional area of the pipe is given by $\pi d^2/4$, where d is the pipe diameter (m).

The flow velocity can be found by rearranging equation 2.12:

$$V = Q / A \quad (2.13)$$

Example 1

Calculate the flow in a nominal 50 mm copper pipe ($d = 48.36$ mm), when the velocity is 1.5 m/s.

From equation 2.12:

$$\begin{aligned} Q &= (\pi \ 0.04836^2 / 4) \times 1.5 = 0.001837 \times 1.5 \\ &= 0.00276 \text{ m}^3 = 2.76 \text{ litre/s} \end{aligned}$$

Example 2

Calculate the flow velocity in the same pipe when the desired flow rate is 2.76 litre/s.

From equation 2.13:

$$V = 0.00276 / (\pi \ 0.04836^2 / 4) = 1.5 \text{ m/s}$$

2.5.4.7 Noise and vibration (water hammer)

Water hammer in a system is created by the sudden change in flow velocity. If the flow velocity changes suddenly, e.g. by the fast closing of a tap, the pressure in the system changes at the point where the velocity change occurs.

Pipes should never be fixed rigidly to lightweight panels as they will transmit noise directly to the structure, which can then amplify the pipe noise. To reduce noise to a minimum the pipes should be installed within substantial and reasonably airtight ducts or enclosures wherever possible, and adequately supported clear of the enclosing walls.

Flow noise in pipework is caused when the pipe surfaces are set into vibration by the action of water flowing through the system at too great a velocity. Care in the design of pipework layouts can minimise the possibility of cavitation in pipework, which is caused by the increase in velocity at changes of direction or at fittings such as valves.

Outlet fittings have sudden changes of direction and the minimal downstream pressures that occur at the seating of an outlet fitting such as a tap or float operated valve can contribute to cavitation. This is the major cause of noise in these types of fittings, and is the common cause of noise problems within the system.

Impulsive noise (water hammer)

When a valve, tap, or float-operated valve closes quickly, thus rapidly cutting-off the flow of water, this creates a shock wave which reflects back along the path it has travelled. The resulting noise is similar to a hammer striking the pipework. Another cause is loose pipework, which moves due to the hydraulic thrust. To minimise water hammer, consideration should be given to the following:

- Velocities in excess of 3.5 m/sec will cause noise and increase the danger of damage due to hydraulic shock.
- Velocities in excess of 3 m/s may cause noise in living/occupied areas and should be avoided.
- Brackets should be used to retain pipes and prevent contact with structure; where pipes pass through the structure they should be sleeved to prevent contact.

Consider providing water hammer arrestors at appropriate locations in the system to relieve sudden pressure surges. Water hammer arrestors should be sized for the corresponding size of service/pipe branch. Suitable locations for water hammer arrestors are:

- upstream from an automatic clothes washing machine
- at the final group of fixtures on a pipe run in an apartment

- at the cold water inlet of a hot water unit, upstream of the inlet control valve.

Water hammer may be alleviated by:

- preventing the sudden closing of valves
- absorbing the hydraulic pressure waves by using pressure arrestors
- designing the pipework to avoid long straight pipe runs to taps and valves
- avoiding servo-operated valves or opening loaded valves
- restricting the water velocities.

2.5.4.8 Cross-connection and backflow prevention

Provide cross-connection control and backflow prevention in the water service to prevent the possible contamination of the water supply. A shut valve is not permitted by the Water Fittings Regulations^(3,20,21) as a means of preventing cross connection or backflow between wholesome and other water supplies.

Backflow prevention should be designed to comply with the requirements of BS EN 806⁽¹⁾ and BS 8558⁽²⁾ and the Water Regulations^(3,20,21). Backflow prevention devices should be selected in accordance with the corresponding hazard rating of a service.

When selecting a valve, give consideration to the maintenance and servicing requirements of the valve and the expertise of the persons who may be required to service it. An un-serviced or poorly serviced valve is likely to fail at a critical moment, causing contamination of a system.

2.5.4.9 System pressure

The system design pressure should be that required for the proper functioning of all taps and outlets. Check with the manufacturer for the minimum required working pressure for all tapware selected.

Provide pressure reduction valves (PRVs) or pressure reducing stations within the system where pressures are expected to exceed 65 m head. PRVs should have a maximum reduction ratio of 2:1.

It should be noted that PRVs must not be located on a domestic hot water pipe that forms part of a circulation circuit.

2.6 Underground pipework

Utility mains located below ground, whether water, gas, or pumped drainage, are required to be of a suitable material to be able to withstand twice the working pressure of the pipe for the ground conditions and at a depth to comply with current National Joint Utilities Group guidance documents (<http://www.njug.org.uk>), see chapter 13, section 13.4.2.

Pipe trenches should be kept to a minimum width that is practical and retain the trench wall to minimise ground loadings transferring onto the pipe. The trench bottom must be firm compacted earth at the correct level and slope, covered with 75 mm of washed sand to allow for bedding-in, and to accommodate the barrel and joints. This is followed by a further level of sand to give a total of 150 mm around the pipe. If the pipe is of a non-metallic material then a 150 mm wide label with the correct identifying marks and magnetic warning tape should be placed 300 mm above the crown of the pipe. This is followed by the trench back-filling, which should be of suitable material consolidated to resist subsequent movement of the pipe. No stones bricks or sharp objects should be allowed to be in contact or near the pipe.

Below-ground pipework requires to be restrained when the fluid changes direction and throughout its length to combat the internal pressures and flows. For the greater part of the pipework length this should be achieved by the weight of the backfill material. Where there is a change of direction such as bends, tees, blank/stop ends, hydrants, valves etc., thrust blocks will be required. The thrust blocks must be placed in a position that is in a line with the direction of the thrust developed in the pipework, see Figure 2.21, to restrain the movement and will require adequate bearing area for the type of ground to resist the thrust.

Table 2.19 gives the bearing capacities for various soil types.

Table 2.19 Safe bearing capacity for various soil types

Soil type	Safe bearing capacity / kN·m ⁻²
Soft clay	24
Sand	48
Sandstone and gravel	72
Sandy gravel with clay	96
Shale	240

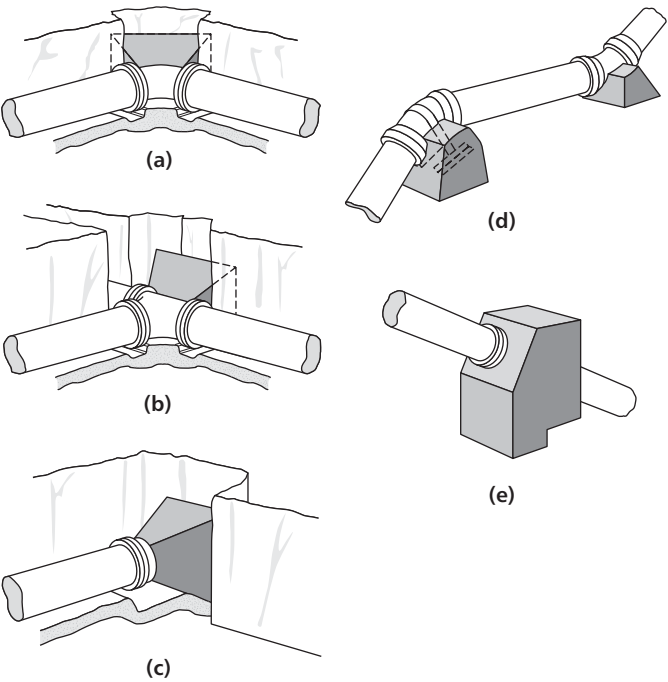


Figure 2.21 Typical thrust blocks — horizontal thrust buried mains; (a) bend, (b) tee, (c) dead end, (d) vertical thrust buried mains, (e) gradient thrust buried or exposed mains (1:6 or steeper)

underground piping should be designed such that the anchor does not :

- slide
- overturn
- shear
- fail in tension.

The design procedure is as follows:

- (1) Determine the safe bearing capacity of the ground (see Table 2.27).
- (2) Determine the thrust exerted on the soil at the changes of direction, both vertical and horizontal.
- (3) Calculate the area required on the bearing surface of the thrust block to spread the resultant force to an acceptable value for the soil type.

For changes of direction, the thrust is determined as follows:

$$T = p A 2 \sin \frac{\theta}{2} \quad (2.14)$$

where T is the thrust (N), p is the internal pressure (bar), A is the cross-sectional area of pipe (mm^2), θ is the angle of bend ($^\circ$).

For end stops, the thrust is given by:

$$T = p A \quad (2.15)$$

Example

Determine the thrust exerted at a 90° bend for a 80 mm pipe and an internal pressure of 1 bar.

Cross-sectional area of pipe:

$$A = (\pi \times 80 \times 80) / 4 = 5026.5 \text{ mm}^2$$

From equation 2.15:

$$\begin{aligned} T &= 1 \times 5026.5 \times 2 \sin (90/2) \\ &= 7108 \text{ N} = 7.2 \text{ kN} \end{aligned}$$

The safe bearing capacity for soft clay is 24 kN/m^2 . Therefore, the surface area of the thrust block required to resist the thrust at a 90° bend is $(7.2 \div 24) = 0.3 \text{ m}^2$.

2.7 Legionnaires' disease

Guidance on minimising the risk of Legionnaires' disease, with recommendations for hot and cold water systems, is given in CIBSE TM13⁽³⁹⁾ and the Health and Safety Commission's Approved Code of Practice and guidance L8⁽³⁷⁾. Additional guidance for health care buildings is given in Health Technical Memorandum HTM 04-01: *The control of Legionella, hygiene, 'safe' hot water, cold water and drinking water systems*⁽⁴⁷⁾.

The design engineer needs to complete a risk assessment for the system to identify the potential for bacteriological contamination, particularly *Legionella*, as the *Legionellae* bacteria multiply actively at temperatures between 20°C and 45°C . Upon completion of the works, the contractor will also be required to provide *Legionella* risk assessments and schematics, in accordance with the HSE ACoP L8.

Although Legionnaires' disease can be associated with the cooling towers for air conditioning systems, evidence from the UK and overseas indicates that hot and cold water service systems can also be a source of infection. The following are thought favourable to significant colonisation and should be avoided:

- dirt, scale, rust, algae, organic particulates and sludge in cisterns and calorifiers
- storage and/or distribution temperatures in the range $20\text{--}45^\circ\text{C}$,
- large volumes of static water or small ratios of water use to system volume.

The above guidance documents provide specific practical guidance on how this is to be achieved in water supply systems. The key aims being to:

- maintain cold water below 20°C (*Note*: current thinking is keep the temperature to 8°C or less to ensure that *Pseudomonas* bacteria remain dormant and that a circulation system be installed to maintain this temperature throughout the building; should be maintained at 8°C)
- maintain stored hot water between 60 and 65°C
- maintain hot water distribution above 50°C , and preferably at 55°C
- insulate all cold and hot water storage vessels and distribution pipework
- minimise the length of non-circulating and non-trace heated hot water pipes
- avoid supplies to little or unused draw-off fittings.
- maintain balanced use and flows through multiple cold water tanks and hot water vessels.

Thermal purging (pasturisation) requires the water temperature to be raised to above 70°C . To provide a margin of safety, the target temperature should be 75°C during the maintenance period (out of hours or through the night) for disinfection purposes. It is important that all the outlets from the heating source have suitable thermostatic mixing valves to safeguard against the risk of scalding. Whilst there would appear to be a shortfall during times of maintenance, peak flows are of short duration. It is considered that little change in temperature would be perceived during any periods of maintenance, especially where hot water outlets employ blending valves set to 43°C .

Calorifiers should be designed to minimise or eliminate stagnation and stratification. This can be achieved by the use of a shunt pump.

Piping layouts that can prove effective in controlling *Legionella* and other microorganisms are those in which pipe runs are designed such that the last outlet is in constant discharge, e.g. a urinal.

Other pathogens

Some pathogens, such as *Legionella* and *methicillin-resistant Staphylococcus aureus* (MRSA), can be carried around water systems by protozoa or live in the biofilm, which can protect the bacteria from harsh conditions and water treatment chemicals such as chlorine. Other pathogens such as *Cryptosporidium* can resist levels of chlorine in excess of 50 ppm. Some of the other pathogenic microorganisms that can be transmitted by water include:

- *viruses*: hepatitis A, enteroviruses (e.g. polio), rotavirus (causes diarrhoea), norovirus ('winter vomiting bug')
- *parasites*: *Giardia*, *Cryptosporidium*
- *bacteria*: *E. coli*, *Pseudomonas sp*, *Campylobacter*
- *protozoa*: *Acanthamoeba*
- *fungi*: *Aspergillus fumigatus*

Breaking the causative link

Exposure to *Legionella* is preventable. The aim of this section is to alert the reader to how attention to detail can break the causative link and thereby reduce considerably the likelihood of future outbreaks. The sequence of linked events that could lead to an outbreak of Legionnaires' disease are shown in Figure 2.22. By breaking as many of the links as possible an outbreak may be prevented.

Correct design of systems and operating procedures will significantly reduce the risk of an outbreak. The following factors can contribute to an outbreak of Legionnaires' disease:

- poor management
- no clear lines of responsibility
- poor communication
- lack of competence

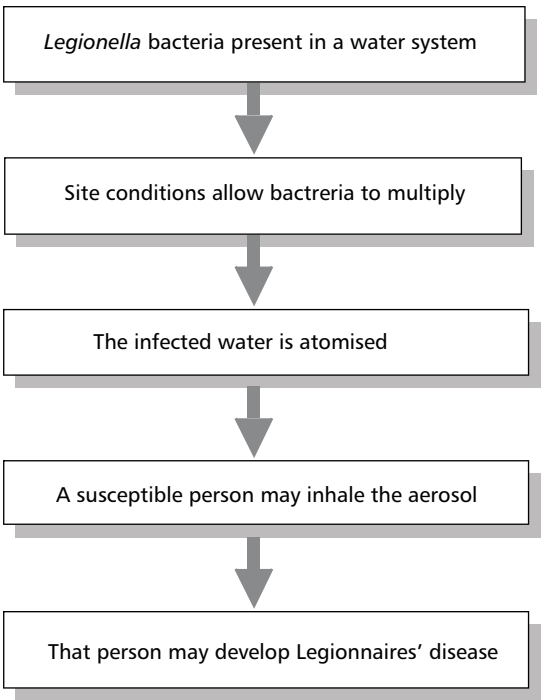


Figure 2.22 Chain of events that may lead to Legionnaires' disease

- poor quality of supplies
- lack of understanding.

Legionella and other bacteria can proliferate almost anywhere in the water systems and various measures are required to control their growth. Potential problem areas include:

- the base of calorifiers, which can release *Legionella* into the system when under high demand
- dead legs and disused branches which may harbour bacteria by allowing biofilms to develop
- mixing valves situated too far away from taps, allowing water to stagnate at temperatures above 20 °C
- under-used sanitary fittings (including WCs) and poor system flushing regimes allowing the water temperature to rise to the ambient temperature
- tap outlets: research has suggested that water can stagnate in the swan necks of some types of outlet
- cooling towers and fume scrubbers
- showers/taps
- spas/hydrotherapy pools
- water sprinklers/irrigation systems
- ornamental fountains
- clinical humidifiers/nebulisers (in health care premises)
- drilling/grinding machines
- ice making machines
- car/lorry washers

The following lists various measures by which bacterial contamination may be minimised:

- high level temperature pasteurisation (70 °C)
- chlorine or chloramines
- chlorine dioxide and non-ion exchange
- silver stabilised hydrogen peroxide (*Note*: this is a relatively new technology and should be treated with caution, particularly with respect to kidney dialysis)
- flushing (*Note*: problems may be experienced with auto-drain showers)
- ultraviolet (UV) filtration
- point-of-use filtration (less than 0.2 microns)
- high and low temperatures
- regular flushing of outlets
- dosing the system with biocides from new, as soon as it is charged
- constant monitoring, as described in HE ACoP L8⁽³⁷⁾.

Although the above measures may seem difficult and may involve additional pipework and fittings, the benefits in breaking the causative link are considerable.

2.8 System maintenance

Water systems should be regularly maintained throughout their life and due consideration should be given to maintainability when systems are designed and installed.

Important features to be considered include:

- ease of access,
- provision for rapid and complete draining of the system, with no water retention, and adequate clean facilities for refilling
- thorough cleaning of the system before first use and regularly thereafter; cleaning should be done according to BS EN 806⁽¹⁾ and BS 8558⁽²⁾ (*Note:* the source of supply should be checked for contaminants prior to filling)
- chemical cleaning and/or de-scaling may also be required prior to commissioning depending on the materials used for installation, jointing etc. to remove biofilms, which act as protection for the bacteria.

2.8.1 Maintenance procedures

The following recommendations relate to general maintenance procedures and could be adopted for non-specialised plant. The maintenance of specialist plant should be detailed within the separate instruction manuals provided by the plant manufacturers.

The engineer should ensure that the client representative for maintenance has all the required manufacturer's literature before handover of the plant and systems.

The engineer must ensure that the maintenance staff are made aware of the following statement or a statement of similar content:

'Warning: Before any personnel commence maintenance work on any item of plant they must ensure that the plant is electrically isolated and disconnected by switching the circuit isolating switch to 'off' and by withdrawing the fuses, that the plant is isolated from the system it is serving, and that all drives are disengaged.'

Pipework

Check the following as indicated.

Every 3 months:

- Check all pipework for leaks or movement.

Every 6 months:

- Pipework supports should be inspected to ensure that pipe hangers and brackets are firmly mounted and undamaged.
- Check all isolating and regulating valves at all floor levels for correct operation.
- The hot water service pump should be checked for leaks and correct operation.
- All plant connections should be checked for correctness of operation. All items should be checked to ensure freedom from blockage, and all

plant isolating valves should be overhauled and washers replaced as necessary.

Every 12 months:

- Clear, clean with high pressure water and run-test the soil and waste stacks and pipes collecting overflows from the water services plant. These checks should be executed by a specialist drain clearance company.
- Check all connections to the cold water storage cistern/tanks, together with the cold water cistern/tanks to ensure the lid/s have not been displaced; check for water leaks, and clean the air vent and the overflow pipe filters. The float operated valve should be checked for correct balance and level and adjusted accordingly.

Water quality

Check the following every 12 months:

- The water quality within the cold water storage cistern should be checked against drinking water standards by a specialist water treatment company and their safety recommendations immediately implemented.
- The internal condition of cold water tanks should be checked annually and the tank cleaned and refurbished as necessary, followed by disinfection of the entire system downstream. Where possible, domestic hot water calorifiers should be accessed internally at the same time, de-scaled, treated for corrosion and cleaned prior to disinfection. The disinfection procedure should follow that set out in HSE ACoP L8⁽³⁷⁾.

Note: for further guidance on monitoring for *Legionella*, refer to HSE ACoP L8⁽³⁷⁾ and CIBSE TM13⁽³⁹⁾.

Pumps

Check the following every 3 months:

- Check the gland leakage rates and pay particular attention to signs of overheating or abnormal operating noise.
- Pump suction and discharge pressures should be checked to ensure that they are maintained at the levels required for the system.
- Where pump lubricators are fitted, the manufacturer's instructions regarding the operation of the lubricators and re-charging (with the correct grade of lubricant) should be carefully observed.
- Gland nuts should be screwed just tightly enough to prevent leakage, always ensuring that the gland face is maintained square with the pump shaft.
- Where mechanical or carbon ring seals are fitted, the manufacturer's instructions on seal adjustments must be carefully observed.
- Where pumps are protected by suction strainers, these must be cleaned with the strainer elements and seals being inspected for damage and wear. All worn and/or damaged items must be replaced and not refitted at the time of inspection.

Valves

Check the following every 6 months:

- All valves should be tested to ensure that they operate freely without undue resistance or jamming.
- All valve glands should be checked for signs of leakage, particularly during the first three months following commissioning.
- Gland nuts should be checked and tightened as necessary, just enough to prevent any leakage from the valve while at the same time allowing free rotational movement of the valve spindle.
- All float operated valves should be checked to ensure that the float arms move easily, the balance and level are correct, and the valve shuts off properly, with the water level being controlled by the float arm. All adjustments should be made as necessary to correct the operation of the float operated valve.

Insulation

Check the following every 12 months:

- All insulation removed from pipework, valves, cisterns, or any equipment, for the purpose of maintenance or repair should be replaced on completion of the work task, repainted and with identification labelling and marking re-instated.
- Insulation should be inspected for external damage, signs of deterioration and slack, or missing securing bands, all of which must be replaced immediately.
- Check for signs of staining on insulation which may be evidence of system leakage and correct immediately.

2.9 Operation

When becoming responsible for a new system, it should be flushed, sterilised and commissioned before use, followed by regular inspections and disinfections whilst in use as required under the risk assessment.

When becoming responsible for an existing system, it should be totally surveyed and if any of the following are found they should be eliminated in a proper manner:

- Occasionally used outlets served from a long dead leg that allow water to be atomised should be re-routed such that the last point to be a large volume, frequently used outlet. The outlet should be flushed on a daily basis. Dead legs should be removed or minimised.
- Blanked-off branches should be removed completely, including the remaining tee in the main pipework. If this is not possible then a branch no longer than the diameter of the branch pipe is permitted.

- Pipework where dirt/debris may collect and become a source of nourishment for bacteria (e.g. food particles) must be removed.

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3 Sanitary pipework, accommodation and rainwater drainage

3.1 Introduction	Summary
3.2 Design considerations	This chapter covers those aspects of sanitation, and foul and surface water disposal in the immediate environs of a building and includes advice on above-ground drainage systems and connections to sewage systems. This chapter should be read in conjunction with chapter 4, relevant British Standards and other highlighted documents.
3.3 Assessment of sanitary accommodation	
3.4 Foul water drainage	
3.5 Rainwater drainage	
References	
Bibliography	
Appendix 3A.1: Nomograms for sizing of gutters	

3.1 Introduction

This chapter covers those aspects of sanitation, and foul and surface water disposal in the immediate environs of a building. Connections to private or public sewerage and storm water disposal systems are dealt with in chapters 4 and 5.

The design and installation of sanitary installations in the UK is controlled by legislation, particularly through the Building Regulations and Scottish Building Standards. The relevant local authority acts as the controlling body in each area, and particular requirements that they may further impose will need to be taken into account. In all cases, the details of design and installation will form part of the submissions for Building Regulations approval, prior to and during construction.

The general statutory requirements are contained in the following legislation.

For England and Wales:

- Building Regulations⁽¹⁾, Parts B, E, G, H and M, and associated Approved Documents^(2–6)
- Environmental Protection Act 1990⁽⁷⁾
- Factories Act 1961⁽⁸⁾
- Offices, Shops and Railway Premises Act 1963⁽⁹⁾
- Public Health Act (Drainage of Trade Premises) 1937⁽¹⁰⁾
- Public Health Act 1961⁽¹¹⁾
- Radioactive Substances Act 1993⁽¹²⁾

Additional legislation for Scotland:

- Building (Scotland) Act 2003⁽¹³⁾

- Building Standards (Scotland) Regulations 1990⁽¹⁴⁾ and associated Technical Standards Part M: *Drainage and sanitary facilities*⁽¹⁵⁾
- Flood Prevention (Scotland) Act 1961⁽¹⁶⁾
- Sewerage (Scotland) Act 1968⁽¹⁷⁾

Additional legislation for Northern Ireland:

- Building Regulations (Northern Ireland) 1990⁽¹⁸⁾ and associated Technical Booklet N: *Drainage*⁽¹⁹⁾.

Reference should also be made to the current Workplace (Health, Safety and Welfare) Regulations 1992⁽²⁰⁾, the Water Supply (Water Fittings) Regulations 1999⁽²¹⁾, the Water Supply (Water Fittings) Regulations (Northern Ireland) 2009⁽²²⁾ and the *Code for Sustainable Homes*⁽²³⁾.

3.2 Design considerations

In order to ensure that the drainage system will deal adequately with the effluent delivered in the system the Designer will need to establish the following criteria prior to commencement of the design:

- geographical location
- the surface levels of the ground upon which the building is located
- the layout and levels of any existing below ground drainage system and sewers
- an indication of the usage of the existing sewers; i.e. whether the sewer channels storm and foul water effluent together or separately
- positions of entries to the drains from the above ground system

- number, type and usage of all sanitary accommodation contributing to each drain entry
- usage pattern of the proposed development
- anticipated lifespan of the proposed development
- any requirements and/or limitations imposed by the client or tenant/user
- any considerations with respect to the likely type of effluent to be discharged i.e. chemical, contaminated, radioactive or trade effluent.

It is recommended that the designer also establishes with the local sewerage undertaker and/or the Environment Agency any limitations on the discharge into the public or private sewage system to be used.

It is then possible to provide an approximate arrangement for the sub-structure drainage, and stacks can be arranged to suit the topography of the site and the drainage requirements of the above ground drainage.

The following sections detail the procedures for providing sanitary accommodation to comply with the relevant regulations and the procedures for the design of the above and below ground drainage for foul and storm water within a building's curtilage.

3.3 Assessment of sanitary accommodation

The assessment and provision of sanitary accommodation generally falls under the responsibilities of the architect. However, there are some instances where the client or architect will seek the advice of a public health engineer.

BS 6465-1⁽²⁴⁾ provides recommendations for the scale of provision of sanitary appliances, portable toilets, toilets for disabled people, and associated appliances. In addition it provides recommendations on the design of sanitary facilities. This standard is applicable to new buildings and refurbished private dwellings, residential and nursing homes for the elderly, workplaces, shops, petrol stations, schools, assembly buildings, bedrooms in hotels and hostels, licensed bars, swimming pools, and public toilets.

In addition, current disability discrimination legislation⁽²⁵⁾ regarding sanitary provision will need to be taken into account (see also Part M of the Building Regulations^(1,6)).

Included within this standard are a series of tables that detail the minimum scale of provision of sanitary appliances in different locations for differing uses. The standard also includes recommendations for WC compartments, water supply, wiring, lighting, heating, layout, walls, floor, ceiling, and ventilation.

The designer should also note that, in addition to BS 6465-1, there are other publications produced by various committees, groups and bodies that are responsible for the design standards for different types of development, such as sports centres, schools, prisons, military installations etc. that require variations to the provisions detailed within BS 6465-1.

3.4 Foul water drainage

3.4.1 General

This section is intended to give the designer an overview of the design and implementation of an above ground foul water drainage installation.

Foul water drainage can be described as being the waste from sanitary conveniences and other sanitary appliances, equipment used for catering or washing purposes, plant room waste water, and other contaminated waste water discharges.

The design of the above ground drainage should ensure that the system efficiently removes foul water from the building whilst preserving the integrity of the water trap seals to the connected appliances.

When considering the type of system to be used, it is imperative that the designer enters into discussion with the other members of the design team, the client and Building Control to ensure that the most suitable system is provided.

Generally foul water drainage can be divided up into five main categories:

- *waste water*: water not containing human waste or trade effluent
- *domestic waste water*: water derived from normal domestic habitation including human waste
- *greywater*: water from showers, baths or basins
- *blackwater*: water containing human waste
- *trade effluent*: water from industrial processes that is contaminated or polluted, having been used for production processes, washing or cooling activities.

With the advent of recycling, grey water systems are becoming more popular with developers in an attempt to meet the BREEAM⁽²⁶⁾ (BRE Environmental Assessment Method) requirements, and to reduce running costs and increase the efficiency of the system. With this in mind the designer should give due consideration to the provision of greywater recycling at an early stage within the project.

3.4.2 System types

Under the dictates of BS EN 12056-2⁽²⁷⁾ there are four systems that can be utilised when considering which system to use; they are defined therein as follows:

- System I: single discharge stack system with partly filled branch discharge pipes
- System II: single discharge stack system with small bore discharge branch pipes
- System III: single discharge stack system with full bore branch discharge pipes
- System IV: separate discharge stack system.

Within the UK the industry-wide accepted system is System III. However, when considering greywater recycling, the use of System IV would be more appropriate as it uses separate discharge stacks.

3.4.3 System configurations

3.4.3.1 General

Once the designer has arrived at a decision as to which system type is to be utilised within the design, the next stage is to select a configuration that best suits the development to provide the most economically viable solution within the scope of the design brief.

A foul water drainage system can be configured in a number of ways depending on the anticipated use, height and layout of the development. In addition, whichever configuration is finally selected, the need for controlling the differential pressures within the pipework will be paramount to prevent foul air entering the building.

BS EN 12056-2⁽²⁷⁾ highlights the three main industry-accepted configurations for discharge stacks and provides basic diagrams illustrating all three configurations.

3.4.3.2 Primary ventilated systems

The primary ventilated stack system is one of the most commonly used systems in the UK and was developed in response to the industry's need for a more commercially acceptable system for residential developments.

The system consists simply of a single stack connected to the underground drainage system and ventilated to atmosphere at roof level or fitted with an air admittance valve. Unventilated branches from individual appliances or groups of appliances are then connected at each floor level.

Pressure fluctuations within the system are controlled by allowing the free movement of air within the discharge stack and stack vent. Therefore offsets within the vertical portion of the stack should be avoided or kept to a minimum to allow the air to move freely.

3.4.3.3 Secondary ventilated systems

Although widely used throughout the UK until the 1970s, as a result of commercial pressures and special constraints, secondary ventilated systems are now becoming less common in favour of the primary and modified single stack systems. However, the designer should be aware that certain local authorities still insist on their use.

Secondary ventilated systems have a tried and tested history. As such, the designer should note that their use should never be discounted on larger developments or installations where it is anticipated that there will be a number of offsets due to the differing floor plans, such as high-rise buildings with multiple offsets.

The control of pressure fluctuations within a secondary ventilated system are achieved by means of a separate dry ventilating stack run in parallel with the discharge stack interconnected at each floor level. In addition, each

branch is also provided with a dry ventilating pipe run in parallel to the branch waste on an opposing fall above the flood level of the highest connected fitting, with individual connections from each appliance. The minimum sizes for these ventilating or anti-siphon pipes can be found within BS 12056-2⁽²⁷⁾.

3.4.3.4 Modified single stack systems

A modified single stack system is simply a primary ventilated stack system with the addition of ventilated branches, thus giving the designer greater flexibility in the layout of the system and its connected branches. Their primary use is where the discharge stack cannot be located adjacent to groups of appliances or where the appliances are widely dispersed. The trap seals are maintained by running both the main discharge stack and associated ventilating stacks to atmosphere and providing individual branch ventilating or anti-siphon pipes.

3.4.4 Discharge stacks

3.4.4.1 General

A discharge stack is described as a vertical pipe conveying foul water from the connected appliances to the main underground drainage system.

As a rule the designer should, wherever practicable, ensure that these stacks are kept vertical within the constraints of the development. Where this is not practicable, the offsets should be kept to a minimum and the use of either a modified single stack or secondary ventilated system should be considered to manage the pressures within the stack effectively.

Generally, discharge stacks should be located as close to the appliance or appliances that are to be connected as the building constraints allow without the need for offsets at different floor levels. To this end the designer should ensure that all routes are agreed with the client, architect and other members of the design team at an early stage.

3.4.4.2 Discharge stack layout

Generally discharge stacks should be arranged so as to drop vertically through the building with no offsets. However, with more multi-use developments, this is proving increasingly difficult to achieve.

Within any discharge stack, several factors need to be addressed to prevent loss of trap seal, noise generation and surcharging, which on their own present nuisance and a risk to health but, when combined, can have dire consequences for the inhabitants and for the building fabric and structure itself.

The main and most common factor that needs to be addressed when routing a discharge stack is the control of any pressure fluctuations. To achieve this, the designer must first consider the following:

- *The total anticipated or calculated flow:* the stack should be sized so as to adequately convey the calculated flow from the connected appliances. If a high frequency of use is anticipated consideration

should be given to increasing the stack diameter from that calculated in order to allow air movement within the core of the stack, or using a secondary ventilated stack instead of a primary ventilated stack.

- *The height of the building:* the height of the building and associated stack height will determine the velocity of the waste water in the stack and the likely positive and negative pressure created.
- *The types of fitting that are to be used:* this will have a bearing of the flow of the waste water within the stack with particular regard to the radius of any offsets and turbulence from any adjoining branches.
- *Any changes in direction:* changes in direction should be avoided wherever practicable as they generate back-pressure leading to loss of trap seal as air is blown through the trap or, in extreme cases, foul water being pushed back into the building through the lowest connected appliances on that floor.
- *How the stack is to be ventilated:* all discharge stacks ideally should be ventilated to atmosphere BS EN 12056-2⁽²⁷⁾. This is the designer's most effective tool in balancing pressures within a discharge stack as it will allow air out under positive pressure situations and entrain air under negative pressure situations. Air admittance valves will only entrain air to relieve negative pressures and therefore cannot be used for positive pressure applications. The designer should also give consideration to the location of the vent termination so as not to be affected by the wind.
- *Surcharging of the underground drain:* if it is anticipated that the underground drainage system is liable to surcharge, measures must be taken to prevent foul water entering the building. This is achieved by ensuring that there are no low-level appliances connected and, in addition, relieving the positive pressures generated whilst the system is still in use during the surcharge period by means of adequate venting.

Figure 3.1 gives an indication of the pressures generated with a discharge stack under normal operation and the effect on the traps connected for a multi-storey building.

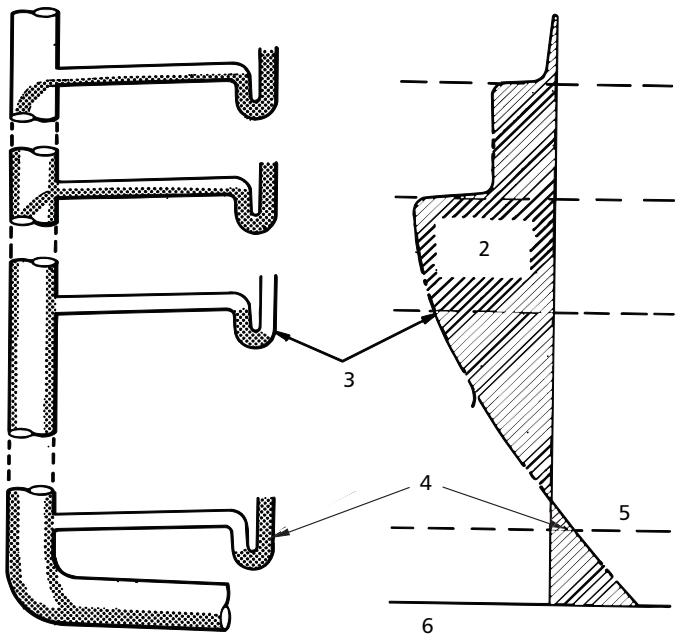
3.4.4.3 Discharge stack sizing

Discharge stack sizing is achieved using the 'discharge unit' method set down in BS EN 12056-2⁽²⁷⁾ for all gravity drainage systems using the following formula:

$$Q_{ww} = K \sqrt{\sum (DU)} \quad (3.1)$$

where Q_{ww} is the waste water design flow rate ($l \cdot s^{-1}$), K is the frequency factor and $\sum DU$ is the sum of the discharge units.

Table 2 of BS EN 12056-2⁽²⁷⁾ gives discharge units for a wide range of appliances and sanitary fittings in common use for all four system types. Some values, drawn from this table, are given in Table 3.1.



Legend:

- 1 Open to atmosphere
- 2 Negative pressure
- 3 Induced siphonage related to suction (negative pressure) in the stack
- 4 Back pressure related to positive pressure in stack
- 5 Positive pressure
- 6 Typical air pressure distribution in stack with two branches discharging

Note: Connection close to base of stack is not recommended but is shown here to illustrate pressure effects.

Figure 3.1 Pressure effects and seal losses due to water flow in a discharge stack (reproduced from BS EN 12056-2⁽²⁷⁾ by permission of the British Standards Institution)

When calculating the discharge stack diameter the designer must first establish the waste water flow rate (Q) by selecting the most appropriate value(s) for the appliance(s) connected to the stack from the table. Once each connected appliance has been allocated an appropriate value, the total number of discharge units for each stack can then be calculated by totalling the number of discharge units from all the connected appliances.

When the sum of the discharge units ($\sum DU$) has been calculated, the designer selects an appropriate frequency factor (K) for the type of building/development using BS EN 12056-2, Table 3. Some values, drawn from this table, are given in Table 3.2.

Having selected a value for the frequency factor (K) and determined the sum of the discharge units ($\sum DU$), these values can then be substituted into equation 3.1 to give the waste water flow rate (Q) for each discharge stack.

Example

Determine the waste water flow rate for 8 apartments each with a WC, wash basin, bath, kitchen sink and domestic washing machine.

From Table 2 of BS EN 12056-2⁽²⁷⁾, a discharge unit (DU) value appropriate to each appliance is selected:

Table 3.1 Minimum discharge unit values for typical sanitary appliances in common use using System III (adapted from Table 2 of BS EN 12056-2⁽²⁷⁾).

Appliance or fitting	Discharge unit (DU)
Wash hand basin	0.3
Shower	0.4
Bath	1.3
WC:	
— 4.0 litre cistern (estimated)	1.2–1.5
— 6.0 litre cistern	1.2–1.8
Urinal:	
— wall-hung	0.4
— slab urinal (per stall)	0.2
Sink	1.3
Dishwasher (domestic)	0.2
Washing machine domestic:	
— 6 kg capacity	0.6
— 12 kg capacity	1.2

Notes:

- (1) For commercial kitchen equipment refer to manufacturers' data.
- (2) For further information, see BS EN 12056-2⁽²⁷⁾, Table 2.

Table 3.2 Frequency factor values (adapted from Table 2 of BS EN 12056-2⁽²⁷⁾)

Appliance or fitting usage	Frequency factor (K-value)
Intermittent use, e.g. domestic, office	0.5
Frequent use, e.g. educational premises, hotel, restaurant, hospital	0.7
Congested use, e.g. public toilets, gyms, cinemas	1.0
Special use, e.g. commercial kitchens, laboratories	1.2

Note: For further information, see BS EN 12056-2⁽²⁷⁾, Table 3.

- WC: 1.5
- basin: 0.3
- bath: 1.3
- kitchen sink: 1.3
- domestic washing machine: 0.6

Hence:

- Total DUS per apartment = 5.0
- Total DUS for the discharge stack = $8 \times 5.0 = 40$

From Table 2 of BS EN 12056-2⁽²⁷⁾, a frequency factor (K) appropriate to a domestic application is selected:

- intermittent use (e.g. dwelling): $K = 0.5$

Hence, from equation 3.1:

$$Q_{ww} = 0.5 \sqrt{40} = 3.16 \text{ litre/s}$$

The above equation will only give the waste water flow rate for appliances with an intermittent use and does not take into account any connected continuous or pumped

flows that may also connect to the discharge stack. For these instances the following formula applies:

$$Q_{\text{tot}} = Q_{ww} + Q_c + Q_p \quad (3.2)$$

where Q_{tot} is the total flow rate ($\text{l}\cdot\text{s}^{-1}$), Q_{ww} is the waste water flow rate ($\text{l}\cdot\text{s}^{-1}$), Q_c is the continuous flow rate ($\text{l}\cdot\text{s}^{-1}$) and Q_p is the pumped water flow rate ($\text{l}\cdot\text{s}^{-1}$).

When using the above formula, no factor for diversity should be applied.

Example

Adding a pumped discharge (Q_p) of 3.0 litre/s to the waste water flow rate (Q_{ww}) calculated in the previous worked example gives:

$$Q_{\text{tot}} = Q_{ww} + Q_p$$

Hence:

$$Q_{\text{tot}} = 3.16 + 3.0 = 6.16 \text{ litre/s}$$

Having established the total flow rate (Q_{tot}) for the discharge stack, a suitable pipe diameter must be selected. Tables 11 and 12 of BS EN 12056-2⁽²⁷⁾ provide a selection of maximum hydraulic capacities (Q_{max}) for commercially available diameters of pipework for both swept and square entries for primary and secondary ventilated stacks.

It should be noted, however, that in the UK the accepted practice is to use the flow rates for swept entries.

Therefore, using the total flow rate (Q_{tot}) calculated in the above example, for a primary ventilated system with swept entries, BS EN 12056-2⁽²⁷⁾ gives the pipe diameter as DN125.

However, if there were neither pumped nor continuous flow rates to be taken into account, using the waste water flow rate (Q_{ww}) only, gives a pipe diameter of DN100.

As a minimum requirement, the pipe diameter selected must be able to convey the greater of the calculated waste water flow rate (Q_{ww}) or the total flow rate (Q_{tot}), and be no less than the diameter of the largest connected trap.

Where there is to be an offset within a vertical discharge stack less than 45° , the designer must then refer to BS EN 12056-2, Tables B.1 or B.2, for the selected filling degree for the respective available fall or gradient. Applying this to the above example, for a filling degree of 50% and a maximum available fall of 1 cm/m (1:100) gives a diameter of DN150.

3.4.5 Layout of branches**3.4.5.1 General**

Branch discharge pipes should be suitably sized so as to convey the waste from an appliance or group of appliances to the discharge stack without loss of trap seal or deposition of solids within the horizontal run. Generally, the diameter of any branch waste pipe should be no less

than the diameter of the outlet from the trap of the largest connected appliance.

When sizing or laying-out the proposed branch waste runs reference should be made to Table 6 and Table 9 of BS EN 12056-2⁽²⁷⁾ to select the minimum pipe diameter and gradient for both unventilated and ventilated branch waste pipes.

In addition to the pipe diameters and gradients provided within these tables, the designer should exercise due care to ensure that, under normal operating conditions, where differing types of appliances are connected to a common branch waste header, the size of the branch and its associated gradient do not cause surcharge to the lowest connected appliance (particularly baths, shower gullies or trays). This problem can be alleviated by either increasing the diameter of the header or, if practicable, by reducing the number of offsets in the horizontal run and using long radius swept bends (or two 45° bends) for those that are necessary to provide a smooth flow.

The designer should also note that, where groups of urinals are to be connected to a single branch waste header, care should be exercised to reduce the length of the branch to a minimum to reduce the risk of deposition. However, where this is not practicable the branch waste should be increased in size.

All connections to branch waste headers should be swept in the direction of flow and offset wherever necessary, to prevent cross-flow between opposing appliances.

In all instances, the designer should consider the likely use of all the connected appliances to a branch waste or branch waste header, and the possible route of that header, in order to ensure that the runs are not too long (to avoid noisy discharge and deposition) and that the number of offsets are kept to a minimum to prevent surcharge.

The designer should note that, due to the ongoing need for the conservation of water, discharge flows for sanitary appliances are likely to continue to reduce. It is therefore important to ensure that the branch discharge pipes are not oversized, as this can lead to problems where there is infrequent use resulting in a build-up of deposits. This is most likely to occur in branch wastes with long horizontal runs of pipework with a large number of offsets and bends and also applies to the underground drainage system, where the continuing reduction in the quantity of water required to flush WCs will in some cases lead to solid matter being left behind.

3.4.5.2 Connections to discharge stacks

Due to the differential pressures created within the main discharge stack, large or equal diameter branch waste pipes should be connected using swept or, preferably, 45° branches to maintain a laminar flow. Smaller diameter branch waste pipes may be connected to the main discharge stack using 90–92½° branches as the suctional effect exerted by the main discharge stack is significantly less.

BS EN 12056-2⁽²⁷⁾ prescribes the limitations for the heights at which a branch waste pipe of any diameter can connect to the main discharge stack from the invert of the

rest bend or offset to the invert of the branch. This is to prevent loss of trap seal due to induced siphonage or back pressures. Simplified, these limits are as follows:

- single storey: 450 mm
- up to 5 storeys: 750 mm
- 5 to 19 storeys: all ground floor appliances to be connected to a separate stack connecting to the horizontal run no less than 2 metres away from the bend in the main discharge stack
- 20 storeys and above: both the ground and first floor appliances are to be connected to a dedicated stack connecting to the horizontal portion of the main discharge stack a minimum of 2 metres from the bend or base of the stack.

Where a number of waste branches are to connect to a discharge stack at a similar height, the designer may wish to employ the use of waste manifold fitting. This will alleviate any problems or issues with cross-flow, induced siphonage, surcharging and small bore pipework configurations, as these units are specifically designed to eliminate these factors.

BS EN 12056-2⁽²⁷⁾ provides a series of standard details indicating the permitted and best practice methods of branch waste connections to main discharge waste stacks for various applications.

In general, all branch connections to discharge stacks should be arranged so as to avoid cross-flow between opposing branches. This can be achieved by offsetting the branch connections by 200 mm in the vertical plane (if heights and gradients allow) although this will prove difficult for appliances with low outlets such as showers, baths and cleaners' sinks. Therefore, where this is not practicable, it will be necessary either to make the connections at 90° to each other in the horizontal plane or utilise a manifold fitting where the pipe diameters are 50 mm or less.

3.4.5.3 Unventilated branches

An unventilated branch is described as being a branch waste pipe that conveys waste from an appliance or group of appliances that is in turn limited to the number of connections permitted based upon its overall length.

Table 6 of BS EN 12056-2⁽²⁷⁾ prescribes the maximum permissible number of appliances that can be connected to an unventilated branch based upon the maximum allowable length, gradient, number of offsets and number of connected appliances. The designer should note, however, that this table gives only the criteria for single types of connected appliances. For differing connected appliances with varying rates of discharge, the designer should ensure that the horizontal run is kept as short as practicable, so as not to promote surcharging, thereby allowing the waste water to enter the lowest connected appliance or creating a high negative pressure leading to induced siphonage. In most instances this can be overcome by ensuring that connections are made at some distance from any changes in direction, and by using fittings swept in the direction of flow.

Where differing types of appliances are to be connected to waste branches, it is advisable to use a ventilated branch to allow the free movement of air within the pipe to alleviate potential problems with noisy discharge, surcharge and induced siphonage.

3.4.5.4 Ventilated branches

Ventilated branches are most commonly used in secondary ventilated and modified single stack systems as they allow the free movement of air within the branch waste pipe by entraining air from another source (such as a ventilating pipe or anti-siphon pipe) to balance any pressures created.

Table 9 of BS EN 12056-2⁽²⁷⁾ gives the maximum permissible number of appliances that can be connected to a ventilated branch based upon the maximum allowable length, gradient, number of offsets and number of connected appliances.

A ventilated branch allows the ingress of air into the horizontal portion of the branch waste pipe by means of a small diameter ventilating or anti-siphon pipe at the point where the appliance connects to the branch waste header in order to relieve any negative or positive pressures under normal operation.

As an alternative to a ventilating or anti-siphon pipe, the designer may wish to utilise an air admittance valve at the head of the waste branch pipe in the horizontal above the spill-over or flood level of the highest connected appliance. However, it should be noted that this will not alleviate problems associated with positive pressures as an air admittance valve will only allow air to be entrained into the system. Other methods of preventing self-siphonage include considering using a resealing trap, anti-siphon trap, self-sealing waste valve, or enlarging the waste pipe. A larger diameter branch waste pipe will need to be provided to allow the free passage of air over the waste water in the branch.

3.4.6 System ventilating

3.4.6.1 General

BS EN 12056-2⁽²⁷⁾ recommends that discharge stacks, in particular the head of the drain, should be vented to atmosphere to adequately ventilate both the above and below ground drainage systems and to control pressure fluctuations and maintain trap seals under normal operation.

3.4.6.2 Venting arrangements

Once the designer has established the locations of and routing of the wet portion of the discharge stacks the overall provision of system venting needs to be determined.

As previously stated, BS EN 12056-2⁽²⁷⁾ recommends that discharge stacks be vented direct to atmosphere as this limits the effect of both positive and negative pressures on the system for the majority of low-rise developments. However, high-rise developments will benefit from a secondary vent as the entrained air will meet a greater

resistance between the vent terminal and its destination, whereas a secondary vent will allow the air to circulate between the two pipes with minimal resistance to airflow. If the addition of a secondary vent is not viable, the designer will need to increase the discharge stack diameter to reduce the resistance, velocity and pressures created within the discharge stack, to maintain the connected trap seals.

BS EN 12056-2⁽²⁷⁾ provides some examples of the different types and layouts of system venting for both primary and secondary ventilated systems.

3.4.6.3 Vent pipe sizing

Primary ventilated systems

The ventilating pipe of a primary ventilated system should be of a diameter no less than the wet portion of the stack. Where a ventilating pipe is to be routed a long distance to vent to atmosphere, or has a number of offsets within its length, the designer should consider increasing the size by one diameter to offset the pressure losses.

Secondary ventilated systems

Table 12 of British Standard BS EN 12056-2⁽²⁷⁾ gives some guidance on the minimum secondary vent sizes required and the associated flow rates that could be achieved. However, it should be noted that from testing carried out at Heriot Watt University, the air-to-water ratio within the stack lies between 8:1 and 15:1, suggesting that the ventilating pipe could be an equal diameter to that of the discharge stack.

Anti-siphon/branch ventilating pipes

Anti-siphon pipes are used to control the pressures generated within the discharge branch pipework to prevent the loss of trap seal. Section ND.3.6 of BS EN 12056-2⁽²⁷⁾ highlights the permissible use of anti-siphon/branch ventilating pipework, giving details of the various configurations and sizes. These can be summarised as follows.

The individual size for each appliance should be a minimum of DN25 unless the installed run will be in excess of 15 m or, have more than five bends in its run, in which case it should be increased to DN30. Pipes from WC branches should be a minimum of DN50 when they are located below the spill level of the WC pan due to the risk of submergence or splashing under normal operation. Where appliances are grouped, a header should be used of a minimum DN30 for wash hand basins and urinals and DN50 for WCs.

These anti-siphon/branch ventilating pipes should then be connected to the secondary vent in an upwards direction at a maximum of 67½°, above the spill-over level of the highest connected appliance with a backfall to drain any internal condensation.

3.4.6.4 Vent terminations to atmosphere

Ventilating stacks should be located in a position, and at a height, that will not be affected by wind or snow and will not allow foul air to re-enter the building through an open window, mechanical services vent or air intake.

Both BS EN 12056-2⁽²⁷⁾ and the Building Regulations Part H^(1,5) set out the rules governing the location of a vent termination. Generally, the termination must be:

- not less than 900 mm vertically above any window or other opening
- not less than 3 metres horizontally from any window or opening
- a minimum of 300 mm vertically from the finished roof level.

All vent pipes should be terminated using a domed wire or plastic cage to prevent the ingress of birds, leaves and other debris, but does not restrict the flow of air. Where it is anticipated that there is or may be a rodent problem, metal pipework should be specified for all vent pipes and vent terminals above roof level.

3.4.6.5 Air admittance valves

An alternative method of ventilating a discharge stack is to provide an air admittance valve (AAV). These devices are in effect a non-return or check valve, which allows air to enter the discharge stack under negative pressure but prevents air from escaping under positive pressure situations. Therefore they should not be used on stacks with offsets or high flow rates.

Air admittance valves should only be used where it is impracticable to provide an open vent⁽²⁷⁾. Where they are used, they must be located in areas where they can be accessed for maintenance, removal and cleaning, as they are liable to malfunction in dust-laden atmospheres.

Air admittance valves should be sized using the formula $8 Q_{\text{tot}}$ for main stacks and Table 10 of BS EN 12056-2, and be compliant with the requirements of BS EN 12056-2 for branch wastes.

3.4.7 Access

Sufficient access should be afforded to all systems to facilitate the removal of blockages and for general maintenance and system testing.

As a general rule, the designer should ensure that access points are provided as follows:

- (a) For single branch pipes additional access fittings should be provided at any changes of direction that cannot be easily rodded by temporarily removing the waste trap.
- (b) For branches serving multiple appliances, an access fitting should be provided at the head of the run, and extended above the spill-over level of the appliance. Additional access fittings should be provided at any changes of direction that cannot be easily rodded from the access at the head of the branch.

- (c) On discharge stacks serving dwelling access intervals should not exceed 3 storey intervals.
- (d) On discharge stacks serving buildings other than dwellings, access should be provided at every floor level.
- (e) On vent stacks forming a secondary ventilated system, access provision should correspond to access locations on the discharge stack, to facilitate phased testing. Sufficient access fittings should also be provided on vent stacks serving as offset relief venting or forming modified systems to enable phased testing, as prescribed within BS EN 12056-2⁽²⁷⁾.

The Construction (Design and Management) Regulations 2007⁽²⁸⁾ (CDM Regulations), require that all access doors and caps should, as far as practicable, be located so as to allow free and unrestricted access to facilitate general periodic maintenance and cleaning of the system without the need for specialist platforms and equipment. Where this cannot be achieved, the designer should make specific reference within the design to alternative provisions for such access.

Access should generally be provided in the vertical plane by means of an access pipe with a bolted, sealed access door located above the flood level of the highest connected appliance to that discharge stack at that level. Where no appliances are connected, an access pipe should be provided at an easily accessible height above finished floor level or surcharge level.

Access to main pipework runs within the horizontal plane is generally achieved by means of push-fit or screw access caps and access junctions or fittings with bolted, sealed access doors.

3.4.8 Traps and fittings

3.4.8.1 Water seal traps

All sanitary appliances, gullies, channels and items of water using equipment are provided with, or have integral waste water traps to prevent the ingress of foul air into the space.

All external traps should be located beneath or adjacent to the appliance allowing sufficient access for maintenance and cleaning and be of a self cleansing design to prevent the build-up of extraneous matter. There should be no more than one trap on the discharge pipework from any appliance.

Trap seals for wastes of DN50 and below should be a minimum of 75 mm in depth unless a flush-grated outlet (such as baths and showers) is used, when a 50 mm deep seal is acceptable. Appliances with outlets in excess of DN50 require a minimum depth of seal of 50 mm.

The National Annex ND of British Standard BS EN 12056-2⁽²⁷⁾ highlights the various permissible trap types and configurations.

3.4.8.2 Anti-vacuum and re-sealing traps

Anti-vacuum and re-sealing traps were specifically designed for use on small diameter unventilated branch discharge pipes to alleviate problems with the loss of trap seal due to self-siphonage. Their use should be restricted to primary ventilated systems on individual appliances as they are not intended as an alternative to an anti-siphon pipe; some types can present problems with noise under normal operation.

3.4.8.3 Self-sealing waste valves or waterless traps

Self-sealing waste valves or waterless traps are intended as an alternative to the water seal trap where the water seal would be compromised by evaporation due to infrequent use, where self-siphonage or induced siphonage might occur, or on appliances with an emergency discharge or condensate waste.

These valves open to allow water to pass from the appliance to the drainage system using the available head of water, once the water has passed the valve then snaps shut preventing the ingress of foul air. They also act as an air admittance valve under negative pressure situations but do not eliminate the need for anti-siphon pipework as they can only be used on certain types of appliances as directed by the manufacturer.

They should not be used on appliances that pass solid or macerated material such as WCs, macerators, slop sinks, plaster sinks, hair dressing salon basins etc.

3.4.9 Acoustic treatment

Under Part E of the Building Regulations^(1,3), the designer must consider the acoustic performance of above-ground soil and waste systems.

The acoustic treatment of a system ranges from materials selection to encasement in an acoustic material or an architectural duct. At the planning stage, the designer should consult the acoustics consultant and architect to establish the design parameters and noise levels to be achieved, and to agree on the measures that will be required to meet these parameters.

In all cases, with respect to acoustic treatment there are a number of factors that need to be considered at the design stage. These include:

- location
- intended use of the space
- occupancy
- construction
- waste water flow rate
- system layout.

The location, intended use and occupancy of the space are all relevant to acoustic treatment. If the space is to be used as a car park, then the acoustic treatment is likely to be limited to materials selection. However, if the space is a domestic or hotel bedroom, more effective treatment, such

as an acoustic wrap or an architectural duct, will be required.

The building construction also has a bearing on the measures required. For example, steel framed buildings transmit sound far more easily than a concrete framed buildings. The designer therefore needs to specify pipework supports with acoustic inserts and sleeves to alleviate structure-borne sound.

Waste water flow within pipes generates noise through impact or turbulence as the laminar flow is disrupted. This may be reduced by careful selection of the pipe material and jointing method. For example, a pipe with a rough inner face and displaced or open joints will induce turbulent flow thereby generating more noise than if pipework with a smooth inner face and closed joints had been specified.

Every junction, offset or bend, regardless of flow rate, will generate noise. The designer should therefore take care to avoid such fittings within spaces where noise is not acceptable. Where they cannot be avoided due to site constraints, the designer should, in conjunction with the acoustics consultant, specify a robust method of treatment for each fitting to eliminate both the airborne and structure-borne noise.

To meet the requirements of the Building Regulations⁽¹⁾ most manufacturers offer acoustic support systems and, in some cases, 'acoustic' pipework systems using high density and mineral-reinforced materials. It should be noted, however, that even these systems will sometimes require some form of acoustic treatment in 'quiet' spaces.

3.4.10 Cross-flow, combined branches and waste manifolds

When detailing the various connections to discharge stacks, care should be taken to avoid cross-flow between opposing branches.

Cross-flow occurs when opposing branches are aligned in a manner that allows waste water under gravity from one branch to flow across the bore of the discharge stack or branch waste to enter the opposing branch and possibly back-flow into another appliance.

To overcome this problem the first, and easiest (space permitting) solution is to stagger the connections using swept junctions in the direction of flow in the horizontal plane, or by offsetting the connections by 200 mm in the vertical. BS EN 12056-2⁽²⁷⁾ provides typical details highlighting the various configurations that can be utilised along with diagrams detailing the zones where connections should not be made.

A second option is to provide a waste manifold connecting all the appliances to a single horizontal waste header, taking care not to mix large and small bore outlets on the same header. For a waste manifold to work effectively it is advisable to include an anti-siphon or ventilating pipe to prevent any traps being siphoned. BS EN 12056-2 again provides a series of typical details showing the varying configurations incorporating the anti-siphon or ventilating pipe connection and the maximum and

minimum distances between the appliance and the manifold or other connected fittings.

Finally, the designer may wish to consider the use of a 'waste manifold' or 'collar boss' fitting. This generally consists of a short section of pipe with an annular chamber, sloped in the direction of flow, with a series of two to four boss connections on the top to allow the installation of small bore waste pipes up to 50 mm in diameter. This fitting alleviates any problems with cross-flow by separating the in-flow from the connected branches and directing them at 90° from their incoming angle. It can also remove the need for a manifold as all the small bore wastes can be connected separately.

3.4.11 Condensate waste

With the increasing provision of air conditioning and comfort cooling, the public health designer is required to play a greater role in the design and specification of condensate waste systems. However, at present there is little guidance and no British Standards relating to the design of condensate waste drainage for air conditioning systems.

Traditionally, condensate waste drainage systems have been an afterthought and designed on-site towards the end of a project, leading to problems of co-ordination with other piped services. For this reason, in the early stages of any project the public health designer should, through liaison with the mechanical services engineer, establish whether or not a condensate waste system will be required.

Without knowledge of the amount of condensate likely to be produced, there is no quick method for condensate waste pipe sizing. However, various rules of thumb are given in the US International and Uniform Plumbing Codes^(29,30) (IPC and UPC) and the Uniform Mechanical Code (UMC)⁽³¹⁾.

These are generally based on the amount of cooling required, expressed either in kilowatts or tons of refrigeration. However, if using these methods, the designer must bear in mind the differences in climatic conditions between the US and Europe with particular regard to temperature and relative humidity.

When routing condensate pipes, a fall of not less than 10 mm/m (i.e. 1:100) with a filling degree of 70% should be maintained. When terminating the condensate waste pipe direct to drain or connecting direct to a discharge stack, a suitably sized tundish and trap must be provided, together with a 50 mm air gap to prevent foul gasses entering the space. Alternatively, waterless traps may be used to achieve this.

Where condensate traps are to be located in heated spaces or areas where the trap could run dry, a borosilicate glass trap and access for manual or automatic topping-up should be provided. Both methods, together with the recommended frequencies for topping-up, should be clearly identified within the operation and maintenance manual.

3.4.12 Pressure and performance testing

The various methods of pressure and performance testing of foul and surface water drainage systems are detailed within the respective parts of BS EN 12056-2⁽²⁷⁾.

Pressure testing can be achieved by using one or more or, a combination of, the following four methods:

- *Air testing*: this is by far the most common method used where an air pressure of not less than 38 mm water gauge is to be maintained for a minimum of 2 minutes; however, this will not identify the source of any leaks.
- *Smoke testing*: smoke generated by a pellet or machine is introduced under pressure to the system to give a visual indication of any leaks.
- *Soap solution*: generally used in conjunction with an air or smoke test, a soap and water solution is applied to each joint. Indication of any leaks is given when bubbles are formed on the outer surface of the joint.
- *Water testing*: generally only used on small sections of a system, the section of pipe, usually the lowest point of the system, is filled with water up to the flood level of the lowest connected appliance. The test however, is not suitable for pressures in excess of 6 metres water gauge.

Performance testing is a necessary undertaking for all systems to ensure that the trap seals are maintained to a level of no less than 25 mm, when subjected to the effects of self- and induced siphonage and back pressures under peak operating conditions.

Connected appliances should be tested individually and as a group as detailed within the schedules that can be found within BS EN 12056-2⁽²⁷⁾.

3.4.13 Maintenance

All drainage pipework systems should be kept in a clean and sound condition to maintain their integrity and operating efficiency. To this end, as detailed in section 3.4.7, adequate access should be provided to facilitate the maintenance procedures with particular respect to the removal of blockages, scaling and mechanical or chemical cleaning.

There are a number of ways in which a discharge stack or branch waste can become blocked, the most common of which is misuse whereby large masses of compacted material (e.g. toilet paper, disposable nappies, paper or sanitary towels) become snagged or are left behind as the liquid element in the waste flows away. There is little the designer can do to alleviate this potential problem other than to make adequate provision for access and ensure that the fittings specified promote laminar flow at a fall that gives a good depth of waste water within the pipe to carry the solid matter away.

The designer should make the client aware of the problems that can be caused by misuse and advise that measures be put in place in the first instance, such as

waste paper and sanitary disposal bins, to prevent larger items entering the system.

BS EN 12056-2⁽²⁷⁾ sets out a number of methods for cleaning and de-scaling the internal bore of the pipework.

3.4.14 Materials

The designer should ensure that the materials specified for use within the system are suitable for the purpose for which they are intended and that they comply with current standards.

There are a number of materials and systems available, ranging from traditional cast iron to modern thermoplastics, all of which have their place. The most common materials in use are:

- *metals*: stainless steel, cast iron, copper, hot dipped galvanised steel
- *thermoplastics*: unplasticized polyvinyl chloride (PVC-u), modified unplasticized polyvinyl chloride (MuPVC), high density polyethylene (HDPE), polypropylene (PP), homopolymer polypropylene (PP-H) and acrylonitrile butadiene styrene (ABS).

When selecting pipework materials, the designer should consider the following questions:

- *Function of the pipe*: is the waste from domestic, trade, chemical, radioactive sources?
- *Location*: is the pipe internal, external, exposed, liable to mechanical damage or vandalism?
- *Operating pressure*: Are the internal pressures generated likely to be excessive? Will surcharging be a problem? How tall is the building?
- *Temperature*: Is the waste water discharge likely to be in excess of 40 °C?
- *Noise*: Is a high level of acoustic performance required?
- *Fire protection*: Is the pipe to be located within an area where fire protection is a requirement?
- *Airborne contaminants*: Will the pipework be located in an area where airborne contaminants will corrode or damage the outer surface of the pipe or seals leading to failure?

Whichever material is finally selected, the designer must ensure that, regardless of commercial pressures, the suitability of the pipe material for the application is maintained.

3.4.15 Fire protection

When routing pipework through any building, consideration must be given to the need for fire protection and containment, as plastic pipework in excess of 40 mm in diameter needs to be provided with a means of retarding the spread of flame between fire compartments⁽³²⁾.

Varying methods and systems are available depending upon the pipework material and the duration of protection that is required by the Fire Officer.

Thermoplastic piping systems generally rely on an intumescent material contained within a metallic outer casing, which expands and crushes the pipe to form a barrier. However, some plastics do not support the spread of flame, therefore the activation of the intumescent collar is wholly dependant upon the temperature of the smoke layer or the flame coming into contact with the unit. If in any doubt, the manufacturer should be consulted.

Metallic systems under normal fire conditions do not support the spread of flame. However, they can allow heat to travel between fire compartments by conduction should the surface temperature of the pipe be sufficiently high to allow combustible materials in contact with the pipe to burst into flame. This can be prevented by cladding the pipe in a non-combustible material such as mineral wool insulation up to a minimum of 1 metre either side of the compartment wall or floor.

3.4.16 Kitchen drainage

Commercial kitchens are designed for a smooth flow in food preparation and as such, do not lend themselves to an ideal layout for waste water disposal with little or no provision for ventilating pipework. The designer should at an early stage, liaise with the chosen specialist kitchen designer/installer to establish the requirements for any drainage points needed and ensure sufficient provision is made for the routing of ventilating pipework.

Generally, commercial kitchens consist of five main areas, each presenting different challenges to the designer they are:

- goods intake and storage
- preparation
- cooking
- wash-up
- servery.

The goods intake and storage area requires very little in the way of waste water drainage as it is generally classed as a dry area. However, larger installations may require the provision of floor drainage and a cleaners sink to cater for any spillages and washing down.

The preparation area is generally one of the most highly serviced areas containing a large number of preparation sinks, peelers and waste disposal units, most of which will operate simultaneously. Therefore, the designer should consider the use of a high frequency factor (*K*).

The main cooking area requires considerable thought when selecting pipework materials and fittings as it contains the majority of the specialist equipment. Most of this equipment, such as combi-ovens, bains-marie and bratt pans, have high temperature, high flow discharges that cannot be connect direct to drain. Therefore, at an early stage in the project, the designer needs to establish the requirements for draining these items of equipment in consultation with the specialist kitchen designer/installer.

The wash-up and pot wash areas need to be treated in much the same manner as the preparation area, as they also contain a large number of sinks, waste disposal units,

scrapping, sterilising and pot soak sinks with a high usage factor together with the main dishwashing machines, all of which can have a high waste water discharge temperature. Some larger commercial kitchens have a requirement for a wash-down hose for floor cleaning, therefore a floor drain will be required.

The servery, like the goods intake area, requires very little in the way of drainage other than provision for condensate wastes for the various chilled cabinets and drains for the drinks dispensers and coffee machines.

For further information on services for commercial kitchens, see CIBSE TM50: *Energy efficiency in commercial kitchens*.

3.4.17 Grease treatment and removal

Wherever a hot food outlet or commercial kitchen is to be provided, the designer must consider means of grease separation and/or removal, or treatment of the waste water prior to discharge to the public sewer. There are a number of methods by which this can be achieved depending on the numbers of meals ('covers') to be served, the main methods being:

- *Dosing*: this involves an enzyme and/or bacterial agent being injected into the head of the drainage system (or into any stack or branch waste to which a pot wash or preparation sink is to be connected), where it coats the internal surface of the pipe. The enzymes attack and break-down the grease film by inhibiting its cohesive qualities allowing it to form a suspension. This system requires little maintenance other than re-filling the dosing pot and is generally suitable for kitchens and food outlets with up to 1000 covers. For outlets with a greater number of covers the designer should consult the manufacturer.
- *Settlement*: the waste water is collected in a chamber, local to the source, sized in accordance with BS EN 1825-2⁽³³⁾. The waste water then cools causing the grease, fats and oils to float to the surface and food waste to settle to the bottom. The waste water, free of grease and food waste, then exits the chamber via a dip pipe or baffle plate. This system requires regular maintenance and therefore must be accessible at all times. Waste disposal units and peeling machines should not be connected to this type of system.
- *Separation*: the waste water is again collected within a chamber local to the source where it is kept at a temperature that allows the grease, fats and oils to rise to the surface in their liquid form and food waste to be either filtered out or allowed to settle. A motorised paddle then periodically skims the surface collecting the liquid grease, fats and oils and pushing them into a trough from which they flow into a collecting pot or container for safe disposal. Again waste disposal units and peeling machines should not be connected to this type of system.

There is a wide range of systems and equipment utilising one or more of the above methods, see chapter 4 section 4.3.9 for further details. The manufacturers of these

systems offer specialist design and installation services, the use of which is recommended to establish the most suitable system for the application.

3.4.18 Laboratory drainage

When considering waste water drainage from a laboratory, and in the absence of any design standards, the designer must take into account a number of factors that will ultimately affect the layout and materials to be utilised. These include the following:

- *Laboratory use*: will the laboratory be used for commercial, educational, healthcare or research purposes? Each of these applications will have different requirements with respect to the layout of the pipework as commercial and research laboratories need to be flexible in their layout whereas educational and healthcare laboratories tend to be more static.
- *Type of chemicals likely to be used*: it is imperative that the designer seeks confirmation from the client/end user regarding the chemicals likely to be discharged to drain as this will determine the pipework materials and the need for any additional effluent collection and treatment prior to disposal of toxic or harmful chemicals or materials.
- *Dilution/storage*: is dilution and/or storage of the waste water required? This may need to be achieved above ground and local to the laboratory. Therefore tank size and space provision will need to be established.
- *Laboratory location*: the location of the laboratory in relation to the adjacent spaces will need to be established to ascertain whether special protection of the pipework will be required.
- *Temperature of chemical discharge*: the temperatures of any chemical discharges need to be considered.

When selecting the materials, the designer must compare the chemicals indicated by the client with the chemical resistance charts provided by the pipework manufacturer. In the majority of instances a heavy duty polyethylene or polypropylene will generally be suitable.

With respect to the design, discharge flow rates are not generally available within BS EN 1825-2⁽³³⁾ or BS EN 12056-2⁽²⁷⁾, therefore the designer must contact the laboratory equipment provider to ascertain the likely discharge flow rates and outlet sizes prior to commencing the design.

3.4.19 Vacuum foul water drainage systems

3.4.19.1 General

Vacuum drainage systems are used for the transportation of waste water where a gravity system cannot be accommodated. There are two separate categories: inside and outside the building envelope. Inside the building envelope is covered below; for systems outside the building refer to chapter 4.

BS EN 12109: *Vacuum drainage systems inside buildings*⁽³⁴⁾ was introduced in the UK in 1999 and covers all aspects of the design and installation of a vacuum drainage system.

The basic principal of operation relies upon the utilisation of atmospheric pressure, acting against a vacuum, to move wastewater through a pipework system to a central collection point.

Vacuum drainage systems have a number of advantages over traditional gravity systems namely:

- reduced pipe sizes
- no vertical discharge stacks
- more flexible routing of the system pipework as no falls are required
- generally no leakage as the system is under a constant negative pressure
- reduced access points.

There are, however, an equal number of disadvantages:

- the collection/receiver station requires a dedicated plant room
- higher capital cost
- higher running costs
- regular maintenance is required
- the discharge flow rate needs to be considered against the allowable discharge rate imposed by the Statutory Undertaker.

3.4.19.2 Applications

Consideration should be given to the use of vacuum drainage systems in the following circumstances:

- shortage of water or where there are other reasons for reducing water consumption
- where there is limited sewerage capacity
- where separation of black and grey water is desired (e.g. where grey water is to be reused)
- where separation of wastewaters is desired (e.g. where different water treatments are required)
- where congestage usage occurs (e.g. hospitals, hotels, offices etc.)
- where flexibility of pipe routing is required to drain appliances or where frequent changes to pipe layout are expected
- in penal establishments where isolation and control of the appliances is necessary to prevent concealment of weapons or drugs
- where drainage by gravity is impracticable
- in complex building structures
- building refurbishment.

3.4.19.3 System descriptions

A complete set of definitions is given in BS EN 12109⁽³⁴⁾. Some fundamental descriptions required to understand

the terminology used in vacuum drainage systems are given below:

- *Buffer volume*: the storage volume of the interface unit that balances the incoming flow of wastewater to the output capacity of the discharge valve.
- *Controller*: the device that, when activated by its level sensor, opens the interface valve and, after the passage of wastewater and (normally) air, closes the valve.
- *Interface valve*: a valve that admits the flow of wastewater only, or wastewater and air, into the vacuum drainage system pipeline.
- *Lift*: a section of vacuum pipeline with an increase in invert level in the direction of flow.
- *Reforming pocket*: a low point in the piping profile installed intentionally to produce a controlled slug flow.
- *Service connection*: the section of vacuum pipeline connecting an individual interface to the vacuum main.
- *Slug*: an isolated quantity of wastewater flowing full bore through the vacuum pipeline.
- *Vacuum*: any pressure below atmospheric.
- *Vacuum station*: an installation comprising vacuum generator(s), a means of discharge, and control equipment and that may also incorporate vacuum vessel/holding tank(s).

3.4.19.4 Design

As with a gravity drainage system, a vacuum drainage system should be designed to accept discharges from all connected appliances together with any likely discharges from appliances that are known to be connected at a later date for example, tenants fit-out works.

The basic information required to design a vacuum drainage system can be summarised as follows:

- type of building and number of occupants
- locations of all appliances and frequency of use
- wastewater flow volumes and temperatures likely to be experienced
- air flow rates and minimum vacuum levels for operation for the various connected appliances (from manufacturers' data)
- required air to water ratios and permissible leakage factors
- system layout and pipework material.

From this information the designer can then ascertain the overall pressure drops between the appliance and vacuum station, pipe sizes, static losses, pump and receiver tank capacity.

Generally, due to the infrequency of their use in the UK, the design and installation of vacuum drainage systems are carried out by specialist companies with the required experience and skills, therefore advice should be sought prior to the commencement of any design.

Where wastewater temperatures in excess of 70 °C are anticipated, the designer should take into consideration the likelihood of 'boiling' due to the reduction in pressure (below atmospheric) required for the system to operate. The designer must then adjust the pipework and vessel sizes to accommodate the increase in volume.

3.4.19.5 Pipework configuration and valving

The pipework system selected should be capable of withstanding the temperatures, negative pressures and velocities generated under normal operation without deformation or loss of cross-sectional area and be suitable for use with the effluent composition anticipated. Bends should be long radius or at a minimum of 45° to prevent blockage and reduce friction losses. Junctions should be swept in the direction of flow ideally at 45° to 67½°, again to reduce frictional losses and maintain a smooth flow pattern. Reducers should be concentric and joints are to be smooth and protrusion free. The use of square junctions, elbows and eccentric reducers should be avoided.

Pipework should be configured so as to present a virtually flat profile without backfall to a dedicated vertical stack (gradients of 0.2–0.5% to the stack are permissible). The vertical stack is then utilised to accept all the various horizontal branches to then connect to the receiver and/or buffer vessel.

The designer should also consider the routing of the pipework taking into account avoiding any noise-sensitive areas. Although, generally, in noise terms a vacuum system is no louder than a gravity system, due to the differing sound produced under normal operation, it can be more noticeable to the occupants.

A check valve is installed in each vacuum pump suction line to maintain the vacuum in the system. Check valves are also fitted on the discharge from a vacuum discharge pump and are often fitted on the service connection from an appliance.

Isolation valves are fitted to all forwarding and vacuum pumps to allow their removal without disrupting the system. Also, they are fitted in strategic locations to enable sections of a system to be isolated for service. Isolation valves should be suitable for vacuum use and may be of the eccentric plug type or resilient face gate type, and have a clean opening of not less than the nominal diameter of the pipe. Both check and isolation valves must be capable of withstanding 0.8 bar gauge vacuum, when open, and a differential pressure of 0.8 bar, after closed on a functioning system.

3.4.19.6 Maintenance

The following considerations are the minimum that should be addressed as part of system design:

- fault finding procedures
- access to all interface units, isolation valves, cleaning eyes, check valves and other items that need inspection or service
- procedures for removal of interface units and their temporary effect on system performance, if any

- maintenance schedules for interface units in relation to cycle frequency and endurance
- estimated repair or replacement times for interface units
- maintenance schedule for vacuum station equipment
- procedures for removal or repair of vacuum station equipment and their temporary effects on system performance, if any
- estimated repair or replacement times for vacuum station equipment
- precaution routines if system performance is temporarily lost or reduced
- training of maintenance personnel
- recommended stocking of spare parts
- estimated cost of maintenance per year.

3.5 Rainwater drainage

This section deals with the conveyance of water that affects a building or its surroundings as a result of rainfall. The terminology adopted is such that rainwater is taken to mean water that is routed from the building roof via downpipes to connect to the below-ground system. Surface water, taken to mean water that is routed from ground-level surfaces within the environs of a building, is referred to throughout this section. However, for guidance on the design of downstream pipework into which both surface water and rainwater may flow, the reader is referred to chapter 4: *Underground drainage and treatment of waste water*.

The following text addresses key design considerations for rainwater systems, and includes guidance on the determination of rainfall intensity and run-off figures. System types discussed include gravity-flow and siphonic.

The terminology, design procedures and equations presented herein have been intentionally mapped to content within BS 12056-3: 2000⁽³⁵⁾ for gravity-fed systems and BS 8490: 2007⁽³⁶⁾ for siphonic systems, in order to allow the reader to cross-reference to these standards as appropriate.

3.5.1 Rainwater drainage: general information

For all rainwater systems:

- All pipework and other component parts of the rainwater drainage system should conform to appropriate standards and should be installed in accordance with manufacturers' recommendations.
- Any limitation on the discharge into the public or private sewage system to be used should be established, and due regard taken of this during the design process. This is particularly important in the case of siphonic rainwater system design where the difference between the return periods selected for the above- and below-ground networks can mean that the frequency with which a sewer may

- surcharge is likely to increase the probability of the siphon break becoming submerged; an event that can result in serious system failure.
- Due regard should always be given to the layout and levels of, and positions of entries to, any existing drainage system and sewers.
 - In all cases where the design of the building or the system changes, the hydraulic capacity of the rainwater provision must be checked.

Furthermore:

- All system components should be adequately fixed and supported, and should always allow access for maintenance and inspection.
- All pipework, fittings and fixings must accommodate any anticipated movement due to, for example, temperature differences, vibration or loads developed during either testing or operation.
- The proper use of materials and the avoidance of any corrosion must be ensured.
- All materials and system components must be able to withstand the maximum hydraulic pressure anticipated should a blockage occur at the lowest point in the system.
- For all pipework and other component parts of the system, the risk of blockage should always be addressed. This is particularly true when small bore pipes are selected; for gravity systems this typically corresponds to pipes less than 63 mm nominal diameter.
- No pipework used for gravity-fed systems should reduce in diameter in the direction of flow.
- Where there is the possibility of condensation occurring, pipework should be insulated.
- Where freezing may occur, consideration should be given to the use of trace heating.
- Inspection and cleaning should be undertaken regularly, the frequency of which will depend on local conditions.

3.5.2 Rainfall intensity and run-off

Before commencing the design of rainwater systems, it is first necessary to establish the design run-off rate from the roof surface under consideration. This involves two stages:

- (1) determination of the design rate of rainfall (including, where applicable, appropriate risk or safety factors)
- (2) determination of the resultant design run-off rate (based on roof dimensions and configuration).

3.5.2.1 Design rate of rainfall

The UK source of statistical rainfall is available in BS EN 12056-3⁽³⁵⁾. The procedure used to determine the design rate of rainfall (*r*) is outlined below:

- *Step 1:* identify or confirm the location of the building.

Table 3.3 Guidance on return period specification (adapted from Annex NB of BS EN 12956-3⁽³⁵⁾)

Category	Application	Return period, RP (years)
1	Applies to eaves gutters and flat roofs	Minimum, 1 year
2	Applies to valley and parapet gutters, and should be considered for laid-to-falls flat roofs, or eaves gutters that are encased in cladding	Life span of building* × 1.5
3	Applies when the level of protection required is greater than that of category 2 (e.g. hospitals, computer server rooms)	Life span of building* × 4.5
4	Applies where the highest possible security is required (normally only used for vital infrastructure)	Maximum probable rainfall data should be used

* The lifespan should be agreed with the client, but in all cases including for speculative buildings, it should not be less than 25 years

- *Step 2:* determine the return period (RP) (years).
Occasionally, this will be pre-defined but, in most cases, the designer will be required to identify an appropriate return period. Table 3.3, adapted from BS EN 12056-3, offers guidance on this determination based on system application and risk.
- *Step 3:* assess the duration of a storm event (*D*) (minutes).
A two-minute ‘peak intensity’ event within a storm of longer duration is the norm used when referencing statistical data in the determination of rainfall (*r*).
- *Step 4:* determine the rainfall intensity (*r*).
BS EN 12056-3 provides statistical rainfall intensity data based on return periods of 1, 5, 50 and 500 years, and also includes data for maximum probable rainfall. These data all refer to a two-minute event (within a storm of longer duration), and are presented for the UK using contour diagrams where, for locations that lie between contours, intensity figures are arrived at through interpolation.

It can be seen that, from steps 1 to 3 above, the location, return period and storm duration can be derived. For a storm duration of two minutes, the contour diagrams presented in BS EN 12056-3 can be used. Where the return period does not match directly to any of the maps presented, the contour diagram corresponding to the closest increase in return period should be selected. For example, for a return period of 30 years, the ‘50-year’ RP map should be used.

BS EN 12056-3 also presents a methodology that allows the determination of rainfall intensity for any storm event of duration up to 10 minutes set against any return period. This process is particularly useful when the storm duration deviates from the two minute norm. This methodology is summarised in Table 3.4 below.

It is worth noting that, regardless of the source of statistical information used to determine the design rainfall rate (*r*), the process must ensure that due

Table 3.4 2minM5 rainfall depth multipliers for varying storm durations up to 10 minutes (adapted from BS EN 12056-3⁽³⁵⁾)

Storm duration, D_s (mins)	Fraction of 2minM5 depth	Amended depth (i.e. D_{minM5})
1	0.58	1minM5 = $0.58 \times 2minM5$ depth
2	1.00	2minM5 = $1.00 \times 2minM5$ depth
3	1.33	3minM5 = $1.33 \times 2minM5$ depth
4	1.62	4minM5 = $1.62 \times 2minM5$ depth
5	1.86	5minM5 = $1.86 \times 2minM5$ depth
6	2.07	6minM5 = $2.07 \times 2minM5$ depth
7	2.30	7minM5 = $2.30 \times 2minM5$ depth
8	2.47	8minM5 = $2.47 \times 2minM5$ depth
9	2.60	9minM5 = $2.60 \times 2minM5$ depth
10	2.74	10minM5 = $2.74 \times 2minM5$ depth

cognisance is taken of the nature of the building and its intended use. A determination of the degree of risk is therefore inherent within the process and the designer should make every effort to make informed decisions. This process should be shared, where necessary, with the client so that they too may take due consideration of the risk assessment and need for mitigation. The architect is also a key stakeholder in ensuring that any assumptions, with regard to overspill points, threshold levels and waterproof upstands have been correctly interpreted.

Absence of applicable statistical data (projects outside the UK only)

When statistical rainfall data are not available, it becomes necessary to select an appropriate minimum intensity figure that is based on knowledge of the climate for the location and that takes into account relevant regulations and practice⁽³⁵⁾. This process also requires the application of a risk factor (as a multiplier) that takes into account the relative vulnerability of a building depending upon the gutter type used and the degree of protection required. These rainfall and risk figures are presented in BS EN 12056-3⁽³⁵⁾, and together yield a value for intensity (r).

High rainfall intensity

It should be noted that for higher rainfall intensity (quantified in Ciphcr *Plumbing Engineering Services Design Guide*⁽³⁷⁾ as above 225 mm/h), provision for additional protection should be made. In some cases, it may be uneconomical to address this point by increasing the size of the rainwater goods; instead a combination of overflows and positive drainage may provide a better solution.

3.5.2.2 Run-off

Steady-state run-off from a roof surface, where no special circumstances apply (i.e. where the roof surface is impermeable and where it is not intended that ponding should occur), is fundamentally based upon the determination of rainfall intensity outlined in section 3.5.2.1 and upon the area contributing to the run-off, where:

$$Q = r A C$$

(3.3)

where Q is the run-off rate (litres/s), r is the rainfall intensity (litre·s⁻¹·m⁻²), A is the effective roof area (m²) and C is the run-off coefficient (may be assumed to be unity unless relevant regulations and practice dictate otherwise).

For a flat roof, the effective area (A) is represented by the plan area of the contributing surface. To this should be added any area that conveys run-off via the flat roof.

For pitched roofs with eaves or parapet gutters, the effective area is taken as greater than the plan area to allow for wind-driven rain, assumed to act at an angle of 26° to the vertical, and effective area calculations must therefore be adjusted accordingly. For valley gutters, one side is likely to be sheltered and an effective area need only be calculated based on the difference in ridge height.

Where applicable, run-off from any vertical surfaces subject to wind-driven rain should also be included, where 50% of the area of any wall (up to a maximum of 10 m in height) should be added to the effective area. For very tall buildings, rainfall is often naturally dispersed by wind and there is therefore no need for the installation of a designed system.

The effective area calculated should account for all surfaces draining onto a flat roof or into the gutter or outlet that the designer is considering. The potential for overspill from adjacent roofs, or properties, should also be assessed and, where necessary, included. It is worth noting that each catchment area should be designed on its worst case, and hence the total flow from a building may be less than the sum of that from all individual roof areas.

Green roofs and inverted roofs will have a slower run-off rate than that for hard surfaces, hence providing an additional factor of safety to the design, but BS EN 12056-3: 2000⁽³⁵⁾ does not make allowance for this. However, making any allowance may be problematic for siphonic drainage, and so the use of siphonic drainage with green or inverted roofs must be considered very carefully. A single siphonic system must never drain a green roof and a hard roof together.

3.5.2.3 Snowfall

There is normally no need to incorporate additional allowance in system design for run-off from snowmelt, although it should be noted that, if appropriate, the need for snowmakers at roof level should be assessed.

3.5.3 Gravity rainwater systems

Gravity rainwater systems are used to remove water from roof surfaces and normally discharge to a soakaway, infiltration strip or underground pipework. Their performance is characterised by free discharge conditions at the gutter outlets and downpipe connections, and near atmospheric pressure in the downpipe.

3.5.3.1 Gutters

Gutters come in a variety of shapes and sizes and are generally classified as either half-round, rectangular, or trapezoidal. Although eaves gutters may adopt any shape classification, these are typically half-round or square/rec-

tangular, described as being 'nominal half-round', 'true half round', 'semi-elliptical' ('deepflow'), 'rectilinear' ('square-ish'), or 'OG' (ornamental gutter, having a flat back edge and decorative front edge). Valley and parapet gutters often tend to be square, rectangular or trapezoidal.

Prefabricated gutters may be installed level, but gutters constructed from roofing materials should incorporate adequate gradients in accordance with industry standards. Where a gutter is taken to be 'nominally level', it should exhibit a gradient of between 1 mm and 3 mm per metre, and should allow appropriate directionality of flow to outlets. However, in many industrial applications this may not be achievable.

Gutters may also be classified as either hydraulically 'short' or 'long', where the threshold defining the difference between the two is taken to be 50 times the design water depth. Where gutters are considered to be 'long', then frictional effects must be taken into account.

Gutters should always be adequately fixed and supported and should always allow access for maintenance. In addition, every effort should be made to ensure that all roof run-off is intercepted by the gutter. A key part of this includes ensuring that backfalls and other causes of ponding are avoided wherever possible.

The main characteristic of the gutter is its hydraulic capacity. Although the design procedure outlined in section 3.5.3.4 deals separately with eaves and with parapet and valley gutters, part of the overall aim, in each case, is to ensure that the hydraulic capacity of the gutter comfortably exceeds the anticipated run-off and that the outlet provides unrestricted discharge.

The following text within this section allows for a calculation of gutter capacity, thereby facilitating a comparison between this and the roof run-off.

The design capacity, Q_d , of a 'short', nominally-level gutter is assumed to be 0.9 times the nominal capacity, Q_n , thus introducing a factor of safety:

$$Q_d = 0.9 \times Q_n \quad (3.4)$$

The nominal capacity of a gutter may be determined either by testing (typically undertaken by the manufacturer as part of the component specification where this has been undertaken in compliance with recognised conditions), or it may be determined as a function of the cross-sectional area of the gutter as defined by the spillover level.

For half-round (or similarly shaped) eaves gutters:

$$Q_n = 2.78 \times 10^{-5} \times A_e^{1.25} \quad (3.5)$$

and for rectangular, trapezoidal or similarly-shaped eaves gutters:

$$Q_n = 3.48 \times 10^{-5} \times A_e^{1.25} \times F_d \times F_s \quad (3.6)$$

and for rectangular, trapezoidal or similarly-shaped valley or parapet gutters:

$$Q_n = 3.89 \times 10^{-5} \times A_w^{1.25} \times F_d \times F_s \quad (3.7)$$

where Q_n is the nominal gutter capacity ($\text{litre} \cdot \text{s}^{-1}$), A_e is the gutter cross sectional area below spillover level (mm^2), A_w is the gutter cross sectional area below the freeboard (mm^2), F_d is the depth factor, defined by rainwater dimensions within the gutter (see BS EN 12056-3⁽³⁵⁾ for values) and F_s is the shape factor, defined by gutter dimensions (see BS EN 12056-3 for values).

When designing hydraulically 'long' gutters that are nominally level or that slope towards an outlet, the design capacity for a short gutter (Q_d) must be multiplied by a reduction factor, F_l , values of which are tabulated in BS 12056-3. Similarly, a multiplier of 0.85 should be applied to Q_d should the gutter exhibit one or more angles of greater than 10° .

The designer should endeavour to ensure that any obstructions in valley and parapet gutters are avoided. Where this is not possible, an area of two times the obstruction should be subtracted from the cross sectional area of the gutter (A_w)⁽³⁵⁾.

An alternative source of information for gutter sizing is offered by the CIPHE's *Plumbing Engineering Services Design Guide*⁽³⁷⁾. Once the roof run-off has been established and the number of outlets selected, nomograms (reproduced in Appendix 3.A1), may be used to determine gutter size. This procedure involves calculating the flow in the section of gutter to be sized (recognising divergence of flow to different outlets), subsequent to which the estimated breadth of the gutter, B_g , should be used as a starting point for use of the appropriate nomogram. Mapping gutter breadth to gutter flow, Q , allows a determination of both depth, y_u (mm), and critical depth, y_c (mm). A further mapping to the length of the gutter, L_g , a known parameter, then allows a determination of y_{uf} , the upstream gutter depth to which the freeboard should be added. Nomograms are available for rectangular and trapezoidal-shaped gutters (the latter with 1:1, 1:1.5 and 1:2 side slopes).

Additionally, a minimum freeboard must be maintained at the upstream end of valley and parapet gutters. BS EN 12056-3⁽³⁵⁾ notes required dimensions as shown in Table 3.5.

For steeply sloping gutters where supercritical flow conditions are likely to occur (nominally 2° and above), BS EN 12056-3: 2000 does not provide an effective tool to evaluate performance. Flow in the gutters should be evaluated using the Manning formula, and effective stilling at outlets based on practical experience or physical testing will be required. Typically this will involve provision of a deep sump, the full width of the gutter, at each outlet, to allow flow to be stilled.

Table 3.5 Minimum freeboard that must be maintained at the upstream end of valley and parapet gutters (reproduced from BS EN 12056-3⁽³⁵⁾ by permission of the British Standards Institution)

Gutter depth including freeboard (mm)	Minimum freeboard (mm)
< 85	25
85 to 250	0.3 × gutter depth inc. freeboard
> 250	75

3.5.3.2 Outlets

Outlets represent a key component in the design of rainwater systems in that they introduce a potential point of flow restriction and therefore must be designed to ensure free-flowing conveyance of rainwater. The hydraulic capacity of any rainwater outlet should ideally be determined using the test procedures outlined in BS EN 12056-3⁽³⁵⁾. Importantly, these note the need for testing of any outlet to be undertaken in conjunction with sufficient length of connected gutter.

Where test data are not available, outlet characteristics may be determined as shown below.

Outlets located in flat-soled gutters

For outlets located in flat-soled gutters, the transition of flow from the gutter via the outlet to the downpipe can normally be described by either weir or orifice flow characteristics. For circular outlets, weir flow will be deemed to apply where the head at the outlet (h mm) is less than or equal to half of the effective diameter (of the outlet), and when the gap between the edge of outlet and the side of the gutter is at least 5% of the diameter of the outlet⁽³⁵⁾. For depths greater than this, orifice flow conditions apply.

For non-circular outlets, the threshold below which weir conditions apply and above which orifice flow conditions apply is defined as:

$$\text{Threshold} = 2 A_o / L_w \quad (3.8)$$

where A_o is the plan area of outlet (mm²) and L_w is the length of the weir (mm).

For circular outlets where weir flow applies, the outlet flow may be calculated from:

$$Q_o = \frac{k_o D h^{1.5}}{7500} \quad (3.9)$$

and for non-circular outlets:

$$Q_o = \frac{k_o L_w h^{1.5}}{24\,000} \quad (3.10)$$

For circular outlets where orifice flow applies, the outlet flow may be calculated from:

$$Q_o = \frac{k_o D^2 h^{0.5}}{15\,000} \quad (3.11)$$

and for non-circular outlets:

$$Q_o = \frac{k_o A_o h^{0.5}}{12\,000} \quad (3.12)$$

where Q_o is the total outlet flow (litre·s⁻¹), k_o is the outlet coefficient (1 for unobstructed outlets, 0.5 where the outlet is fitted with a strainer or grating), D is the effective diameter of outlet (mm) and h is the head at outlet (mm).

It should be noted that for trapezoidal, rectangular or triangular gutters, the design maximum depth should be multiplied by an outlet head factor, F_h , to give the appropriate value for the head at the gutter outlet⁽³⁵⁾.

Outlets located in gutters that are not flat-soled

For outlets located in gutters that are not flat-soled, it is generally accepted that an outlet may be deemed as having sufficient capacity to accept flow from a nominally level gutter if the transition of flow from the gutter is maintained as smooth and if the plan area of the opening in the sole of the gutter is approximately twice that of the smallest downpipe with capacity for the anticipated flow⁽³⁵⁾.

Outlets located in a sump or box receiver

For outlets located in a sump or box receiver, it is necessary, to check that the length of the weir from the gutter to the receiver permits free discharge conditions in the gutter. BS EN 12056-3⁽³⁵⁾ suggests the use of equation 3.13:

$$Q_w = \frac{L_w h^{1.5}}{24\,000} \quad (3.13)$$

where Q_w is the flow of rainwater over the weir (litre/s), L_w is the length of the weir (mm) and h is the head over the weir (mm).

In all cases above, where a strainer is installed at the outlet, it is necessary to adjust the design capacity of the gutter by multiplying Q_l by 0.5. For outlets located in flat-soled gutters, this is implemented by setting the outlet coefficient (k_o) to 0.5 in equations 3.9 to 3.12.

Where angles exist in eaves gutters, outlets should be located near these angles.

3.5.3.3 Downpipes

The capacity of any downpipe is principally determined by the diameter and the degree of filling that is deemed acceptable as indicated in Table 8 of BS EN 12056-3⁽³⁵⁾. The application of the Wyly-Eaton equation allows the capacity, Q , for different pipe characteristics, to be defined as:

$$Q = 2.5 \times 10^{-4} \times k_b^{0.167} \times d_i^{2.667} \times f^{1.667} \quad (3.14)$$

where k_b is the pipe roughness (mm), d_i is the internal diameter of the downpipe (mm) and f is the degree of filling (defined as a function of the total cross sectional area of the downpipe, and normally assumed to be between 0.2 and 0.33).

Offsets in downpipes can sometimes be ignored. However, if greater than 10°, it is worth noting that downpipe capacity should be based upon the worst condition in any part of that pipe. This should take account of any conditions whereby a flat roof outlet may drain via horizontal pipework.

The flow conveyed via any given outlet and downpipe within the rainwater system should not exceed the capacity calculated using equation 3.14.

Downpipes will typically connect to a gully or a drain, although discharge onto other surfaces that are drained is also permissible. It is worth noting that connected drains should be no smaller in diameter than the rainwater pipes they serve, and should be at least 100 mm diameter, except where intentionally designed rooftop attenuation is integrated. Where connected to foul discharge, a trap should be provided between the two systems in order to prevent the inadvertent release of odour. Rainwater can be directed towards a sanitary stack, *only* if permissible, as long as the connection is trapped, the diameter of the stack is at least 100 mm and the rainwater flow is less than 1 litre/s.

3.5.3.4 Design procedure

The design procedure for rainwater systems relies upon a number of sources of information that characterise component hydraulics, the details of which have been outlined in sections 3.5.2 and 3.5.3.1 to 3.5.3.3. Fundamentally, the steps involved require:

- determination of the run-off from the roof surface (this two-part process involves a determination of the design rate of rainfall and the run-off for different gutter sections as defined by the designed 'pathways' of rainwater conveyance)
- calculation of gutter capacity in order to ensure that this exceeds anticipated run-off; if not, then the gutter size and shape and/or downpipe locations must be reassessed
- determination of the downpipe capacity in order to ensure that this is greater than the anticipated flow
- where a sump, receiver or chute is used, confirmation that free discharge conditions exist at the gutter-receiver transition
- confirmation that free discharge conditions exist at the outlet.

Eaves gutters

For eaves gutters, this approach may be presented in terms of the following step-by-step design procedure.

- *Step 1:* determine the design rate of rainfall and roof run-off.

The first stage in the design of any rainwater system involves the determination of the design rate of rainfall, r (litre·s⁻¹·m⁻²), and the resultant run-off from the roof surface, Q (litre·s⁻¹). Guidance on the determination of r and Q is provided in section 3.5.2.

- *Step 2:* assume downpipe location(s) and gutter shapes/sizes.

Before any check on hydraulic capacity can commence, it is necessary to assume the location of each rainwater downpipe. This then facilitates a determination of rainfall run-off from the roof surface into each section of the gutter. Gutter sections should include those between outlets

(where the length is normally taken as half of the section distance) and those between an outlet and a stop-end. At this stage, the gutter shape and size should also be assumed, in order to allow a determination of hydraulic capacity (step 3). Step 2 will be revisited if it is found that there is under-capacity.

- *Step 3:* confirm that the hydraulic capacity of the gutter section exceeds the corresponding anticipated run-off from the roof surface.

Based on the assumption of gutter shape and size (step 2), the design capacity for the gutter (initially assumed to be 'short' and nominally level) is calculated. This includes a determination of nominal capacity (Q_n). Where applicable, the design capacity should then be adjusted to take account of hydraulic length, slope and any angles in the gutter. In addition, the integration of a strainer at the outlet also requires an adjustment to the gutter capacity. The design factors, and guidance on how and when they should be applied, are given in sections 3.5.3.1 and 3.5.3.2. In summary:

$$Q' = Q_1 \times F_1 \times 0.85 \times 0.5 \quad (3.15)$$

where Q' is the adjusted design capacity, Q_1 is the design capacity and F_1 is the reduction factor.

Note: the reduction factor (F_1) (see section 3.5.3.1) is applied when the gutter gradient exceeds 3 mm/m or when the gutter is deemed 'hydraulically long'. The numerical factor 0.85 is applied only when the gutter exhibits one or more angles of greater than 10° and the factor 0.5 is applied only when a strainer is fitted at the outlet.

Once established, it is then crucial that the final calculated hydraulic capacity of the gutter is compared with the corresponding anticipated run-off. If this indicates under-capacity, the gutter size and shape and/or downpipe locations must be reassessed and steps 2 and 3 repeated.

- *Step 4:* confirm that the downpipe capacity exceeds the anticipated flow.

After calculating the anticipated run-off to each outlet, the capacity of the corresponding downpipe should then be established using equation 3.14. This will require an assumption of an acceptable degree of filling (normally taken, in the UK, to be 0.2). At this point, it is worthwhile ensuring that the outlet and downpipe locations assumed in step 2 provide the optimum configuration with regard to resultant flow conditions. Recasting the design at this stage will require steps 1 to 4 to be repeated.

- *Step 5:* confirm that free discharge conditions exist at the gutter-receiver transition (applies only where a sump or box receiver is installed).

Where a sump or box receiver is installed, it is necessary to ensure that the length of the weir from the gutter to the receiver permits free discharge conditions. This requires a check that the free discharge depth in the gutter exceeds the critical depth of discharge from the gutter to the receiver. The critical depth (h) is calculated using equation 3.13 where Q_w is set to the appropriate

run-off value and L_w is the perimeter of the receiver over which water can flow or the gutter sole width. The free discharge depth in the gutter is represented by the design depth (W) multiplied by the outlet head factor (F_h)⁽³⁵⁾.

Establishing that free discharge conditions exist then allows for a final determination of the sump or receiver dimensions. Where free discharge conditions cannot be guaranteed, it will be necessary either to resize the sump or to revisit the assumptions concerning downpipe and outlet positioning.

- *Step 6:* confirm that free discharge conditions exist at the outlet.

Where a gutter with a non-flat sole is used, the hydraulic capacity of any outlet should be determined by test or will be as specified by the manufacturer. In either case, the capacity of the outlet should exceed the anticipated run-off.

Where gutters are flat-soled, equations 3.9 and 3.10 or equations 3.11 and 3.12 (dependent on the outlet shape) should be used to determine the head at the outlet (h). If the outlet is located in a sump, then the largest calculated value of h should be used to determine the sump dimensions. Otherwise the operating head should be compared with the free discharge depth (similarly found by multiplying the design depth (W) by the outlet head factor (F_h)⁽³⁵⁾) to ensure free discharge. If free discharge cannot be guaranteed, then the positioning of outlets and/or gutter design should be revisited.

Valley and parapet gutters

For valley and parapet gutters, this approach may be presented in terms of the following step-by-step design procedure.

- *Step 1:* determination of design rate of rainfall and roof runoff.

As for eaves gutters, the first stage in the design of any rainwater system involves the determination of the design rate of rainfall, r (litres·s⁻¹·m⁻²), and the resultant runoff from the roof surface, Q (litres·s⁻¹). Guidance on the determination of r and Q is provided in section 3.5.2.

- *Step 2:* assumption of outlet positions.

This assumption facilitates a determination of rainfall runoff from the roof surface into each section of the gutter. Gutter sections must include those between outlets (where the length is normally taken as half of the section distance) and those between an outlet and a stop-end. At this stage, the gutter shape and size should also be assumed, in order to allow a determination of hydraulic capacity (step 3). Step 2 will be revisited if it is found that there is under-capacity.

- *Step 3:* confirmation that the hydraulic capacity of the gutter section exceeds the corresponding anticipated run-off from the roof surface.

Based on the assumption of gutter shape and size (step 2), the design capacity, Q_1 , for the gutter (initially assumed to be hydraulically 'short' and

nominally level) is calculated. For valley or parapet gutters, this includes a determination of the minimum freeboard height (Table 3.3) and corresponding gutter depth, as well as of the cross-sectional area (minus twice that of any obstructions) below the freeboard. Where applicable, the design capacity, Q_1 , should then be adjusted to take account of hydraulic length, slope and any angles in the gutter. In addition, the integration of a strainer at the outlet also requires an adjustment to the gutter capacity. All design factors, and guidance on how and when they should be applied, are presented in sections 3.5.3.1 and 3.5.3.2. In summary, however:

$$\text{Adjusted design capacity} = Q_1 \times F_1 \times 0.85 \times 0.5 \quad (3.16)$$

Note: the reduction factor (F_1) (see section 3.5.3.1) is applied when the gutter gradient exceeds 3 mm/m or when the gutter is deemed 'hydraulically long'. The numerical factor 0.85 is applied only when the gutter exhibits one or more angles of greater than 10° and the factor 0.5 is applied only when a strainer is fitted at the outlet.

Once established, it is then crucial that the final calculated hydraulic capacity of the gutter is compared with the corresponding anticipated runoff. If there is any under-capacity, the selection of gutter size and shape and/or downpipe locations must be reassessed, and steps 2 and 3 repeated.

- *Step 4:* confirmation that the downpipe capacity exceeds the anticipated flow.

After calculating the anticipated runoff to each outlet, the capacity of the corresponding downpipe should now be established using equation 3.14. This will require an assumption of an acceptable degree of filling (normally taken, in the UK, to be 0.2). At this point within the design process, it is worthwhile ensuring that the outlet and downpipe locations assumed in step 2 provide the optimum configuration with regard to resultant flow conditions. Recasting the design at this stage will require steps 1 to 4 to be repeated.

- *Step 5:* applicable only where a sump or chute is installed.

Where a sump or chute is installed, it is necessary to ensure that the length of the weir from the gutter to the receiver permits free discharge conditions in the gutter. This requires a check that the free discharge depth in the gutter exceeds the critical depth of discharge from the gutter to the receiver. The critical depth value, h , is calculated using equation 3.13 where Q_w is set as the appropriate runoff value and L_w is the perimeter of the receiver over which water can flow or the gutter sole width. The free discharge depth in the gutter is represented by the design depth, W , multiplied by the outlet head factor, F_h ⁽³⁵⁾.

Establishing that free discharge conditions exist, then allows for a final determination of the sump or receiver dimensions. Where free discharge conditions cannot be guaranteed, it will be necessary either to resize the sump or to revisit the assumptions of downpipe and outlet positioning.

- *Step 6:* confirmation that free discharge conditions exist at the outlet.

Where a gutter with a non-flat sole is used, the hydraulic capacity of any outlet should be determined by test or will be as specified by the manufacturer. In either case, the capacity of the outlet should exceed the anticipated runoff.

Where gutters are flat-soled, equations 3.9 and 3.10 or equations 3.11 and 3.12 (dependent on outlet shape) should be used to determine h , the head at the outlet. If the outlet is located in a sump, then the largest calculated value of the head of water, h , should be used to determine the sump dimensions. Otherwise the operating head should be compared with the free discharge depth (similarly found by multiplying the design depth, W , by the outlet head factor, $F_h^{(35)}$) to ensure free discharge. If free discharge cannot be guaranteed, then the positioning of outlets and/or gutter design should be revisited.

3.5.3.5 Flat roofs

Drainage from a flat roof can be either by falls that direct runoff to outlets, or without falls, where water must slowly travel in a thin layer to the outlet. The design procedure for flat roofs is much simpler than that for gutters, and is usually based on a pre-defined depth of water on the roof (typically 35 mm).

This difference in approach can sometimes mean that the numbers of outlets used for a flat roof can exceed that defined by the hydraulic requirements, as the design features of the structure are the main determinant.

For completely flat roofs, the catchment area will be the whole roof; for laid-to-falls roofs, it will be the amount of roof leading to a particular outlet or outlets. Rainfall intensity multiplied by this catchment area will give the design flow. Using published data for flat roof outlets, or the formulae in section 3.5.3.2 based on 35 mm depth, an outlet capacity can be established. The design flow divided by the outlet flow will identify how many outlets are required.

The capacity of outlets can often be improved by installing them in sumps. The perimeter of the sump can be checked by treating it as a large rectangular outlet (a useful rule of thumb is 500 mm² for sumped outlets for downpipes up to 100 mm diameter, and 900 mm² for downpipes up to 150 mm diameter).

At all times, the design and positioning of outlets should ensure that the head of water at the outlet does not jeopardise the integrity of the watertight seal used for the roof to avoid ponding.

Rainwater downpipes serving flat roofs should be designed as for eaves and parapet gutters, see section 3.5.3.4.

3.5.3.6 Further design considerations

The following general points should be noted when designing gravity-fed rainwater drainage systems:

- Where appropriate, valley and parapet gutters can facilitate the use of any surplus capacity introduced by dimensions that have been determined more as a result of the design or structural features of the building, rather than by the calculated hydraulic capacity of the rainwater system. In such cases, it is important that these gutters are laid nominally level. Use is made of this additional capacity through the design of small outlets that restrict flow and increase the working head. BS EN 12056-3⁽³⁵⁾ details the procedure required to check whether or not an outlet will restrict flow and, if so, how to determine the resulting head and gutter capacity. Restricted flow design is the norm for industrial gutters, where significant spare capacity is usually available as they are usually sized for pedestrian access.
- For horizontal pipes, it is necessary to ascertain whether or not this pipework flows full at the design rate for the system gutters and outlets. If so, then an assessment of the standing water level must be made, and an adjustment of pipe size made if deemed necessary.
- Where appropriate, warning pipes, with a nominal diameter of at least 20 mm should be incorporated and located at a height of less than 6 m. Alternatively, some type of sensing device can be used to initiate a warning signal and convey it to the BMS.
- Where deemed appropriate, overflows should always be provided.
- Overflow weirs are sometimes located at the end of a gutter. It should be noted, however, that these seldom have sufficient capacity to prevent overtopping at the gutter overspill level should a blockage occur.

3.5.4 Siphonic rainwater systems

3.5.4.1 Introduction

Siphonic rainwater systems operate differently from conventional, i.e. gravity-driven, drainage systems insofar as they are generally characterised by full-bore flow and sub-atmospheric pressure conditions in the associated pipework. The increased flow capacity afforded by this full-bore flow means that siphonic systems are able to drain relatively large roof surface areas with fewer, and smaller diameter, downpipes than those required by an equivalent conventional system. They are therefore most commonly used on larger-scale commercial or industrial buildings. The high-velocity, sub-atmospheric pressure conditions within the pipework mean that the designer may be less concerned with pipework routing and achieving velocity levels to ensure self-cleansing. This reduces the visual impact upon the exterior of a building.

The main components of a typical system are shown schematically in Figure 3.2.

3.5.4.2 Rainfall intensity and run-off

The determination of rainfall intensity for use in the design of siphonic systems follows the procedure outlined

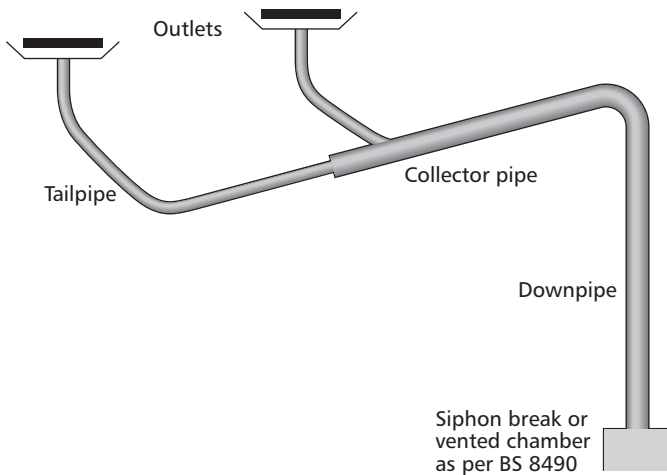


Figure 3.2 Siphonic rainwater system, shown schematically (reproduced from BS 8490 by permission of the British Standards Institution)

in section 3.5.2, which addresses location, return period (RP) and storm duration (D , typically taken as 2 minutes). Once established, this design intensity rate (r) should be multiplied by a safety factor (SF) of at least 1.1. Coupling the resultant rainfall intensity with the calculated effective roof surface area draining to each outlet will yield the design rate of runoff to the outlet (Q_o):

$$Q_o = SF A r \quad (3.17)$$

where Q_o is the design rate of runoff to outlet (l/s), SF is the safety factor, A is the effective roof area draining to the outlet (m^2) and r is the design rainfall intensity (l/s per m^2).

3.5.4.3 Priming and system capacity

At lower rainfall intensity rates, a siphonic rainwater system will operate, more or less, as a conventional system, i.e. where the conveyance of flow is dependent upon the configuration of the outlets and the depth of flow at the outlets. It is important during this mode of operation (and up until the point where the design run-off rate is reached) that anticipated water depths on the roof surface or in the gutter do not exceed levels anticipated during siphonic action.

As the rainfall rate increases and reaches that of the design rate, the siphonic system will 'prime', i.e. full-bore flow will propagate through the pipework. Ideally, upon reaching the design rainfall rate, priming should occur quickly as otherwise there is a risk that the water depth on the flat roof or in the gutter becomes excessive. The priming process is reliant upon the design of the outlet which, through the use of a specially-designed baffle plate or as a function of the design of the outlet itself, restricts air entrainment and inhibits turbulent and vortex flow conditions. When gutter or local surface depths are sufficiently high (normally only 30–40 mm), the flow within the system will be subject to a transition from free surface to full-bore flow. This transition is seldom smooth and can result in some noise and vibration within the system. Although the term 'full-bore' is used, this flow is seldom homogeneous in that a small degree of entrained air, present in the primed system, persists.

Once priming is complete, it is assumed that the system effectively operates under steady state conditions defined

by the design run-off rate. The rate of rainfall at which this design condition occurs essentially represents the maximum capacity of the system, as the available head between the outlet and the point of discharge is being wholly used to overcome the hydraulic resistance of all pipework and fittings.

It can be seen that, to function effectively at the design rainfall, the available head between the outlet and the point of discharge must be matched with the hydraulic resistance of the pipework and associated fittings. This is a highly complex process, which means design is normally undertaken by the siphonic manufacturer/installer. Some third party consulting organisations can check siphonic systems using their own proprietary software.

3.5.4.4 Speed of priming

As noted in section 3.5.4.3, it is important that the siphonic system is designed in such a way that priming occurs as quickly as possible. It is incumbent upon the designer to ensure that all component parts of the system, including both the tailpipe and collector pipe, aid rapid priming by facilitating high-velocity flow. This also helps ensure self-cleansing, and BS 8490⁽³⁶⁾ recommends that, during design flow conditions, minimum flow velocities of 1.0 and 2.2 m/s for tailpipes (and horizontal pipes greater than 1 m) and for downpipes, respectively, are maintained. Generally, priming should occur in less than one minute, i.e. well within the duration of the reference storm event.

Although there is no widely-recognised method for ascertaining the speed of priming for a particular system, BS 8940 suggests that equation 3.18 may be used to establish an approximate timescale. This equation is based on a balance of the sum of all tailpipe flows (where each is assumed to be running siphonically but performing independently and discharging to a collector pipe at atmospheric pressure) with the space or volume available within the collector pipe and the downpipe to accommodate rainwater.

$$T_f = 1.2 V_p / Q_{in} \quad (3.18)$$

where T_f is the time taken to prime (s), V_p is the volume available within the collector pipe and the downpipe (litres) and Q_{in} is the inflow rate to collector pipe during priming (litre·s⁻¹).

This time estimate is underpinned by the need for the design of the tailpipe and collector pipe to facilitate high-velocity flow in order to yield a sufficient level of negative pressure within the system.

3.5.4.5 Application of the Bernoulli equation

An assumption that the flow in the pipework of siphonic systems, once primed, is full-bore (i.e. 100% water) allows the application of the Bernoulli equation as part of the design procedure.

Equation 3.19 shows how, for steady state flow conditions, the contributory terms representative of the difference in pressure, kinetic and potential energy (head) can be equated to the sum of the system head losses. The suffixes 1 and 2 identify the upstream and downstream points, respectively, on the flow streamline under consideration.

$$\left(h_1 + \frac{u_1^2}{2g} + z_1\right) - \left(h_2 + \frac{u_2^2}{2g} + z_2\right) = \Delta h_{1,2} = \frac{k u^2}{2g} \quad (3.19)$$

where h_1 and h_2 are the static pressure head at the upstream and downstream points, respectively (metres head of water), u_1 and u_2 are the mean flow velocities at the upstream and downstream points, respectively (m/s), g is the acceleration due to gravity, taken as $9.81 \text{ (m/s}^2\text{)}$, z_1 and z_2 are the elevations of the upstream and downstream points respectively above a given reference point (m), k is the head loss coefficient and $\Delta h_{1,2}$ is the energy head loss between points 1 and 2 (metres head of water).

It is recognised that for siphonic systems that are said to run full-bore, there generally exists a small percentage of entrained air within the flow. However, the assumptions that allow the application of the Bernoulli equation have been shown to yield a close approximation of actual operating conditions^(38,39).

Where the percentage of entrained air is likely to be more significant than that noted above, independent verification of the design, using experimental data, is required.

3.5.4.6 Available head and connection to site drainage

A key determinant in defining the capacity of the system is the available head — generally defined as the height difference between the lip of the outlet and the (above-ground) siphon break. Where the downpipe discharges to a chamber, the lower datum should be identified as the level of the chamber cover. This allows for the possibility of surcharge of the underground system — a condition that can result in pressure limits being exceeded and potential system failure. This point is important as problems at the lower termination or in the receiving underground drainage may manifest at roof level as, for example, ponding or overtopping.

Identification and preservation of the lower datum for the system, i.e. the point at which pressure returns to atmospheric, is important. It is incumbent upon the designer to provide either a well-ventilated chamber (normally below ground and connected to site drainage) or a robust (i.e. well-ventilated and well-positioned) siphon break. BS 8490⁽³⁶⁾ notes that the exit velocity of the flow into a chamber should not exceed 3 m/s.

It is worth noting that the rate at which siphonic rainwater drainage systems discharge to the receiving chamber or network will be significantly higher than that for conventional systems, (although the overall volume of

water is unchanged) and this should be taken into account when designing the rainwater system as part of the wider water management framework. Overall, it is therefore important that the design of rainwater systems and the provision of local site drainage is viewed as an integral process.

Minimum pressure limits to comply with BS 8490⁽³⁶⁾ are shown in Table 3.6.

3.5.4.7 Siphonic rainwater outlets

Siphonic rainwater outlets can be fitted on either a flat roof surface or in a gutter, and their design is crucial in ensuring the performance of the overall system. The design of the outlet should be such that the degree of turbulence and the potential for vortex formation in the inflow is minimised. In addition, the outlet should incorporate a leaf-guard or strainer to inhibit the ingress of any debris. In some cases, depending upon the configuration of this leaf-guard or strainer, the water depth at the outlet may be affected, and this should be taken into account in the design of the system.

The strategy adopted in determining the number and location of outlets should be such that the design run-off flow, as determined by the appropriately selected rainfall intensity rate and effective roof area, is adequately drained. More than one outlet can be connected to a single downpipe but the flow capacity of each outlet should be balanced so as to ensure the overall system performs as intended. In addition, inflow to the outlet from each direction should, as far as is possible, be balanced so as to avoid swirl and resultant air entrainment.

The performance of the outlet is key to successful operation of the siphonic system and for this reason the characteristics of each type must be known in order to facilitate the design procedure.

The rating curve for each outlet type yields key information on the relationship between the inflow and the flow depth in the gutter or on the flat roof. Rating curves should be established using the methodology outlined in BS 8490⁽³⁶⁾.

Each outlet will have associated with it a pressure head loss that will vary dependent upon the design features of the fitting and on the flow velocity of rainwater conveyed. Given the wide variation in outlet types available, the loss coefficient for each should similarly be established from manufacturers' information or using the methodology outlined in BS 8490. This allows a determination of the pressure head loss for the outlet as:

Table 3.6 Minimum pressure limits (adapted from BS 8490⁽³⁶⁾)

Pipe material	Minimum design pressure, $h_{\min}$ (metres of water)	Corresponding minimum cavitation index	Corresponding maximum flow velocity (m/s) at 25 °C*	Adjustment in minimum design pressure, $h_{\min}$ (metres of water), for velocity and vapour pressure (i.e. temperature)
Greater susceptibility to damage by cavitation	$2.5 - H_o$	1.2	6	$h_{\min} = 0.06 u^2 + h_{vp} - H_o$
Lesser susceptibility to damage by cavitation	$1.5 - H_o$	0.6	6	$h_{\min} = 0.03 u^2 + h_{vp} - H_o$

* where the flow velocity exceeds 6 m/s, the pressure limit should be higher (i.e. less negative)

$$\Delta h_o = \zeta_o \frac{u^2}{2g} \quad (3.20)$$

$$\Delta h_L = \zeta \frac{u^2}{2g} \quad (3.21)$$

where Δh_o is the outlet head loss (metres head of water), ζ_o is the outlet loss coefficient, u is the mean flow velocity at the downpipe exit (m/s) and g is the acceleration due to gravity, taken as 9.81 (m/s²).

where Δh_L is the fitting head loss (metres head of water), ζ is the head loss coefficient (from manufacturers' data or established through recognised test procedures), u is the mean flow velocity (m/s) and g is the acceleration due to gravity, taken as 9.81 (m/s²).

3.5.4.8 Siphonic rainwater gutters

Siphonic rainwater gutter design and sizing should be undertaken using the procedure outlined in section 3.5.3.1. Information on the depth of water at the outlet for the design run-off rate is often provided by the manufacturer or can be determined from the relevant rating curve. It should be noted that excessive gutter slope, i.e. greater than 10 mm per metre, should be avoided as this introduces high flow velocities at outlets.

3.5.4.9 Siphonic rainwater pipework and fittings

Siphonic rainwater drainage pipework comprises the tailpipe, the collector pipe and the downpipe, see Figure 3.2. The main requirements of all sections of pipework are closely tied to those outlined in the design procedure (see section 3.5.4.11). However, it is worth noting here that:

- all pipework and fittings should be capable of withstanding the pressures anticipated during pre-defined test procedures or those pressures achieved whilst the system operates at its (maximum) design capacity
- the minimum permissible internal pipe diameter is 32 mm, although the risk of blockage within pipes of less than 44 mm diameter should be recognised^(35,36)
- although a reduction in the diameter of pipework (in the direction of flow) is permissible for siphonic systems, any increase in diameter is prohibited as this can inhibit priming or can prompt established siphonic action to cease (for exceptions see BS 8490⁽³⁶⁾)
- the use of sloping pipes should be avoided as these inhibit siphonic action
- internal beads introduced as a result of butt welding should be avoided
- ovality (the difference between the minimum and maximum diameter at any given pipe cross-section) in pipes should be avoided and, if present, should not exceed half of the thickness of the pipe wall⁽³⁶⁾.

Head losses in straight pipe sections are typically determined using the (iterative) Colebrook-White equation (see CIBSE Guide C⁽⁴⁰⁾, section 4.3.3), where the pipe roughness (k) is set to a minimum of 0.15 mm. In many circumstances, however, it is more appropriate to use a value greater than 0.15 to better reflect the material type and/or condition of the pipework.

Fittings head losses are calculated using the following equation:

3.5.4.10 Cavitation

Given that, once primed, siphonic rainwater systems operate at sub-atmospheric pressures, it will be appreciated that, in some cases, the resultant pressure may fall low enough to induce cavitation. Cavitation occurs when local system pressures approach that of the vapour pressure of the liquid, in this case rainwater. The formation of vapour cavities, and in particular the subsequent collapse of these cavities in regions of relatively higher pressure, can not only disrupt flow conditions but can also result in damage to the internal surface of the pipework, especially with header materials such as cast iron. The risk of cavitation increases with increased velocity, and with flow curvature and turbulence.

Limiting values for most of the UK* are:

- HDPE pipework: -8.8 m
- all other pipework: -7.8 m.

3.5.4.11 Design procedure

The design procedure for siphonic rainwater systems is concerned mainly with ensuring that, during design flow conditions:

- pressures in the system do not fall below the negative pressure design limit
- the total head loss between any outlet and the discharge point does not exceed the available head, or is greater than 1 m under the available head
- rapid priming occurs (reference section 3.5.4.4)
- cavitation is avoided (reference section 3.5.4.10) (BS 8490 recommends that a risk of cavitation exists at pressures below -7.8 metres head of water)
- self-cleansing velocities are achieved (generally, velocity requirements noted in section 3.5.4.4 will meet the criteria for self-cleansing)
- the system is balanced (where more than one outlet is connected to the same downpipe, it is incumbent upon the designer to check that the system is adequately balanced by ensuring that the difference in head loss (between the outlet and the discharge point at the lower termination of the downpipe) for each does not exceed 1 metre or 10% of the available head (whichever is the smaller)⁽³⁶⁾.

The design procedure is illustrated in Figure 3.3. Although this represents a process normally only

* Based on atmospheric pressure at sea level. Different limits apply at or locations at significant altitudes (see BS 8490⁽³⁶⁾).

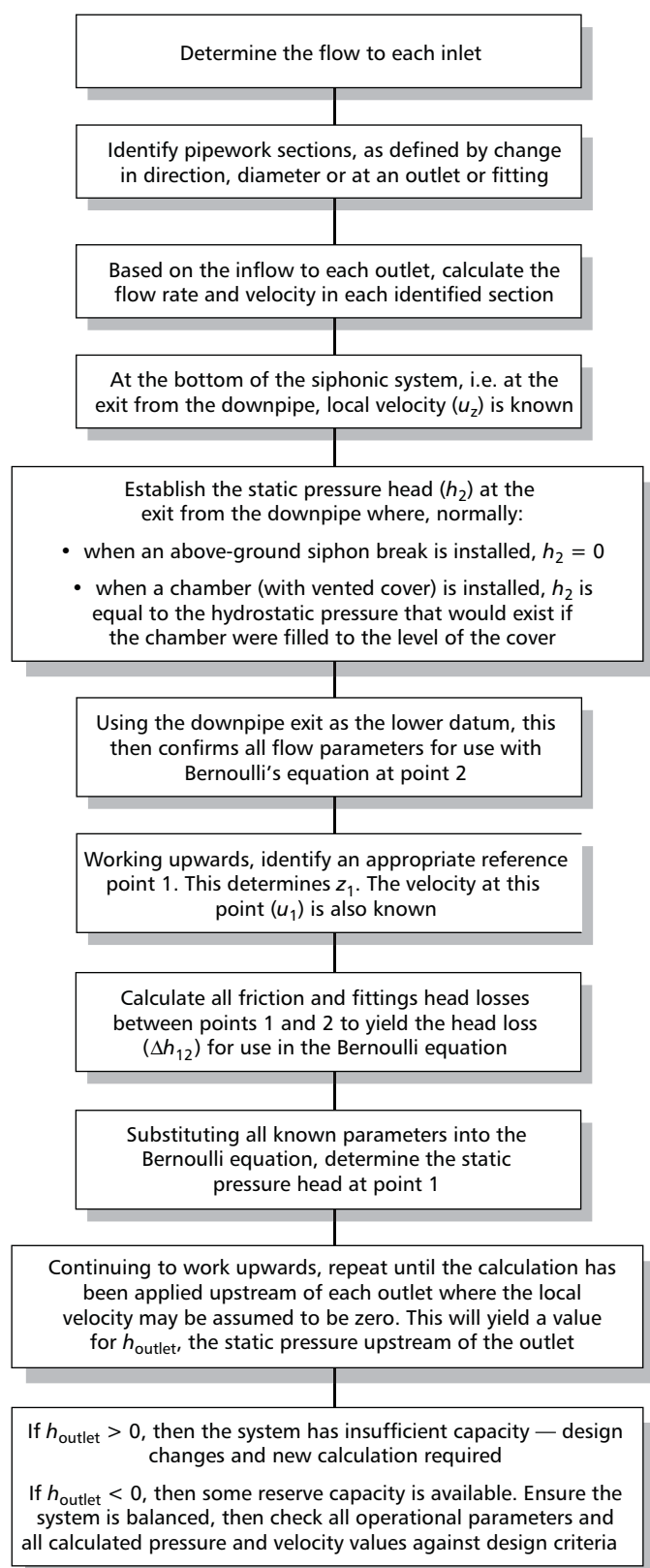


Figure 3.3 Design procedure for siphonic rainwater systems

undertaken by siphonic manufacturers/installers, the flowchart and the following text are intended to aid understanding of system design and operation.

Before commencing detailed design, it is helpful to develop an outline of the system by defining separate pipe sections. These sections should be identified by changes in pipe diameter and, where appropriate, by fittings (particularly where there is a change in flow direction that will alter the local pressure and/or flow velocity). This

separation approach is important as it will help to identify pressure extremes at key points in the system, and can be adopted for either proposed or installed systems for which the following procedure is undertaken for the purposes of checking hydraulic capacity.

Based on the known inflow to each outlet, the flow rate and velocity in each separate section should then be determined. As noted in section 3.5.4.5, the design process relies entirely upon the application of steady state principles and, in this case, the use of Bernoulli's equation (equation 3.19). The designer should apply Bernoulli's equation, working from the lowest point in the system (i.e. the downpipe exit) through to a point that is upstream of the outlet. It can be seen that at the downpipe exit, the flow velocity is known. Additionally, the static pressure head may be set to zero if a siphon break is installed, or to the hydrostatic pressure that would exist if a receiving chamber (with a vented cover) were to become full. Because account must always be taken of any possible surcharge condition in the downstream drainage network, the designer may find it useful to undertake two sets of calculations, one where the siphon is broken where intended, and another that assumes surcharge conditions.

Identification of an upstream point then allows a determination of elevation difference and also of the local flow velocity at reference point 1. Importantly, the friction and fitting losses between points 1 and 2 should be established using the methods outlined in section 3.5.4.9. Substituting all known parameters into the Bernoulli equation at this stage will thus allow a determination of the static pressure head at point 1, h_1 .

This process should then be repeated until the calculation has been applied upstream of each outlet, where the local velocity is low and may be assumed to be zero. The resultant static pressure value upstream of the outlet will determine the outcome of the process. A value greater than zero indicates that the system has insufficient capacity and that design changes and a repeat calculation procedure are required; a value less than zero indicates that some reserve capacity is available. Once reserve capacity has been identified, a check to ensure that the system is adequately balanced should then be undertaken. Once done, it is important that all operational parameters, such as speed of priming, and calculated values of pressure and velocity for each section of pipework are checked against the criteria noted above.

Particular attention should be paid to the region at the top of the downpipe where pressures are most negative, and, to avoid cavitation, the use of sharp elbows should be avoided. Any design that may introduce air pockets should also be avoided.

Although the design procedure for siphonic systems is underpinned by a number of simplifying assumptions, the process remains, to an extent (and often depending upon the system and its application), complex. For this reason, many designers and suppliers use software to assess the hydraulic capacity of a system. Such programs should always be accurate, robust and readily verified.

For siphonic rainwater systems in particular, it is important that if the installed or refitted characteristics of a system vary from those that underpin the design

calculations, then the hydraulic capacity and operating characteristics of the system must be reassessed.

3.5.4.12 Secondary systems

Where the design of a building or the provision for rainwater is such that one system cannot readily provide the hydraulic capacity required, or where a supplementary system may be used. These systems operate wholly independently of the primary system, with positioning of the outlets such that they will receive rainwater once gutter depths exceed a pre-defined threshold. The design process requires recognition that there will be two systems in place, and that secondary system outlets will affect primary system gutter depths and time of priming⁽³⁶⁾.

3.5.4.13 Pipe cross-section

Although siphonic pipework with a cross-sectional shape other than circular may be used, specialist advice should be sought when designing such systems, particularly since the guidance offered in BS EN 12056-3⁽³⁵⁾, BS 8490⁽³⁶⁾ and BS EN 752⁽⁴¹⁾ does not apply.

3.5.4.14 Overflows

Overflows for siphonic roof drainage systems should be provided:

- for flat roofs with parapets
- in non-eaves gutters
- where temporary retention of rainwater on a building roof is permitted
- where any additional risk exists.

3.5.4.15 Testing

All pipework should be water tested to maximum operating level prior to handover of the building to determine watertightness.

3.5.4.16 Maintenance

It is important that all rainwater systems are properly and regularly maintained. This is especially the case for siphonic systems and even more so during the first year of use. In particular, debris accumulation at the outlet should be avoided. It should be noted that the maintenance regime established is likely to vary depending upon the geographical location and local conditions.

With the aim of preserving the integrity of the siphonic system, access points for maintenance should not be provided as an integral part of the pipework. If maintenance checks demand that the pipework or other parts of the system require dismantling, all components should later be re-instated using appropriate fittings.

3.5.4.17 Further information

Further information regarding siphonic drainage can be obtained from the Siphonic Roof Drainage Association (<http://www.siphonic.org>).

3.5.5 Pumped rainwater systems

This section covers above-ground facilities. Guidance on buried sumps is provided in chapters 4 and 6.

Most rainwater systems discharge to below ground drainage by gravity, but in some instances this may not be possible due to a variety of reasons, such as:

- drainage unavailable locally
- building configuration does not allow gravity drainage
- the use of the building does not allow gravity drainage.

To overcome these difficulties the only solution is to store and pump the rainwater to a suitable discharge point.

Consideration should at this point in the design be given to reusing the water, e.g. in a rainwater harvesting system see chapter 5, section 5.4.3.1. If this is not possible then the tank or storage vessel required will need to be of a size to accommodate the worse storm condition for the area being considered to be drained.

The vessel (which should be of a material to give 30 years life or more depending upon the client's requirements) should be located in conjunction with the structural engineer. Associated equipment will be required as follows:

- high and low water level switches to operate the pumps
- an open vent with insect screen
- a sealed manhole and internal/external ladder for access for maintenance etc.
- a means of drain down for maintenance
- an easily and fully maintainable filter system on the inlet
- an outlet sized to accommodate the flow requirements when the pumps operate
- a bund equivalent to the tank capacity to prevent flooding of the building (with a means of emptying).

In addition to the above, if failure of the pump station due to power failure during a storm could result in flooding the inside of a building, then the pumps should be provided with a secondary power supply or an emergency storage provision should be arranged to accommodate for a 24-hour design rainfall event.

The pump set should be variable speed to cope with the highest duty at its maximum speed and should have a minimum of run and standby pumps (see chapter 6) or, for large installations, a run/assist/standby combination to deal with a variety of flow conditions. All controls should raise an alarm in case of fault and, if possible, be connected to a building management system (BMS).

The pipework should be sized to cope with the highest flow rate required; the materials of the pipework system should be compatible with the tank and pumps, and have the same notional life span.

The point of discharge should:

- be adequately sized to take maximum discharge
- be fully maintainable
- have a system of pressure relief if it becomes blocked to prevent flooding
- be sealed to prevent the spread of rabies.

The routing of the pipework system should be such as to prevent noise problems and be insulated to avoid condensation.

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Appendix 3.A1: Nomograms for sizing of gutters

The nomograms contained in this appendix provide a method of selecting gutter sizes and produce results similar to those given by BS EN 12056-3⁽³⁵⁾. They are reproduced from the *Plumbing Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering.

The procedure is as follows:

- Calculate the flow of water (Q).
- Select breadth (B_s) and length (L_g) of gutter and use nomogram to obtain depth of water at point of discharge (y_c) and the upstream depth (y_{uf}) to which a suitable freeboard must be added ($0.4 y_{uf}$ subject to minimum of 25 mm).

The use of the nomogram is illustrated in the following example.

Example

Roof size = 382 m²; rainfall intensity = 75 mm·h⁻¹; 100% run-off = 8 litre·s⁻¹.

The gutter runs off the full length of the building (20 m), with an outlet at each end. Half the water will discharge in each direction (i.e. 4 litre·s⁻¹ into 10 m lengths of gutter).

Having selected the appropriate nomogram for the gutter profile and range of sizes, choose a suitable gutter breadth (e.g. 200 mm). Starting at the bottom right hand side of the chart at $B_s = 200$ mm, project vertically upwards to meet the flow rate curve for $Q = 4$ litre·s⁻¹ and note the value of y_u (60 mm). Read across to the centre axis and note the depth at the outlet, y_c (32 mm). Continue horizontally to meet the curve corresponding to the gutter length, $L_g = 10$ m. Project vertically downwards to meet the value of y_u previously established (60 mm), then horizontally to obtain the value for y_{uf} . The freeboard is added to this value to give the required gutter depth.

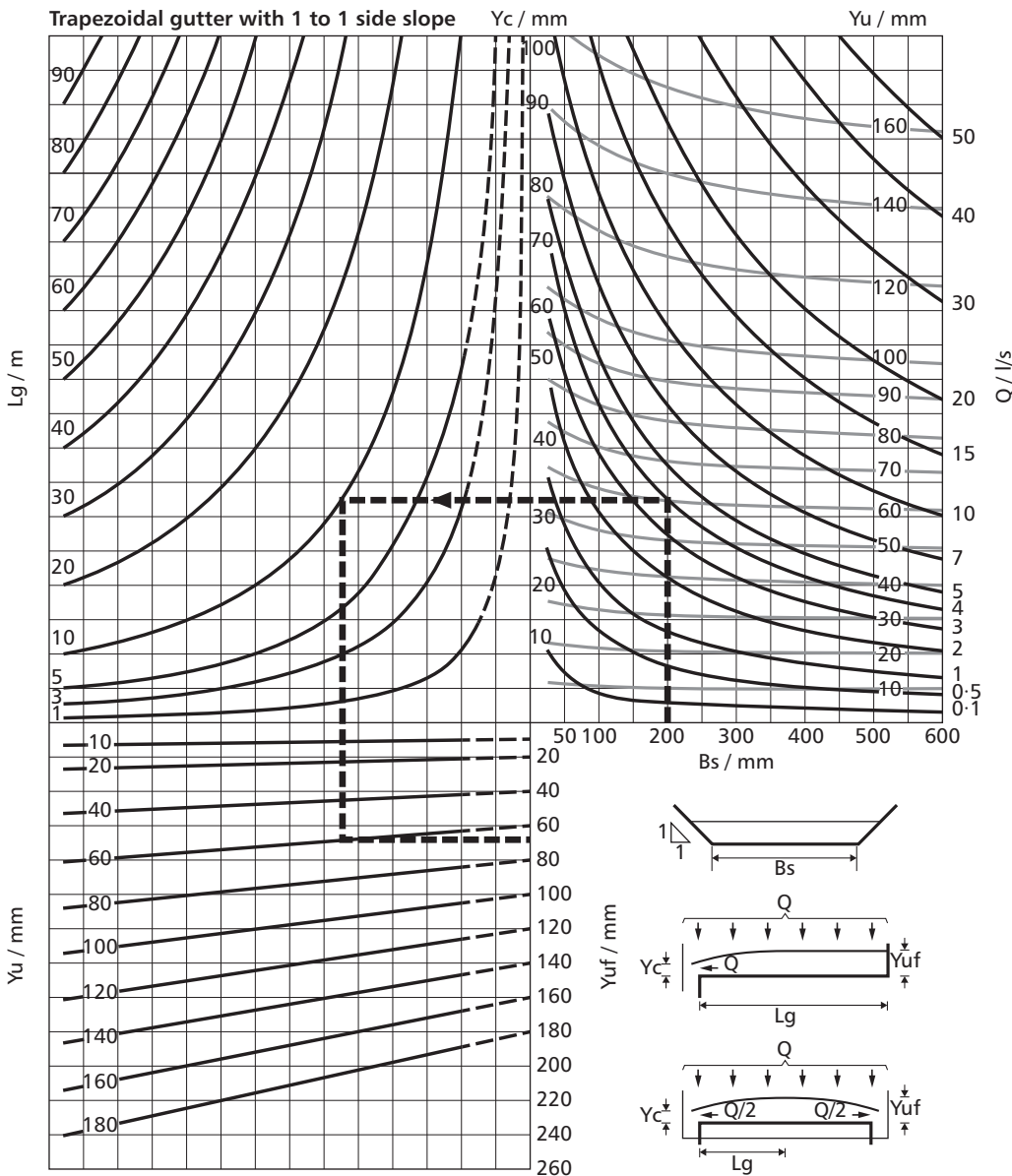


Figure 3.A1 Gutter sizing nomograms; worked example (reproduced from *Plumbing and Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

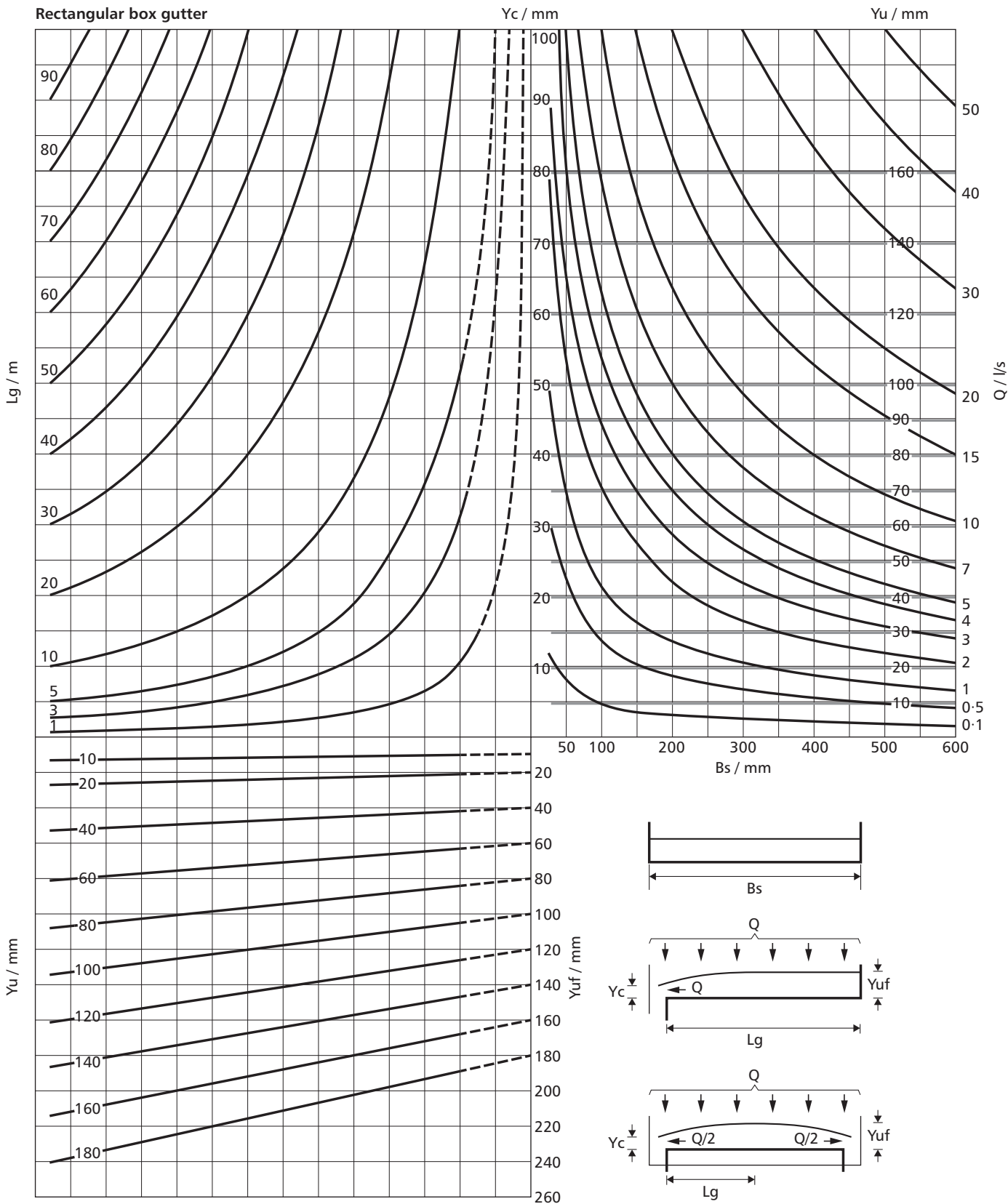


Figure 3.A2 Gutter sizing nomogram: rectangular box gutter (reproduced from *Plumbing and Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

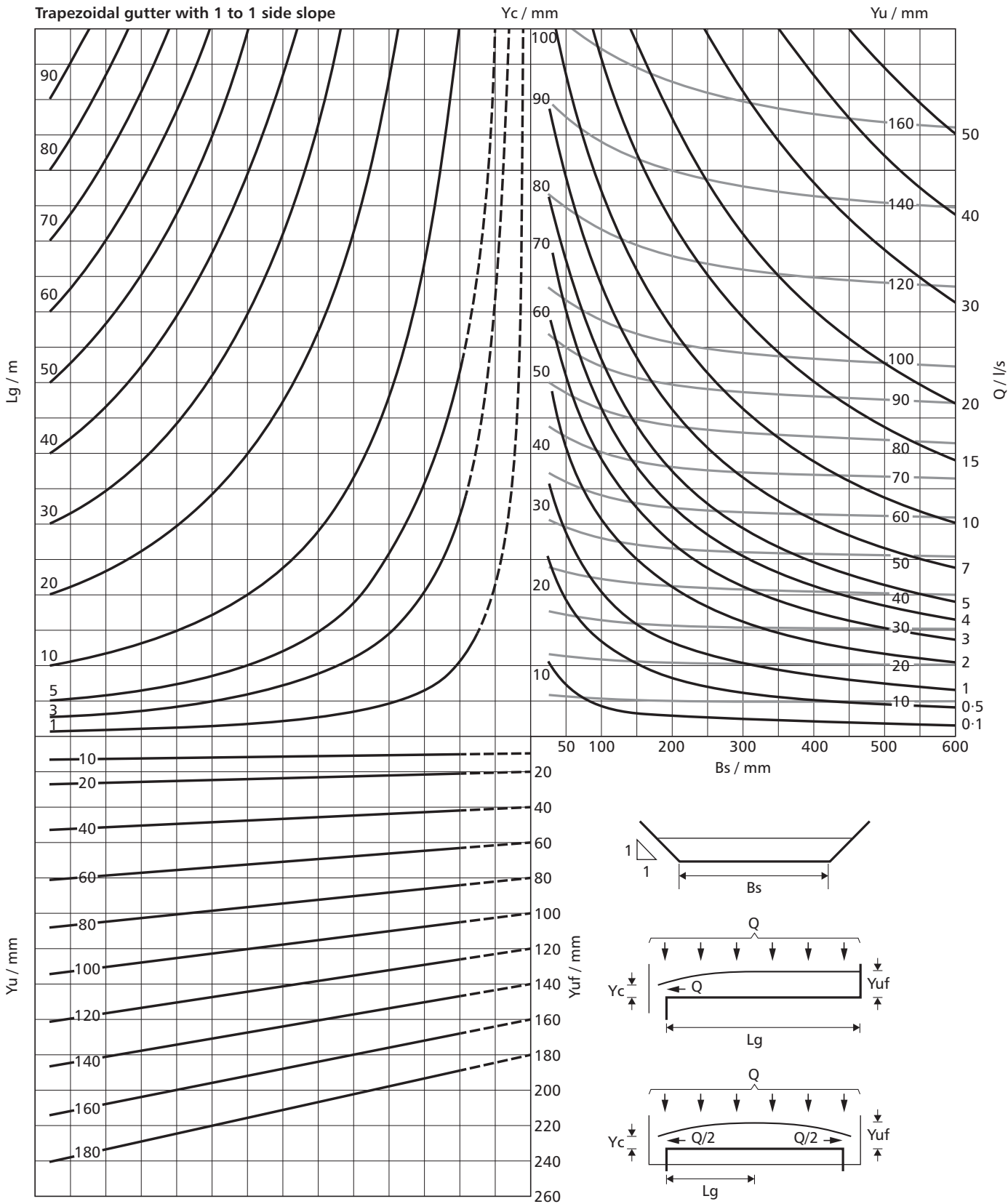


Figure 3.A3 Gutter sizing nomogram: trapezoidal gutter (side slope 1:1) (reproduced from *Plumbing and Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

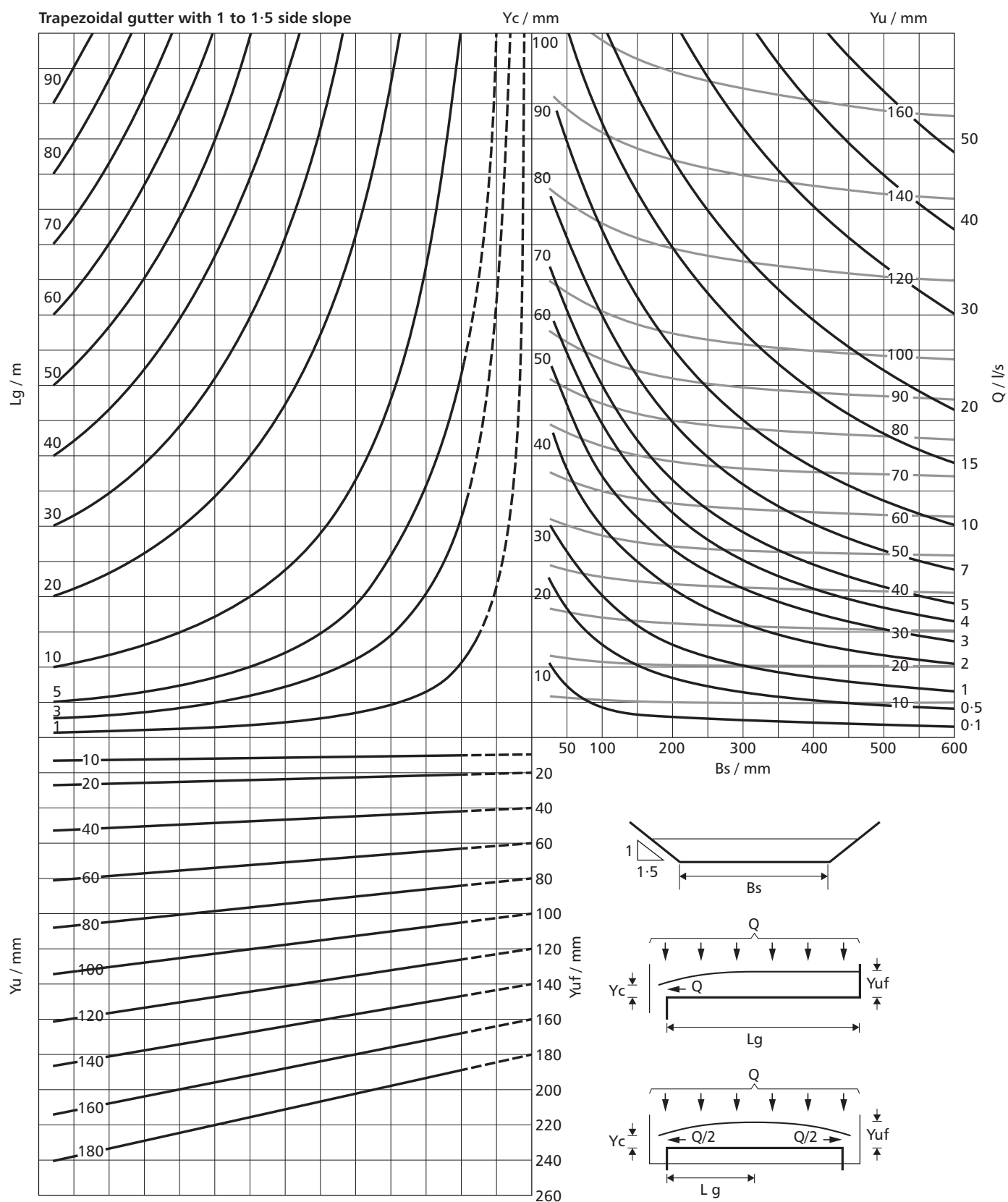


Figure 3.A4 Gutter sizing nomogram: trapezoidal gutter (side slope 1:1.5) (reproduced from *Plumbing and Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

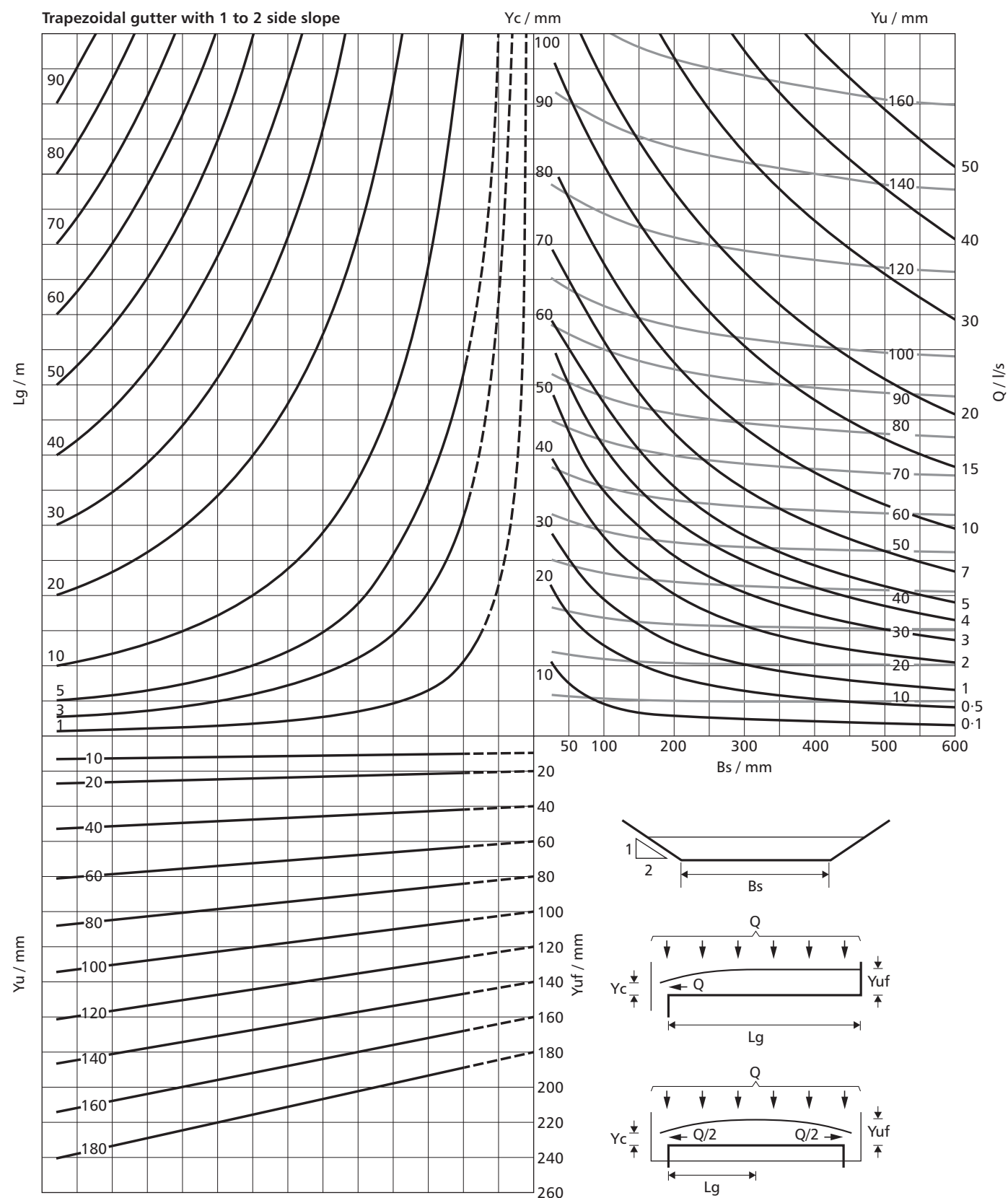


Figure 3.A5 Gutter sizing nomogram: trapezoidal gutter (side slope 1:1.5)) (reproduced from *Plumbing and Engineering Services Design Guide*⁽³⁷⁾ by permission of the Chartered Institute of Plumbing and Heating Engineering)

4 Underground drainage and treatment of waste water

4.1 Introduction	Summary
4.2 Principles of good design	This chapter considers various aspects of stormwater, sanitary and sewer drainage, and deals with treatment as well as design. Various updates to British and European Standards have necessitated this chapter to be revised. This chapter provides the engineer with design guidance on below-ground drainage system with the aid of worked examples, and should be read in conjunction with chapters 3 and 7.
4.3 Design of foul drainage systems	
4.4 Pumped systems and vacuum systems	
4.5 Sewage treatment	
4.6 Surface water systems	
4.7 Anti-flooding precautions	
References	

4.1 Introduction

This chapter is intended to provide the engineer with a first point of reference for all aspects relating to the design of underground drainage, sewage and sewerage systems that might be encountered in the field of building services-related public health engineering. The design of underground systems must necessarily be considered in close relationship with above ground systems, and reference should be made to chapter 3 for all aspects of above ground sanitary pipework and drainage.

Some information given in this chapter is applicable to larger sites, although it is not intended as a guide to the design of major infrastructure or public works, which would normally be considered as civil engineering. The appropriate standards and guides should be sought for advice on civil engineering works.

4.1.1 Sustainability and drainage

Recent policy and regulatory changes in water efficiency are intended to result in significant reductions in the demand for water, and it will be recognised that reduced WC flush volume offers the greatest opportunity for demand reduction. The most significant wastewater discharge to drainage and sewerage systems from dwellings is from baths and WCs, with the WC providing the most force to move solid matter along pipe networks.

One potential consequence of reduced water usage will be a reduction in wastewater flowing into drains and sewers, and it has been suggested that this could adversely affect existing drainage and sewerage systems. Since systems are designed upon the principal of self cleansing velocities being maintained, the reduction in flow rates, and hence in flow velocities, could result in an increase in blockages and other operational problems.

When designing new drainage and sewerage systems, or making alterations to existing systems, it is therefore important to use up-to-date information about sanitary appliances, and to consult up-to-date design guidance to prevent oversizing.

The Environment Agency suggests that the likelihood of blockages and other operational problems caused, in part, by reduced wastewater flows, could be reduced by changing design standards for drainage systems⁽¹⁾. The new standards could include the use of smaller diameter pipes (subject to certain practical limitations), pipes with steeper gradients and pipe layouts with fewer pipes taking very little flow.

Until new design standards are developed, engineers should ensure that the drain diameter and gradient produces a self-cleansing velocity for average daily flows, which might be noticeably less than the peak design flow.

Whilst revised design methods may be possible for new-build construction, there is far less scope to update systems when connecting to an existing drainage network. This is because the pipe gradient will be fixed and, whilst reducing pipe diameter by relining is possible, this will rarely be a cost-effective, affordable or sustainable option.

The sustainable technologies that can be applied to underground drainage systems, such as SUDS, rainwater harvesting and grey water recycling, are discussed briefly as they arise within this chapter but are explored more fully in chapter 5.

4.1.2 Types of drainage system

Systems fall into two main categories: foul and surface water. The purpose of both is to take liquid waste, whether this be foul effluent or rainwater, away from buildings efficiently and effectively and to discharge it safely into sewers, treatment works, pump chambers, water courses,

soakaways etc. as appropriate for the particular type of discharge and the site. Drainage systems may or may not be pumped, or include facilities for treatment and attenuation may also be included.

Foul water systems may be subdivided as follows:

- black/grey water
- commercial waste
- underground car parks
- kitchen waste
- laboratory, nuclear and/or radioactive waste.

Surface water systems may also be subdivided:

- roof drainage
- open car parks/podiums
- subsoil/cavity drainage.

The purpose of this chapter is to give general design guidance; for specialist applications it is recommended that specialist design guidance be sought.

4.1.3 Drains and sewers

The terms 'drain' and 'sewer' are often used interchangeably, but the difference between these terms must be recognised in order to ascertain ownership of the pipework and infrastructure, and responsibility for upkeep and maintenance. In general terms:

- Systems conveying liquid waste from one premises are designated as drains and are owned and must be maintained by the owner of the premises.
- Systems conveying liquid waste from more than one premises situated on private property are designated as 'private sewers'. These are owned and should be maintained jointly by the owners of the premises but, in practice, such sewers are frequently neglected. Private sewers should therefore be offered for adoption wherever possible, although not all will be accepted for adoption by the authority, and the engineer should obtain consent at an early stage.
- Systems conveying liquid waste from more than one premises situated on public property, or situated on private property having been adopted by the relevant authority, are designated as 'public sewers'. These are owned and should be maintained by the relevant authority (see section 4.1.4).

4.1.4 Approving and adopting authorities

The following authorities are responsible for the approval of drainage and sewerage. Their roles are defined more fully in the relevant legislation and guidance documents (see section 4.1.5). The various authorities are effectively summarised in BS EN 752⁽²⁾.

4.1.4.1 The sewerage undertaker

The Water Industry Act 1991⁽³⁾ determines responsibilities regarding public sewerage. Essentially the Act directs that each local water company owns its respective sewerage network and is responsible for the provision of public foul and surface water drainage networks. The Act charges the Water Services Regulation Authority (OFWAT) with monitoring these roles. All consultation regarding public sewerage should therefore be directed to the correct water company in the first instance.

When proposing connections of foul and surface water to the public sewerage infrastructure, the engineer must firstly reach agreement with the relevant water company regarding location and the rate of the respective discharges.

4.1.4.2 The Highways Authority

Systems accepting surface water runoff only from adopted highways and land adopted by the Highways Authority (normally adjacent to highways) is deemed highway drainage. The Highways Authority is responsible for the operation and maintenance of highway drains and their adoption, if they have been constructed and procured by others.

4.1.4.3 The Environment Agency

The Environment Agency (EA) (previously the National Rivers Authority) enjoys statutory powers under the terms of the Environment Act 1995⁽⁴⁾, and is charged with contributing towards the achievement of sustainable development of the environment. Its powers with regard to water and drainage include the management of water resources and the control of pollution in inland, estuarial and coastal waters (i.e. main rivers and lakes), and flood defence including water level management.

The EA can therefore oppose any project during the planning process if it believes that the receiving watercourse is overloaded and sufficient flood defence measures are not in place. The same reasoning also applies to pollution control. Thus, at the planning stage, the engineer must seek agreements with the EA on issues of quantity and quality of the proposed discharge.

In Scotland, the Scottish Environmental Protection Agency (SEPA) plays a similar role to that played by the EA in England and Wales.

4.1.4.4 Local authorities

Local planning authorities are the operating authorities for ordinary watercourses (i.e. those not under the remit of the EA) and have delegated powers under the Land Drainage Act 1991⁽⁵⁾ (amended 1994)⁽⁶⁾. The local authority should therefore be consulted, in conjunction with the EA, when maintaining or improving existing works or constructing new works, except in districts regulated by Internal Drainage Boards (see section 4.1.4.5). Local authorities also have certain powers of enforcement regarding ordinary watercourses.

4.1.4.5 Internal Drainage Boards

In certain areas of lowland Britain with special drainage needs, the operating authorities stipulated by the Land Drainage Act 1991⁽⁵⁾ (amended 1994⁽⁶⁾) are Internal Drainage Boards (IDBs). IDBs have powers under the Act to undertake works to secure drainage and water level management of their districts. They may also undertake flood defence works on ordinary watercourses within their district (that is, watercourses other than those designated as 'main rivers', which are the province of the EA). There are now some 170 IDBs in England and Wales, concentrated in East Anglia, Yorkshire, Somerset and Lincolnshire.

4.1.5 Legislation and design guidance

Sewage and sewerage are controlled by many Acts of Parliament and Regulations. In addition to these, many codes of practice cover aspects of acceptable design and workmanship, satisfactory materials and correct testing and maintenance procedures.

The following documents cover essential legislation and commonly accepted standards for drainage design, although the list should not be considered exhaustive.

Legislation includes the following:

- Water Industry Act 1991⁽³⁾
- Water Industry Act 1999⁽⁷⁾
- Water Act 1989⁽⁸⁾ (amended 2003)⁽⁹⁾
- Building Act 1984⁽¹⁰⁾
- Building Regulations⁽¹¹⁾★ (especially Part H (2002))
- Highways Act 1980⁽¹⁴⁾
- Environmental Protection Act 1990⁽¹⁵⁾
- Environment Act 1995⁽¹⁶⁾
- Water Resources Act 1991⁽¹⁷⁾
- Land Drainage Act 1991⁽¹⁸⁾ (amended 1994)⁽¹⁹⁾
- Health and Safety at Work etc. Act 1974⁽²⁰⁾
- Flood and Water Management Act 2010⁽²¹⁾
- Town and Country Planning (General Permitted Development) (Amendment) (No. 2) (England) Order 2008⁽²²⁾
- Water Framework Directive (2000/60/EC)⁽²³⁾.

Relevant British and European Standards include:

- BS EN 752: 2008: *Drain and sewer systems outside buildings*⁽²⁾. This document supersedes BS 8301: 1985 and BS EN 752: 1996–1998, although these older documents are cited in Building Regulations Part H.
- BS EN 1610: 1998: *Construction and testing of drains and sewers*⁽²⁴⁾

★ Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

4.2 Principles of good design

Below-ground drainage and sewerage systems should be designed in accordance with the functional requirements of BS EN 752⁽²⁾, as well as the following:

- (a) Public health and safety:
 - quick, efficient and safe passage of harmful or noxious effluents and rainwater away from buildings and populated areas
 - prevention of ingress of noxious gases to buildings
 - provision for surcharge and flood control for buildings and populated areas.
- (b) Capacity and sustainability:
 - adequately sized to receive design flow without surcharge
 - sized with due regard to future developments
 - need for pumping kept to a minimum
 - need for sewage treatment to be kept to a minimum.
- (c) Minimal maintenance requirements and simplicity of design:
 - pipelines to run straight wherever possible
 - minimum number of changes of direction, bends and other fittings
 - minimum number of branches and junctions
 - effluent should always discharge by gravity unless this is absolutely impossible
 - sudden or sharp changes of direction avoided, junctions and bends to be slow radius type
 - appropriate gradients to ensure self cleansing velocities
 - systems to be ventilated to minimise build-up of noxious gases
 - adequate access for occasional maintenance/repair.

These points are explored in the following sections and encapsulated within the design guidance offered.

4.2.1 Access

Safe access must be provided at reasonable intervals to allow for inspection and maintenance, and, wherever possible provisions should be made for work to be carried out from surface level. Where it is necessary for entry to and egress from the drainage system by operatives, access points affording such entry and egress should be designed to allow sufficient space to facilitate safe working.

'Manhole' is the common term for an access chamber that is large enough for safe human entry and egress. Smaller access chambers not designed for personnel to work inside are known as 'inspection chambers' or 'access chambers'. However, these terms are often used interchangeably.

Traditionally, systems have always been designed with manholes and/or inspection and access chambers as the principal means for gaining access, but an alternative (and nowadays preferred) option is to base the design on the rodding point system, which minimises the need for costly manholes or inspection and access chambers. Figure 4.1 shows a 'traditional' design detail with an access chamber, and the same detail with the rodding point principle applied. Both systems comply with Building Regulations Approved Document H⁽²⁵⁾ and BS EN 752⁽²⁾, and are designed so that every aspect of the system is accessible. It is important when designing a rodding point system to ensure that the maximum spacing of access points as given in Building Regulations Approved Document H and BS EN 752 are observed, and also that connections to drains incorporating rodding access (e.g. back inlet gullies, see Figure 4.2) are used. The rodding point system gully, commonly known as a 'syphon bell gully' is becoming more commonly available within the UK from both European and British manufacturers.

Access provision *must* comply with the requirements of Building Regulations Approved Document H⁽²⁵⁾ and BS EN 752⁽²⁾. Where practicable, access should be provided:

- at every change of alignment or gradient
- at the head of all drains/sewers
- at every junction of two or more drains/sewers (blind connections may be made, although access provision for rodding should be considered)
- wherever there is a change in the size of a drain/sewer
- at reasonable intervals for inspection and maintenance by means of manholes, inspection chambers or rodding points.

Where providing an access point is not practicable, it should be ensured that the critical points referred to above can be reached from an alternative access location.

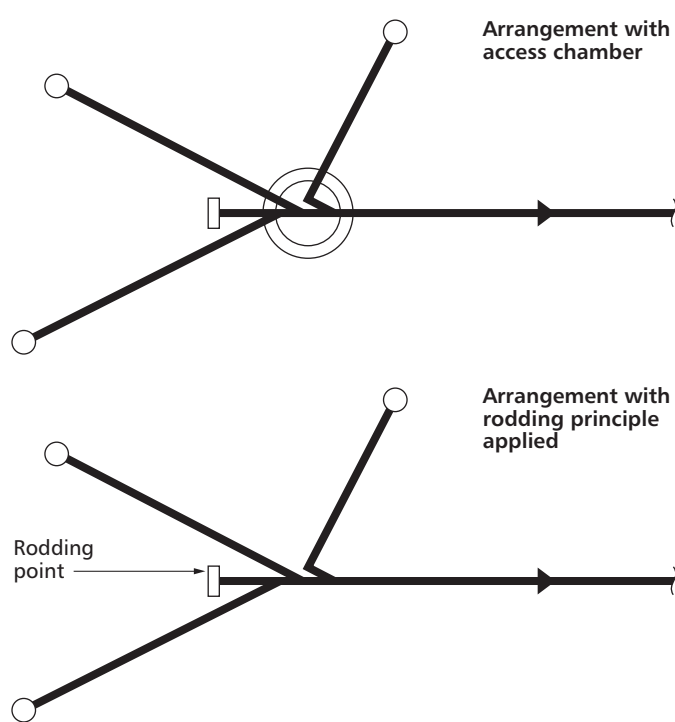


Figure 4.1 Rodding point principle

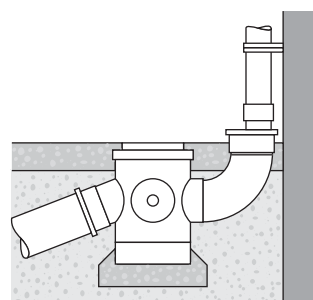


Figure 4.2 Back inlet gully type connection to drain

Manholes and inspection chambers should be designed and installed so as to avoid any acute changes in direction of flow from branch drains.

The dimensions for manholes and inspection chambers are given in BS EN 476⁽²⁶⁾.

Manholes providing access for cleaning, inspection and maintenance by personnel are required to have a minimum nominal diameter of 1000 mm or, for rectangular sections, a minimum nominal size of 750 mm × 1200 mm or, for elliptical sections, a minimum nominal size of 900 mm × 1100 mm.

Manholes providing access for the introduction of cleaning equipment, inspection, and test equipment, with only occasional possibility of access for personnel equipped with a harness, must have a minimum nominal diameter of 800 mm, but less than 1000 mm.

Inspection or connection chambers smaller than the above designated sizes permit the introduction of cleaning, inspection and test equipment, but do not provide access for personnel.

4.2.2 Sewage separation

Building Regulations Approved Document H⁽²⁵⁾ confirms that modern schemes must consist of separate sewerage systems, such that water polluted by human activities will discharge to a foul water sewer and rainwater will discharge to a surface water sewer. Discharges from sanitary accommodations and trade effluent constitute foul water and, in the vast majority of instances, this will be subject to some form of treatment before being discharged back into the natural water cycle. Surface water is considered to be the runoff arising during rainfall from roofs and external impermeable surfaces. Surface water should be discharged back into the natural water cycle at the earliest opportunity, and it will usually not require treatment.

4.2.3 Existing legacies and outdated systems

In some urban areas combined or partially separate drainage and sewerage systems are in evidence. Combined systems were an early drainage solution whereby both foul and surface water were discharged into one common set of drains and sewers. This practice has long since been discontinued, although combined public sewers may still be encountered. Where new developments are planned in areas with combined public sewers, it must be assumed that the public sewers will be modernised at some future time, and the new site drainage system must therefore be

designed as separate, even if both drains eventually discharge to a combined sewerage system.

During the rapid growth of urbanisation in the UK in the second half of the 20th century, the partially separate system of drainage and sewerage was utilised. This system allows, where convenient, for surface water to discharge into foul water sewers. The view at the time was that this practice made economic sense, and that rainwater would periodically cleanse foul drains and sewers. This practice has been long since abandoned, however, and its legacy is reckoned to be very costly in terms of sewage treatment.

4.2.4 Illegal cross-connections

Unwanted and possibly illegal cross-connections in separate sewerage can give rise to flooding problems on foul water sewers and pollution problems on surface water sewers. Many of these mistaken cross-connections tend to occur as a result of home improvements (kitchen alterations, extensions, patios etc.).

On properties with separate drainage systems, rainwater pipework should not be connected to foul drains, and foul drains or boiler condensate pipes should not connect to surface water drains.

4.3 Design of foul drainage systems

Foul drainage and sewerage systems should be designed to collect and transport wastewater from domestic, public and commercial premises to the point of treatment without prejudice to health and safety. The design should also include allowances for future growth and for extraneous discharges up to such flow that will justify rehabilitation.

4.3.1 Basic information

Prior to starting design the following basic information needs to be obtained:

- details of existing sewers (or new sewers to be provided): designation, type, size, materials, capacity, current usage, expected future usage, location, depth etc.
- existing drainage survey/drawings
- site topography and geotechnical survey
- layout of new buildings
- planning requirements
- ground conditions
- new site plan showing landscape, levels and any special finishes
- details of any archaeology or site constraints
- employer's/client's requirements
- details of any historical drainage problems
- foundation principles

- location of all sanitation drain points and rainwater connections
- details of the type and magnitude of discharge flow from all drain points, and whether any chemical discharges are proposed.

4.3.2 System layout

Having determined the basic information outlined above, and ascertained as much detail as possible about the flows into the proposed drainage system, it is now important to link together areas that require drainage in an economic and effective layout. The system layout will usually consist of branches into a main run and be 'tree-like' in nature. Flow should normally move in one general downhill direction only towards a single outfall.

Particulars of the site topography may mean that this is not always possible, however, and it is sometimes necessary to design sewerage systems with multiple outfalls or that require sewerage to be pumped to higher levels (see section 4.4.1). Pumped systems are not seen as a sustainable solution and should be avoided where possible, and adopting authorities will sometimes not adopt pumped sewers. Where foul systems serve a number of small properties in flat low-lying areas, vacuum drainage systems may be an appropriate alternative (see section 4.4.5).

As previously discussed, combined and partially separate drainage and sewerage systems are not permitted in new developments, and completely separate systems must be used. In situations where a new development's foul and surface water sewers will both discharge into the same combined sewer (not uncommon for city or town developments), separate sewerage on-site is still required. Both sewers will then discharge to a chamber located at the edge of the site, where the two flows are permitted to mix, before connecting to the main combined sewer. This allows for the option of easily separating and re-routing the surface water flow if future developments provide a new surface water sewer in the vicinity of the site.

In residential developments sewers are commonly located side-by-side beneath roadways, though not on the centreline. This avoids clashes with the services located under verges and footpaths. This also enables inspection chambers and manholes to be accessed whilst maintaining traffic flow. From a maintenance and safety viewpoint there are considerable advantages for chambers to be located on verges or footpaths if there is adequate space.

Sewers for Adoption⁽²⁷⁾ and BS EN 752⁽²⁾ both provide detailed information on the layout of drainage systems.

4.3.3 Design flow rates

Various approaches to determine design flow rate are valid. Within the curtilage of a building and for a small group of houses, discharge units are normally used to assess the peak design flow rate. Determination of design flow rate may be achieved by considering the expected daily flow rate, based on an assessment of expected water usage or from metered water consumptions, and then applying a factor to estimate the flow rate at peak times. Alternatively flow rate can be determined based on

experience of similar developments, or by assessment of the number and type of appliances and their relative contributions to the peak flow.

In the absence of any known or empirical data, such as data from a similar development, the engineer should employ the method given in *Sewers for Adoption*⁽²⁷⁾. This source advises 200 litres per person per day as the average flow rate, or dry weather flow (DWF).

4.3.3.1 Dry weather flow method

To determine the design flow, the DWF should be multiplied by an appropriate factor to allow for peak flows arising from diurnal and seasonal fluctuations in water consumption. For new developments this factor is normally taken as 6.

Thus, assuming 3 persons per dwelling and including a 10% margin for infiltration during heavy rainfall, the figure arrived at is approximately 4000 litres per dwelling per 24 hours. This equates to an expected peak flow rate of 167 litres per dwelling per hour.

4.3.3.2 Discharge unit method

Alternatively, section 6 of BS EN 12056-2⁽²⁸⁾ details a method of calculating industrial, commercial and residential peak flows using the discharge unit method (previously cited in BS 8301 and BS EN 752-4, both now superseded). This method is intended for above ground drainage sizing, though once the above ground flow rate is determined the same figure may be used for the below ground design.

The discharge unit method calculates the flow from a group of mixed appliances from different types of buildings and allocates discharge unit values in litres/second and frequency factors to take account of typical usage patterns and demand. The expected flow rate in a particular discharge stack, and hence the underground drain to which it is connected, can then be inferred.

Table 4.1 shows discharge unit values for different types of appliances and Table 4.2 details frequency factors for different categories of use.

The two factors are then inputted into equation 4.1 to derive the peak flow rate:

$$Q=K\sqrt{\sum(DU)}$$
 (4.1)

where Q is the wastewater design flow rate ($l\cdot s^{-1}$), K is the frequency factor and DU is the discharge unit.

4.3.4 Selection of pipe sizes and gradients

There is a considerable amount of sizing data available in BS EN 12056-2⁽²⁸⁾, BS EN 752⁽²⁾, in Building Regulations Approved Document H⁽²⁵⁾ and the *Plumbing Engineering Services Design Guide*⁽²⁹⁾. Accepted methods are based upon

the Colebrook-White equation, which states that for circular pipes flowing full, the velocity of flow is given by:

$$V=-2\sqrt{(2gDJ_E)}\log_{10}\left(\frac{k}{3.71D}+\frac{2.51\nu}{D\sqrt{(2gDJ_E)}}\right)$$
 (4.2)

where V is the velocity averaged across the flow cross-section ($m\cdot s^{-1}$), g is the gravitational constant ($m\cdot s^{-2}$), D is the internal pipe diameter (m), J_E is the hydraulic gradient (energy loss per unit length) (dimensionless), k is the hydraulic pipeline roughness (m), and ν is the kinematic viscosity of fluid ($m^2\cdot s^{-1}$).

For partially full pipes (or pipes with non-circular cross-sections) the velocity of flow is given by the same equation but D is replaced by $4R_h$ where R_h is the hydraulic radius (flow cross-sectional area divided by the wetted perimeter).

The *Plumbing Engineering Services Design Guide*⁽²⁹⁾ offers sizing and gradient ‘ready reckoner’ type charts based on the Colebrook-White equation for simplicity of use. Both of these are valid. CIBSE Guide C⁽³⁰⁾ gives an alternative

Table 4.1 Discharge unit (DU) values for a range of typical appliances*

Appliance	Discharge units (litres/second)
Wash basin	0.5
Shower	0.6
Shower with plug	0.8
Single urinal with cistern	0.8
Urinal with flushing valve	0.5
Slab urinal	0.2 per person
Bath	0.8
Kitchen sink	0.8
Dishwasher (household)	0.8
Washing machine:	
— up to 6 kg	0.8
— up to 12 kg	1.5
WC:	
— 6 or 7.5 litre cistern	2.0
— 9 litre cistern	2.5
Floor gully	
— DN 50	0.8
— DN 70	1.5
— DN 100	2.0

* Figures assume single stack system with branch discharge pipes running maximum half bore; for other systems refer to BS EN 12056-2⁽²⁸⁾

Table 4.2 Frequency factors (K) (reproduced from BS 12056-2⁽²⁸⁾ by permission of the British Standards Institution)

Usage of appliance	K
Intermittent use (e.g. dwelling, office)	0.5
Frequent use (e.g. school, hotel, hospital)	0.7
Congested use (e.g. public toilets, gym changing rooms)	1.0
Special use (e.g. laboratories)	1.2

Table 4.3 Typical values for pipe roughness

Material used	k_s / mm
PVC-U or pitch fibre	0.06
Vitrified clay pipes	0.15
Cast iron	0.30
Spun concrete	0.15

equation by Haaland and an accompanying CD-ROM includes a spreadsheet that enables pipe sizing tables to be generated using this equation.

Hydraulics Research (Wallingford) Limited has prepared a series of charts and tables⁽³¹⁾ based on the Colebrook-White formula. Values are recommended for the discharge rate, hydraulic gradient, pipe diameter and mean velocity for difference values of k . The information also includes recommended values for k in pipes of different materials and in varying condition. The graphs are represented in Figures 4.3 to 4.6. The flows are set out for 60% and full bore flow for four different surface roughness coefficients (see Table 4.3).

The capacity of foul systems should not normally exceed a proportional depth of 0.7 (70%) (at which conditions for maximum flow rate occur) during peak flow conditions and (as previously stated elsewhere) flow velocities should be maintained between $0.75 \text{ m}\cdot\text{s}^{-1}$ and $1.5 \text{ m}\cdot\text{s}^{-1}$ to ensure self cleansing systems. The practice of using a proportional depth of 70% to determine pipe sizes and gradients ensures that some extra capacity is available whilst maintaining self cleansing velocities at lower flow rates.

Since it is often customary for unskilled labour to install drainage and sewerage pipework, longstanding practice is for common pipe sizes to be laid at familiar gradients. These are generally:

- 100 mm pipe diameter at 1:40 or 1:80
- 150 mm pipe diameter at 1:80 or 1:100
- 225 mm pipe diameter at 1:100 or 1:125

This practice allows for self cleansing velocities to be maintained at periods of peak and off peak flow rates.

4.3.5 Maximum pipe lengths

Lengths of drainage pipework are generally determined by the requirement for inspection chambers or manholes to be located at all changes of direction, gradient, pipe diameter and at junctions. Where lengths of straight pipe are to be installed, unless there is specific guidance from the sewerage undertaker to the contrary, the maximum length between inspection chambers (for human entry) or manholes should be taken as 90 m. This figure is based upon maintenance and cleansing requirements and the effectiveness of high pressure water jetting.

4.3.6 Depth of drainage pipework

When specifying the depth of cover over drainage pipework the distance between the ground level to top of the pipe barrel (i.e. the top of jointing sockets) should be considered.

Sewers for Adoption⁽²⁷⁾ recommends that sewers under roads and highways should have a minimum cover of 1.2 m and all other drains and sewers should be laid to a minimum depth of 0.9 m. These figures are absolute minima, however, providing for protection against frost and ground movement caused by vehicles. Usually other on-site factors contribute to decisions about depth.

Since separate systems must normally be used there will be two sets of drains/sewers, and connections may clash and pipework crossovers may be awkward. To avoid these problems the foul pipework should therefore normally be laid at a greater depth than the surface water pipework. This arrangement also ensures that any water loss from the foul sewer does not infiltrate into the surface water sewer.

Bedding and backfilling

Careful consideration must be given to selecting the appropriate bedding and backfill for the type of pipework material specified and the depth they are to be installed. In general pipework materials may be classified as rigid (e.g. clayware, cast iron etc.) or flexible (e.g. plastics) and different bedding and backfilling techniques apply to each. For typical drain laying applications flexible drains require imported granular material for bedding and side fill, whereas rigid drains normally require only a bed of imported granular material. Beddings comprise the trimmed trench bottom with selected backfill and/or granular material to provide a smooth surface with the correct gradient upon which pipework may be laid. On no account must bricks or similar large items of masonry be used to support any part of the pipes. Backfill will comprise selected granular materials and/or concrete, reinforced where necessary.

Basic information on bedding and backfilling may be found in Building Regulations Approved Document H^{(25)*}.

4.3.7 Grey and black water

Waste water from all sources other than toilets, and not contaminated by industrial or chemical waste products, is categorised as grey water. This type of effluent can often be recycled quite easily. Other, more contaminated discharge, containing effluent from WCs and urinals and chemical waste is known as black water and this is usually not recycled, although special processes do exist for the treatment and recycling of black water (see chapter 5).

Most grey water recycling systems collect and treat wastewater from showers, baths and wash basins, excluding the more contaminated water from washing machines, kitchen sinks and dishwashers. Grey water recycling systems collect this water, treat it and re-use it for purposes that do not require drinking water quality. This recycled water can be used to flush toilets, water gardens and sometimes feed washing machines.

Grey water recycling systems can be installed in new or existing buildings and have the potential to meet a significant proportion of domestic demand for water.

* Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

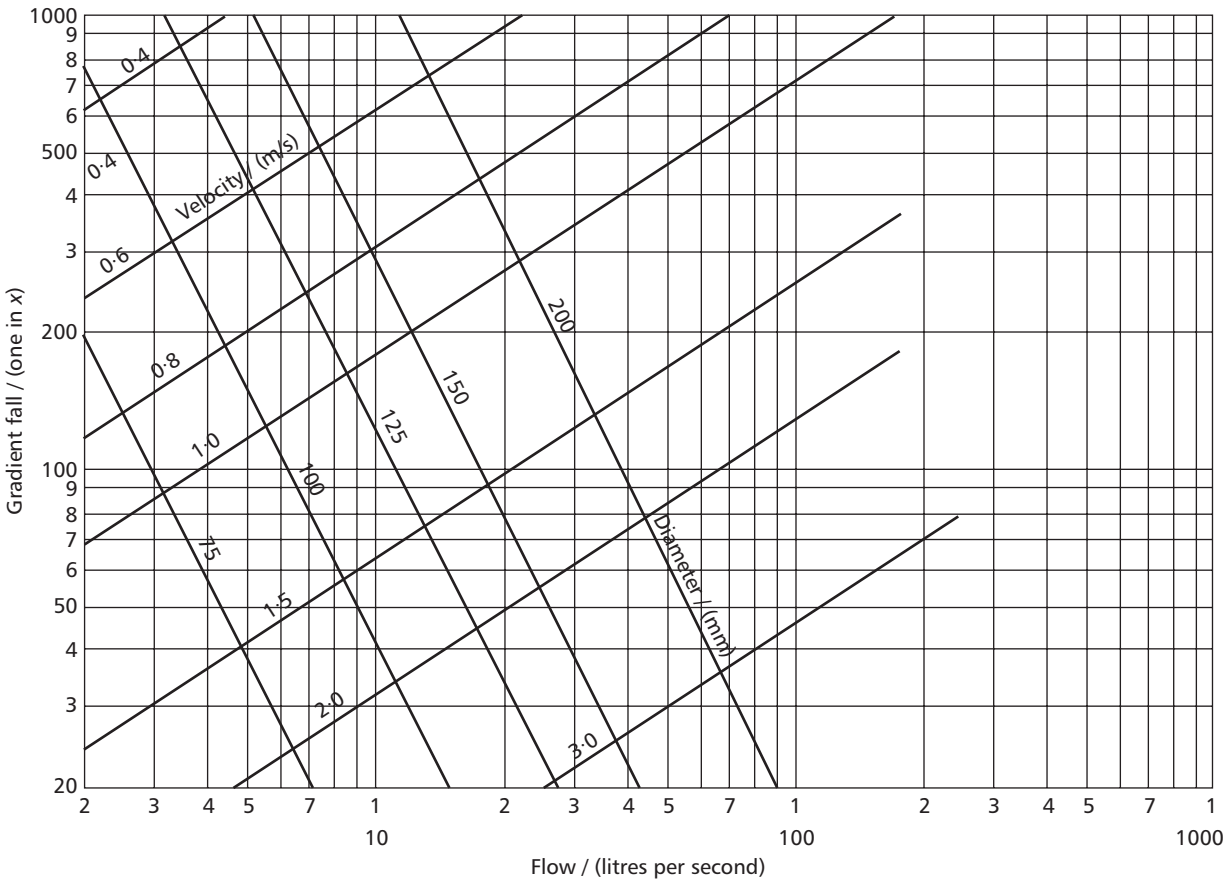
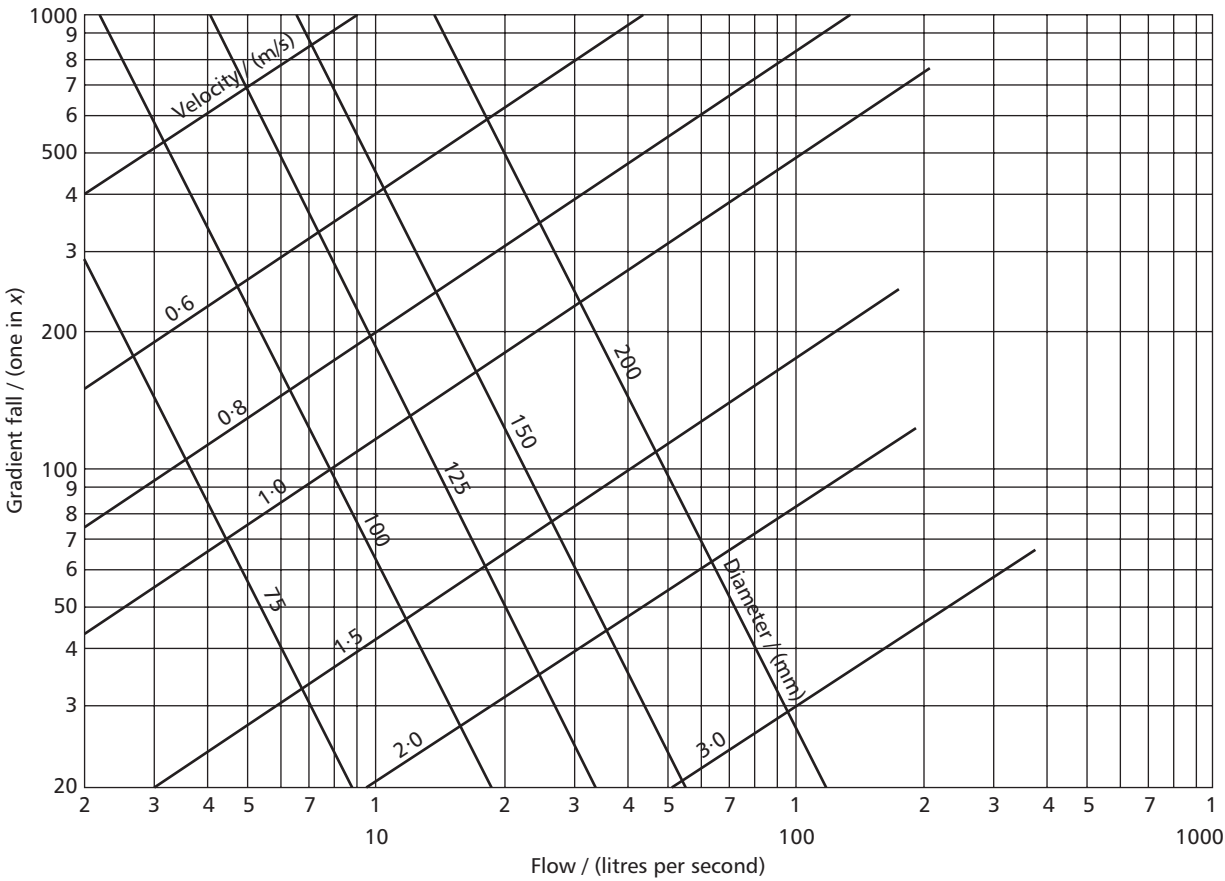


Figure 4.3 Sewage flow in pipes ($k_s = 0.03 \text{ mm}$) (top: 60% flow; bottom: full bore flow)

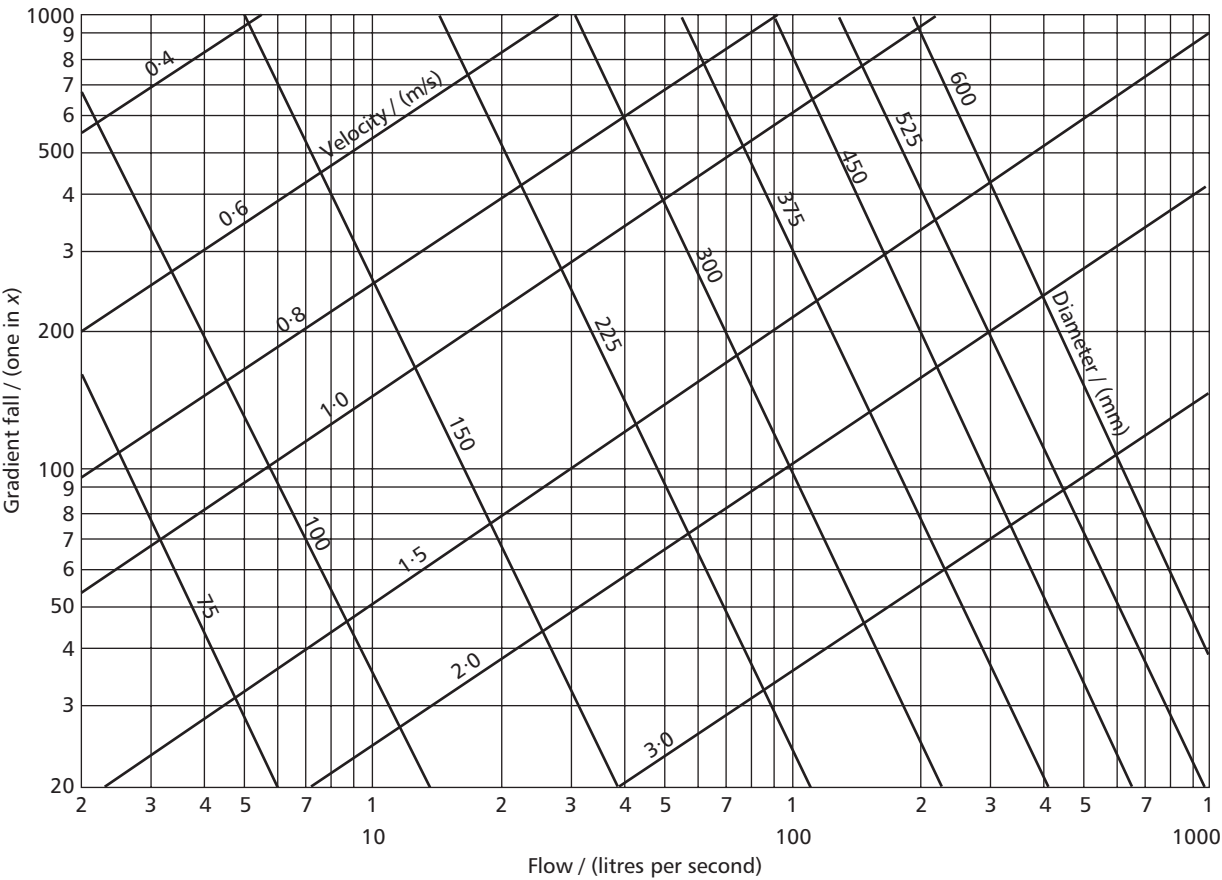
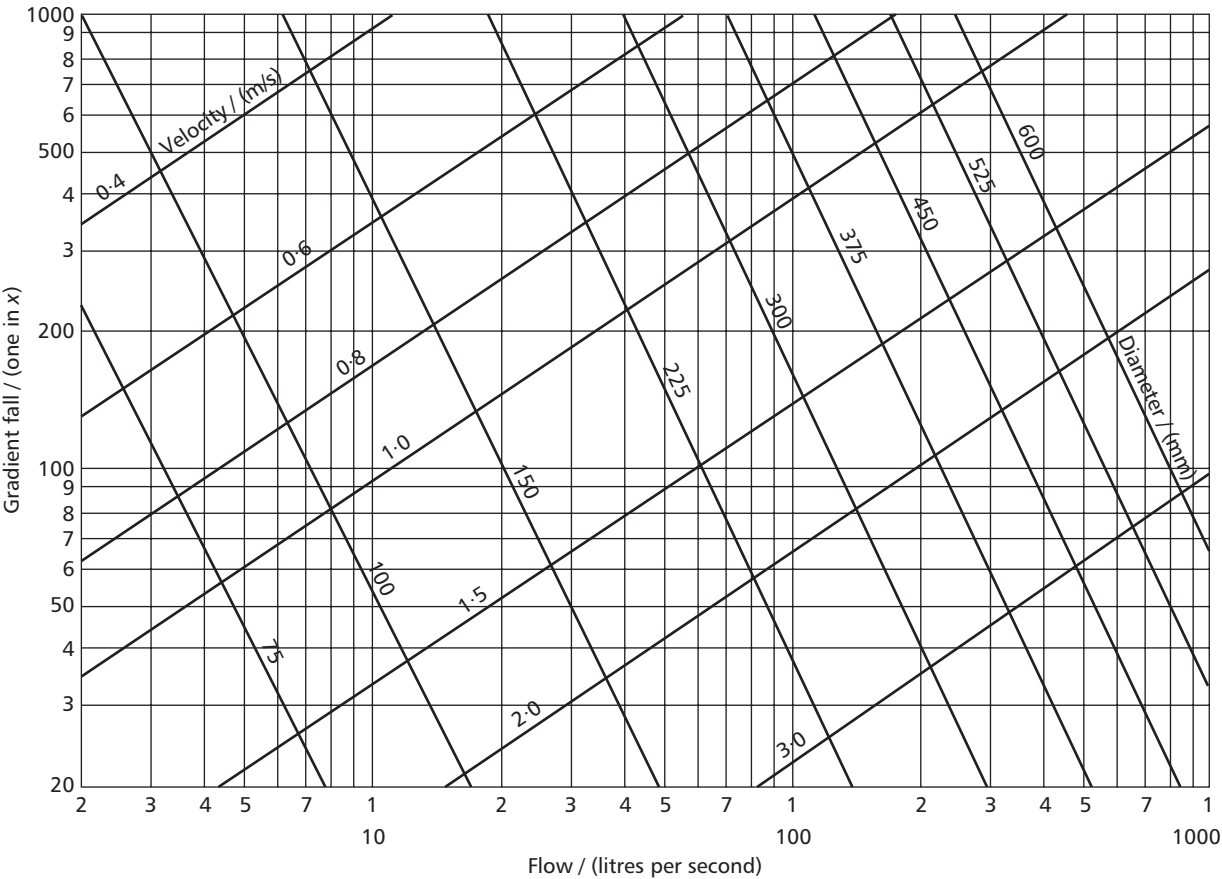


Figure 4.4 Sewage flow in pipes ($k_s = 0.15 \text{ mm}$) (top: 60% flow; bottom: full bore flow)

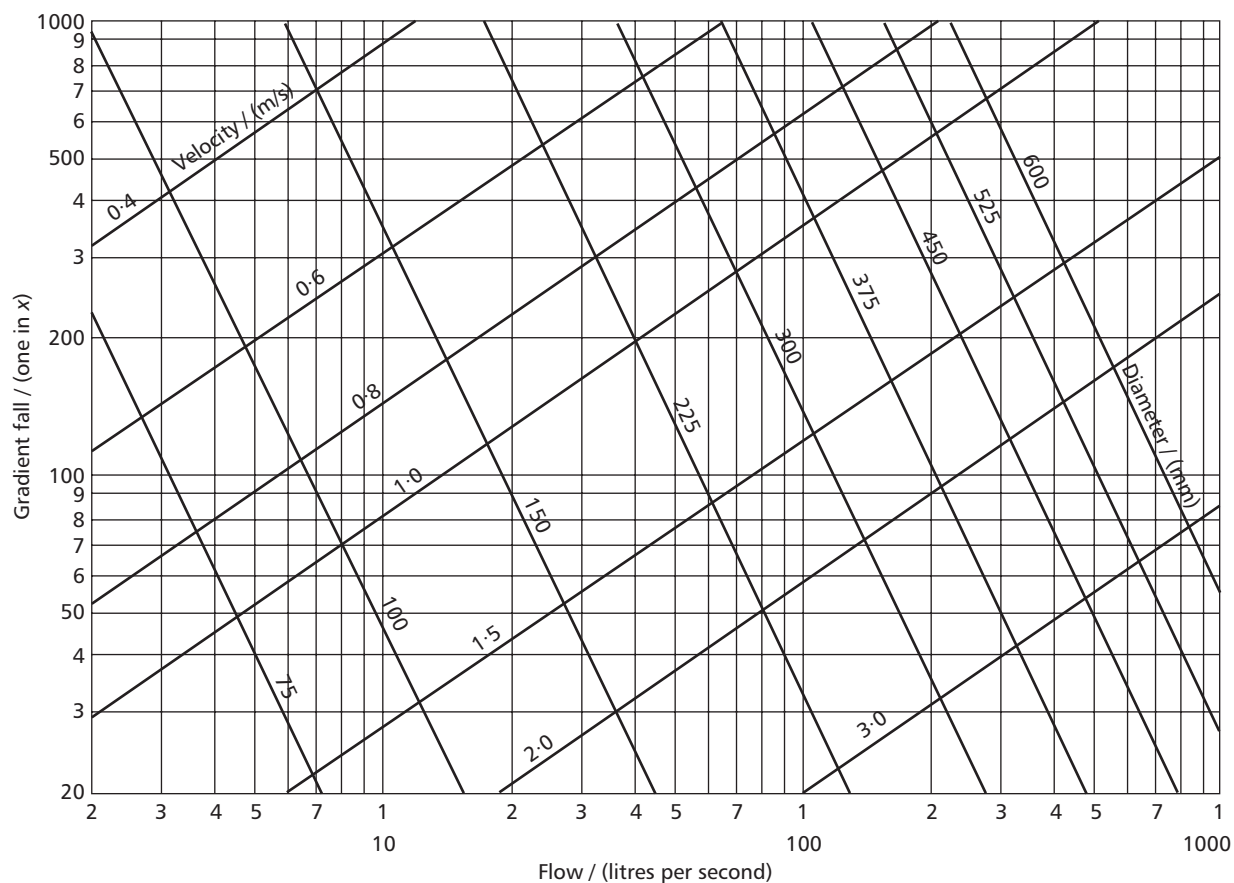


Figure 4.5 Sewage flow in pipes ($k_s = 0.30$ mm) (top: 60% flow; bottom: full bore flow)

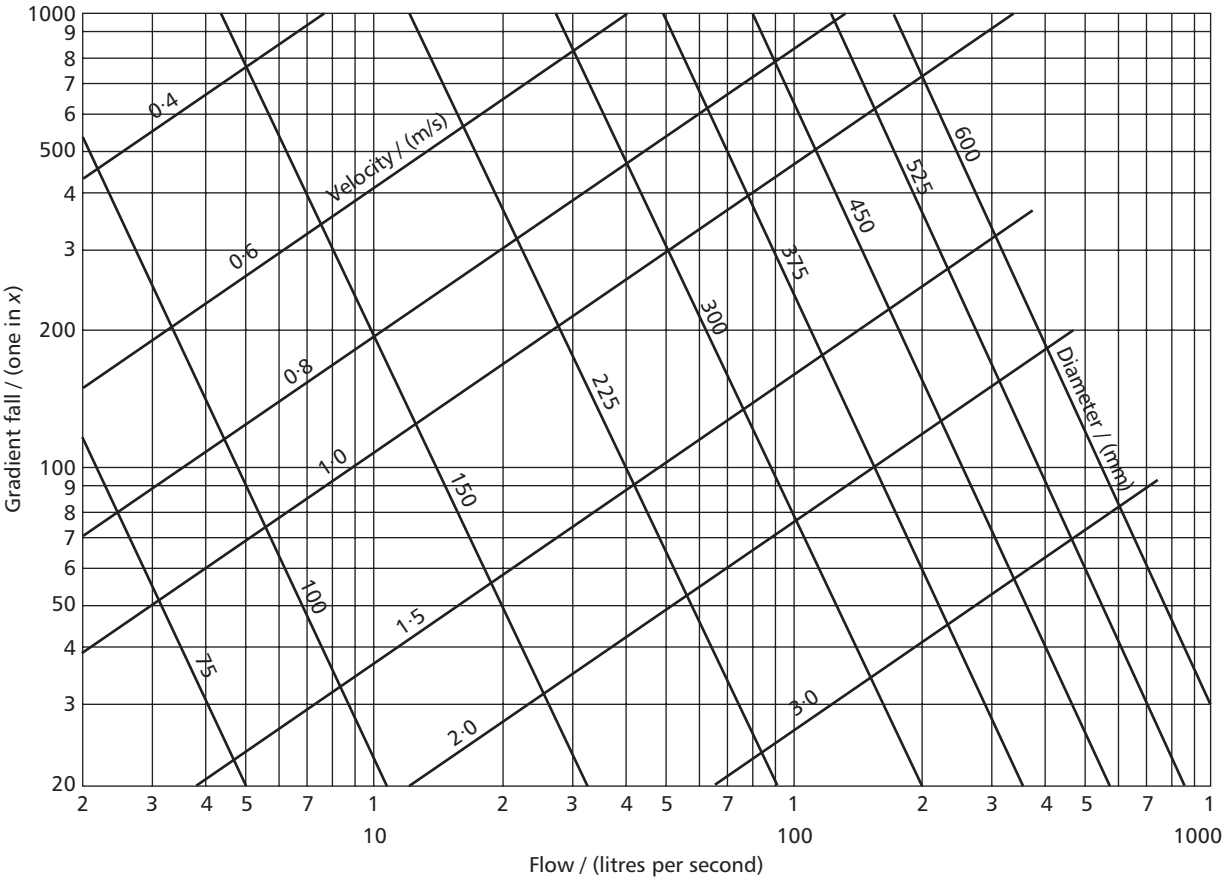
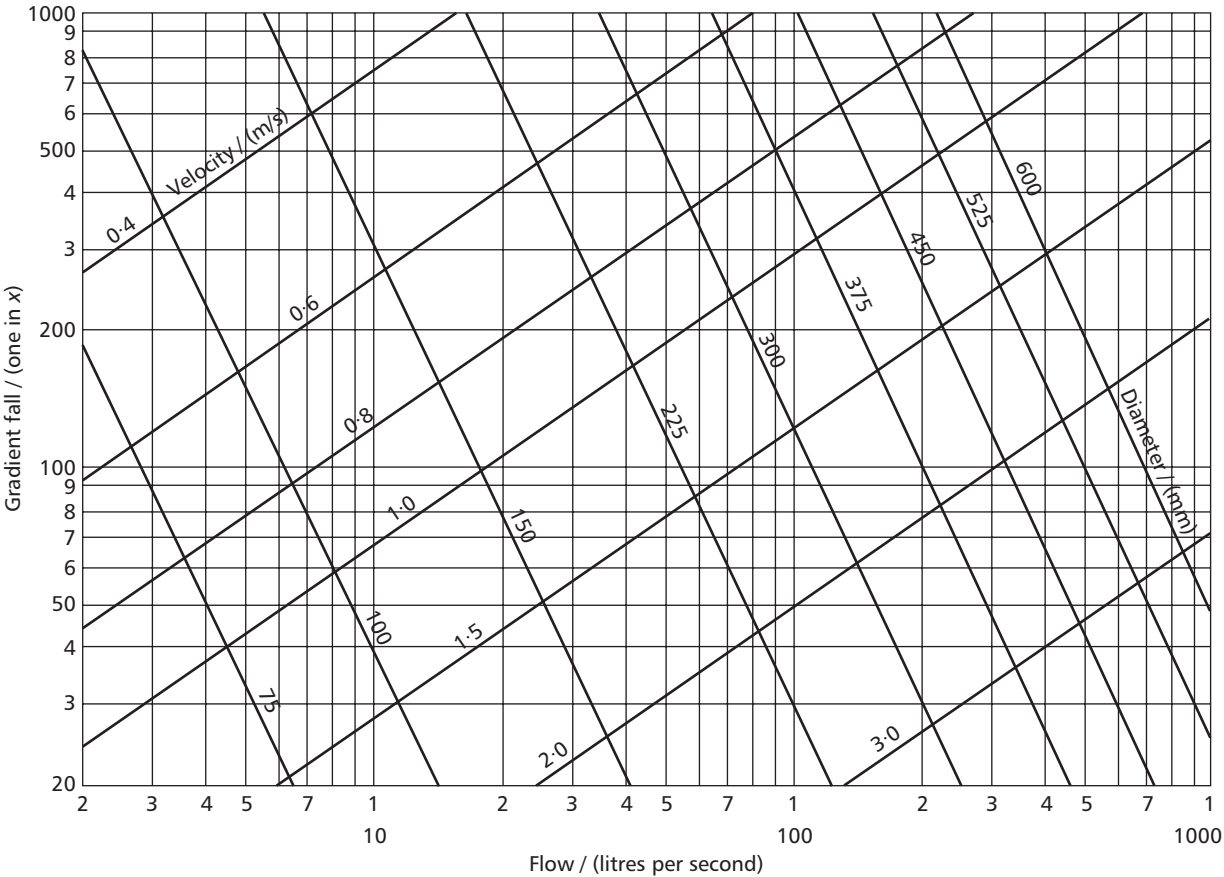


Figure 4.6 Sewage flow in pipes ($k_s = 0.60 \text{ mm}$) (top: 60% flow; bottom: full bore flow)

The method and standard of treatment in a grey water system generally varies with the size of the system. Larger grey water systems that supply more than one property tend to use more sophisticated treatment methods than smaller, individual systems.

Treatment can be classified as 'physical' or 'biological'. Physical treatment is common in small-scale systems and usually consists of a basic filtration process. Biological treatment is generally used in larger systems and works in a similar way to the processes used at a sewage treatment works. Some systems use a combination of the two methods, giving a 'bio-mechanical' process.

Basic physical systems tend to require the use of chemicals similar to bleach to stop the growth of bacteria while the water is in storage.

A more complete description of grey water recycling may be found in chapter 5.

4.3.8 Internal drainage

More detailed guidance on both internal and external above ground drainage is given in chapter 3; this section seeks to highlight particular specialist design issues such as commercial kitchens.

4.3.8.1 General design and layout considerations

Each installation requiring drainage will need to be assessed on a site-by-site basis as there is no preferred methodology to suit all applications. Depending upon the application, the layout of room, plant and equipment, point gullies, linear drainage or a combination of the two may be appropriate.

Key areas for consideration are covered in the following sections.

4.3.8.2 Hydraulic capacity

For many internal drainage applications, hydraulic capacity does not present a particular problem as many drainage points are provided for wash down only or continual processes where the flow rates are relatively low. By way of example, a typical cold water tap on a 15 mm pipe supply will deliver a maximum flow rate of around 0.25 litres per second.

Some kitchens are configured so that tilting kettles, for example, have their waste water contents discharged to a gully adjacent to the appliance. In these applications, the receiving gully or drain may have to accommodate over 100 litres of water within a few tens of seconds. It is generally not feasible to provide a drainage system with a hydraulic flow rate of up to 10 litres per second, therefore the receiving gully is then generally provided with an adequate volume to safely accommodate the bulk of the (usually near boiling) discharge until the outlet can safely discharge the waste.

Where there is either a short term potential for a burst of hydraulic flow or continued near-capacity flows to the receiving drainage element, then the designer should

assess the risks and consequences of temporary flooding of the area.

4.3.8.3 Foul air traps

Drainage gullies and channels can be conveniently supplied with integral in-line foul air traps and provide quick and convenient access for service and cleaning. In-line traps will, however, generally result in a lower flow rate through the drain than straight pipes. For high flow rate applications, P-traps provided in the slab will significantly increase flow rate performance over in-line traps, and these are less likely to be blocked by solid detritus in the waste stream, though traps should nevertheless be removable or be provided with a cleaning eye.

It is not uncommon for kitchen staff to remove foul air traps to increase flow rate and/or dispose of unwanted food residues into the foul drainage system. Exposing the foul drain and associated odours to the food processing area significantly increases risks to health and hygiene and should be avoided, therefore staff training issues should be addressed.

BS EN 1253-1⁽³²⁾ states that trapped gullies for waste water should provide a minimum depth of water seal of 50 mm.

4.3.8.4 Strainers and filters

Sink strainers and gully filter baskets are provided to prevent solid detritus entering the foul drain that could lead to blockage and subsequent flooding in the food preparation area. As with removable foul air traps, it is not uncommon for kitchen staff to remove the filters and strainers to increase flow rate of wastewater into the drainage system to save them time.

At all times, strainers and filters should be retained and maintained in sinks and gullies to prevent blockage. Staff training and regular housekeeping regimes will pay immediate dividends.

4.3.8.5 Corrosion resistance and material compatibility

Drainage products should be selected so as to ensure they are and will remain durable and corrosion resistant for the selected application (see also chapter 12). In corrosive or potentially corrosive applications, the following factors should be taken into consideration:

- the chemical(s) exposed to the drainage system, either present within the effluent (including any cleaning materials used) or within contaminated ground through which the drainage system may pass
- the concentration of the chemicals
- the temperature of the solutions subject to the drainage system
- the exposure time of the chemicals to the drainage system.

It is not always easy to obtain the above information from the client or specifier as such data is often unknown at the

design stage. The temperature of the solution(s) is often overlooked in the selection process but is highly important as most materials corrode faster at temperatures above ambient.

Temperature can also play an important part on the integrity of the installation due to thermal expansion if the drainage system is subjected to hot wastewater. Plastics materials, whilst exhibiting quite good general corrosion resistance, have far higher coefficients of linear expansion in comparison to steel and copper. The various types of steel which may be used, including stainless steel, have similar expansion coefficients to concrete and will be less problematic in this regard than plastics.

There is a common misconception that stainless steels are immune to corrosion. Stainless steels will corrode and stain if they are not used correctly and it is suggested that advice be sought from the manufacturer as to the correct material specification. Seal and gasket materials also need to be considered in the material specification to ensure reliable installation integrity.

For kitchen and food processing applications, '304' grade austenitic stainless steels containing around 18% chromium and 8% nickel in the alloy are generally more than adequate for drainage applications. For swimming pools where the drainage system is exposed to chlorinated pool water, the superior '316' family of stainless steel should be used as the corrosion resistance is significantly enhanced with the addition of molybdenum in the alloy.

Clients and specifiers should avoid the temptation to reduce installation costs by incorporating different metallic materials in any drainage system. For example, if a kitchen has stainless steel channels fitted, it is not recommended that lower cost galvanised steel gratings are installed as the zinc/stainless steel interface, since the zinc will form an anode adjacent to the stainless steel and galvanic corrosion will occur.

4.3.8.6 Gully and drainage gratings

Grating materials

To minimise risks to health and hygiene, particularly in food preparation areas, careful consideration should be given to material selection and design of drainage components. Stainless steel is durable and can be readily cleaned using sanitising agents and cleaning materials that are used in kitchen environments without detriment to the products.

Gully and linear drainage gratings should be selected not only to satisfy load class and hydraulic requirements, but also to avoid design features that present voids on the underside of the grating. Such features allow pathogens to develop and therefore require greater attention for cleaning. Gratings of this nature are best suited for external use.

Depending upon the application, mesh or ladder gratings are preferred for their hydraulic capacity and convenience to clean thoroughly. Electropolished stainless steel gratings not only have an attractive lustre, but the electropolishing effect produces a flatter, smoother surface

thus further reducing the opportunity for bacterial growth.

Grating load classes

It is important to fully assess the application environment and what traffic will access drainage system gratings, otherwise damage may inadvertently occur to gratings in service which may well in turn present a pedestrian trip hazard. Consideration must be given to the vehicle type accessing the drainage system.

Solid wheeled vehicles such as fork lift trucks and pallet trucks present much higher bending, torsion and shear stresses to the grating than pneumatic tyres, so this should be taken into account during the selection process. An assessment of maximum vehicle wheel load is recommended as opposed to axle or total laden vehicle weight. Fork lift trucks generally have most weight applied to the front wheels, so total vehicle weight is misleading, particularly if the vehicle has solid tyres which increase the stresses to the gratings.

Unfortunately, for historical reasons, application variances and materials specific reasons, there is no one standard reference document detailing load class criteria covering all building products and applications. This can be confusing for the specifier.

Standard and bespoke drainage gratings and covers can be manufactured to the specification published by the Fabricated Access Covers Trade Association (FACTA)⁽³³⁾. FACTA was formed to represent the fabrication industry in response to the publication of BS EN 124⁽³⁴⁾ (now superseded), which was a standard that primarily addressed rigid cast iron products and did not adequately account for 'elastic' materials such as steels and aluminium alloys. Additional load classes were also introduced to fill-in between the wide gulf of A15 and B125 load classes described in BS EN 124.

The method of assessing load class does vary across the applicable standards, however. Table 4.4 provides a practical approximate comparison to assist the specifier. If there is any doubt, the specifier should refer to the specific standard for further details or consult with the manufacturer for advice and guidance.

Slip resistant drainage gratings

The Health and Safety at Work etc. Act 1974⁽²⁰⁾ (HSWA) requires employers to ensure the health and safety of all employees and anyone who may be affected by their work and this includes taking steps to control slip and trip risks. The Management of Health and Safety at Work Regulations 1999⁽³⁶⁾ build upon the HSWA and include duties on employers to assess risks (including slip and trip risks) and where necessary take action to safeguard health and safety. Furthermore, the Workplace (Health, Safety and Welfare) Regulations 1992⁽³⁷⁾ require floors to be suitable, in good condition and free from obstructions as people must be able to move around safely.

Drainage gratings for point gullies and linear drainage systems for kitchens, pedestrian areas, commercial and industrial buildings are available in a wide variety of designs to accommodate load class, vehicular traffic,

Table 4.4 Comparisons of load class for drainage covers

Application icon	BS EN 1433 ⁽³⁵⁾ (Drainage channels) and BS EN 124 ⁽³⁴⁾ (Manhole and gully tops)	BS EN 1253 ⁽³²⁾ (Gullies for buildings)	FACTA load class ⁽³³⁾ (all products)	Slow moving wheel load (tonnes)	
				Pneumatic tyres	Solid tyres
	—	H1.5	—	Non-load bearing	
	A15	K3	A	0.5	N/A
	—	L15	AA	1.5	N/A
	—	—	AAA	2.5	0.5
	B125	M125	B	5.0	0.75
	C250	—	C	6.5	1.0
	D400	—	D	11.0	3.0
	E600	—	E	16.0	5.0

hydraulic capacity, corrosion resistance, barefoot and shoe safety. Some drainage grating designs are specifically designed to offer a low pedestrian slip potential in food processing areas, for example, by virtue of the specific design on the upper surface. However care must be taken if such gratings are subject to fork lift truck or pallet truck movements where turning truck wheels can damage the grating construction.

Manufacturers and suppliers have a duty to ensure that their products are safe and must also provide adequate information about appropriate use.

BS EN 1253: *Gullies for buildings*⁽³²⁾ does not have a requirement for slip resistance of gratings. However, both BSI and CEN are taking a closer interest in slip resistance performance for a variety of drainage products, but this change of emphasis may take some time to implement.

4.3.8.7 Fire protection

There is now a wealth of material to consider regarding fire safety. The Regulatory Reform (Fire Safety Order) 2005⁽³⁸⁾ sets out ways to reduce both hazard and risk where there is a likelihood of fire.

Building Regulations Approved Document B: *Fire safety*⁽³⁹⁾ incorporates design guidance where, given certain

building types, compartmentation is used to reduce fire propagation. The efficacy of such schemes is dependent upon both integrity and insulation.

In the case of fire, integrity prevents the passage of flame and hot gas from the exposed to the unexposed side of any material or structure, whereas insulation restricts temperature rise to specific levels. The testing protocol is described in BS EN 1366-1⁽⁴⁰⁾. Preserving the integrity and insulation performance of the separating element is problematic if gullies are used for other than ground floor drainage. In effect, they present an 'open ended' pipe penetration when the water trap is depleted and the connecting pipework has been destroyed and is, indeed, the worst-case scenario.

Temperatures in building fires can reach 1000 °C. Gullies manufactured from cast iron and stainless steel are deemed fireproof, but materials such as aluminium alloys and plastics are not. Protection against fire is augmented by an intumescent cartridge that sits in the outlet spigot of the gully. This material rapidly expands at around 150 °C, closing off the system completely.

Fire gullies should be independently tested to BS EN 1366-3⁽⁴⁰⁾ and classified to BS EN 13501-2⁽⁴¹⁾.

A typical specification for a fire resistant floor gully might be described as 'EI 120-U/U', where 'E' denotes 'integrity, prevention of passage of flame and hot gas from exposed to unexposed side', 'I' denotes 'insulation, restriction of temperature rise (180 °C above ambient of the upper surface)', '120' indicates the number of minutes achieved to pass fire test, and 'U/U' indicates that the gully is uncapped both inside and outside the furnace.

Fire resistant gullies should be selected to provide the appropriate degree of protection for the application in the event of a building fire.

Active valves

Users should consider the extra efficiency of active valves, beyond the requirements of Building Regulations or British/European Standards, see Table 4.5. The control electronics of such units can contain audible alarms, diagnostic information and, for commercial applications, integration with building management systems. Product manufacturers may also provide optional chambers to house the device if sited below finished floor level. In such applications a valve may be sited externally. In this case, where an active Type 3 valve is used it is important to accommodate ingress protection to IP67⁽⁴²⁾, as the chamber may be subject to flooding.

4.3.9 Discharge of fats, oils and grease to drains

In any foul sewerage network the presence of fats, oils and grease (FOGs) is likely as they are an obvious constituent part and by-product of the food production and preparation process. This is particularly a concern for commercial kitchens and also dairies. The inevitable loading on our finite drainage infrastructure with FOGs results from both population and economic growth. The trend towards increased numbers of businesses that offer choice in what and when we eat has grown dramatically over the last two decades to the point where FOGs now pose a considerable burden on the sewerage infrastructure and the environment.

FOGs are usually discharged as molten liquids, but the effluent cools rapidly in the drainage system and fats tend to solidify and thence cause obstructions and ultimately blockages. Such obstructions may be difficult to clear since the common method of clearing blockages involves the use of high pressure jets of cold water. This technique

may temporarily break-up the blockage but will not break down the fat in its solid form; ultimately this method will only move the problem to another part of the drainage system.

4.3.9.1 Guidance and legislation

Water UK reports that every year, there are around 200 000 sewer blockages in the UK, of which up to 75% are caused by FOGs and furthermore, blockages are responsible for approximately 55% of sewer flooding and account for over 3000 property flooding incidents⁽⁴³⁾. Blocked drains within the food preparation area clearly present a risk to hygiene and under the Food Safety Act 1990⁽⁴⁴⁾ local authorities have the power to inspect premises and any problems arising from FOGs resulting in a failure to comply with the Food Hygiene Regulations 2006⁽⁴⁵⁾ could result in prosecution or an emergency prohibition order preventing trading from the premises.

The impact of problems caused by FOGs can be categorised at national, regional and local level. The key items of legislation, namely the Water Industry Act 1991⁽³⁾ and the Water Resources Act 1991⁽¹⁷⁾, make it an offence to impair the operation of a sewer and to prevent pollution of controlled waters respectively. Furthermore, the UK government estimates that £15 million is spent each year on clearing blockages nationwide⁽⁴⁶⁾.

Some degree of localised control is afforded by the Building Regulations for England and Wales⁽¹¹⁾* whereby Approved Document H⁽²⁵⁾ advises that commercial hot food premises should be fitted with a separator complying with BS EN 1825-1⁽⁴⁷⁾, or other effective means of grease removal (e.g. emulsifying enzyme dosing units, with or without a grease trap unit). Scottish Building Standards⁽¹²⁾ make the mandatory provision that for non-domestic properties, facilities for the separation of FOGs are provided and specifically recommend that the use of emulsification agents are not used as they can cause problems downstream by FOGs de-emulsifying and causing blockages.

4.3.9.2 Removal of FOGs

A traditional means of catching and removing FOGs is the use of a grease trap, of which there are various types. Protection of the drainage system is effected by siting a grease trap at a strategic point to provide a known location

* Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

Table 4.5 Active valves and fire gullies (source: BS EN 13501-2)⁽⁴⁰⁾

Valve configuration		Grey water (passive actuation)			Black water (active actuation)
Position	Type	1 × auto	1 × auto plus emergency combined	2 × auto plus emergency combined	1 × auto plus separate emergency
In-line	0	●			
In-line	1		●		
In-line	2			●	
In-line	3				●
Gully	4		●		
Gully	5			●	

for FOGs to solidify. The grease trap must then be periodically emptied, the fat and grease deposits removed for recycling or safe disposal. This charges the system owner with a maintenance responsibility and possibly the adopting authority with an enforcement role.

Some manufacturers of grease traps recommend that the effectiveness of grease traps may be improved by dosing the system with enzymes to break down grease. This treatment prolongs times between emptying of the grease trap, but is again reliant on the owner of the system to ensure that correct dosing is carried out along with periodic emptying.

When incorporating grease traps into a design, the engineer should seek appropriate guidance from the manufacturer as to the correct siting of the trap. If too close to the discharge, the effluent will not have time to cool sufficiently for the fat and grease to solidify in the trap and fat deposits will occur elsewhere in the drainage system. If it is sited too far away from the source the opposite problem may occur. Caution should also be exercised if a warm discharge, e.g. from a dishwasher, is located near the grease trap. For similar reasons it is also necessary to exercise caution when making alterations to systems with existing grease traps.

4.3.9.3 Grease separator hardware

Grease separator hardware design and testing, whilst anchored by BS EN 1825⁽⁴⁷⁾, has developed over the years with increasing levels of automation available. The question for the specifier is to what degree these competing technologies differ in performance and cost, in both the short and longer terms.

Biological- or enzyme-based dosing units are commonplace in the UK, and can share in common a trap designed to remove large detritus, and allow a prior injected enzyme-based biological agent to take effect. Such agents act on the FOGs in two ways: firstly to break down the long chain molecular structure of the fats, preventing grease solidification though this emulsification process and thus reducing the incidence of drain blockage locally; secondly to (in part) convert the FOGs into their chemical constituent parts increasing chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the process. This process is affected by the rapid growth of 'helpful' bacteria which actively feed on the FOGs. As such, the process is heavily dependent on temperature, availability of oxygen and food, all of which are a function of the dwell time in the grease trap unit. Once out of the unit and in the drain the variability of these factors may reduce efficiency.

The European favoured alternative (BS EN 1825⁽⁴⁷⁾) relies on the relative density differentials naturally present in the influent. FOGs, whilst wide ranging in relative density will always be less dense than water and float on the surface of the water within the separator unit. Similarly, solid particulates common to most cooking processes are denser than water and sink to the separator base. It follows that the Standard prescribes the various separator 'compartment' dimensions, which are a function of the required flow through the separator. Conveniently the design section of the Standard allows the specifier to arrive at a single figure expressed as nominal size (NS)

which relates to the flow through the separator in litres per second. A secondary 'figure' is also derived that relates specifically to the size of the silt retention compartment, thus a typical specification would read NS7-700, relating to a separator capable of sustaining 7 litres/s flow and with sludge capacity of 700 litres.

4.3.9.4 Design decisions

A key challenge facing the specifier is establishing the size of the unit required. The ideal case, that of new-build, affords the designer access to known data regarding flow from various kitchen appliances and the Standard accommodates design where these data are known. If such information is not known, but the nature and number of appliances is (e.g. two tilting boiling pans, one rinse sink and one dishwasher), then the Standard stipulates generic nominal outputs for such appliances. The worst case situation is that of retrofit, where many appliances are not catered for in the generic description, is also accommodated by the Standard. Here, reference is made to the establishment type (hotel, factory canteen or other), 'meals per day' and the number of kitchen operational hours per day. Given these data the specifier can easily arrive at the nominal size of separator using the algorithms described in the Standard.

Grease separators and trapped enzyme systems tend to be physically large units requiring space either above or below ground installations, not only for installation but also for access for servicing. Direct dosing enzyme systems provide a solution to the problems of restricted space but do not manage the solids entering the waste pipes or from preventing FOGs entering the drainage system as they are largely in an emulsified form.

Ideally, FOGs should be prevented from entering the drainage system in the first place to prevent blockage of waste pipes and sewerage infrastructure. Removal of the source of food for rodents will also reduce the possibility of infestation in and around the kitchen.

The use of food waste disposal units (macerators) in commercial kitchens is controversial. They present a convenient method of solids waste disposal but, in so doing, can present the sewerage undertaker with potentially large volumes of sludge which can be particularly problematic at the sewage treatment plant in densely populated areas. Additionally, macerators can artificially occupy downstream grease separators/traps with sludge and emulsify FOGs, causing a reduction in separation efficiency.

Water UK recommends that food macerators are not installed and that waste food should be placed in the bin and collected by a commercial waste contractor⁽⁴³⁾. Used cooking oils and fats should likewise not be disposed of in the general waste stream or with the rest of the kitchen waste as this can cause odour and pollution and waste contractors may refuse to remove such waste.

The Environment Agency encourages composting of food wastes but acknowledges that this is not always practicable. There are a growing number of companies who will collect food waste for composting⁽⁴⁸⁾. Some restaurant chains have contracts with companies who take

their waste for animal feed, but failing that, the only option is to 'bag it and bin it'.

In terms of ranking, the preferred grease management methodologies should be:

- grease separators to BS EN 1825⁽⁴⁷⁾
- bio-chemical dosing systems
- combinations of the above for some applications.

It is important to note that BS EN 1825 does not relate to biological units or mechanical skimming systems. Whilst Part H of the Building Regulations for England and Wales^(12,25) infers that such units have a place in the commercial premises, it is clear that BS EN 1825 provides the specifier with a useful tool to assess the critical issue of size.

4.4 Pumped systems and vacuum systems

When it is not possible to effect an efficient drainage or sewerage system by gravity, usually due to differing ground levels, pumping is the usual solution, though vacuum systems are also an option. The main reasons why a pumped or vacuum system may need to be included in a drainage or sewerage scheme are:

- where a site has insufficient gradient for part of a drainage system to connect to a sewer by gravity
- where the lowest sanitary appliances or surface water gullies are below the sewer level
- where the local sewer system is known to be subject to surcharging; which could put the building at risk to flooding, and where anti-flood valves do not provide sufficient protection
- where a building has sanitary appliances or surface water gullies below ground level but above the level of the sewer, i.e. within a basement, and the surcharge risk is unknown; in such cases, the surcharge level should be assumed to be to road (ground) level.

Although the sewerage undertaking may provide historic surcharge level data, variations in foul and surface water flows, due to future development and climate change should be taken in to account, when considering the use of pumped or vacuum systems.

The following sections provide general guidance on the use of both types of system and the relative advantages and disadvantages of each.

4.4.1 Pumped systems

Pumped systems require pumping stations. Unlike gravity systems, which are designed to be self-cleansing and thus largely maintenance free (as described in section 4.3.2), pumping stations have definite maintenance requirements. They can also create odour, noise and vibration nuisance and are prone to mechanical failure or breakdown from time to time. Pumped systems should

therefore be considered only if a gravity system is not practicable.

Detailed information on the design and installation of pumped drainage systems is given in BS EN 752⁽²⁾ (for external pumped systems) and BS EN 12056⁽²⁸⁾ (for internal pumped systems). In addition to these documents, BS EN 12050⁽⁴⁹⁾ covers packaged pump stations. For larger systems, particularly those incorporated into adopted drainage systems, see *Sewers for Adoption*⁽²⁷⁾.

4.4.2 Pumping stations

This section focusses on the types of pumping station likely to be encountered in public health engineering projects rather than in civil engineering works, guidance for which may be found elsewhere.

The adopting authorities (see section 4.1.4) will agree to adopt pumping stations for public sewerage systems, providing the case is demonstrated that a gravity system is not feasible. If the pumping station is required to be adopted, therefore, the adopting authority must be contacted at the earliest opportunity to discuss the proposals and obtain details of any specific requirements. Smaller pumping stations for private sewers or drainage schemes will not generally be adopted and must be maintained by the property owner.

Pumping stations, by their very nature, must store a quantity of effluent. The storage requirement can be accurately sized for foul water sewers where flow rates are relatively constant and known (or can be estimated with a degree of confidence). Pumping stations dealing with surface water, however, need to incorporate very large storage capacities due to the uncertain nature of weather conditions, and, during extremely heavy rainfall these may be liable to surcharging. Installations that pump surface water are therefore very difficult to have accepted for adoption and consequently should only be considered in exceptional circumstances.

4.4.2.1 Types of pumping station

Packaged pump units

These range from units for a single appliance (or small group of appliances) to units serving whole buildings or residential estates. For the purpose of this document the single appliance type units are not covered in any detail.

Pumping stations that receive inflow from several appliances or from whole buildings (such as hotels etc.) can be floor mounted, generally with polypropylene tanks and either semi-submersible or free standing pumps, and are usually installed internally in purpose-built plant rooms, see Figure 4.7. The units are designed such that pumps and valves are accessible for maintenance without the need to enter the tank.

Alternatively, where it is not possible to have a floor mounted pump station, due to spatial limitations or inflows in excess of the tank capacity of the floor mounted units etc., the pumping station can be buried. Buried pumping stations have submersible pumps, with guide

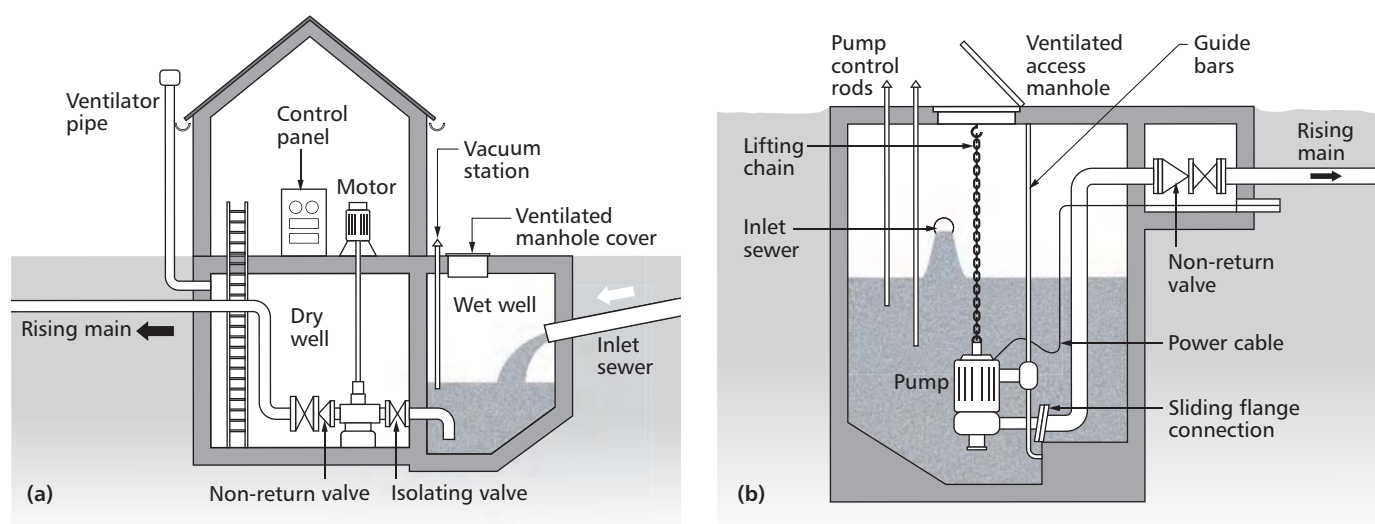


Figure 4.7 Typical pumping station installations; (a) free standing pump, (b) submerged pump

rails and lifting chains to facilitate maintenance, and chambers generally constructed from glass reinforced plastic. The valves are located at high level in the chamber and are accessible via an access cover.

Packaged pump stations come complete with all pumps, controls, control panel, isolation and non-return valves and other ancillaries, and are factory tested prior to dispatch. The installation will generally be carried out by the builder to the manufacturer's installation specification and the manufacturer provides commissioning services, which can be extended to maintenance service contracts.

Packaged pump stations are generally available from major pump manufacturers or pump supply companies, who will, given the system performance requirements, assist in the sizing and selection of the tank/chamber and pumps. They will also require invert levels and sizes of the vent, inflow, discharge pipe and cable duct connection.

Non-packaged pumping stations

Sometimes site constraints or construction requirements mean that packaged units are not practical. In such situations, bespoke pumping installations can be produced whereby the pumps, controls, valves and ancillaries etc. (provided by the pump manufacturer/supplier) are installed in either a chamber, constructed from reinforced concrete and cast as part of the structural slab (if internal, for example) or in a chamber similar to a conventional manhole, from brick or concrete ring. Generally, the pump manufacturer or supplier will install the pumps in the pre-prepared chamber, as well as providing a commissioning service. The size and format of the pump chamber and size and location of the access points will need to be agreed with the pump manufacturer.

Adoptable pumping stations

These are constructed to meet the specific requirements of the sewerage utility companies and the design, construction and materials specification etc. are detailed in *Sewers for Adoption*⁽²⁷⁾ and the *Civil Engineering Specification for the Water Industry*⁽⁵⁰⁾. Adoptable pumping stations can be of either the packaged or non-packaged

type, and will always be buried externally in a land easement. An access cover or purpose built housing must be provided so that full 24-hour, 365-day access is available. For ease of access, stations are normally sited adjacent to a public highway, and the adopting authority would normally insist upon owning the land upon which the station is sited. There are, however, alternative arrangements and the adopting authority would be able to advise on these.

It must be noted that, although *Sewers for Adoption*⁽²⁷⁾ is regarded as authoritative, and has been approved by all the sewerage utility companies, each company has its own variations on design and specification etc. and must be consulted prior to commencing any design work.

On completion of the commissioning works, written confirmation should be provided by the manufacturer, for inclusion in the project operation and maintenance manuals.

4.4.2.2 Structural design of pumping stations

Advice from the project structural engineer must always be sought in all aspects relating to the integration of a pumping station into a building or the stability of a buried chamber. However, the engineer should be aware of some of the issues relating to pump stations.

With floor mounted units, as well as the weight of the unit itself, the weight of the effluent in the tank will have an impact on structural loadings. The weight when full, and location of the unit should therefore be communicated to the structural engineer.

If the site is subject to a high water table there will be a risk of flotation. Flotation occurs when the upward force exerted by the water pressure on the area of the sump base is greater than the downward force exerted by the structure and its contents (per m² over the base) and the whole assembly may tend to 'float'. The sump can be considered to be satisfactorily resistant to flotation if the downward force of the sump is no less than 1.25 times the upward force due to the water pressure.

4.4.2.3 General considerations for pumping stations

Pumping installations should take into consideration not only the operation and maintenance requirements (including the health and safety impact on the operating staff and public), but also the environmental impact of its construction and operation and the risk and consequences of failure.

The pipework to the pump system should be designed and installed in accordance with BS EN 752⁽²⁾ or BS EN 12056-4⁽²⁸⁾ (as applicable).

The discharge pipework should be as short as possible, self draining, not reduce in diameter nor be restricted in the direction of flow and connect to a looped anti-flooding connection over the top of a ventilated drain. The connection should be in the direction of flow, so as not to impede the normal flow conditions within the drain.

The pump chamber should be ventilated to atmosphere, preferably at roof level. This can be via a dedicated ventilation stack or via a ventilation stack connecting to the dry section of a soil vent pipe; air admittance valves must not be used. For small pump stations, if it is not possible to vent to atmosphere, carbon filter vents that terminate within the building are available. Carbon filter vents should only be used on limited application sumps (usually installed directly adjacent to the sanitary appliance) in accordance with BS EN 12050-3⁽⁴⁹⁾, and then preferably not within buildings used by the public. In all other cases the vent pipe should be terminated outside the building. These require access for maintenance and replacement, and need to be installed above the flood level of the pump station. Consent from the approving authority must be sought before considering these.

For all but the smallest installations, the pump installation should ideally be a two-pump system, operating as duty/standby with auto-changeover to avoid excessive wear on one of the pumps. Larger installations will have more pumps, operating as duty/assist/standby etc.

The levels in the sump can be controlled by float switches, probes or level controls built into the pump and set to turn the pumps on and off as the water level in the sump varies. Regardless of the level control method, they will all be wired back to a control panel. The panel should preferably be adjacent to the pump installation, in a well ventilated, dry location. If this is not possible and the panel is located remotely from the pumps, then a suitably IP (ingress protected) rated isolator should be provided adjacent to the pumps, for maintenance purposes.

The control panel should provide a high level pump and/or power failure alarm, but may also include an 'hours run' meter for each pump etc. Building Regulations Approved Document H⁽²⁵⁾ requirements for 24-hour emergency storage, or alternative secondary power supply for the pumps should be noted*. The panel should have a battery back-up or alternative electrical supply, in case of power outages, and be linked to a BMS to identify alarm status. Where the pump station and control panel are external and isolated, the control panel should be linked

to a nominated contact via telemetry and be provided with a visual alarm, to show when in failure mode.

Due consideration should be given to the acoustic isolation of the system from any occupied structure, to prevent noise from the pumps starting and the water flow through the pipes being transferred through the building. This may include anti-vibration floor mounts and flexible joints on the inflow and discharge connection to the tank.

Purpose built plantrooms should be large enough to afford adequate space around and above the unit or access cover, for maintenance; nominally 600 mm is considered the minimum. Consideration should be given to pump removal which, depending on the pumps installed, could require additional headroom for lifting equipment or the installation of a lifting beam. The plantroom should be dry, well lit and well ventilated. Consideration should also be given for the provision of a hose union tap (meeting the requirements of the Water Supply Regulations 2010⁽⁵¹⁾) in or near the plantroom, for washing down spillages that may occur during pump removal and maintenance.

Due consideration must be given to where the sump should be sited. Ideally, it should be placed equidistant from the heads of the inlet branches to avoid excessive invert depths. This may not always be feasible and a number of sumps may need to be considered to avoid the expense of deep sumps and the associated potential problems of ground water and stability.

Although most of the larger glass-reinforced plastic (GRP) pump stations have the valves installed in the chamber; where required and, in particular, with adoptable pump stations, the valves can be installed external to the chamber in manholes to ensure ease of access for maintenance.

For larger installations, particularly where immediate access to the pumps for maintenance is required, the provision of separate wet and dry wells should be considered. The provision of a dry pumping well also provides a housing for controls and maintenance equipment. The choice between submersible or dry pumps depends on many factors including capital cost and the space required by the pumps.

On completion of the installation, the entire system should be tested in accordance with BS EN 12056⁽²⁸⁾, BS EN 752⁽²⁾, BS EN 1610⁽²⁴⁾ and BS EN 12050⁽⁴⁹⁾ to ensure it is watertight and that all components are working correctly. The electrical components should be tested by an approved electrical engineer.

4.4.2.4 Inspection and maintenance of pumping stations

BS EN 752⁽²⁾ and BS EN 12056⁽²⁸⁾ provide guidance on the minimum maintenance requirements including:

- time intervals between maintenance checks
- works to be included in the maintenance check
- keeping a maintenance log
- recommendations for a maintenance contract.

* Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

All maintenance work undertaken on a pump station should be carried out by suitably qualified operatives and using the appropriate safety equipment, i.e. due consideration given to working in confined spaces and working in areas contaminated with faecal material etc.

4.4.2.5 Sizing and selection of pumps and sumps

Building Regulations Approved Document H1^{(25)*}, provides limited requirements for drainage pumping installations, as follows:

- the sump volume should incorporate provision for 24-hour emergency storage; alternatively, a secondary power supply for the pumps may be acceptable to the relevant authority
- for domestic installations the total inflow should be taken as 150 litres per person per day
- for non-domestic installation, the total inflow should be calculated based on BS EN 12056⁽²⁸⁾ or BS EN 752⁽²⁾, as applicable and on a pro-rata basis where only a proportion of the foul water is pumped
- controls should be arranged to optimise pump operation.

The design criteria for the pump main and sump are outlined below; for more detailed information on pump selection and sizing, see chapter 6.

Pump sizing

The main hydraulic requirements, in determining the pump duty are:

- total inflow, Q_i (litre/s): determined in accordance with BS EN 752⁽²⁾ and BS EN 12056⁽²⁸⁾, as applicable
- total head, H_{tot} (m)
- duty flow of pump, Q_p (litre/s)
- duty head of pump, H_p (m).

Generally, Q_p should be equal to Q_i , although in special circumstances Q_p may be less than Q_i (see BS EN 12050-3) and, of course, $H_p \geq H_{tot}$.

When considering the pump selection, minimum energy usage should be taken into account.

Useful sump volume

The useful sump volume is the volume between the high level and low level operating points, as set by the pump on/off level controls within the sump. The volume below the low level operating point is ignored in the calculations, as it is only required for an adequate water depth at the pump suction intake.

Approved Document H⁽²⁵⁾ specifies that the sump should be sized to allow for emergency storage over and above the normal working volume. BS EN 12056⁽²⁸⁾ recommends that the useful sump volume V in litres be determined by:

* Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

$$V = T \times Q_p \quad (4.3)$$

where V is the useful pump volume (litre), T is the pump run time (s) and Q_p is the duty flow of the pump (litre·s⁻¹).

BS EN 12056 gives minimum pump run times based on pump motor power. These values, if used exclusively, may give rise to small sump volumes and this will lead to an excessive number of pump starts and consequently excessive pump wear. Run times should be as recommended by the pump manufacturer or should be limited to between 10 and 15 starts per hour to minimise wear etc.

Although Q_p should be equal to Q_i , in sizing the useful sump volume the most economic sump volume from a pumping viewpoint can be found when $Q_p = 2 Q_i$, and this gives rise to the expression:

$$V = \frac{t \times Q_p}{4} \quad (4.4)$$

where t is the pump cycle time (minutes).

If the number of pump starts per hour (N) is:

$$N = 3600 / t \quad (4.5)$$

then:

$$V = \frac{900 \times Q_p}{4} \quad (4.6)$$

However, using this method needs to be considered carefully, as Q_p may exceed the capacity of the receiving drain or sewer or exceed the consented discharge rate. The flow in the receiving drain should not exceed 70% of its pipe full capacity, this figure being made up of 100% of Q_p plus any gravity inflow. If there is more than one pump station discharging to a single receiving drain, then the 70% capacity should comprise 100% of the largest pumped flow plus 30% of the sum of the other pumped flows, plus any other gravity flows.

The sump in a foul drainage system should not be oversized, as this can lead to septicity and result in health risks. Septic conditions typically arise when raw sewage is retained for too long and begins to be anaerobically digested, and this process is accelerated when ambient temperatures exceed approximately 20 °C. Septic sewage generates hydrogen sulphide, which in turn oxidises to form sulphuric acid and this can cause damage to the concrete and metal surfaces of the pump chamber. Septic sewage also produces unpleasant odours, methane gas and dangerous working conditions; it is therefore undesirable and is to be avoided. The period of retention of raw sewage in pumping mains should not exceed 8 hours.

4.4.3 Pumping mains

The pumping main (also known sometimes as the rising main) is the pipe that carries the pumped discharge from a pumping station to the main drain or sewer at a higher level. Connection should be made via an access chamber or manhole, which serves to neutralise the pump pressure. The pumping main operates under pressure both from the

head imposed by the pumps, and also from the static head due to the height difference between the high and low points in the pumping main. Thus the choice of pipework material and quality of workmanship are important.

4.4.3.1 Hydraulic design

The design of pressure pipes for pumping mains can be derived by the charts in BS EN 12056-4⁽²⁸⁾ or by use of standard hydraulic methods for pipes running full bore. The engineer should determine the equivalent friction head at the maximum chosen velocity for a given pipe diameter. The main size will depend upon the design flow rate and the resultant frictional resistance that is calculated. One or two recalculations may be required if the initial results are outside design limits.

4.4.3.2 Head losses in pipework

The Colebrook-White formula (see section 4.3.4) is now universally used in calculation of head loss in pipework systems. In its standard form, the formula can be difficult to use and manipulate. However, the use of computers and the advent of hydraulic software programmes have overcome these difficulties. This method is described in CIBSE Guide C⁽³⁰⁾, chapter 4 and Appendix 4.A2, along with an alternative equation by Haaland. When using the Colebrook-White formula BS EN 12056⁽²⁸⁾ suggests a kinematic viscosity (ν) of $1.3004 \times 10^{-6} \text{ m}^2\text{s}^{-1}$ (i.e. water at 10 °C) and full bore pipe flow.

Also acceptable, as a hydraulic method for the determination of friction head, is use of the Hazen-Williams formula, a form of which is given below with its numerical factors in metric units:

$$h = \frac{1128 \times 10^9}{d^{4.87}} \times \left(\frac{Q}{C} \right)^{1.8} \quad (4.7)$$

where h is the friction head loss per 1000 m of pipeline (m) of water, Q is the volumetric flow rate (m^3/h), d is the inside pipe diameter (mm) and C is the coefficient of friction.

Table 4.6 shows values of coefficients of friction (C) for a variety of materials typically used in hydraulic modelling programmes. For other pipe materials, the manufacturer should be consulted to obtain the correct value for C .

Note: the maximum permissible head loss per metre should be calculated using the head of the pump at the maximum flow rate, divided by the total equivalent length of the main.

4.4.3.3 Head losses due to fittings and valves

When calculating the frictional resistance, the engineer should also make allowances for losses at fitting and valves, and losses at entries and exits, as well as those losses arising from the frictional resistance of the flow in the pipe line. The method described in BS EN 12056-4⁽²⁸⁾ calculates the head losses of each individual valve and fitting in the discharge pipework up to the backflow loop and totals these using the following formula:

Table 4.6 Coefficient of friction (C) for Hazen-Williams formula

Pipe material	Condition	Coefficient of friction, C , for stated pipe diameter	
		< 300mm	> 300mm
Cast iron:			
— uncoated	New	125	130
	5 years old	120	—
	10 years old	110	—
	18 years old	100	—
— coated	New	135	140
Steel:			
— coated	New	135	—
— uncoated	New	140	145
— galvanized	Clean	120	—
Asbestos cement:			
— uncoated	Clean	140	145
— coated	Clean	145	150
Plastics	Clean	150	—
Concrete	Clean	110	115
Copper	Clean	130	—

Table 4.7 Resistance factors (ζ) for valves and fittings

Fitting	Resistance factor, ζ
Shut-off valve	0.5
Non-return valve	2.2
Bend:	
— 90°	0.5
— 45°	0.3
Free outflow	1.0
Branch:	
— 45° passage (flow merging)	0.3
— 90° passage (flow merging)	0.5
— 45° branch (flow merging)	0.6
— 90° branch (flow merging)	1.0
— 90° (opposite direction)	1.3
Increase in diameter	0.3

Note: relevant manufacturers should be contacted if specific, accurate data are required

$$H_{va} = \sum \zeta \left(\frac{v^2}{2g} \right) \quad (4.8)$$

where H_{va} is the head losses in valves and fittings (m), ζ is the dimensionless resistance factor for valves and fittings, g is the acceleration due to gravity ($\text{m}\cdot\text{s}^{-2}$) and v is the velocity in the valve or fitting ($\text{m}\cdot\text{s}^{-1}$).

Resistance factors for valves and fittings (ζ) for use with the BS EN 12056-4⁽²⁸⁾ formula are given in Table 4.7.

Once the total head loss due to fittings is determined, this figure should be added to the static head and friction losses due to flow, to obtain the overall head loss. Generally, fittings losses account for a small proportion of the total head losses and can, in some cases, be estimated, typically assuming 25% of the static head.

4.4.3.4 Flow velocities

Velocities in a pumping main must be sufficiently high to ensure self-cleansing is achieved. BS EN 12056⁽²⁸⁾ suggests that a minimum velocity of $0.7 \text{ m}\cdot\text{s}^{-1}$ should be maintained for prolonged flows. Velocities should not normally be permitted to exceed $2.3 \text{ m}\cdot\text{s}^{-1}$.

The velocity within the pumped main can be calculated using the methodology in CIBSE Guide C (as above) or using the Hazen-Williams method, for which the formula is given as:

$$v = 10.93 \times 10^{-3} \left(\frac{d^{0.63}}{4} \right) s^{0.54} \quad (4.9)$$

where v is the velocity ($\text{m}\cdot\text{s}^{-1}$), d is the pipe diameter (mm) and s is the hydraulic gradient, expressed as a decimal value (e.g. $1:100 = 0.01$).

4.4.3.5 Pumping main pipe size

BS EN 12056⁽²⁸⁾ provides guidance on pipe diameter, relative to the type of pump and waste being pumped, i.e. minimum diameters of DN 80 for non macerating pumps and DN 32 for macerating and non-faecal waste pumps. In all cases, guidance should be sought from the pump manufacturer on the optimum pipe size for the application, as well as the consideration of the velocities and head losses derived for the above.

4.4.3.6 Surge in pipelines

Pressure waves (water hammer), referred to as surge in pumping mains, can occur where the main is particularly long or where high velocities are used. The effects of surge on the pipeline can in time cause stress failure of the pipe material, fractured joints and unacceptable movement.

Computational analysis methods are now available that check the designed main so as to determine the likely effects of surge, and to enable the engineer to take precautionary design measures. Such analysis should only be undertaken if surge is considered a problem.

Measures that the engineer can take to lessen the effects of surge occurring in the pumping main include:

- avoid high velocities (above $3 \text{ m}\cdot\text{s}^{-1}$)
- select pumps which do not have a sudden, concussive shut-off, i.e. those with flywheels
- incorporate surge relief valves and appropriate regulating valves on the pipeline
- incorporate a vertical standpipe on the pumping main close to the pumps, thus acting as a shock accumulator.

4.4.3.7 Pipework materials

The materials for pumping mains must be capable of withstanding the maximum operating pressure, as well as the test pressure, which is 1.5 times the maximum operating pressure or the surge pressure, whichever is greater. The chosen pipe jointing method should not

incorporate support sleeves internally within the pipe (black MDPE pressure pipe with compression fittings is a good example of what *not* to use). Also bends should have a radius ('knuckle bends' should not be used), or two 45° bends should be used at each 90° change of direction.

Materials that can be used for pumping mains include the following:

- ductile iron
- glass reinforced plastic (GRP)
- polyethylene
- polybutylene
- PVC-U
- copper (rarely used due to cost).

The material selection for the pumping main must take in to consideration the nature of the fluid being pumped, its location within a building (e.g. will it be routed through trafficked areas where impact damage may occur or will acoustic treatment necessary etc?).

Where the pipework is to be buried, the engineer should refer to the site investigation report as no single pipework system is suitable for all soil conditions. Soil conditions can vary across a site, particularly on brownfield sites where the chemical and structural characteristics can vary considerably.

4.4.3.7 Structural design

For buried pipelines, the material selection must also take into account loads imposed by backfill and traffic, in particular construction traffic if the pipeline is part of an enabling works contract.

In most cases, detailed calculations on the bedding and backfilling will not be necessary; generally the only exception is where the pipework forms part of an adoptable installation. As such, reference to manufacturers' published bedding and backfilling charts and tables will be adequate but paying particular attention to loads in trafficked areas.

As well as the imposed loads, internal pressures can also influence the structural design of the pipeline. Pipelines can fail at junctions and bends as a result of high internal pressures and velocities, which would necessitate the need for anchor points at junctions and changes in direction. However, by maintaining low velocities and head pressures, and using a self-anchoring pipe system, the need for anchor points such as thrust block and straps can be avoided, but must be considered as part of the design.

The pipework manufacturer should be consulted if there is any doubts about the chemical or structural suitability of the pipe system.

4.4.4 Surface water pumping

Pumping surface water should be avoided wherever possible as the inflow, although occurring only when it is raining, will be constant during the rainfall event and will generate larger volumes of water at higher flow rates than

are generated in foul water drainage systems. This can give rise to excessively large sump volumes, which can have considerable cost implications. Also, surface water runoff, being an inflow which cannot be controlled, could result in flooding if a power outage should occur and neither an alternative power supply nor emergency 24-hour storage are available.

The surface water runoff should be assessed in accordance with BS EN 752⁽²⁾ and, if there are no restrictions on the discharge, then the useful sump volume can be determined using the method described above. However, if the discharge is restricted, whether by the receiving drain capacity, the sewerage utility or the Environment Agency, this will have an impact on both the size of the useful sump and the pump duty. In such cases the useful sump volume will need to be treated as pumped storage and the entire pump station modelled as an attenuation facility.

4.4.5 Vacuum drainage systems

Although not common in the UK, vacuum drainage systems have been used in Europe since the late 1800s but it is only recently that they have been accepted as an acceptable sewage system.

In many respects they can be considered a hybrid system, as they comprise not only a vacuum transport system but also incorporate gravity and pumped drainage components.

Vacuum drainage systems can be used both inside and outside buildings; this section covers those outside the building. The design of vacuum drainage systems outside buildings is covered by BS EN 1091⁽⁵²⁾. These are specialist systems and need careful design and, in the first instance, advice from a vacuum drainage system designer/manufacture should be sought.

The basic operating principle is the use of differential pressure to move wastewater along the pipeline.

Figure 4.8 illustrates a typical vacuum sewerage system and Figure 4.9 shows the connection of an individual

property to a vacuum system. The main components of the system are described below.

Valve chamber

This is essentially a manhole, into which the wastewater flows by gravity from the various parts of the building. Inside the valve chamber is an interface valve which is installed in-line on a suction pipe.

The suction pipe is used to evacuate the wastewater from the chamber and acts as a sensor pipe for controlling the interface valve. As the level of the wastewater rises in the chamber, the pressure of the trapped air in the suction pipe increases until the pressure is sufficient to open the valve. When the valve opens, the wastewater is sucked out of the chamber into the vacuum sewer. The valve remains open to entrain air in to the system. Generally, the valve chambers are located in a similar manner to conventional drainage manholes.

Vacuum sewer

This is normally of high density polyethylene (HDPE) pipework, rated as SDR17 ('standard dimension ratio') and ranging in size between 90 mm diameter and 250 mm diameter, and with wastewater flows at velocities up to 6 m/s.

The pipelines are installed at depths between 500 and 700 mm under paths and 900 mm under roads. The suction pipe exits the valve chamber with a downward gradient, generally at 0.2% or, if ground levels permit, following the ground slope, and then rises up; the rise up is called a 'lift'. The distance between lifts is a maximum of 150 m and the lift, constructed by using $2 \times 45^\circ$ bends, is limited to approximately 300 mm. This means that the top of the pipeline should remain at a constant depth below ground level. The only restriction on the length of a vacuum sewer pipeline is the layout of the system; there have been pipeline installations with lengths in excess of 2 km.

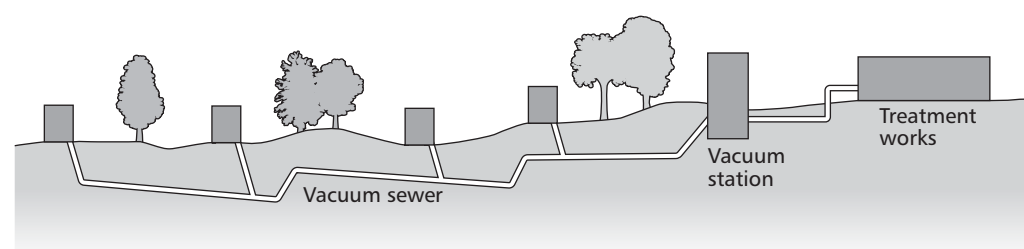


Figure 4.8 Typical vacuum sewerage system

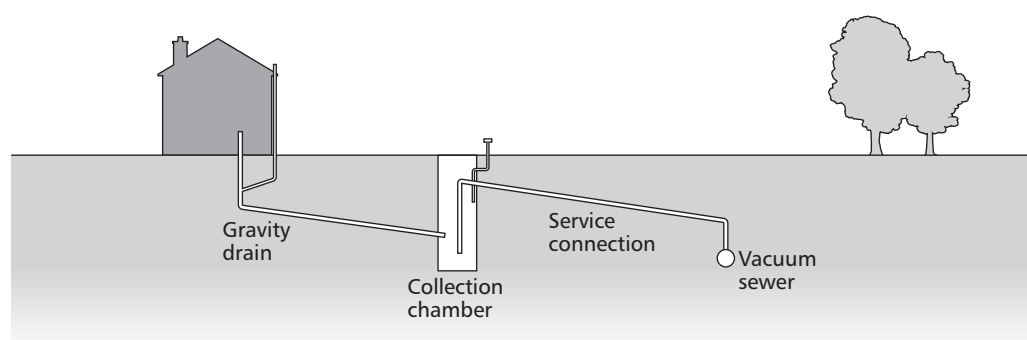


Figure 4.9 Individual connection to vacuum sewerage system

Collection station

The collection station consists of four main components

- *vacuum pumps*: these generate the vacuum for the whole system
- *collection vessel*: the transported wastewater is collected in the vessel prior to discharge to the utility sewer
- *discharge pumps*: these discharge the wastewater to the sewer, via a pump main; the pumps are controlled via probes within the vessel.
- *control panel*: this controls the operation of the collection station.

Ideally, the collection station should be positioned in a central location, as this will help equalise the flows in the branches, reduce the pipe lengths and reduce frictional losses in the system; simplifying the hydraulic design.

4.4.5.1 Uses of vacuum drainage systems

Typically, vacuum drainage systems are used on flat sites, where conventional drainage systems would result in excessively deep pipework and manholes. They are also used where the nature of the soil may cause difficulty, e.g. where it is subject to high water table or the ground is difficult to excavate due to rock or running sand. Vacuum systems allow pipes to be run at shallow and constant depths, thus simplifying the excavations.

4.4.5.2 Advantages and disadvantages of vacuum drainage systems

The utilisation of a vacuum drainage system needs to be considered carefully since particular aspects of the site can influence the selection and layout of the system.

Advantages of vacuum systems over gravity systems include:

- smaller pipe sizes: for example, a 100 mm diameter vacuum sewer would be adequate for 70 dwellings
- narrower and shallower excavations
- reduced pipeline installation costs
- no exfiltration in cases of damaged pipelines as the system is under negative internal pressure
- the installation is independent of the topography of the site
- fewer access points required (except for the valve chambers and hatchboxes, where access is required for maintenance).

Disadvantages include the following:

- the collection station is generally located above ground and therefore a plant room is required
- although the size of the plant room does not usually pose problems, its location (depending on the site) may; alternatively, the collection vessel can be installed below ground, necessitating potentially deep excavation works
- potentially high capital cost

- vacuum systems require power to operate and must incorporate a back-up power supply of sufficient capacity in the valve chambers to allow for a minimum of 6 hours operation (i.e. 25% of the daily load) of the properties
- systems require regular maintenance including, as suggested in BS EN 1091⁽⁵²⁾, a 5-yearly strip-down of the interface units
- due to the power and maintenance requirements, running costs are comparatively high
- the discharge flow rate from the collection vessel to the sewer needs to be considered carefully; there may be a maximum discharge rate allowed for the sewer, or a long distance from the sewer may necessitate excessively large pumps.

4.5 Sewage treatment

Most buildings in the UK are connected to the public sewer networks, which are controlled by water utility companies. These companies take on the legal responsibilities of collection, treatment and discharge of the effluent that is generated so as not to cause a risk to public health or damage to the environment.

The water companies are required to operate and maintain their sewer networks and wastewater treatment plants within the parameters of numerous Acts and Regulations, including the Water Industries Act 1999⁽⁷⁾, the Environment Act 1995⁽¹⁶⁾, the Bathing Water Regulations 2008⁽⁵³⁾ and the Urban Waste Water Directive⁽⁵⁴⁾.

These and other documents set out the legal standards of service and, more importantly, final effluent quality standards that are required, primarily to ensure that the effluent quality does not create a health risk to humans and the natural environment, either by composition or volume. The responsibility for regulation of wastewater treatment in the UK is divided between three national authorities, the Environment Agency (EA) in England and Wales, the Scottish Environmental Protection Agency (SEPA), and the Northern Ireland Environment Agency (NIEA).

Typically, in England and Wales, the EA has an expectation that, where it is reasonable to do so, developments discharging domestic sewage and or trade effluent should connect to the public foul sewer. In respect of this, any development within 30 m of an existing public foul sewer is deemed to be sufficiently close to be considered as being served by that sewer. The responsibility of local authorities to oversee and enforce this is covered by Section 21 of the Building Act 1984⁽¹⁰⁾ and the Water Industry Act 1991⁽³⁾.

In cases where it is not reasonable, practical or possible to connect a development to the public sewer network, an application must be made to the regulating authority (the EA, NIEA or SEPA) to sanction the installation and use of a private wastewater treatment system. The regulating authority, however, has powers to request improvements or extensions to existing sewers or may even requisition a sewer, and in certain circumstances these powers may be

invoked before reliance upon private wastewater treatment plant is permitted.

If the use of on-site treatment is being considered, it is important that the regulating authority is consulted at the earliest possible stage, as this early consultation will help inform the engineer as to whether on-site treatment is viable and appropriate.

4.5.1 Composition of discharge

The typical composition of raw sewage is shown in Table 4.8.

Although made up of 99.9% water, the other 0.1% of raw sewage can have a devastating impact, if allowed to enter the natural environment untreated. Typical measurements of the composition of domestic raw sewage are shown in Table 4.9.

The constituents are described as follows:

- Biochemical oxygen demand (BOD₅): this is a measure of the organic load of sewage, determined by the oxygen required by microorganisms to break down organic matter, expressed as mg of oxygen removed per litre of water, over a stated period. All BOD₅ tests are carried out over a 5-day period, in a laboratory, at a standard temperature of 20 °C, to ensure meaningful results.
- Chemical oxygen demand (COD): this is an approximate measure of the organic load in raw sewage, determined by chemical oxidation with dichromate. Typically, COD is higher than BOD₅ but the measure of COD can be determined within three hours and used to assess the BOD₅ where, for domestic sewage, approximately:

$$\text{COD} = (1.64 \times \text{BOD}_5) + 11.36$$
- Suspended solids (SS): this is a measure of the suspended matter in 1 litre of sewage; 60% of the organic load in raw sewage is in the form of suspended solids.

Table 4.8 Composition of raw sewage

Constituent	Volume / %
Water	99.9
Solids:	
— organic (proteins, carbohydrates and fats)	0.07
— inorganic (grit, salts and metals)	0.03
Total	100.0

Table 4.9 Composition of raw domestic sewage

Constituent	Concentration / (mg·litre ⁻¹)
Biochemical oxygen demand (BOD ₅)	350
Chemical oxygen demand (COD)	700
Suspended solids (SS)	180–450
Ammonia nitrogen	40
Nitrate nitrogen	<1
Total phosphorus	15
Basicity (acidity/alkalinity)	pH 7.0

- Nitrogen: regarded as a nutrient, it exists in four forms: organic (in proteins), ammonia, nitrite and nitrate. Total nitrogen is the sum of all the forms of nitrogen, which are mainly organic and ammonia. Excessive levels of nitrogen can result in eutrophication* (reduced oxygen levels, odours and discolouration). In addition, high levels of ammonia can be toxic to aquatic organisms, in particularly young fish.
- Phosphorus: regarded as a nutrient, phosphorus levels in the environment are naturally low. Discharges of phosphorus, in particular into waters classified as sensitive, are restricted as elevated levels can result in eutrophication.
- Basicity (pH): this is a measure of the acidity or alkalinity of the raw sewage. Rapid changes in the pH of the incoming sewage have a negative effect on the bacteria. Typically, a consistent pH value within the range pH 6–8 is acceptable for organic reduction. The rate of nitrification declines markedly below pH 7. Furthermore, nitrification may reduce the pH if the initial alkalinity of the sewage is low.

Other constituents of wastewater that need to be considered are fats, oils and grease (FOGs). FOGs can have a negative effect on the performance of settlement tanks and aerobic treatment plants. If high levels are anticipated, specialist guidance should be sought from the treatment equipment supplier, or allow for an effective grease-removal system (see section 4.3.9).

The minimum temperature of the incoming sewage should be stated. This is particularly important in the case of treatment plant required to reduce the level of ammoniacal nitrogen as the nitrification rate is particularly temperature-dependent. As the temperature can have a major impact on the effectiveness of the treatment process, this guide will deal only with treatment processes applicable to the UK.

High sulphate levels may cause problems in aerobic sewage treatment plants, such as the corrosion of concrete structures.

4.5.2 Discharge consents

Once the wastewater has been collected and treated, the effluent has to be disposed of and any discharge, whether from a simple septic tank or a more complex municipal works, despite having undergone some level of treatment contributes pollutants to the receiving waters or land.

However, before this point is reached, to minimise the impact of the effluent discharge on the receiving water or land, the amount of pollutant in the effluent is strictly

* Eutrophication describes the biological effects of an increase in the concentration of nutrients. The collective term 'nutrients' refers to those elements that are essential for primary production by plants or other photosynthetic organisms. Eutrophication is most often caused by increases in the availability of nitrogen and phosphorus, commonly present in soil and water in the form of nitrate and phosphate, respectively. However, altered concentrations of any plant nutrient may have a recognizable biological effect. Eutrophication can occur in any aquatic system (freshwater or marine), and the term is also used to describe the process whereby terrestrial vegetation is affected by nutrient-enriched soil water.

controlled by discharge consents. The growing awareness of the impact of effluent discharges to receiving water and to land, the regulating authorities are imposing more and more stringent discharge consents.

The most basic discharge consent standard quoted in the UK was laid down by the Royal Commission in 1912, setting a minimum discharge standard (assuming a dilution ratio in the receiving water of 8 parts water to 1 part sewage) of 30 mg/l suspended solids (ss) and 20 mg/l biochemical oxygen demand (BOD₅), more commonly referred to as 30:20 standard. It should be noted, however, that the Urban Waste Water Treatment (England and Wales) Regulations 1994⁽⁵⁵⁾, set a BOD₅ standard of 25 mg/l.

Despite there being preset discharge consents, which must be assumed to be the absolute minimum consent standard, in reality, the regulating authority will base a discharge consent on specific factors related to the point of discharge, such as those given below:

- Whether the receiving waters are used for bathing or fishing: the consent would need to reflect the requirements of applicable Regulations such as the Bathing Waters (Classification) Regulations 1991⁽⁵⁶⁾ or the Surface Waters (Fishlife) (Classification) Regulations 1997⁽⁵⁷⁾.
- Whether the receiving waters are designated as sensitive, as defined in The Urban Waste Water Treatment (England and Wales) Regulations 1994⁽⁵⁵⁾.
- Whether the flows in the receiving waters are capable of accepting the volumetric flow from the discharge and whether it can sufficiently dilute the effluent.
- Whether there are existing discharge consents, either upstream or downstream, which may influence the final consent, in respect to either quality and or volumetric flow.

For discharges to land via a leachfield, the consent will hinge on the percolation rate of the soil, i.e. whether the volume of discharge will drain away without the soil becoming saturated, and proximity to habitable buildings, watercourses and aquifers etc.

All wastewater plants are required to have adequate provision for regular effluent quality monitoring at the outfall point, either by continuous monitoring or periodic monitoring as required by the consent; this monitoring is undertaken via sampling chambers installed on the discharge side of the treatment plant. The results from the monitoring are required to be made available to the regulating authority who will, in addition, undertake their own monitoring to ensure accuracy of the data provided by the treatment plant owner and compliance with the consent. If there is a contravention of the consent, the regulating authority can take action through the courts.

The frequency of the sampling will be dependant on the on the size of the plant, as set out by the Urban Waste Water Treatment (England and Wales) Regulations 1994⁽⁵⁵⁾, which also defines the limits for failures in any single year. The time of sampling will influence the results. A series of daily spot samples taken at the same

time will provide more consistent results than a series taken at random times.

In making any application for a discharge consent, the regulating authority will make charges, for processing the application, as well as charges for monitoring the effluent.

4.5.3 Design flows and loads

To enable a decision to be made as to the appropriate treatment process for a building or development, an assessment of the volumetric and organic loads of the effluent must be made, and this will be dependant on the use of the building or buildings that make up a development.

In order to standardise the design process, typical values are allocated to various building types, usages and occupancy types. The UK water industry uses the values shown in Table 4.10.

These, taken from a British Water publication⁽⁵⁸⁾ represents assumed figures for various building types and usages.

To simplify flow and load calculations, a treatment system is sized on its population equivalent (PE); this is defined as the wastewater flow, BOD₅ and nitrogen load produced by one person per day in a standard residential building. As such, one PE is equal to 200 litres of wastewater flow per day, 60 grams/litre of BOD₅ and 8 grams/litre of nitrogen.

The resultant PE is determined as follows.

- (a) Wastewater:
$$\text{PE (litres)} = \text{sum of all wastewater flow} / 200$$
- (b) BOD₅:
$$\text{PE (grams/litre BOD}_5\text{)} = \text{sum of all BOD}_5 / 60$$
- (c) Nitrogen:
$$\text{PE (grams/litre N}_2\text{)} = \text{sum of all N}_2 / 8$$

Example

A mixed development of 200 homes, each with three bedrooms and office accommodation, with canteen, for 1000 persons. *Note:* the number of occupants in a residential dwelling is assumed to be the number of bedrooms plus 2.

Total residential population = $200 \times (3 + 2) = 1000$; total office population = 1000. Hence, total population = 2000

From Table 4.10 for the residential area:

- *Flow*: $1000 \times 200 = 200\,000$ litres of wastewater flow per day
- *BOD₅*: $1000 \times 60 = 60\,000$ g/litre BOD₅ per day
- *Nitrogen*: $1000 \times 8 = 8000$ g/litre N₂ per day

For the office accommodation (with canteen):

- *Flow*: $1000 \times 100 = 100\,000$ litres of wastewater flow per day
- *BOD₅*: $1000 \times 38 = 38\,000$ g/litre BOD₅ per day

Table 4.10 Standard values of volumetric and organic load for common building types

Building type	Capacity / litres	BOD5 / g-litre ⁻¹	Ammonia (N) / g-litre ⁻¹
Domestic dwellings:			
— standard residential	200	60	8
— mobile home type caravans with full service	180	78	8
Commercial/industrial:			
— office/factory without canteen	50	25	5
— office/factory with canteen	100	38	5
— open industrial site, e.g. construction, quarry without canteen	60	25	5
— full-time day staff*	90	38	5
— part-time staff (4-hour shift)*	45	25	3
Schools:			
— non-residential with canteen cooking on site	90	38	5
— non-residential without canteen	50	25	5
— boarding school (residents)	200	75	5
— boarding school (day staff, including mid-day meal)	90	38	5
Hotels, pubs and clubs:			
— hotel guest (prestige hotels)	300	105	12
— hotel guest (3 and 4 star)	250	94	10
— hotel guest (bedroom only, no meals)	80	50	6
— residential training/conference guest (inclusive all meals)	300	150	15
— non-residential conference guest	60	25	2.5
— drinkers	12	15	5
— holiday camp chalet resident	227	94	10
— residential staff	180	75	10
Restaurants:			
— full meals (luxury catering)	30	38	4
— pre-prepared catering	25	30	2.5
— snack bars and bar meals	15	19	2.5
— function rooms including buffets	15	19	2.5
— fast food (roadside)	12	12	2.5
— fast food (burger chain and similar)	12	15	4
Student accommodation	100	56	5
Amenities:			
— toilets blocks (per use)	10	12	2.5
— toilet (WC per use)	10	12	2.5
— toilet (urinal per use)	5	12	2.5
— toilet blocks in long stay car parks/lorry parks (per use)	10	19	4
— shower (per use)	40	19	2
Sports/health facilities:			
— golf club	20	19	5
— local community sports club (e.g. squash, rugby and football)	40	25	6
— swimming (separate pool without an associated sports centre)	10	12	2.5
— health club/sports centre	50	19	4
Camping:			
— camp sites	75	44	8
— caravan sites (touring, not serviced)	100	44	8
— caravan sites (static, not serviced)	100	44	8
— caravan sites (fully serviced)	180	75	8
Hospitals and residential care homes:			
— residential old peoples/nursing home	350	110	13
— small hospitals	350	140	Assess
— large hospitals	— Assess individually —		

* Staff figures also apply to other applications

— Nitrogen: $1000 \times 5 = 5000$ g/litre N₂ per day— Flow: $300\,000 / 200 = 1500$

Totals for residential and office populations:

— BOD5: $98\,000 / 60 = 1633$

— Flow: 300 000 litres of wastewater flow per day

— Nitrogen: $13\,000 / 8 = 1625$

— BOD5: 98 000 g/litre BOD5 per day

— Nitrogen: 13 000 g/litre N₂ per day

Therefore, PE values are:

The size of a wastewater treatment plant for a development is determined by taking the highest PE value from the calculation, which in this case is the PE based on BOD5.

4.5.4 Wastewater treatment processes

In all wastewater treatment systems there are a series of treatment stages used to bring the raw sewage to an acceptable standard. The number of stages and degree of sophistication used will depend upon the standard of effluent required and the nature of the effluent being treated, i.e. whether the treatment is for an isolated dwelling with occasional use, a larger development with a large volume of domestic effluent or a development with industrial wastes.

The objective of sewage treatment is to obtain a final effluent capable of being discharged to the receiving waters or a leachfield in an efficient manner. Treatment plant should provide and maintain the conditions for this largely natural process to occur.

The main stages of sewage treatment can be summarised as follows.

Preliminary treatment

Preliminary treatment usually comprises a series of screens and rakes for the removal of rags and large suspended solids, using grit removal channels and, in some cases, macerators. Grit is not usually a problem if the flow is wholly foul. Preliminary treatment varies in size and nature according to the magnitude of the works and is, in any case, provided only where there is a fairly sizeable treatment plant and it would not normally be provided for plant serving small developments of less than, say, 100 dwellings.

Primary settlement

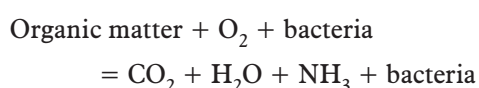
Primary settlement tanks are designed to remove the majority of solids prior to biological treatment, thus reducing the BOD₅ on the biological treatment plant. The efficient settlement of the effluent depends on its velocity as it passes through the tank. The dimensions of the tank are therefore critical and are usually designed by a specialist.

Secondary treatment

Despite the preliminary and primary treatment, the liquid discharged from the primary settlement tanks will still contain a considerable amount of polluting matter either in suspension or dissolved in solution. Secondary treatment is carried out in the presence of oxygen, which is embodied in the form of filter beds, rotating biological contactors or activated sludge. The solid or colloidal matter is organic and can be removed by aerobic oxidation.

The effluent is therefore treated biologically using the effects of aerobic microorganisms.

The basic process of aerobic biological oxidation is summarised as follows:



In order for the bacteria to operate at their optimum and achieve the maximum removal of organic matter from the solution, the microorganisms are allowed to form a microbial mass. This mass forms a flocculant capable of easily absorbing the organic material due to its large surface area.

As a result of the bacterial action the 'slime' layer increases on the surface of the filter media. This biological layer is held together by weak attractive forces known as the Van der Waal force. The shearing forces of the passing effluent detach pieces of the material over time and they are carried to the secondary settling (humus) tank where they settle out.

The removal of portions of the bacterial slime, if controlled, is beneficial as it removes old bacteria and helps to prevent clogging; the removal depends on the hydraulic loading rate of the filter bed and thus control of the flow rate is important.

Secondary settlement

Secondary settlement tanks, often known as humus tanks are used in conjunction with biological treatment, where a good effluent quality of at least 30:20 is required. These are usually an integral part of packaged units and should have sufficient capacity to store the accumulation of about three months' sludge. In larger plant situations, secondary settlement tanks immediately follow the biological treatment in the process. Recirculation of the effluent back through the biological filters at this stage is common to remove further organic matter. Sludge is continually removed in activated sludge units and in trickling filter units, for disposal or further sludge treatment techniques.

Tertiary treatment

Also known as polishing, this is necessary where the discharge standards are high or where the raw effluent is particularly poor. There are a number of methods used to 'polish' the effluent prior to final disposal, based on removing further biological solids and these rely on flocculation, sedimentation, and filtration. It is possible to achieve a standard of at least 10 mg/litre BOD₅ and 10 mg/litre SS with a suitable method based on a good quality of effluent entering the tertiary process.

The most common tertiary treatment methods can be summarised as follows:

- *grass plots*: the effluent is passed over grass plots which can remove up to 70% of suspended solids and up to 50% of BOD₅. The method is relatively inexpensive, although it requires the use of large surface areas.
- *upward flow clarifiers*: the effluent is passed upwards through a bed of granular material and is more efficient than the grass plots method, but requires specialist plant.
- *reed beds*: these are a popular method of providing tertiary treatment, particularly as they can provide very good quality final effluent but also wildlife habitat and, to some extent, amenity value.

4.5.4.1 Vertical flow reed beds

These work on a similar principal to traditional filter beds, where the effluent is spread over the top of the reed bed and allowed to pass vertically down through the filter media (generally gravel and sand as well as the rhizomes of the planting) to the outfall point. Organic matter can settle on the surface, which can give rise to some odour issues.

High levels of treatment are possible and so can be used to for secondary treatment, following a primary settlement tank such as a septic tank, but are generally used as tertiary treatment.

The effluent flow into the reed bed can occur under gravity, providing there is sufficient hydraulic head, generally around 1.5 m from inlet to outlet, hence they do not necessarily require external power.

They are easy to maintain as failure tends to be gradual and, as such, preventative and remedial action can be carried out well in advance of total failure.

Visually, they can be very attractive and can provide a wildlife habitat. Generally they require between 2 and 5 m² of land per person and can be quite expensive to install, and can be sensitive to shock loads.

4.5.4.2 Horizontal flow reed bed

Unlike the vertical flow reed bed, the flow occurs horizontally through the filter medium. The air flow through the filter medium is limited and so strong effluent can be poorly treated and potentially anaerobic conditions can occur, giving rise to odour issues. Similar to vertical flow reed beds, they are generally seen as a tertiary form of treatment but can be used for secondary treatment, following a septic tank. They require more land take than a vertical flow reed bed, between 5 and 10 m² per person.

Although many consider that they are suitable for secondary treatment, there are some who suggest that they are really suitable only for tertiary treatment. Therefore, there is some uncertainty on their suitability.

Visually, they can be attractive and natural looking being able to accommodate a wide range of plants. They can be cost effective, if installed as a DIY item but, again, the design needs to be considered very carefully.

As the flow is horizontal through the medium, it can become blocked and therefore needs careful maintenance. Normally, with good pre-treatment, the bed can be used for up to 10 years before the medium and planting require replacing and replanting.

4.5.5 On-site wastewater treatment systems

Where connection to the public sewerage system is not possible and, following consultation with the regulating authority that an on-site treatment system is acceptable, the choice of system needs to be made. Private wastewater treatment systems range from simple septic tanks to

complex plant such as membrane bioreactors (MBR), and can be used for single houses or even small communities.

The use of wastewater treatment plant is now covered by the section H2 of Building Regulations Approved Document H⁽²⁵⁾ and advice on selection can be found in documents such as the EA, SEPA and NIEA Pollution Prevention Guidelines PPG 4⁽⁵⁹⁾. Currently, on-site treatment systems should be designed in accordance with BS EN 12566-3⁽⁶⁰⁾ (applicable for plants suitable for populations up to 50).

There are a number of systems available and the manufacturers must be consulted to determine which system is best suited to the application, as it is critical to ensure that the discharge consent is adhered to. The level of treatment and, thus, the quality of the effluent being discharged will vary depending on the process used and if the process is not the correct one there is the risk of prosecution.

With the exception of cess pools and septic tanks, which are mostly suited for single dwellings, on-site treatment systems are mechanical and are examples of aerobic action. The effluent from packaged systems may require further treatment, i.e. tertiary treatment by means of reed beds, for example.

It is not possible within the scope of this document to suggest or recommend which system is the best, as the final selection will always depend on the various factors but, as a guide, when selecting an on-site packaged treatment system, consideration should be given, but not limited, to the following:

- *The site itself:* is there a suitable receiving water-course available or is the soil suitable for receiving the effluent discharge via a leachfield?
- *Land take:* the plant needs to be sited such that it does not interfere with the building layouts, plus there needs to be adequate space around the plant for maintenance purposes.
- *Cost effectiveness:* the cost of treatment systems varies considerably, in capital cost as well as running costs, and the final selection must be appropriate for the development. The cost of the system must be considered alongside the cost of any sewer upgrade works as the life cycle costs may in time exceed the capital cost of sewer upgrade works
- *Durability:* the capital outlay of a treatment system is considerable and therefore, as a guide, the plant should have a life of at least 20 years.
- *Maintainability:* the complexity of the system should be appropriate for the application, particularly for single dwellings.
- *Approval:* the system must have been tested in accordance with BS EN 12566-3⁽⁶⁰⁾ or other approved body.

On-site treatment systems typically have the following benefits:

- They are 'off the shelf' products, i.e. most manufacturers have a range of units to suit most

* Similar legislation applies to Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

applications but, as mentioned above, need careful selection.

- They can be relatively compact and easy to install.
- Easily maintained, by reputable manufacturers/installers who can offer maintenance contracts.
- Once installed, they can be relatively unobtrusive, as they are predominantly installed below ground.

However, they do have some disadvantages:

- They are not a 'fit-and-forget' item and need specialist maintenance; this is particularly important when considering single dwelling installations.
- They incorporate mechanical and electrical components that wear out over time and will need replacement.
- They require de-sludging at intervals which, depending on the plant and usage, can vary between 6 months and 2 years.
- They require a power supply and will not provide any treatment in the event of a power outage or mechanical breakdown. On larger sites a back-up power supply should be factored-in to the overall site infrastructure design.
- They can generate noise and occasionally odour problems.

In general, on-site plants are reliable and will, if properly maintained, provide years of service. They work best when there is a constant flow. If large variations in flow are expected precautionary measures, such as an additional balancing tank, are required to ensure the flow is kept at a constant rate. A consequence of intermittent flow is that, if there are long periods of low flow, the biomass can reduce, which can result in effluent not being treated to the correct standard.

The most common on-site wastewater treatment systems are the following.

4.5.5.1 Cess pools

These are the simplest system and provide only storage and not treatment. They are simply a large sealed underground tank where sewage is stored. The capacity of the cess pool below the inlet drain must be a minimum of 18 000 litres for 2 persons and must be increased by 6800 litres for each additional user.

They need emptying on a regular basis, as they cannot be allowed to exceed their capacity. Generally, cess pools should be avoided, except where no other option is viable; they are not acceptable in Scotland.

4.5.5.2 Septic tanks

Typically these consist of a two-chambered, buried tank with an effluent outlet to a drainage field. The principal of operation of a septic tank is wastewater enters the first tank, where heavy solids sink to the bottom and grease and oils float to the top. The effluent passes from the first chamber to a second chamber, by gravity, where further

settlement occurs. The effluent then passes to a soakaway or a drainage field, where the majority of the treatment occurs. Direct discharge to watercourses is not permitted.

To be effective, the soil must be suitable and, in order to determine this, a permeability test to BS 6297⁽⁶¹⁾ must be carried out and the result submitted to the EA as part of the consent to discharge application. If the soil is not suitable, then the ground can become waterlogged and give rise to odours.

The septic tank must have a minimum capacity of 2700 litres. This is deemed adequate for a four-person dwelling; additional occupants require the tank capacity to be increased by 180 litres per person. They need to be emptied on a regular basis, at least once per year.

4.5.5.3 Rotating biological contactor (RBC)

These are usually a single unit comprising three chambers, the first stage being the primary settlement tank where the solids are settled out and retained as sludge. The partially treated effluent passes first to the anoxic and then the aerobic stage, where the secondary treatment occurs. The anoxic and aerobic stages of the plant consist of a series of discs that rotate through the effluent; at any one time only about 40% of the disc is submerged. The discs provide a medium on which biomass can grow and as the discs pass through the effluent the organic load is absorbed by the biomass and treated by oxidation.

RBCs generally protrude above ground and are therefore visually intrusive. They require a power supply, although the motor is generally small as the speed required is between 2 and 4 r/min. An RBC can tolerate some fluctuations in hydraulic and organic load but can suffer if there is a shock load. RBCs have no scope for adaption should the building (or building use) change, i.e. if the wastewater flows are increased, the increase in size will have to be within the scope of the plant or new plant will be needed. Overall, RBCs are a simple and stable treatment process that has been proven over the years.

4.5.5.4 Activated sludge

An activated sludge plant uses the injection of air in to the wastewater to breakdown the organic load. The plant can be either two- or three-chambered units with the air being bubbled up through the effluent from an aerator in the base. The process generates slurry which settles in the base and sludge is formed containing active microbes. Some of the sludge is re-circulated back in to the unit and retreated, keeping the unit's biomass active. The quality of the effluent can be very high and can provide some nutrient removal, such as nitrates. Similar to RBCs, they can accept some load variations but not sudden shock loads.

Generally, activated sludge plants are wholly buried and only the top is visible so are therefore less visually obtrusive than RBCs. However, the air blower needs a surface mounted fan, which can give rise to aesthetic and noise issues. They use more power than RBCs.

A variation of the activated sludge treatment is the sequencing batch reactor (SBR). The treatment occurs in a

single chamber, where the blower is operated intermittently, to allow settling-out of the sludge.

4.5.5.5 Membrane bioreactor (MBR)

Generally, these use simple flat-sheet membrane panels, housed in a stainless steel activated sludge unit and air is injected. The membranes are submerged in the effluent and, as the membranes have pore sizes between 0.1 and 0.4 microns, the effluent is filtered as it passes through the membranes.

This process provides very efficient treatment and has the advantage that the incoming wastewater requires only preliminary treatment and no secondary or tertiary treatment. The final effluent is very high quality and is typically at or better than 5 mg/litre BOD₅, SS and N₂.

Membrane treatment can cope with variations in incoming wastewater strength but the flow rate to the unit should not be permitted to vary appreciably.

4.5.6 Other considerations

The siting of an on-site treatment systems will be critical. A septic tank, packaged treatment plant or cess pool should be sited at least 7 m from any habitable part of building and not more than 30 m from an access road.

Drainage fields from septic tanks etc. should be a minimum 10 m from a watercourse and 50 m from any abstraction point and 15 m from any building. The proximity to other soakaways and infiltration drainage systems needs to be considered, as being too close will reduce the soakage capacity of the soil.

No access roads or paved areas should be constructed over a drainage field and no services should pass through the drainage field.

Reed beds should be constructed at distances, similar to drainage fields, away from buildings, watercourses and abstraction points etc.

4.6 Surface water systems

4.6.1 Introduction

Surface water drainage includes the collection, control, conveyance (including overland flow paths) and discharge of rainwater runoff from impervious surfaces such as roofs, paved areas, highways, car parks etc. In this context, surface water drainage refers to building drainage systems that are exposed to rainfall. Such systems may be point gullies or linear drainage channels and can be located in pavements, car parks, podium decks, green roofs or traditional roof structures.

During the last two decades the emphasis on SUDS (sustainable urban drainage systems) and the effects of climate change are having a great impact on the design of surface water drainage systems. Building regulations⁽¹¹⁻¹³⁾ now stipulate an order of priority for final discharge methods, with infiltration being the preferred option,

followed by discharge to a watercourse, with connection to a sewer being the least preferred.

Planning conditions are becoming stricter with regard to limiting outflows where discharges are made to watercourses or sewers. Even existing buildings that are being redeveloped in densely constructed city centres are coming under scrutiny for possible use of SUDS and limiting outflows. Where outflow limits are imposed, on-site attenuation or rainwater storage devices are necessary, with controlled outflows leading to the final point of discharge. Re-cycling of rainwater by using rainwater harvesting systems is now strongly encouraged by UK planning authorities.

The above emphasises the increasing importance of correctly designed surface water drainage systems to the built and natural environment.

4.6.2 Principles of good design

The guidance given in section 4.2 is equally applicable to surface water drainage systems.

In addition, surface water drainage systems should be designed with the following principles in mind:

- Rainfall intensity, likely storm duration and return period must be investigated fully before undertaking design work (see section 4.3.3) and these quantities factor in sizing calculations. Moreover, the degree of risk and consequences of flooding to buildings and surrounding areas must increasingly be considered as climate change takes effect incidences of flooding become more regular.
- Surface water should be discharged in accordance with the hierarchy stipulated in Building regulations⁽¹¹⁻¹³⁾, in order of priority to:
 - (1) a soakaway or other infiltration system
 - (2) a watercourse
 - (3) a sewer.
- When discharging to a watercourse or sewer, limitations on discharge flow rates may be imposed by the Environment Agency and/or the local authority and these must be checked in advance of carrying out works.
- Permission from the Environment Agency must be obtained for discharging surface water to a watercourse, and details of design outfalls must be agreed with the Environment Agency to avoid erosion of watercourse banks and beds.
- Surface water runoff should be reduced wherever practical by minimising paved areas, using rainwater harvesting systems and living roofs (see chapter 5). Pervious paving systems may also be used to collect and store surface water for re-cycling.
- Paved areas and small car parks up to 4000 m² may be designed in accordance with Building Regulations H2⁽¹¹⁾. For larger catchments reference must be made to BS EN 752⁽²⁾.
- Pathways and narrow paved areas should be arranged to be free-draining to an adjacent

pervious area such as grassland, provided it is not adjacent to building foundations and the soakage capacity of the ground is not overloaded.

- Infiltration drainage devices should not be installed:
 - (a) within 5 m of a building or road or in areas of unstable land
 - (b) where the soil infiltration rate is not sufficient
 - (c) in ground where the water table reaches the bottom of the device at any time of year
 - (d) where any contamination in the runoff could result in pollution of a water source.
- Infiltration drainage devices must be located sufficiently far from any drainage fields, drainage mounds or other soakaways so that the overall soakage capacity of the ground is not exceeded.
- Where sewers are to be adopted (see section 4.1.4) design must be carried out to the requirements of *Sewers For Adoption*⁽²⁷⁾.
- All surface water connections to combined sewers must be made via fittings incorporating water traps to prevent escape of foul air.
- Suitably sized gully pots or catchpits must be incorporated in any design to reduce the amount of silt and grit entering the drainage system.
- Pollutants such as oil and petrol must be prevented from entering the drainage system by the provision of suitable interceptor fittings (see section 4.3.9), following the guidelines of EA Pollution Prevention Guideline PPG 3⁽⁶²⁾.
- Adequate access must be provided for the cleaning and maintenance of oil interceptors.

4.6.3 Design and sizing

To assist the engineer with the design of surface drainage systems, BS EN 752⁽²⁾ and BS EN 12056⁽²⁸⁾ are excellent sources. Guidance on the design and classification of linear drainage systems can be found in BS EN 1433⁽³⁵⁾.

Sizing is based on three fundamental characteristics of rainfall:

- *intensity*: the rate of rainfall, expressed in mm/hour
- *duration*: the length of time of the rainfall, expressed in minutes, hours or days
- *frequency*: the recurrence interval or 'return period', expressed in years.

Observed statistical rainfall data have shown that intensity is dependent on and variable about the duration and frequency of the storm event. It is important to understand the inter-relationship of these characteristics:

- Intensity variation with duration: shorter duration storms are more intense than longer duration storms, for the same frequency of recurrence.
- Intensity variation with frequency: the more intense a storm of a particular duration is, the less frequently it will occur.

The calculation of hydraulic capacity for many drainage designs simply assume a linear rainfall intensity of say, 0.015 l/s per m² (50 mm/h) for car parks or 0.020 l/s per m² (75 mm/h) for roof drainage. However, in real storm situations, a graph of rainfall intensity versus duration is not the horizontal straight line that would be seen for a constant rainfall intensity. Instead, the profile follows a Gaussian distribution where the intensity peaks at some time during the storm. This is illustrated by the drizzle detected before and after the main tranche of rainfall.

Geographical location can play an important part in the assessment of drainage performance. For example, although East Anglia experiences less annual rainfall than elsewhere in the UK, this region experiences the highest rainfall intensities in the form of summer storms.

There are two main statistical rainfall methods used in the United Kingdom: the Wallingford Procedure⁽³¹⁾ and the method described in the *Flood Estimation Handbook*⁽⁶³⁾. It is usual to use the former for the design of surface water drainage.

4.6.3.1 Linear drainage and point gullies

Both point gullies and linear drainage systems are applicable to surface water drainage. In either system, adequate falls to the receiving drain will need to be provided. In some applications, the earthworks and associated underground drainage pipes required to install a linear drainage system can be less than for point gullies.

Other considerations, apart from hydraulic capacity, include grating design (with respect to pedestrian stiletto heels, for example), load class, aesthetics, material selection, maintenance and anti-theft security.

4.6.3.2 Determining distance to outlet in linear channel systems

In order to calculate the position of an outlet in a channel system, it is necessary to use models and formulae that account for steady non-uniform flow. Here the flow depth at successive cross-sections of the channel due to the 'continuous inlet' that the channel system presents. Historically some manufacturers have incorrectly applied pipe and flow formulae (e.g. Manning formula) to the problem, where flow is in essence steady and uniform from a design perspective.

Additionally, the manufacturer may be consulted for guidance and advice.

4.6.4 Soakaways and infiltration devices

There is growing awareness that surface water runoff may, under certain circumstances, have an adverse effect on receiving water courses and upon groundwater.

This section provides design guidance into methods in which soakaways and infiltration devices may be incorporated into systems used to treat and store surface water runoff prior to discharging to the ground. It details the requirements to protect receiving groundwater and the various constraints established within soakaway design

and construction. In addition, an explanation is included of the processes operating above the water table, and how this influences soakaway design and thus prevents groundwater pollution.

Overseeing organisations have a duty under pollution protection legislation to ensure that surface water runoff does not pollute receiving waters. Uncontaminated rainwater (from roofs) can be discharged using infiltration without the need for discharge consent, although compliance with regulations is still required. For discharges to ground, the Groundwater Regulations 1998⁽⁶⁴⁾ in England, Scotland and Wales or the Groundwater Regulations (Northern Ireland) 1998⁽⁶⁵⁾ include lists of substances whose entry to groundwater must be prevented or controlled. These substances are commonly referred to as 'List I' and 'List II' substances.

4.6.4.1 Design concepts

In order to operate successfully, soakaways should be sited in porous and permeable ground of sufficient depth and lateral extent to be able to accommodate potential maximum discharges under storm conditions. The design of soakaways, of any description, should also take into account constraints arising from the possible impact on landscape and ecology. Discharges to groundwater may potentially affect biodiversity (e.g. through impacts on wetland habitats) and any such effects should be considered both in the location and the function of the soakaways.

4.6.4.2 Soakaway systems

There is a range of drainage systems that may act as soakaways, where the primary discharge from the system is to groundwater. Effectively, these aim to encourage efficient hydraulic contact between the drainage system and the underlying ground in order to provide effective drainage. Such options include, for example:

- combined surface and groundwater filter drains
- fin drains
- filter drains
- informal drains or 'over the edge drainage'.

Additionally a number of surface water drainage features also incorporate discharges to the unsaturated zone for example:

- retention ponds
- sedimentation ponds
- infiltration basins
- wetlands
- swales/grassed channels.

These options all provide varying degrees of protection to groundwater resources, primarily through maximising the depth of the unsaturated zone beneath the drain. In order to produce a suitable design and to minimise the impact of surface water drainage on groundwater quality, whilst accounting for the attenuation properties of the unsaturated zone, soakaway drainage incorporating any of these options should also embrace the design principles.

There are a wide range of these soakaway types that have been put into use including, for example:

- segmental concrete chambers within excavated pits (with the chamber used as storage)
- pre-cast concrete perforated ring units
- brickwork within previously created excavations
- trenches
- open pits
- rubble/aggregate filled pits
- pits/trenches with proprietary 'geo-cellular' units.

4.6.4.3 Pre-cast perforated concrete ring type soakaway

This configuration is commonly used for its simplicity of construction and ease with which compatible components can be supplied from various sources. An excavation to the required depth is made, a concrete footing formed and then segments lowered one on top of the other until the hole is filled. The area between the outside of the rings and the excavation can be backfilled with aggregate (see Figure 4.10).

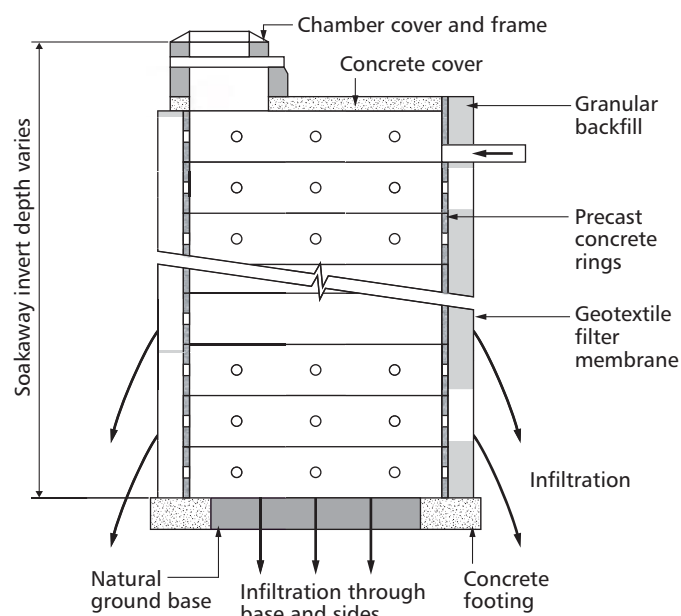


Figure 4.10 Pre-cast concrete rings type soakaway

4.6.4.4 Trench type soakaway

Trench type soakaways should be constructed with inspection tubes at regular intervals. These inspection tubes (observation wells) should be connected by a horizontal perforated or porous distributor pipe laid in the top of the granular fill along the trench. The extreme ends of the trenches should be identified by inspection tube covers or other access covers.

Trenches are generally constructed with a horizontal base and the volume between the structure and the excavation backfilled with granular material. Typically a minimum width of 300 mm will be considered (see Figure 4.11).

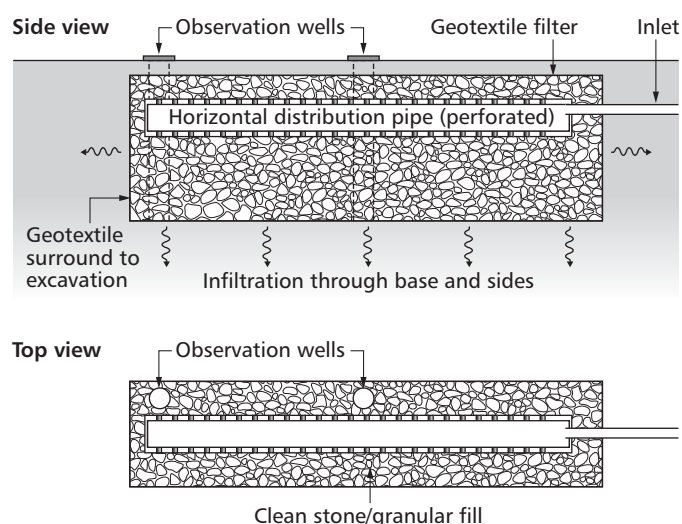


Figure 4.11 Trench type soakaway with horizontal distributor pipe

4.6.4.5 Design and construction of soakaway systems

Soakaways are normally designed primarily on hydraulic grounds, i.e. simply to transmit runoff efficiently and facilitate drainage into the underlying unsaturated zone, using 1 in 10 year return periods for volume requirements. A longer design return period (e.g. 1 in 30 years) might be appropriate for sensitive sites where the risk of flooding needs to be further reduced.

Under current legislation and with the introduction of tighter controls within the Water Framework Directive⁽²³⁾ allowing direct discharge to groundwater through structures such as boreholes is considered inappropriate and should not be used within a soakaway system design.

There are three fundamental principles that should be applied to soakaway discharge system design, which are to:

- ensure that the hydraulic performance of the soakaway 'outfall' allows sufficient storage and infiltration capacity such that the system will have the capacity to drain the 'design storm' (and hence prevent flooding of the impermeable surface)
- ensure protection of receiving groundwater, and
- provide measures to prevent the possibility of an accidental spillage passing through the discharge system.

The most fundamental hydraulic design principle for soakaway discharge systems for surface water drainage applications is to provide sufficient storage capacity to allow the removal of storm runoff from the impermeable surface, quickly and effectively. The principal hydraulic design criterion is therefore to provide sufficient capacity within the system to cover peak runoff. This is generally achieved by constructing large detention ponds, to temporarily store the water discharging from the impermeable surfaces, upstream of the soakaways or by constructing underground chambers with porous sides or bases that also have sufficient internal capacity to store the runoff.

4.6.4.6 Site-specific issues

There are a number of potential limiting factors in the design of a soakaway in order to minimise the pollution potential and also to maximise the scope for attenuation within the unsaturated zone, these include the following:

- The hydrogeological potential of the site: is the substrate an aquifer?
- The discharge of List II substances to groundwater is permitted with adequate risk assessment, and the presence of an SPZ will affect the level of permissible risk.
- Depth to groundwater at the site (thickness of the unsaturated zone).
- Soil or rock type and thickness encountered at the site.
- The microclimate of the region: climatic factors including precipitation and surface evaporation rates are important considerations when assessing the amount of road runoff, particularly peak storm flows.
- Would a soakaway lead to mobilisation of pollutants in existing contaminated land?

4.6.4.7 Site-specific design

Once the general area where a soakaway is to be situated is identified, the detailed specific design is required. In the past, designs have tended to be general for a whole scheme with no variations to take into account differences in ground conditions along the route. In low lying areas near rivers there may be little unsaturated zone available and a soakaway should perhaps be broad and flat, whereas, on high ground, the depth of the unsaturated zone is large enough for smaller, deeper structures, reducing the amount of land take.

There are a number of factors to be considered when selecting a soakaway for a specific location. The key factors are the topography and the shape of the area available adjacent to the road. The design should ensure that:

- the soakaway selected suits the site dimensions
- the soakaway is not within 5 m of a building, to meet practices nationally (see note below)
- the road sub-base remains unsaturated when the soakaway is at its maximum design capacity
- the vertical distance between the soakaway and the ground water is maximised
- the soakaway does not lead to (harmful) groundwater emergence downgradient
- the soakaway does not surcharge groundwater leading to (harmful) waterlogging or exacerbate groundwater flooding
- the soakaway does not lead to the washing out of fines (causing instability) or lead to (harmful) dissolution of the subsurface.

Some of these aspects of soakaway design are critical to minimise impacts on nearby structures and the water environment.

Certain issues have been reported concerning sites on an underlying stratum of chalk, where the drainage from surface car parks was taken to soakaways resulting in subsidence.

Although chalk is permeable, it appears that soakaways create new preferred drainage paths in materials which may already have been affected by solution features, leading to cavities. The upper strata of such materials then subside into the cavities, forming 'sinkholes' and consequently ground subsidence occurs. Soakaways should only be avoided in chalk when recommended by the geotechnical surveyor.

4.6.4.8 Soakaway design

The risk assessment process includes evaluation of the geological setting of the site, which should be a fundamental consideration in the development of the design.

Based on the criteria detailed in the following sections, and subject to the risk assessment, the key elements in the design and construction of an effective soakaway are:

- where identified as necessary, the introduction of containment and control measures for potential pollution from accidental spillage
- where identified as necessary, pre-treatment to remove non-soluble and particulate contaminants
- sufficient capacity to accommodate the quantity of design runoff
- sufficient drainage paths/ports to allow water to infiltrate into surrounding ground
- filter or settlement mechanisms to prevent the blockage of drains or siltation of the drainage paths plus the surrounding ground
- maximising depth of unsaturated zone
- allowance for the controlled overflow of extreme storm events
- the provision of observation wells/pipes (inspection tubes/chambers) to allow inspection and maintenance.

The performance of a soakaway system will depend to a large extent on the ability of water to infiltrate through the unsaturated zone, which is in turn dependant on the physical properties of the ground and the surface area in contact with the soakaway. The ability of a soakaway to transmit water will be influenced by a number of factors, such as the number and size of drainage ports, the amount of sediment allowed to settle and remain in the chambers and the degree of choking that occurs immediately outside the chamber in the surrounding ground. A proprietary filtration device or a catch-pit should always be used on the inlet drain or rainwater pipe to intercept debris and sediment.

4.6.4.9 Design procedures

Soakaways store storm water runoff and provide for its infiltration into the surrounding soil. The infiltration must occur sufficiently quickly to provide the necessary capacity within the drainage system to cope with the expected runoff, based on expected rainfall intensity and

frequency or the outflow calculations from the use of modelling. Providing adequate storage volume and subsequent discharge are the two design parameters that govern the calculations for soakaway design. Design of soakaways and infiltration trenches should be undertaken in accordance with BRE Digest 365⁽⁶⁶⁾ and CIRIA Report 156⁽⁶⁷⁾.

BRE Digest 365 provides advice on the design of soakaways in urban environments and provides methods for determining the size of the soakaway required to deal with anticipated levels of runoff. The methodology uses a 10-year return period for a 15 minute duration storm to determine the required storm flow capacity. This may not be appropriate for roads design.

CIRIA Report 156 provides brief guidance on designs of drainage systems to remove pollutants, based on physical and biological systems, such as sediment traps, interceptors, soakaways and vegetative treatment systems for a range of drainage scenarios, including roads.

4.6.4.10 General construction guidelines

Soakaways should be constructed sufficiently far away from the building structure in order to prevent the risk of undermining foundations. Building practices recommend that a minimum distance of 5 m should be adopted between a subsurface drainage system and a building, depending on ground conditions. In addition, soakaways should not normally be deeper than 3–4 m in order to maximise the length of the flowpath to the watertable through the unsaturated zone.

The long term performance of the soakaway depends on maintaining the initial storage volume by keeping the pores clear within the granular fill. In order to maximise the effective life of the soakaway between cleaning, any material that is likely to clog the pores of the drainage material or seal the interface between the storage and the adjacent soil should be intercepted before discharge to the soakaway. Consideration of the need for sediment traps and, where appropriate, oil interceptors to treat the surface water prior to discharge to soakaways may be required, based on an assessment of the risks.

Whilst the interception of sediments prior to entry into the soakaway is an essential pre-requisite to good design, various soakaway designs should incorporate the use of geotextiles to prevent the migration of fine materials. Geotextiles may be used to:

- separate granular backfill materials from ground material in the walls of excavated pits
- prevent fines within the soakaway from migrating outward into granular surround materials hence reducing clogging of those materials
- lay over the top surface of a granular fill to prevent downward ingress of backfill material during and after surface reinstatement.

The requirements for the use of geotextiles will be specific to the type of soakaway design adopted.

4.6.5 Oil separators

4.6.5.1 Background

It has long since been a legal requirement to prevent drains from conveying oil and petrol into sewers and from polluting natural waters. Up to about the 1980s the normal method of controlling this risk was typically by constructing a brick built 3-chamber 'petrol interceptor'. Each chamber incorporated a dip pipe outlet intended to create separation so that the petroleum fluids would be trapped on the surface of the retained effluent within each chamber. As more stringent environmental standards evolved it was recognised that this type of interceptor was unable to provide the level of assurance required to meet the latest environmental standards.

4.6.5.2 Current requirements

The Water Industry Act 1991⁽³⁾ prohibits the discharge of any 'petroleum spirit' into a public sewer (or adopted sewer), and this is enforced by the relevant water supplier. In addition the Water Resources Act 1991⁽¹⁷⁾ prohibits the discharge of any 'mineral oil or hydrocarbons' into any natural watercourse or into ground waters and this is enforced by the Environment Agency (in England and Wales), the Scottish Environmental Protection Agency and the Department of Environment in Northern Ireland). To meet these requirements, pre-fabricated 'oil separators', manufactured to meet specific criteria within BS EN 858⁽⁶⁸⁾ are normally required for typical applications, although this Standard permits separators built in-situ where the size of the unit is large (NS150 or greater, subject to agreement of the relevant authority), providing that the constructional dimensions, materials and performance meet the prescribed criteria.

Some SUDS techniques (see chapter 5) have the ability to naturally treat small hydrocarbon contamination within effluent by biodegradation and other removal mechanisms. Therefore for limited risk areas such as car parks, alternative SUDS techniques may be acceptable to the relevant authority.

For small car parks with less than 50 spaces, the use of garage gullies in lieu of an oil separator may be acceptable to the relevant authority. In this application the gullies need to be the trapped type and should be subject to regular emptying.

The selection, installation, and maintenance of the oil separator should comply with BS EN 858⁽⁶⁸⁾ and Part H3 of the Building Regulations^{(11)*}. For installations where the Petroleum (Consolidation) Act 1928⁽⁶⁹⁾ applies, the relevant licensing authorities' requirements should also be observed. Oil separators are typically required for:

- fuel stations and commercial/industrial garages
- car parks larger than 800 m² (where there are 50 or more car parking bays)
- smaller car parks discharging to a sensitive environment (such as a river)
- areas where goods vehicles are parked or manoeuvred

- industrial sites where liquid hydrocarbons are stored or used.

It is important to note that where hydrocarbons are stored in bulk, the storage vessel must incorporate emergency containment facilities, such as a bund arrangement (further guidance can be found in PPG 7⁽⁷⁰⁾ and PPG 21⁽⁷¹⁾).

The guidance in this section is based on BS EN 858⁽⁶⁸⁾, and PPG 3⁽⁶²⁾, which should be consulted for further information.

4.6.5.3 Selection of oil separators

Oil separators are designed to retain any liquid hydrocarbons or similar 'light liquid' contaminants that float on water such as diesel, petrol or engine oil, and provide settlement for any associated sludge or silt. Prefabricated oil separators are normally formed from glass-reinforced plastic (GRP) or medium density polyethylene (MDPE), and vary in size up to about 3.2 m in length, depending upon the required flow rate, storage capability, classification and type. Separators are given a declared NS ('nominal size') or NSB ('nominal size, bypass unit') rating, which relates to their flow capacity in litres per second, and should have provision for a sludge trap having a volume in accordance with BS EN 858-2⁽⁶⁸⁾. The sludge trap may be integral within the separator design or provided as an external unit. There should be provision for sampling the quality of the effluent from a separator, this may be included within the separator design or provided by a separate chamber. Separators are classified according to their ability to limit carry-over or contamination to within prescribed limits. A Class 1 oil separator is designed to limit contamination of the outlet effluent to less than 5 mg/litre (when works tested in accordance with BS EN 858-1⁽⁶⁸⁾). They are normally required when the discharge is to be conveyed to a surface water sewer or to a water course. These separators normally incorporate a special baffle designed to create the necessary coalescence. Whereas a Class 2 oil separator is designed to limit contamination of the outlet effluent to less than 100 mg/litre (when works tested in accordance with BS EN 858⁽⁶⁸⁾), these are only acceptable where the discharge is to be conveyed to a foul sewer (subject to agreement with the appropriate water undertaking). Both classifications are available in three different types:

- *Full retention separator*: designed to accept the full design flow of the catchment area, these should have a NS rating (nominal size) that is normally based on a rainfall intensity of 0.018 litre/s per m², with a silt storage volume (in litres) of not less than 100 × NS. In addition the oil storage volume of the separator needs to be sufficient to retain the quantity from any likely spillage incident (the largest volume of any fuel tank likely to be on the site). Full retention separators are also required to incorporate an automatic closure device to prevent effluent passing through the separator when the oil storage volume is full.
- *Bypass separator*: designed to accept 10% of the normal design flow of the catchment area that will cater for the majority of average storm events, these should have a NSB rating (nominal size for a bypass unit) normally based on rainfall intensity

* Similar legislation applies in Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

of 0.0018 litre/s per m², with a silt storage volume (in litres) or not less than 100 × NSB. Any flows in excess of this are directed to bypass the separator treatment process by flow control device such as a weir. This arrangement is limited to applications where relatively small spillages are likely, as may be the case in short-stay parking areas for motor cars.

- *Forecourt separator:* these are designed as full retention separators, for use in applications where petrol and/or diesel is to be dispensed (either retail or non-retail). This application presents a high volume spillage risk if, for example, the delivery tanker develops a leak. Therefore the separator should have an oil storage capacity of at least 7600 litres, although this would need to be increased if the size of the fuel compartments within the delivery tankers likely to visit the site exceed this volume.

Figure 4.12 gives a basic overview of typical applications, based on PPG 3⁽⁶²⁾ where further guidance can be obtained. It is important to note that the selection of oil separators (or alternative facilities) should include consultation with the relevant authorities and with the manufacturer.

4.6.5.4 System design considerations

System design considerations include the following:

- Very large catchment areas may be divided and more than one oil separator provided.
- Catchment areas not subjected to contamination risk (such as roofs) should connect to the drainage system downstream of the oil separator.
- BS 858-2⁽⁶⁸⁾ states that oil separators should be installed so the level of the turret access covers is higher than the ground flooding level of the inlet drain (e.g. gully grating). This is to prevent the escape of liquid hydrocarbons near the separator in the event that the effluent level in the separator rises above normal operating level for any reason.
- Oil separators need to be provided with suitable vent piping that terminates in a safe and nuisance-free location.
- An automatic visual and audible alarm should be initiated when the oil storage volume of the separator reaches 90 per cent full. The provision of a silt volume alarm is also recommended. All electrical alarm controls should be intrinsically safe and certified against explosion.

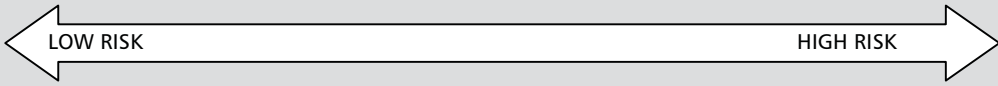
Typical drainage for liquid hydrocarbon contamination risk management					
					
Type of risk	No perceivable risk of contamination on catchment area.	Infrequent risk or risk limited to small spills.	Risk of regular contamination or contamination from larger spills.	Risk includes dissolved oils, detergents or degreasers.	Liquid hydrocarbons are delivered or dispensed on the site.
Example of risk	Roof area not accessible to cars and not used for storage of hydrocarbons.	Parking area for motor cars.	Vehicle servicing or access areas where goods vehicles are manoeuvring or are parked.	Vehicle washing facilities or trade effluent from industrial sites.	Petrol station forecourt.
Typical requirements	Oil separator NOT required. If a separator is used for other catchment areas on the site, then the roof drainage should connect downstream of the oil separator	Use SUDS techniques to provide natural treatment, or; Use a bypass oil separator: Class 1 if discharging to a surface water sewer or Class 2 (subject to approval) if discharging to a foul sewer.	Use a full retention separator: Class 1 if discharging to a surface water sewer or Class 2 (subject to approval) if discharging to a foul sewer.	Trade effluent should discharge to the foul sewer. The type of separator that is required will be dependent on the effluent contamination	Forecourt separator (full retention): Class 1 if discharging to a surface water sewer or Class 2 (subject to approval) if discharging to a foul sewer.
Notes	Consider the use of SUDS techniques to minimise the flow.	Consider the use of SUDS techniques to 'polish' or further improve the effluent quality downstream of the oil separator where the discharge is intended to enter the natural environment.			

Figure 4.12 Drainage risk management

- Prefabricated separators need to be installed strictly in accordance with the manufacturer's instructions in order to prevent flotation during construction, and to ensure that the necessary structural integrity is provided.
- Provisions to allow safe emptying, inspection, and maintenance activities should be included in accordance with the CDM Regulations^(72,73). In addition to the oil separator manufacturer's recommendations, BS 858-2⁽⁶⁸⁾ states that maintenance inspections should at least six-monthly. CIRIA document C697⁽⁷⁴⁾ also lists items that should be inspected at six-monthly and five-yearly intervals.
- The installation should be provided with operating and maintenance instructions which list routine actions to ensure its continued effectiveness, and include methods for dealing with an emergency pollution incident.
- Separators should be emptied in accordance with *Waste Management: the Duty of Care*⁽⁷⁵⁾. The separator should be refilled with clean water immediately after emptying otherwise the efficiency of the unit may be adversely affected, therefore a suitable water supply point should be provided.

4.7 Anti-flooding precautions

4.7.1 Introduction

This section covers precautions that should be considered to prevent flooding within buildings in the event that the sewer serving a building being subjected to 'surcharge' conditions. Surcharge occurs when the sewer is receiving more effluent than it was designed to carry, and it has become full with flowing effluent and is being subjected to a head of water by the inlet drains that are discharging into it from a higher elevation upstream. Thus the sewer has become pressurised and will expel effluent at any inlets which are lower than the hydraulic surcharge level by backflowing at each drain connection to the sewer. Surcharge flooding, also known as 'backflow' thus occurs.

Figure 4.13 shows an example of a building vulnerable to flooding if the known sewer surcharge level results in flooding of the road. Surcharge flooding or backflow typically occurs within old combined sewers that convey both foul and surface water, when the capacity of the sewer is unable cope with the volume of rainwater being discharged during an intense or prolonged storm event. In order to assess the level of risk of flooding within the building due to sewer surcharge, it is necessary to obtain historical and predictive hydraulic surcharge level data from the relevant authority, and compare this with the lowest flood level of any connected sanitary appliances or gullies within the building. This information would then be used to formulate a professional judgement about the level of risk.

4.7.2 Prevention of flooding

Preventing flooding of premises has become a national concern recently with numerous events highlighting the fragility of the UK's drainage infrastructure at local and regional levels.

Whilst further controls can and are being effected to reduce risk on new-build sites, many established properties are now more at risk than was the case. This is due to a number of factors, including:

- rainfall pattern changes, particularly storm intensity and duration
- changes to upstream hydrographical structure
- increased drainage load (local and regional)
- failure of some aspect of the drainage system
- restrictions in the drainage system, either immediate or gradually occurring caused by, for example, grease build-up in the sewer.

Among the various solutions available, the use of anti-flood valves requires specific circumstances and an understanding of the types of valve available. But, used correctly such products can provide an economical defence with varying levels of sophistication available.

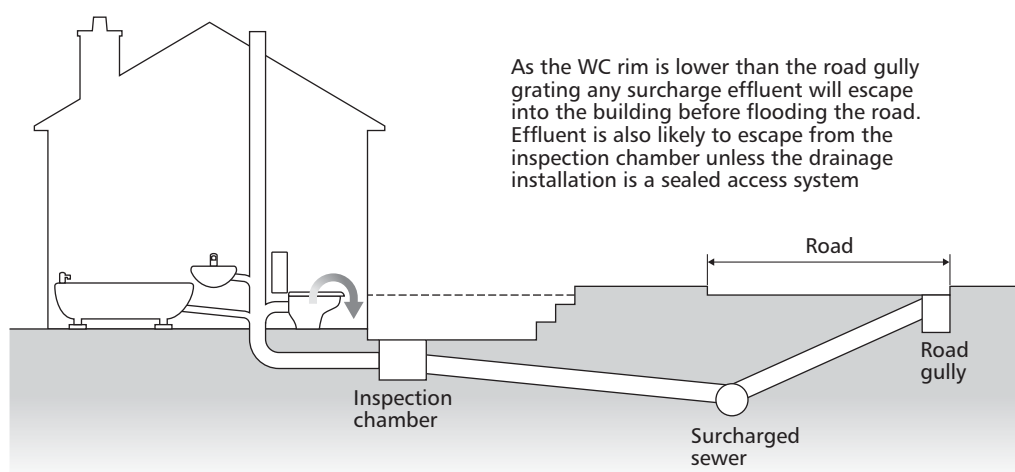


Figure 4.13 Example of an installation vulnerable to surcharge flooding

4.7.3 Current regulations and design guidance

Part H of the Building Regulations^{(11)*} requires that drainage systems are 'adequate', and Approved Document H⁽²⁵⁾ (ADH) gives guidance on anti-flooding provisions. The drainage system should not increase the risk of flooding inside the building in the event that the connected sewer becomes surcharged. The recommendations include the following (see particularly ADH sections 2.10 and 2.11):

- Where sanitary appliances are located at basement level (or below street level) where the risk of flooding due to surcharge is considered to be 'high', the drainage from this level should be pumped. Where the risk is 'low' an anti-flooding valve may be considered to be an acceptable facility.
- For other low lying sites (excluding basements), where the risk is considered to be 'low', and where the ground level surrounding building is lower than street level, sufficient protection against flooding inside the building may be facilitated by the provision of one or more external gullies. These external gullies may be adequate to act as emergency effluent outlets, providing that they are at least 75 mm below the internal floor level (or in the case of a ventilated suspended floor, not less than 75 mm below the underside of any air bricks), and providing that the escaping effluent can drain off the ground without causing flooding within any buildings. Alternatively, an anti-flooding device should be used or the lower level drainage system pumped.
- Anti-flooding devices should comply with BS EN 13564⁽⁷⁶⁾, preferably incorporating two automatic closing valves, one of which should be provided with an additional manual control. The installation should be provided with a notice identifying the location of each anti-flooding device, and giving guidance on the need for regular maintenance. Each anti-flooding device should not serve more than one building.
- Parts of the drainage system on floor levels unaffected by surcharge should bypass any anti-flooding device or pumping facility.

Building Regulations Part H^{(11)*} thus allows anti-flood valve use in basements where the risk is low, and use in low lying sites (not a basement) in higher risk areas. Where risk is deemed high in basements, a valve is insufficient and a wastewater lifting station should be employed. ADH section 2.11 states a preference for a 'double valve' — a feature described in BS EN 13564⁽⁷⁶⁾ and summarised below.

Scottish Building Regulations⁽¹²⁾ quantify the extent of the problem, stating some 500 building basements per year are flooded as a result of sewer backflows. Both documents note the need to bypass anti-flood devices where drainage appliances are above the flood level.

BS EN 12056-4⁽²⁸⁾ assists by defining the flood level as the level of the highway, and providing other specific circumstances where such devices may be used, namely:

- there is a fall to the sewer
- the rooms are of minor importance with respect to valuable goods and the health of occupants in case of flood
- the user number is small and a WC is available above flood level, and
- that sanitary appliances do not need to be used during flooding.

Note: local authorities insist on all habitable basements being protected by the use of pumping, and will not allow anti-flooding valves to be used.

These requirements can be represented diagrammatically; here the flood level clearly means the basement is at risk in a sewer surcharge event. The anti-flood valve connects only to basement appliance drainage and appliances at higher levels than the surcharge level would remain usable, although the drainage system would become flooded. Without the fall to the sewer a lifting plant is required.

4.7.4 Anti-flooding devices

As previously stated anti-flood valves should meet the requirements set out in BS EN 13564⁽⁷⁶⁾. The acceptable types of device are summarised in Table 4.10, however Building Regulations Part H^(11,25) and the stated preference for a double valve effectively rules out types 0, 1 and 4. Valves may be in-line with horizontal drainage pipe runs or contained within a gully or other waste fitting. The valve itself can be passive in that it operates under the pressure of water or active in that it is actuated by external energy. Valves are further distinguished in that they are automatic (passive or active) and capable of manual locking, or a combination of both.

Selection depends on the level of assurance required. Type 3 valves are only a requirement for faecal wastewater in some European countries such as Germany and Denmark; there is no legal requirement for this type in the UK.

BS EN 13564 classifies anti-flooding products depending on their features and application, see Table 4.11.

Anti-flooding devices should have a declaration of conformity which indicates the classification Type that applies to the product design. Products certified to BS EN 13564 are required to meet several performance tests for durability, backflow reliability, etc, which includes backflow testing at 1 kPa (about 102 mm head of water) and 50 kPa (about 5.1 m head of water).

Inspection of anti-flooding devices

BS EN 13564⁽⁷⁶⁾ recommends that anti-flooding devices are inspected and serviced at intervals not exceeding six months. Inspection and servicing activities should follow the relevant manufacturer's instructions.

* Similar legislation applies in Scotland⁽¹²⁾ and Northern Ireland⁽¹³⁾.

Table 4.11 Classifications for anti-flooding devices to BS EN 13564

Classification	Description
Type 0	Having a single self-activating valve. For use on a drain pipe.
Type 1	Having a single self-activating valve and a manual closure control (the manual control may be combined with the valve). For use on a drain pipe.
Type 2	Having two self-activating valves and a manual closure control (the manual control may be combined with one of the other valves). For use on a drain pipe.
Type 3	Having a single valve activated by an external energy source (e.g. electrically or pneumatically driven), and a separate manually controlled closing valve. For use on a drain pipe. Note the external energy source should be operative in the event of normal power supply failure.
Type 4	A facility incorporated into a waste fitting or gully having a single self-activating valve and a manual closure control (the manual control may be combined with the valve).
Type 5	A facility incorporated into a waste fitting or gully having two self-activating valves and a manual closure control (the manual control may be combined with one of the other valves).

References

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- 2 BS EN 752: 2008: *Drain and sewer systems outside buildings* (London: British Standards Institution) (2008)
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5 Conservation and sustainability

5.1 Introduction	Summary
5.2 Legislation and guidance	Conservation and sustainability are now consistent threads to any public health engineering design.
5.3 Water conservation	This can be anything from considering the embodied energy or water footprint of specified items to the design of solar systems, heat pumps or wastewater heat recovery systems. This chapter concentrates on water supply and stormwater disposal with other sources of information being referenced as appropriate.
5.4 Harvesting, re-use and alternative supplies	
5.5 Sustainable drainage	
5.6 Flood protection	
5.7 Living roofs	
References	

5.1 Introduction

5.1.1 Scope

Scientific evidence shows that climate change resulting from carbon dioxide emissions associated with energy use is both real and underway. The way vital water resources are used also plays a critical role in creating a built environment in a sustainable form. The modern day public health design engineer has a significant role to play, not only in reducing the consumption of water and energy but also in looking at the wider environmental impact of the systems designed and materials specified.

There are numerous guidance documents that explore individual topics and therefore this chapter is intended to give a only brief overview of some of the primary areas relating to public health engineering and will refer to other sources for specific design guidance. CIBSE Guide L: *Sustainability*⁽¹⁾ is a good source of initial guidance.

5.1.2 Definitions

Within the context of this chapter, the following definitions apply.

Attenuation

Limiting the peak flow rate in a drainage system during a storm by including a throttling method and providing a temporary storage facility to accommodate the excess rainwater.

Biodegradation

Decomposition of organic matter by micro-organisms and other living things.

Blackwater

Water contaminated with animal, human, or food waste for example from WCs, bidets, urinals, kitchen sinks, dishwashers.

Detention basin

A vegetated depression, normally dry except after storm events, constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground.

Environmental footprint

A measure of environmental impact based on the distance that resources for a development are transported.

Filter strip

A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and filter out silt and other particulates.

Flood routing

Design and consideration of above-ground areas that act as pathways permitting water to run safely over land to minimise the adverse effect of flooding. This is required when the design capacity of the drainage system has been exceeded.

Greywater

Water that was originally supplied as wholesome water, but has already been used for some other application such as bathing, showering, hand washing or laundry (but not water from WCs or from dish washing).

Infiltration potential

The rate at which water flows through a soil (mm/h).

Infiltration trench

A trench, usually filled with stone or geo-cellular modules, designed to promote infiltration of surface water to the ground.

Lagoon

A pond designed for the settlement of suspended solids.

Rainwater

Water arising from atmospheric precipitation

Reclaimed water

Water which has been used for another purpose and then treated so that the quality is suitable for a particular specified re-use.

Retention pond

A pond where runoff is detained (e.g. for several days) to allow settlement and biological treatment of some pollutants.

Source control

The control of runoff or pollution at or near its source.

Swale

A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration; the vegetation filters particulate matter.

Wetland

A pond that has a high proportion of emergent vegetation in relation to open water.

5.2 Legislation and guidance

5.2.1 General

Public health engineers have a direct influence over many significant sustainability issues, see Table 5.1. As such, it is essential to be involved at the early stages of a project where there is the best opportunity to assess and integrate the most appropriate solutions at the lowest possible cost.

In a rapidly changing legislative environment it is important that engineers have, and maintain, a good understanding of the key processes, legislation and parties that should be consulted during the design process.

The following are examples of some of the considerations current at the time of publication.

Table 5.1 Key principles for sustainability and conservation for a public health engineer

Issue	Example
Water use/supply	● Reduce demand ● Minimise use and prevent waste while meeting demand efficiently ● Evaluate the most appropriate source of water (mains, greywater, harvested rainwater, ground water, desalinisation etc.) ● Facilitate/incorporate methods of effective water management
Energy and CO ₂ emissions	● Reduce demand ● Facilitate / incorporate methods of effective energy management ● Understand and minimise the embodied energy and carbon footprint of specified systems and components
Sustainable drainage	● Reduce run-off from the site ● Attenuate storm flows from the site ● Mimic the natural drainage process as closely as possible ● Incorporate additional benefits where possible (habitats, amenity etc.)
Flood risk	● Avoid the risk of flooding and design flood resilience where necessary ● Avoid increasing the risk of flooding to off-site areas
Transport	● Consider the maintenance requirements for systems or delivery of consumables
Ecology and biodiversity	● Conserve, protect and enhance site ecology ● Provide new habitats ● Compensate for unavoidable damage or loss of biodiversity
Pollution	● Prevent or reduce pollution at source ● Treat unpreventable pollution (in an environmentally safe manner) ● Undertake disposal of intercepted pollutants in an environmentally safe manner
Waste	● Reduce waste and recycle residual waste wherever possible
Health and wellbeing	● Avoid or reduce health risk factors, discharge all health and safety obligations etc. ● Assess and 'design-out' risk at every opportunity
Lifecycle impacts	● Select materials, equipment and processes from sustainable sources with the lowest in-use and embodied environmental impacts and with the highest recycled content
Local environment and community	● Avoid causing others nuisance or pollution

5.2.2 The planning process and the National Planning Policy Framework

The National Planning Policy Framework was published on 27 March 2012 and was seen as a key part of plans to make the planning system less complex. Prior to this, specific guidance was given within separate Planning Policy Statements (PPSs) and, before that, Planning Policy Guidelines (PPGs).

Many parts of the country also have Land Drainage Authorities. The role of these and other parties interested in flood protection are reviewed further in section 5.5.

5.2.2 Building Regulations

Building Regulations exist to ensure that buildings are safe, energy efficient and accessible for everyone who uses, lives or works in and around them. The regulations apply to most new buildings and many alterations of existing buildings, whether domestic or non-domestic.

Scotland has separate regulations to England and Wales but both are supported by a variety of Approved Documents, procedural handbooks or guides which give further guidance on how the requirements of the Regulations can be satisfied. Details of the regulations and supporting documents, for all parts of the UK, may be found on the Government's 'Planning Portal' website (<http://www.planningportal.gov.uk>).

5.2.3 Climate Change Act 2008

This UK legislation claims to introduce the world's first long-term, legally binding framework to tackle the dangers of climate change.

The Climate Change Bill was introduced into Parliament on 14 November 2007 and became law as the Climate Change Act 2008⁽²⁾ on 26 November 2008.

5.2.4 Future Water

Future Water: The Government's water strategy for England⁽³⁾ sets out the Government's long-term vision for water and the framework for water management in England.

The strategy's proposals included:

- the aim to reduce water usage to 120 litres per person per day by 2030 from the current level of approximately 150 litres per person per day
- new proposals to tackle surface water drainage and flood risk
- new proposals to reduce water pollution by tackling contaminants at source.

5.2.5 Code for Sustainable Homes

The *Code for Sustainable Homes*⁽⁴⁾ is an environmental assessment method for rating and certifying the performance of new homes. It is a national standard for use in the

design and construction of new homes with a view to encouraging continuous improvement in sustainable home building. Each of the categories listed below is a source of impact on the environment that can be assessed against a performance target with credits awarded for the approach adopted. The performance targets are more demanding than the minimum standard needed to satisfy Building Regulations or other legislation

The *Code for Sustainable Homes* covers categories of sustainable design including:

- *Energy and CO₂ emissions*: covers such areas as hot water generation.
- *Water*: credits are available for reducing the amount of potable water used in dwellings.
- *Materials*: although predominantly addressing building elements such as walls and floors the overall aim is to encourage the use of materials with lower environmental impacts over their lifecycle.
- *Surface water run-off*: this aims to ensure that the peak rate of runoff into watercourses is no greater for the developed site than it was for the pre-development site. Most elements are mandatory with points available for improving discharge water quality, for example.
- *Pollution*: to reduce climate change from emissions that arise from the manufacture, installation, use and disposal of items such as foamed thermal and acoustic insulating materials in hot water cylinders and cold water cistern insulation.

5.3 Water conservation

5.3.1 General

Water is a precious natural resource and its sustainable management is essential to protect the water environment and to meet current and future demand. Population, household size, industrial output and affluence all affect how much water we use. Factors such as climate change are also likely to put supplies under greater pressure in the future, making it important that we adopt more efficient water usage patterns.

5.3.2 Conservation techniques and products

New techniques and products are constantly being developed to minimise the amount of water used by appliances and processes in domestic, commercial and industrial applications. Table 5.2 provides examples of measures and appliances that can help deliver reductions in water consumption in domestic and commercial buildings.

It is important to reduce the total consumption and wastage of water. However, minimising the use of treated mains water should be strived for in particular.

Table 5.2 Examples of measures to reduce water consumption

Method	Measure
Reduce WC flushing volumes	● Low volume/dual flush cisterns ● Cistern inserts in existing installations to reduce flushing volume ● Usage of delayed-fill inlet valves.
Reduce/eliminate urinal flush	● Proximity controls to match flush frequency to occupancy ● Utilise waterless urinals
Temperature control to prevent waste	● Minimise HWS dead-legs to prevent cool water being wasted to drain ● Circulate/insulate cold water to prevent warm water being wasted to drain
Education and changes to behaviours	● Much water use in domestic applications, such as hosepipes and taps, is controlled by the user; educating people in the benefits of conservation and careful use can therefore yield significant savings
Drought resistant planting/efficient irrigation systems	● Careful selection of planting can significantly reduce in irrigation water requirements
Composting toilets	● Composting toilets (also called biological, dry or waterless toilets) are systems that treat human excrement through biological processes, turning it into organic compost material
Aerated flows	● Taps and showers can be fitted with aerated flow devices reducing volumes in use without significant adverse impact on usage quality
User display consumptions meters/timers	● Reminding users of the volume of water being consumed can be an effective method of reducing consumption on appliances such as showers ● Tenant or dwelling level metering also often proves effective in reducing waste
Automatic switch-off taps and showers	● Various methods are available to prevent taps, for example, being left on beyond a set time period
Avoid evaporative cooling methods	● An analysis should be made to confirm that the evaporative cooling is the most appropriate option from a sustainability perspective
Leak detection and prevention systems	● Underground leakage in particular accounts for a significant proportion of potable water wastage. Measures such as leak detection monitors linked to building management systems can reduce the potential for this type of wastage
Waterless/reduced volume vehicle washing systems	● Products are available to facilitate the waterless/reduced water systems for vehicle cleaning
Flow/pressure control devices	● Careful planning of system design will allow flow and pressure to be more closely matched to specific outlet requirements and therefore prevent undue consumption or waste
Water efficient appliances such as low volume dishwashers and washing machines	● Consideration should be given to specifying the most water efficient items as possible

5.4 Harvesting, re-use and alternative supplies

5.4.1 Introduction

The concept of capturing rainwater and storing it for later use is well documented through history. However, this dwindled in industrialised countries as reliable and inexpensive mains water supplies became the normal supply route. With the ever-growing demand for water, increasing costs and potential environmental impacts, the local harvesting and re-use of water is once again becoming a viable addition to the water supply cycle.

The options for water reclamation include:

- rainwater collection
- greywater recycling
- blackwater treatment
- condensate from cooling units.

Other sources of water that can also be considered as alternatives to mains supplies (or where there is no suitable mains water supply) include:

- groundwater
- desalination systems

— river abstractions.

In identifying alternative sources of water, the first consideration is the use to which these sources will be put. Potable (drinking) water, which can be used for consumption, cooking, and bathing, among other uses, must meet a high level of purity and safety. Non-potable water is less pure but, when handled properly, it can be acceptable for landscape irrigation, as make-up water for cooling towers, and for toilet flushing. Many alternative water sources are best suited to non-potable uses, though some can be made potable with additional treatment.

5.4.2 Design considerations

In order to design a reclaimed water system it is first essential to understand the use to which the reclaimed water is to be put and hence what level of quality is necessary. A risk assessment examining the use of the water and the exposure/risk to occupants should be used to identify the degree of treatment that should be incorporated into a system design.

The risk assessment should follow a recognised process, such as that described in BS 31100⁽⁵⁾. Additional guidance and examples are provided in WRAS Information and Guidance Note No. 9-02-04: *Reclaimed water systems*⁽⁶⁾ and HSE Approved Code of Practice and guidance L8:

Legionnaires' disease. The control of legionella bacteria in water systems⁽⁷⁾.

The risk assessment should consider the effects of exposure to, and the potential impacts of, the water within the reclaimed system and any of the system's treatment processes on:

- people, including operators, installers, maintainers, and water users, particularly those who might be more susceptible to poor water quality (e.g. children or the elderly)
- the environment, including domestic and feral animals, birds and fish, plants, water courses and groundwater
- physical assets, including buildings, building fabrics, room decorations, and where external tanks are used; foundations, drains, paved areas and gardens.

The risk assessment should be used to identify additional actions, process improvements or enhanced controls that can reduce risks in a cost-effective manner.

5.4.3 Reclaimed water

5.4.3.1 General

The biggest advantage of collecting and using rainwater over using mains water is that it is free of charge. Additionally, it reduces the load on treated mains water whilst potentially also reducing the impact of storm-water runoff. The main disadvantage being that during long dry spells, when the public water supply is struggling to meet demand, the rainwater harvesting system may be empty requiring the user to rely on mains water during such periods.

The sizing of rainwater collection and storage systems requires assessment of the average annual rainwater yield, available and the likely demand for its use within the building. Some methods for this are outlined below.

Calculating yield

The maximum amount of rainwater collected each year can be calculated from the following equation:

$$Y_r = A_c R_m C_r \eta_f \quad (5.1)$$

where Y_r is the annual rainwater yield (litre/year), A_c is the collection area (m^2), R_m is the average annual rainfall (mm), C_r is the run-off coefficient and η_f is the fractional collector efficiency.

These variables are described as follows:

- *Collection area*: the plan area available for rainwater collection, i.e. for roofs, the plan area (rather than the slope area) of the roof surface feeding into the downpipe.
- *Annual rainfall*: the average annual rainfall for the particular location. (Average rainfall figures for the UK are available from the Met Office (<http://www.meto.gov.uk>) or from BS 8515⁽⁸⁾).

— *Runoff coefficient*: the percentage of water actually coming off the roof or paved area after allowing for evaporation, and absorption by the construction materials. Typical values are shown in Table 5.3. A more extensive list of runoff coefficients can be found in BS 8515.

— *Filter efficiency*: the percentage of water captured by rainwater collection filters. This value is typically 90% but should be checked with the manufacturer.

Table 5.3 Typical run-off coefficients

Type	Runoff coefficient
Pitched with smooth surface, e.g. glazed tiles	0.9
Pitched roof with tiles, e.g. concrete tiles	0.8
Flat roof	0.6–0.7
Green roof (intensive)	0.2–0.3

Calculating demand

In order to ensure maximum efficiency (and hence use as little mains water as possible) the annual yield of reclaimed water should, as near as possible, match the estimated annual demand.

Generally, the demand can be obtained by adding up the demand for the targeted non-potable applications, which can be calculated as follows:

$$DNP = [(PNP \times n) + ANP] \times 365 \quad (5.2)$$

where DNP is the annual non-potable demand (litre/year), PNP is the non-potable demand per person ((litre/person)/day), n is the number of persons and ANP is the non-potable demand per application which cannot be determined per person (e.g. irrigation demand) (litre/day).

For a more detailed approach to calculating the demand per person reference can be made to the greywater yield calculation described in BS 8525⁽⁹⁾. There is a balance between maximising rainwater use and not wasting energy in specifying an excessively large storage volume (thereby requiring more initial excavation and greater replacement cost). BS 8542: *Calculating domestic water consumption in non-domestic buildings. Code of practice*⁽¹⁰⁾ suggests that the efficiency of a rainwater harvesting system is 'excellent' if the system supplies 75% of all the WC and urinal demand.

Collection tank sizing

As rainfall is unpredictable, the storage tank size must be sufficient to allow for rainfall variability and should hold enough rainwater to cover normal seasonal dry periods when there is no rainfall.

Depending on the cleanliness of the rainwater and any treatments applied, storage to cover 20 days' demand or more is feasible. This is helpful to ensure sufficient collection of water during wet periods to cover for drier periods. Longer storage periods may however reduce the frequency of beneficial periodic overflowing and lead to larger tanks than necessary.

Where a design is required to meet specific requirements, such as BREEAM⁽¹¹⁾, there may be specific requirements for the storage volume or catchment areas.

In situations where the demand is irregular (e.g. external use, non-residential use, tourism), the yield is uncertain or the system will be costly, larger or complex, a more detailed analysis should be considered. A model should be built to estimate the storage capacity based on the different patterns of demand and yield. Further guidance is given in BS 8515⁽⁸⁾.

Rainwater filtration

Rainwater should be filtered before entering the main body of the stored water. Any filter must be easily accessible for inspection and cleaning purposes. BS 8515⁽⁸⁾ recommends that a harvested rainwater system be provided with a filter that does not pass a particle size greater than 1.25 mm. In practice, it is normal to have a leaf filter (and sometimes a sediment trap) on the drain inlet to the storage tank, a coarse filter on the pump suction, and a fine filter on the pump discharge pipe prior to feeding any appliance.

To help avoid stagnation and consequent bad smells in tanks where there is no disinfection, it helps to keep the water aerated. One way of achieving this is to introduce rainwater at low level within the tank. The pipe outlet should be upturned (or be fitted with a 'calmed inlet') to minimise the risk of disturbing any sediment at the bottom of the tank.

Water discoloration may also occur. Although the water is safe its appearance may be objectionable to the client or may affect white porcelain WCs; refer to treatment requirements below.

Tanks should exclude daylight so as not to stimulate bacteriological or algae growth.

A floating filter inlet to the pump means that pumped water can be filtered before entry to the pump. Also, in floating just below surface level, such inlets ensure that clean, warmer water is drawn from the tank.

Consideration should be given to direct pumping to terminal fittings rather than pumping to a gravity storage cistern. If a direct system is chosen, it is also necessary to consider security of the water supply to WCs, i.e. the provision of duplicate pumps and standby power (this is particularly important in commercial buildings).

Landscape-scale stormwater harvesting

Ground level stormwater is nearly always managed in the landscape surrounding a building, and it is commonly channeled into retention ponds. Occasionally, such retention ponds are designed so that water from them can be pumped out for non-potable uses with higher levels of treatment.

5.4.3.2 Greywater collection and treatment

General

Treated greywater is suitable for toilet flushing and other non-potable uses. In terms their design implications, greywater recycling systems have the benefit that the supply of water for recycling is often closely matched to the demands to be served. This means that, to satisfy a given proportion of the demand, storage tanks can be smaller than for rainwater collection. However, management of water quality is more onerous and systems need to be carefully managed to maintain water quality.

The key advantage over rainwater harvesting systems is that recycled greywater will be available all the time that the building is occupied, and that during periods of consistent occupation the greywater yield will be consistent.

Calculating yield

In standard situations, the yield is likely to be higher than the demand. Therefore greywater collection should always aim for the shower/bath first and then the water from hand wash basins before collecting water from washing machines, if appropriate.

Wash basin wastewater should be avoided because there is more risk of user abuse (particularly in non-domestic situations) causing discoloration of the water due to rinsing cups/mugs, cleaning paintbrushes, contamination by vomit, hair dye, etc.

Typically the yield per person from shower/bath and hand wash basin can be estimated to be around 50 litres per person per day.

For a more precise yield calculation see BS 8525⁽⁹⁾.

Calculating demand

The demand can be calculated by using the same approach as for the rainwater harvesting, see section 5.4.3.1.

Collection pipework

Measures should be taken to avoid the risk of cross connection of greywater and blackwater collection systems and pipework should be identified as described later in this section. It is recommended that a bypass is incorporated at the storage tank to allow the treatment system to be taken off-line without disruption to the sanitary provision of the building.

Greywater collection piping should be designed and installed to appropriate sanitary system standards (see chapter 3).

Collection tanks

Collection tank size should be considered carefully so as to minimise the time untreated water is left standing. Automatic drain-downs, controlled by timeclocks, should be employed to prevent septicity.

Consideration should also be applied to the design options in terms of (a) simple appliance based units, (b) small localised packaged units, (c) large modular central units. BS 8542⁽¹⁰⁾ classifies a greywater system as 'excellent' if it is able to supply 50% of the demand from WCs and urinals.

Treatment

The collected greywater will require treatment to ensure the water quality meets the requirements of the proposed use for the recycled water. This analysis should include a risk assessment, a consideration of the limitations of the equipment being supplied and the client's expectations.

There are many ways in which satisfactory treatment of greywater can be achieved using one or a combination of the following:

- physical, e.g. filtration
- chemical, e.g. chlorination
- biological, e.g. aeration.

5.4.3.3 Blackwater treatment

Sewage effluent, or blackwater, can be treated on site. This can reduce the environmental impact of a development and reduce the load on local water treatment works. However, municipal treatment is also biologically based and can have energy use and quality control advantages over smaller scale on-site treatment plants. Blackwater treatment and/or recycling have significant capital costs and there are operational costs associated with maintaining water quality. The two end products of the treatment are sludge and water. The options for treating and using these end products need to be carefully considered.

5.4.3.4 Air conditioner condensate

While air conditioning condensate is inherently pure, there is potential for contamination, especially if it sits in a warm environment. For this reason it is often provided with some form of disinfection. Consideration should be given to contamination, such as heavy metals, which may have been collected during the process. Corrosivity may also be an issue.

5.4.3.5 Cooling tower blowdown

A considerable amount of water is lost from cooling towers through evaporation and drift losses. Water is also intentionally drawn-off because minerals and other contaminants become more concentrated as a result of evaporation; a process referred to as 'blowdown'. Typically, the blowdown water is sent to drain, but it can be collected and reused for applications where the salinity or mineral content is acceptable.

While air conditioning condensate is reasonably pure when first produced, this is not the case with blowdown water. Along with concentrating minerals, cooling towers also concentrate bacteria and other contaminants, including *Legionnella*. If blowdown water is used for irrigation, treatment is essential.

5.4.3.6 Seawater

There are a few places in the world where seawater is used directly for toilet flushing. However, there are issues with the corrosive nature of the water and potential deposits.

5.4.3.7 Desalinated water

Desalination is the process of removing salts (and other impurities) from seawater or brackish water. Ninety-seven percent of the world's water is saline, so tapping this resource as a freshwater source has long been attractive.

Consideration should be given to reverse osmosis. For example several Mediterranean and Middle Eastern countries rely on desalination for public water supplies.

5.4.3.8 Boreholes

The availability of groundwater will depend upon the water table and receiving the necessary permissions for abstraction. Where adequate yield and permissions are available, groundwater can often provide a reliable, cost-effective alternative to mains water.

5.4.4 Distribution of reclaimed water

Reclaimed water may have unexpected corrosive properties due to its original usage, or residual treatment chemicals. For example, a pH of 5 should be expected for greywater. System materials must be selected with due respect to this.

Pipework for reclaimed pipework should be designed such that deadleg lengths are minimised. If it is likely that water is to remain stationary in pipes for long periods (i.e. longer than 3 days), consideration should be given to establishing some form of flushing or recirculation back to the treatment facility.

Care must be taken to minimise the risk of cross connection between potable water supplies and reclaimed water. It is recommended therefore that the two systems are installed in different materials or pipe systems, in addition to pipework identification measures. Alternative water supplies are required to be 'readily identified' as a legal requirement of the Water Fittings Regulations^(12,13). For guidance on marking and identification, refer to WRAS Information and Guidance Note 9-02-05: *Marking and identification of water re-use systems*⁽¹⁴⁾. Maintaining the reclaimed water at lower pressure than the mains water will help to mitigate the effects in the event of accidental cross-connection.

Any outlets supplying reclaimed water must be clearly labeled as not suitable for drinking and identifying the permissible uses (i.e. suitable for WC flushing or garden watering only etc.).

5.4.5 Back-up supplies for reclaimed water systems

Reclaimed water systems need to be equipped with a mains water back-up supply in case of inadequate reclaimed water or malfunction of the treatment process.

In addition, some installations will require that duplicate pumps are installed, with standby power available.

To prevent non-potable water entering the potable or public mains water supply, the back-up supply should be fitted with a backflow prevention device that is capable of providing category 5 protection.

5.4.6 System operation

5.4.6.1 Control systems

Controls provide greater safety and security of operation but obviously add to the cost of the system. Controls in the reclaimed water system are to ensure, at least, that users are aware that the system operates effectively.

They should:

- control pumps and minimise operational wear
- activate the back-up water supply automatically when the minimum water level is reached
- provide a volt-free outlet to enable connection to building management system (BMS), where appropriate.

For greywater systems, depending on the design of the system and its application, the following control features should be considered:

- alarm indication when any consumable items need replenishment or replacement to prevent system failure
- system operation to ensure that greywater treatment continues or that greywater is not stored for periods that would allow water quality to deteriorate
- alarm indication in the event of backflow from the drains into the tank, pump failure or filter blockage.

In all situations, reclaimed water systems must be configured such that in the event of a power failure, all systems are left in a safe condition.

5.4.6.2 Water quality

There are no specific legal requirements defining an acceptable standard for reclaimed water to be used for toilet flushing, garden watering or vehicle washing.

The biological parameters are most important and as a guide line should not exceed the following values when used for toilet flushing or garden watering:

- *Escherichia coli*: 250 per 100 ml
- Intestinal enterococci: 100 per 100 ml
- Total coliforms: 1000 per 100 ml

BS 8515⁽⁸⁾ provides guideline water quality properties for different applications.

Generally a risk assessment should be carried out. It will determine whether the system is suitable. Risk assess-

ments can follow the process described in BS 31100⁽⁵⁾. The advice of a water hygiene specialist may be required for specific applications.

5.4.6.3 System maintenance

All reclaimed water systems require adequate and continuing maintenance as part of a formal maintenance regime to ensure correct system operation and acceptable water quality. This should be carefully considered when deciding if a reclaimed water system is a feasible option, particularly for smaller or domestic properties. Long term maintenance requirements must form part of the system selection criteria.

5.4.6.4 Resilience of supply

It must be remembered that when essential sanitary fittings such as WCs are supplied from a recycled water system this alternative supply must be as secure as possible to ensure continuity of supply. It is not only the water supply that should be considered but also the electrical supply and any other features required to allow system maintenance without disruption of the supply.

5.4.6.5 Client handover

Upon handover of any reclaimed water system, the users should be provided with sufficient information to enable them to operate the system satisfactorily. The users should be advised of any procedures or precautions that need to be followed. This information should cover those aspects that will ensure the reliable operation of the system, e.g. chemicals that might have either a detrimental or beneficial effect on the treatment process, and any routines that could reduce maintenance requirements.

5.4.7 Combined systems

In cases where there is a requirement of, for example, attenuation or fire sprinkler systems, the combination of reclaimed water systems might provide significant reductions in both capital and maintenance costs.

BS 8515⁽⁸⁾ gives recommendations with regards to combination of rainwater harvesting with attenuation.

5.5 Sustainable drainage

5.5.1 Introduction

Sustainable drainage systems (SUDS) is an approach to managing rainfall that aims to mimic natural drainage and avoid the problems associated with conventional positive drainage (flooding and pollution).

Specific SUDS techniques are reviewed within chapter 4, however the following provides an overview of the guiding principles.

On 'greenfield' sites a relatively low percentage of rainfall flows from the surface to watercourses such as rivers or

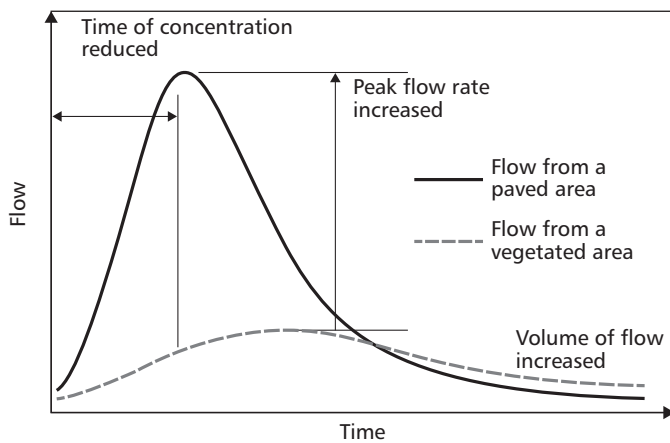


Figure 5.1 Attenuation of water run-off (reproduced from *Sustainable urban drainage systems — design manual for England and Wales*⁽¹⁵⁾, by permission of CIRIA)

streams. The presence of grass and other vegetation slows down the surface flow to the watercourses, see Figure 5.1. When sites are developed and the amount of impervious surfaces increases (e.g. roofs and roads) infiltration, evapotranspiration and the amount of vegetation are reduced. The aim of SUDS is to retain the post-development run-off as near to natural conditions as possible, thereby minimising the adverse effects of urbanisation on the water environment.

Sustainable drainage should be considered from a ‘roof to river’ approach, with potential elements being integrated across the conventional construction industry boundaries/disciplines to allow a co-ordinated approach to sustainability.

5.5.2 Surface water management train

A useful concept used in the development of drainage systems is the surface water management train, see Figure 5.2. Just as in a natural catchment, drainage techniques can be used in series to change the flow and quality characteristics of the runoff in stages.

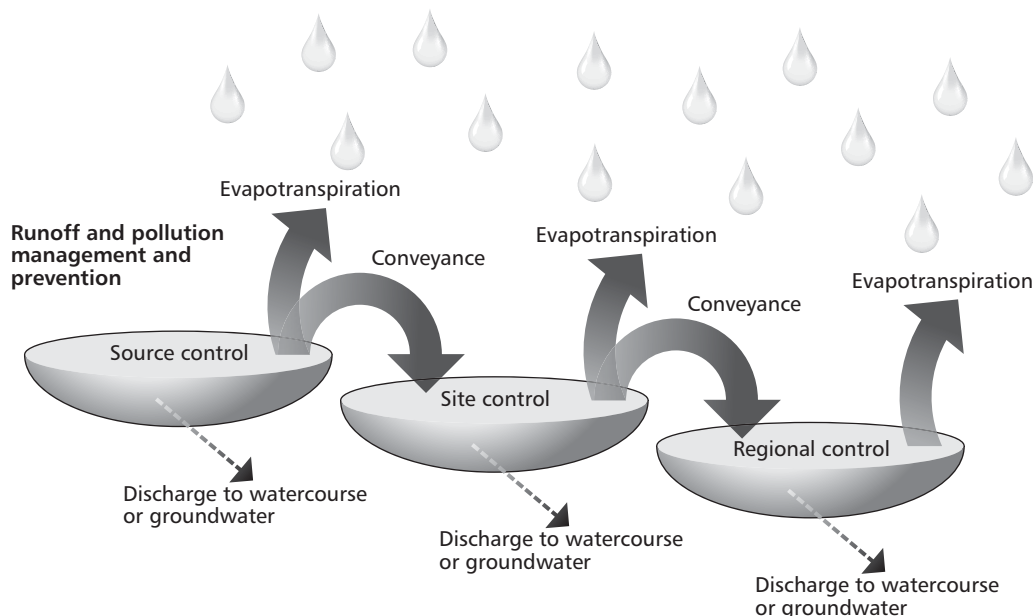


Figure 5.2 Water management train (reproduced from *Sustainable urban drainage systems — design manual for England and Wales*⁽¹⁵⁾, by permission of CIRIA)

5.5.3 SUDS techniques

SUDS are made up of one or more elements built to manage surface water runoff. They are used in conjunction with good management of the site, to prevent flooding and pollution. Primary methods of control are:

- filter strips and swales
- permeable surfaces and filter drains
- infiltration devices
- basins and ponds
- underground storage
- rooftop attenuation.

These controls should be located as close as possible to where the rainwater falls, providing attenuation for the run-off. They also provide varying degrees of treatment for surface water, using the natural processes of sedimentation, filtration, adsorption and biological degradation.

SUDS can be designed to function in most urban settings, from hard-surfaced areas to soft landscaped features. The variety of design options available allows designers and planners to consider local land use, land-take, future management and the needs of local people when undertaking the drainage design, going beyond simple drainage and flood control. The range of options means that active decisions have to be made that balance the wishes of different stakeholders and the risks associated with each option.

Amenity and wildlife habitat benefits are often created by SUDS features.

5.6 Flood protection

5.6.1 Introduction

Under the Land Drainage Act 1991⁽¹⁶⁾ a number of bodies have an interest in land drainage. They are the Environment Agency, internal drainage boards, local

authorities, navigation authorities and riparian owners (i.e. those who own land or property adjacent to a river or other watercourse). Each has a role to play in the mitigation of flooding.

Flooding is a natural process that can never be stopped or prevented entirely; however steps can be taken to reduce flood risk and impacts.

In the design of a building the flood risk at that development site must be considered in addition to the potential impact that a building will have on flood risk in the surrounding catchment area. It must be recognised that, as a result of climate change an area not currently at significant risk of flooding could become so during the lifetime of the development.

5.6.1.1 Role of the Environment Agency

Under the Water Resources Act 1991⁽¹⁷⁾, the Environment Agency has powers to maintain and improve main rivers for the efficient passage of flood flow and the management of water levels. There is no obligation on the agency to carry out either maintenance or new works on main rivers.

The agency has powers to construct and maintain defences against flooding, to issue flood warnings, and to manage water levels.

The agency also has powers to issue byelaws.

The agency is a statutory consultee in the planning process. As such, it makes representations to local planning authorities on matters in development plans and certain planning applications that are of concern to its functions.

5.6.1.2 Role of internal drainage boards

Internal drainage boards were established in the 1930s in areas of special drainage need in England and Wales. They exercise operational and regulatory powers on identified ordinary watercourses.

5.6.1.3 Role of the local authority

Under the Land Drainage Act 1991, where there are no internal drainage boards, local authorities are the operating authority for ordinary watercourses. They have permissive powers to carry out works on ordinary watercourses for certain purposes. Their response to work on ordinary watercourses may vary, and they often have their own regulations and byelaws affecting what may and may not be done on an ordinary watercourse.

5.6.1.4 Role of navigation authorities

A navigation authority is a company or statutory body which is concerned with the management of a navigable canal or river. Navigation authorities include British Waterways, private companies and, in some specific instances, the Environment Agency

5.6.2 Example measures

At the site level the aim is to reduce the effect of development by managing surface water in a sustainable manner to enable the following targets to be achieved. The developed site should:

- achieve levels of surface water leaving the site equal to that of the undeveloped site, i.e. achieve 'green field' run-off rates (or other lesser rate that may be accepted by the approving authorities)
- reduce flood risk to site itself
- reduce risk to other parts of the catchment area.

CIRIA documents in particular detail various methods available to attenuate and infiltrate stormwater flows. However, many of these solutions will fall outside the normal remit of public health engineers.

5.6.3 Rooftop attenuation

A basic concept of sustainable drainage is source control, i.e. the control of rainwater at or close to where it lands. As the designer of the rainwater disposal system, the public health engineer has the opportunity to achieve this by attenuating flows from the building roof.

Living roofs (see section 5.7) achieve this but the outflow rates are variable and uncontrolled. An alternative is to specifically design a flat roof to have a specified outflow rate, with water being temporarily stored on the roof. This method of attenuation is often referred to as a 'blue roof'.

Consideration will need to be given to the structural and water proofing aspects.

5.6.4 Key actions

The building services engineer should recommend that the project team establishes the flood risk of a proposed development. In particular, it is important to consult with the local authority to establish whether a strategic flood risk assessment has been undertaken and to check the site status with the Environment Agency.

Sustainable drainage systems (SUDS) should be employed, where feasible. Building services engineers should aim to incorporate flood resistant measures into the design of building services and work with the project team to raise awareness of flood risk and flood resistance.

5.7 Living roofs

5.7.1 Introduction

5.7.1.1 General

The benefits of 'green' or 'living' roofs are varied and extensive. This section provides an overview and concentrates on the interfaces these systems have with drainage systems and their impact upon rainfall disposal in the built environment. Detailed guidance on all aspects

of green roofs is available in the CIBSE's *Guidelines for the design and application of green roof systems*⁽¹⁸⁾.

5.7.1.2 Types of system

Living roofs can be considered in two categories:

- *Extensive*: these roofs have a thin growing medium and require minimal maintenance and, in general, do not require irrigation once they are established. They are generally less costly to install than intensive green roofs.
- *Intensive*: these have a deep growing medium which allows the use of trees and shrubs. They are often more suited for use in SUDS due to their larger capacity to store water.

5.7.1.3 Typical components

Although systems will vary depending on the type of roof and its proposed use, commonly used components include the following.

- *Root barrier*: prevents the roots of vigorous plants penetrating through to the waterproofing and damaging the membrane. The root barrier can either be a biocide or a copper or heavy grade polythene-based material.
- *Drainage layer*: controls the water retention properties of the roof in combination with the substrate. Drainage layers can be composed of either granular materials (e.g. sand and gravel, lava and pumice, crushed brick etc.) or lightweight cellular components.
- *Substrate (or growing medium)*: provides the mechanical strength, pore structure, nutrients, chemical composition and drainage properties for the desired plant species. A wide range of natural and manufactured substrates are available.
- *Vegetation layer*: this can be established using vegetation (e.g. sedum) mats, through plug-planting pot-grown plants into the substrate, by distributing seeds or cuttings by hand, or simply by natural colonisation.

Further components can be added depending on the specification or the particular system manufacturer, including filter membranes, moisture mats, protection boards, water retention systems, irrigation systems, special features to locate trees (e.g. anchorage fixings) and additional thermal insulation.

The construction of a typical green roof is illustrated in Figure 5.3.

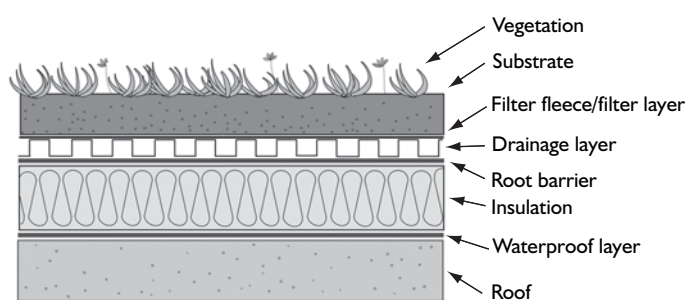


Figure 5.3 Construction of a typical green roof

5.7.2 Benefits

5.7.2.1 Biodiversity

Living roofs have the potential to provide considerable benefits for biodiversity and can often form part of specific biodiversity action plans. Particularly important in urban areas, they can also be used as mitigation for the loss of brownfield habitats.

In addition to a wide range of plants, grasses, mosses and so on, living roofs can also provide habitat for a range of birds and invertebrates. To achieve specific local biodiversity objectives the planting and substrate must be carefully designed and hence specialist ecological input should be sought. The use of objects such as dead wood can significantly improve the roof as a habitat.

5.7.2.2 Surface water runoff

Living roofs are ideal components of sustainable drainage systems (SUDS) and can make a valuable contribution to mitigating the adverse effects of development on rainfall runoff.

A fundamental concept of SUDS is the use of source control, i.e. the control of run-off at or very near its source. Green roofs can contribute to source control objectives through:

- retention of rainwater in substrate, drainage layers and on plants
- uptake of water and release by plants as vapour (evapotranspiration)
- uptake of water and biochemical incorporation by plants (photosynthesis)
- evaporation from substrate and foliage.

Research in the UK^(19,20) indicates that green roofs are effective in providing both attenuation and volume reduction in run-off for small events, and suggests that these advantages are reduced but not lost for larger events.

The German Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) *Guidelines for the Planning, Execution and Upkeep of Green-roof Sites*⁽²¹⁾ provides a wealth of information, including coefficient of run-off factors ranging from 0.8 to 0.1, depending upon the depth of the growing course and the roof slope.

The performance of a green roof will depend on the depth and type of substrate used and the particular rainfall patterns and season. In addition to their impact on the volume of run-off from a site, green roofs can also contribute to pollution removal from stormwater run-off by retaining and binding contaminants that are introduced to the surface as dust or suspended/dissolved in rainwater. Research suggests that 95% of heavy metals can be removed from run-off by green roofs and nitrogen levels can also be reduced⁽²²⁾. Careful attention should be paid to the materials to be used in the green/brown roof construction, especially where they have been reclaimed, to ensure that pollutants do not leach out of the green roof substrate.

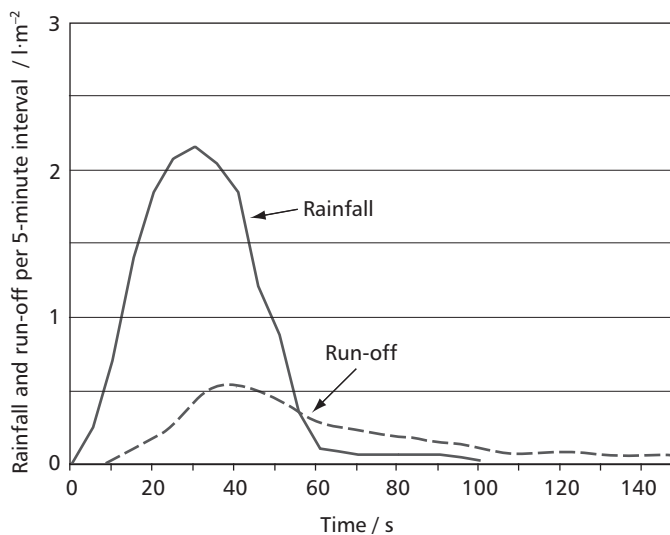


Figure 5.4 Potential attenuation of rainwater by a green roof

Figure 5.4 shows the attenuation of rainwater possible using a green roof.

5.7.2.3 Other benefits

Other benefits of green roofs include the following:

- air quality improvements
- water quality improvements
- building energy conservation
- green space
- insulation (sound and temperature)
- reduction of heat island effect
- financial.

5.7.3 Design considerations

5.7.3.1 General

Irrespective of the type of living roof or planting, the following essential elements must be adequately provided:

- water
- drainage
- nutrients
- aeration to root systems.

Detailed guidance on green roofs may be found in CIBSE Knowledge Series KS11: *Green roofs*⁽²³⁾ and *Guidelines for the design and application of green roof systems*⁽¹⁸⁾.

5.7.3.2 Structural loadings

Living roofs and other landscape structures must be considered in terms of the increased load potentially imposed upon the structure. The saturated weight of any features should be used to calculate the structural load and this approved by a structural engineer.

5.7.3.3 Maintenance

The level of maintenance required to the roof system will vary depending upon the complexity and the planting with the period after installation likely to be more intensive than once the living roof is established. Irrespective of the anticipated frequency of maintenance visits, the health and safety of those accessing the roof must be a prime consideration during the design process.

Maintenance and upkeep of the roof is especially important during the project construction phase and the first 1–2 years to ensure that the client is delivered a healthy and established system.

5.7.3.4 Irrigation

Both when designing a living roof, and where one is proposed for a project, the requirements for irrigation should be established at an early stage with the use of mains water minimised where possible, particularly where irrigation water is subject to evaporation losses.

5.7.3.5 Water quality

Where it is proposed to re-use the residual rainwater run-off from the living roof for a rainwater harvesting system or similar, care should be taken to ensure that any nutrients on the living roof do not impact upon the performance of the harvested water distribution system. Consideration should also be given to the transfer of particulates, especially whilst the roof is becoming established, and if discolouration of water will cause complaints from end users.

5.7.3.6 Fire spread

It is worthwhile discussing the use of a green roof with the building insurers in relation to the perceived benefits/risks that a living roof may pose in terms of fire spread.

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6 Pumps and pumping

6.1	Types of pumps
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Summary

This chapter is intended to assist the engineer with pump and pumping requirements for most scenarios within building services engineering. Pump design and application to hot and cold water circulation, sewage and foul water systems, water features and swimming pools are considered. Furthermore a short summary on geothermal and hydrothermal energy systems is included. Throughout the chapter various worked examples are provided.

6.1 Types of pumps

The two main types of pump are 'centrifugal' and 'positive displacement'. There are many different types within each category but the main characteristics referred to in the following sections may be regarded as generally applicable.

6.1.1 Centrifugal pumps

In its simplest form, a centrifugal pump consists of an impeller and a volute casing that must be completely filled with liquid while the pump is in operation. The impeller 'throws' the liquid to the outside of the volute, thus imparting kinetic energy. In this way, a centrifugal pump is capable of generating a pressure that varies with the pump speed. The relationship between the capacity and the pressure is expressed in the form of a 'characteristic curve', see Figure 6.1.

Centrifugal pumps should be selected such that they operate as close as possible to the peak efficiency indicated on the characteristic curve. The point where the curve intersects the pressure ordinate is referred to as the 'closed value pressure' and represents the maximum power achievable and corresponds to a 'no flow' condition. Centrifugal pumps must not be allowed to operate in this condition for any length of time since their pumping energy is almost completely converted to heat energy,

leading rapidly to overheating of the pump. Many manufacturers give a recommended minimum flow rate for a pump model, this is sometimes based on 10% of the rated flow rate of the pump.

The main characteristics of centrifugal pumps may be summarised as follows:

- capacity varies with pressure (see characteristic curve)
- capacity is proportional to the pump speed
- pressure is proportional to the square of the pump speed
- pump is not self-priming
- suitable for low viscosity fluids.

6.1.2 Positive displacement pumps

A positive displacement pump causes a fluid to move by trapping a fixed quantity of the fluid and then forcing (i.e. displacing) that trapped volume into the discharge pipe. Positive displacement pumps can be further classified according to the mechanism used to move the fluid; e.g. rotary (in which the fluid is driven by a rotating gear, screw, vane, scroll etc.), and reciprocating (in which the fluid is driven by a piston or diaphragm).

Due to the fine tolerances involved, most positive displacement pumps are self-priming and some are able to handle entrained gas or air. Neglecting leakage, they deliver almost constant capacity, irrespective of variations in pressure. The characteristic curve for a typical displacement pump is an almost vertical straight line, therefore it is not usual to provide characteristic curves for positive displacement pumps.

Their main characteristics are as follows:

- capacity is substantially independent of pressure
- capacity is proportional to speed
- pump is self-priming
- suitable for viscous liquids.

6.2 Variable speed pumping

Many pumping systems require a variation in the flow or pressure, due to system variations and changes. Either the system curve or the pump curve therefore must be changed to obtain a different operating point. Where a single pump has been installed for a range of duties, it will have been sized to meet the greatest required output. Inevitably this pump may have to operate inefficiently for lower flow rates.

Variable speed drives reduce the speed of a pump motor, which in turn reduces the need for electrical power during the periods of reduced system demand, thus providing an opportunity to save energy.

For detailed guidance on variable speed pumping, see CIBSE Knowledge Series KS7: *Variable flow pipework systems*⁽¹⁾ and KS9: *Commissioning variable flow pipework systems*⁽²⁾.

6.2.1 Theory of pump speed change

A centrifugal pump develops head by a rotating impeller. There is a relationship between the peripheral velocity of the impeller and this generated head. For a fixed impeller diameter, the peripheral velocity is directly related to shaft rotational speed. Varying the rotational speed therefore has a direct effect on the performance of the pump. The equations relating to centrifugal pump performance parameters are known as the affinity or pump laws. These are summarised as follows.

Law 1 (for constant impeller diameter (D)):

- Law 1a: flow is proportional to shaft speed:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \quad (6.1)$$

- Law 1b: pressure (head) is proportional to the square of the shaft speed:

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \quad (6.2)$$

- Law 1c: power is proportional to the cube of the shaft speed:

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 \quad (6.3)$$

Law 2 (for shaft constant speed (n)):

- Law 2a: flow is proportional to the impeller diameter:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad (6.4)$$

- Law 2b: pressure (head) is proportional to the square of impeller diameter:

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \quad (6.5)$$

- Law 2c: power is proportional to the cube of the impeller diameter:

$$\frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3 \quad (6.6)$$

where Q is the volumetric flow rate (L/s or m³/s), D is the impeller diameter (mm), n is the shaft rotational speed (r/min), H is the pressure or head developed by the fan/pump (m) and P is the shaft power (W).

Changing the impeller diameter changes the duty point, see Figure 6.1, but this can only be used for permanent adjustment of the pump curve and is not suitable as a method of control.

For systems where friction loss predominates, reducing pump speed moves the operating point on the system curve along a line of almost constant efficiency, see Figure 6.2. The operating point of the pump, relative to its best efficiency point, remains almost constant and the pump continues to operate in its ideal region which means that there is a reduction in power absorbed accompanying the reduction in flow and head.

In systems with high static head, the friction system curve does not start from the zero but at a respective point on the y-axis of the pump graph corresponding to the static head of the system, see Figure 6.3. The system curve does

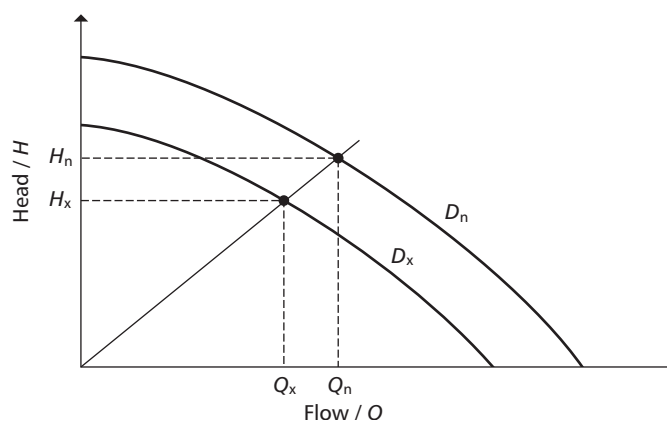


Figure 6.1 Characteristic curve showing effect of changing impeller diameter

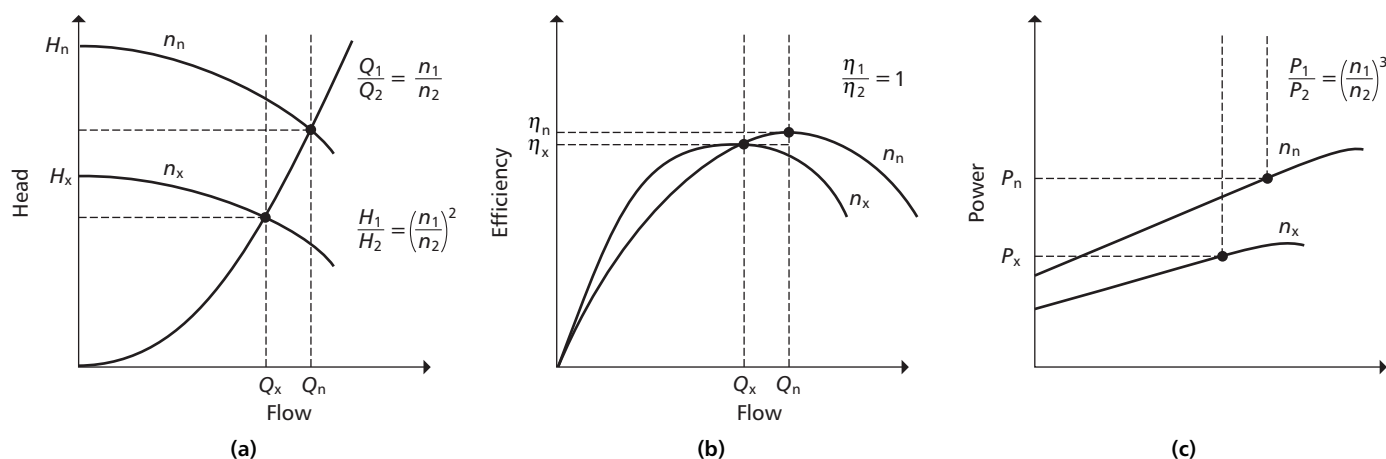


Figure 6.2 Curves showing (a) pressure (head) versus capacity, (b) efficiency versus capacity, (c) absorbed power versus pump speed

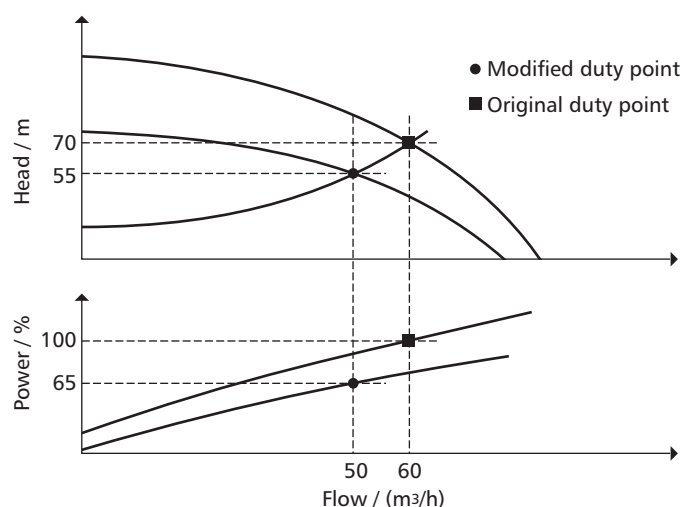


Figure 6.3 Characteristic curve for systems with high static head

not follow the curves of constant efficiency but now intersects them. The reduction in flow is no longer directly proportional to speed and reducing the speed now influences both the flow rate and the pump efficiency.

6.2.2 Benefits of using variable speed pumping

The benefits of variable speed pumping may be summarised as follows:

- Flow control by speed regulation is more efficient than flow control using a control valve and saves electrical energy.
- The hydraulic forces on the impeller, which are carried by the pump bearings, reduce approximately with the square of the speed. Therefore reducing the pump speed increases bearing life.
- Reducing the pump speed reduces vibration and noise.
- Reducing the pump speed increases shaft seal life.
- Reducing the pump speed reduces the possibility of cavitation (see section 6.3).

6.2.3 Variable speed drives

There are several types of variable speed drives (VSDs). In applications that require flow or pressure control, particularly in systems with high friction loss, the most energy-efficient option for control is an electronic VSD, commonly referred to as a variable frequency drive (VFD). The most common form of VSD is the voltage-source, pulse-width modulated (PWM) frequency converter. The converter develops a voltage directly proportional to the frequency, which produces a constant magnetic flux in the motor. This electronic control can match the motor speed to the load requirement.

Most modern 3-phase electric motor drives with outputs above about 2.2 kW are designed to withstand the output of a modern frequency converter. On small electric motors or older motors still in service or on applications where there are long cable runs between the VSD and the electric motor then consideration should be given to fitting an output filter to reduce stress on the motor windings.

6.2.4 Issues associated with variable speed drives

6.2.4.1 Structural resonance

Some system designs fitted with VSDs can suffer from vibration. Resonance can cause excessive vibration, which can be harmful to the equipment. Pumps, their structure and piping are subject to a variety of structural vibrations. Pumps fitted with fixed-speed electric motors can avoid such resonance because the common excitation harmonics due to running speed, vane passing frequency etc. do not coincide with the natural frequencies associated with the structure. However, for applications using VSDs the excitation frequencies are variable and, at certain speeds, may induce structural vibrations through resonance. Pump vibration problems typically occur with bearing housings and the supporting structure. Pressure pulsations are often the outcome. These pulsations may be further amplified by acoustic resonance within the adjacent pipework.

6.2.4.2 Rotor dynamics

The risk of the rotating element encountering a lateral critical speed increases with the application of a VSD.

Lateral critical speeds occur when running speed excitation coincides with one of the rotor's lateral natural frequencies. The resulting rotor vibration may be excessive. In most systems this can be resolved by arranging, during commissioning, for the VSD to avoid the critical speeds.

6.2.4.3 System design considerations

The introduction of VSDs requires additional design and application considerations. VSDs can be fitted to most existing motors which use a 400 V network. The high rate of switching in the PWM waveform can occasionally lead to problems, for example:

- The rate of the wave front rise can cause electromagnetic disturbances, requiring adequate electrical screening (screened output cables). Filters fitted in the VSD output can remedy this problem.
- Older motor insulation systems may deteriorate rapidly due to the rapid rate of voltage change.
- Long cable runs can cause 'transmission line' effects, and cause higher voltages at the motor terminals.

Consideration should be given to fitting suitable filters in order to avoid these problems.

In very large motors (typically 75 kW and above), there can also be electrical currents set up along the rotating shaft and into the motor bearings. This excess heat energy can cause bearings to prematurely fail. Some motor manufacturers can offer insulated type bearings on large motor frame sizes to avoid this problem.

6.3 Pump cavitation

Operational problems with pumps are often associated with the static pressure at the pump inlet/suction being too low. This can be attributed to:

- inappropriate pump selection
- faulty system design
- air ingress into the suction pipe
- poor installation.

The rotation of the pump impeller creates a partial vacuum on the suction side of the impeller. The resulting 'negative' pressure at the pump inlet depends upon:

- the height between the inlet and the surface of the liquid being pumped
- the friction losses in the suction pipe work and fittings
- the density of the liquid.

This negative pressure is limited by the vapour pressure of the liquid at the actual temperature, i.e. the pressure at which vapour bubbles will form. If the static pressure is below the vapour pressure point of the liquid, then the liquid will form vapour bubbles and begin to boil. This is known as 'cavitation'.

6.3.1 Consequences of cavitation

When the vapour bubbles are then transported through the impeller from the low pressure area to a region of high pressure in the impeller, they collapse (implode) and the resulting implosions can damage the rotating components of the pump. The vibrations caused by severe cavitation can also affect the motor bearings. Therefore, the most vulnerable parts of the pump are the bearings, shaft seals and the impeller(s).

The rate of damage to the impeller depends on the properties of the material of which it is made. For example, for the same operating conditions, the loss of material from an impeller made of stainless steel is only 5% compared to an impeller made from cast iron.

The estimated weight loss due to cavitation for different materials, compared with cast iron (1.0), is:

- stainless steel: 0.05
- bronze: 0.5
- bronze alloys: 0.1

Evidence that cavitation may be occurring includes:

- increased hydraulic noise level
- drop in the pump developed head
- unstable pump operation.

In pumps with large cast impellers and casings the damage may often remain undetected until the pump and motor are dismantled. In more modern, well designed, pumps manufactured from lighter materials, the signs of cavitation and consequent damage are usually detected more quickly.

6.3.2 Calculating the risk of cavitation

The maximum suction head $H_{\max}$ to avoid cavitation is given by:

$$H_{\max} = H_b - H_{fs} - \text{NPSHR} - H_v - H_s \quad (6.7)$$

where $H_{\max}$ is the maximum suction head (m), H_b is the atmospheric pressure on the liquid (m), H_{nr} is the friction loss in the non-return valve and connecting pipe (m), NPSHR is the net positive suction head required (m), H_v is the vapour pressure of the pumped liquid (m) and H_s is a safety factor (m).

If the maximum suction head ($H_{\max}$) is positive, the pump can operate with a suction lift; if negative, the pump requires a positive suction head.

The atmospheric pressure on the liquid (H_b) is the theoretical maximum suction lift and thus depends on the density of the liquid, i.e:

$$H_b = \frac{p_b}{\rho \times g} \quad (6.8)$$

where p_b is atmospheric pressure (Pa), ρ is the density of the liquid ($\text{kg}\cdot\text{m}^{-3}$) and g is the acceleration due to gravity (9.81) ($\text{m}\cdot\text{s}^{-2}$).

The friction loss (H_{fs}) also depends on the density of liquid, i.e:

$$H_b = \frac{p_{fs}}{\rho \times g} \quad (6.9)$$

where p_{fs} is the pressure loss due to friction (Pa).

The net positive suction head required (NPSHR) indicates the minimum inlet pressure required by the pump to avoid cavitation. It represents the friction loss from the pump inlet to the point in the first impeller where the pressure is lowest and is a measure of the extent to which the pump is not able to suck the full water column of 10.33 m. Thus the net positive suction head value will increase with flow, as can be seen from the NPSHR curve for a particular pump.

The vapour pressure of the pumped liquid (H_v) is involved because the liquid boils faster at higher temperatures. This also depends on the density of the liquid, i.e:

$$H_v = \frac{p_v}{\rho \times g} \quad (6.10)$$

where p_v is the vapour pressure of the liquid (Pa).

The safety factor (H_s) which must be determined for the particular situation, depending on the credibility of the applied calculations. In practice a value of 1 m is generally applied. Where the water contains high levels of dissolved gas the safety factor is usually 2 m.

6.4 Pressure surge (water hammer)

6.4.1 Pressure surge on pump start and stop

6.4.1.1 Transfer of pressure energy

In large distribution pipe systems there may be many tons of water put into motion or suddenly arrested when a pump starts or stops. The resulting pressure variations between the liquid and the pipework may be outside of the acceptable pressure limits of the pipe system.

6.4.1.2 Vacuum

When the horizontal discharge pipe of a system is long, water hammer could arise when the pump is switched off. When the pump stops, the water flow in the riser pipe will stop rapidly due to gravity. However, the flow in the horizontal discharge pipe is stopped more gradually by friction with the inner surface of the pipe. This can create a vacuum in the riser pipe which causes the water column to be broken and the liquid water at the intersection will be transformed into water vapour.

When the water flow in the horizontal pipe has lost its velocity, water will then be pulled back by the vacuum created in the main riser. When the returning water

collides with the water in the riser main, collapsing the water vapor pocket, then a pressure surge will occur in the pipework.

6.4.1.3 Design considerations

For pumps fitted in very long pipe distribution systems with a vertical riser main, it is possible to reduce the effects of pressure variations by considering one of the following:

- fitting a diaphragm expansion vessel with a pre-charge pressure of 0.7 times the actual system operating pressure
- utilising a variable speed drive with a 'soft' start-up of the pump; e.g from 25 Hz to 50 Hz over a minimum start-up period of 30 seconds
- installing a time-controlled, motor-driven butterfly valve with an opening time of approx. 60 seconds; the valve slowly begins to open at pump start-up and must be activated to close 60 seconds before the pump stops.

The size of the expansion vessel required is based on the expected volume of water necessary to refill the expected vapor pocket that could form. This volume depends on the quantity of water in the pipe line and how quickly it will be stopped by friction.

6.4.2 Pressure surges in riser pipes in tall buildings

If the developed pressure is removed while the system is in use, the water in the top sections of the riser pipe(s) can vaporise under the vacuum resulting from water being drawn off from outlets lower down on the riser pipe(s). When the system pressure is restored the conditions for a pressure surge could, and often do, occur. The resultant surge pressure can be many times the maximum developed dynamic pressure of the pumps. The amplitude of a surge pressure is based on the velocity of the water when it is moving, and how quickly this water is then brought to a stop.

The effects of a sudden high-amplitude surge pressure can be to break a fitting on the end of a pipe or even to break the pipe itself, resulting in flooding and subsequent water damage.

Surge pressures caused by a vacuum forming in a riser pipe can be created as a result of the following:

- a power cut to the booster pump(s): power is then reinstated without consideration of the effect on the reduced stored pressure in the system riser pipes
- temporary loss of available water pressure (loss of prime) to the booster pumps
- temporary blockage/restriction on the discharge side of the booster pump(s).

The risk of creating a vapour pocket may be minimised by installing a device known as a 'vacuum breaker'. Vacuum breakers dampen the effect of pressure surge at pump start-up, and provide vacuum protection when the

pump(s) are stopped and the riser pipe drains. They should be fitted on all riser pipes, including hot water risers, above 10 m in height. If isolation is required for maintenance, only lockshield valves should be used for this purpose.

The vacuum breaker usually incorporates a large orifice to admit air into the riser pipe(s) in the event of a vacuum occurring (typically, if the booster pump set is switched off). When the pressure is re-applied the air is forced back through the 'anti-shock' orifice resulting in the deceleration of the approaching water column due to the resistance of the rising air pressure in the valve. This reduces the risk of pressure transients when the air valve finally closes.

6.5 Cold water boosting in commercial buildings

As discussed in chapter 3, water must be stored for the following reasons:

- to prevent backflow of water into a mains supply
- to avoid depressurising the mains supply and causing contamination by ingress of materials into the mains
- to ensure continuity of water supply under peak flow demands.

Where the water is stored within a building depends upon many factors, including the structural advantage of storing the maximum amount of water at or below ground level, the need to ensure that any water stored does not stagnate, and the potential vulnerability of the water supply in the event of power failure. Generally the storing of potable water at high level on rooftops and in water towers is now less popular as it is difficult to ensure that the water is not contaminated by insects and microorganisms.

For factories, commercial and research establishments with high water usage, and where the loss of water supply could have serious economic implications then sufficient water is stored to provide coverage for a typical 24-hour period.

6.5.1 Packaged booster pump sets

On small to medium sized buildings pressure boosting equipment is commonly provided as standard packaged assemblies, arriving at site on a common base frame, see Figure 6.4. On very large pumped systems, 'part packages' are preferred where the equipment is delivered on two or more baseplate assemblies. This allows the installers some flexibility in moving these part packages into the plant room. Large floor mounted expansion vessels are commonly supplied separately for connection to the discharge pipework on site.

Pumps used for water supply are generally vertical multi-stage centrifugal pumps, having a stack of multiple impellers. Check valves on packaged booster sets ideally should be the spring loaded type to enable rapid closure, otherwise a quick-closing check valve should be fitted on the main discharge connection.

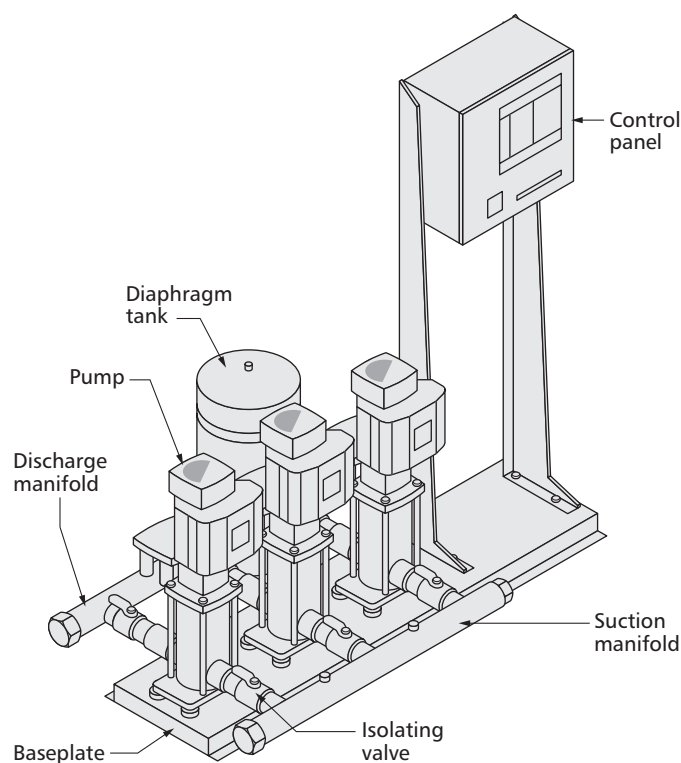


Figure 6.4 Main components of a packaged booster pump set

6.5.2 Break tank (storage cistern) supply

The most common arrangements are as follows:

- Flooded suction or suction lift arrangement to transfer cold water from a low level break tank(s) to an elevated cold water storage cistern located within the building.

Typically, the elevated cold water storage cistern are mounted at a level high enough to ensure sufficient static pressure is available to meet the peak flow demands of the system by gravity flow. Rooftop mounted tanks are not as popular in modern potable water systems due to higher risks of contamination from undesirable microorganisms and insect larvae.

- Flooded suction or suction lift arrangement to directly pressurise both the hot and cold water systems in the building.

This is the most popular arrangement for modern commercial buildings in the UK. It minimises the risk of water contamination associated with elevated cold water storage cisterns. The water is only potentially open to airborne contamination at the low level break(s) supplying the booster set. These break tank(s) are usually located well within the building structure in a low level plant room, well away from direct sunlight.

The incoming water from the mains fills the break tank by passing through an equilibrium float valve or other flow control device, see Figure 6.5. This valve controls the upper water level so that the tank does not overflow and flood the plant room.

If the water level drops to a point near the pump suction port then the low water cut-out switch disables the booster

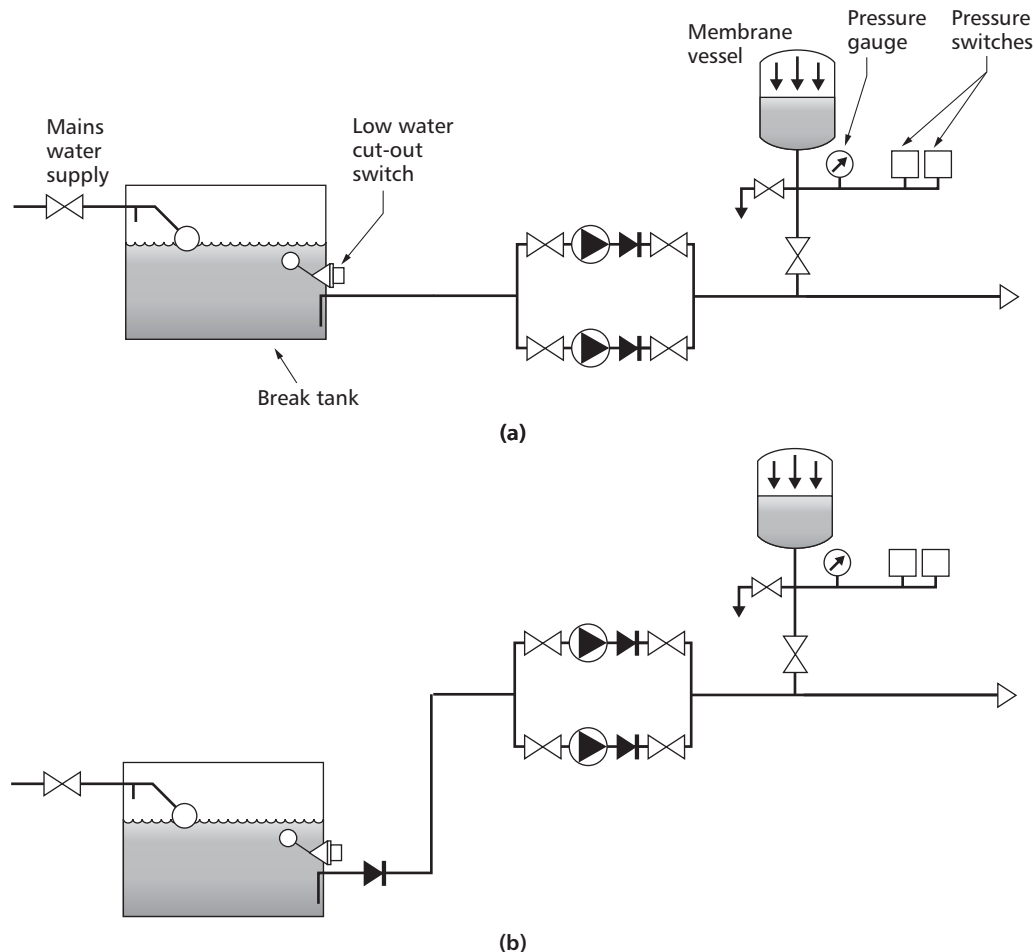


Figure 6.5 Flooded suction (a) and suction lift (b) booster arrangements

pump set. The low water switch prevents a vortex occurring over the suction pipe in the tank which could allow air to be drawn into the suction pipe work leading to loss of prime, pump cavitation and damage to the pump shaft seals. A 90° bend fitted to the suction pipe inside the tank, pointing downwards, reduces the possibility of a vortex forming at low water levels and helps to maximise the storage volume.

The expansion membrane vessel(s) connected to the discharge pipework is designed to hydraulically satisfy the system demand between pump 'start' and 'stop'. When the water content in the expansion vessel has been consumed, the system pressure will drop more quickly and at a chosen lower pressure the respective controls will operate, causing the pump controller to start one pump. This pump will then run until the system demand is satisfied and the expansion vessel(s) are replenished. If the flow demand continues to increase then the pressure will continue to fall causing the controller to start additional pumps on the pump package.

Suction lift arrangements carry higher risks with respect to maintaining a water prime in the suction pipework and suction ports of the booster pumps. Loss of prime will inevitably mean loss of the pumped water supply. System designers should only consider suction lift arrangements if there is no other choice. The following installation guidance should be noted:

- Pump non-return valves must be relocated to the pump suction ports in order to prevent air ingress through shaft seals and gland points on the standby or idle pumps.

- A separate foot valve needs to be positioned on the end of the suction pipe work. This additional valve plus the relocated non-return valves increases losses in the suction pipework which, if not allowed for in calculations, could create conditions for pump cavitation.
- Suction pipework and any joints must be able to remain resistant to air ingress under vacuum conditions when the pump(s) are operating. Poor joints in the suction pipe work will lead to serious operational problems with the system.

6.5.3 Expansion vessel storage

Depending on the system design and the location of the pump set, one or more pressure vessels may be required to act as a hydraulic store.

These vessels act as buffers to store energy in the form of water under pressure in the vessel to prevent the set operating on every reduction in the system pressure.

The volume of water stored in the expansion vessel(s) can be calculated using Boyle's law. The pump start and stop pressures need to be known. Then:

$$V = \frac{(p_{\text{stop}} - p_{\text{start}}) \times C_e}{p_{\text{stop}} + 1} \quad (6.11)$$

where V is the stored volume (litre), p_{stop} is the pressure at pump stop (bar), p_{start} is the pressure at pump start (bar) and C_e is the capacity of the expansion vessel (litre).

Example

Calculate the stored volume for a system having a start pressure of 3 bar and a higher stop pressure of 4 bar, with expansion vessel(s) of 200 litres capacity.

$$V = \frac{(4 - 3) \times 200}{4 + 1} = 40 \text{ litres}$$

The time taken to empty the vessel(s) due to flow demand will determine the time between the last stop command and the next start command. The vessels will gradually recharge with water when the system is running and at pressures above the lower start pressure.

On boosted water systems with variable speed pumps, the expansion vessel(s) are generally re-charged at the ‘no flow’ or automatic stop function. Just before the controller stops the pumps it will ‘boost’ the expansion vessel(s) to a higher pressure. Expansion vessels fitted to pump sets with variable speed drives are typically much smaller than those required on pump sets with fixed speed motors, as they only need to store some water for very low flow conditions.

6.5.4 Fixed speed booster sets

Traditional packaged booster pump sets are fitted with electric motors with a fixed operating speed. This fixed speed creates the characteristic centrifugal pump performance curve. The controls use the rising and falling pressure characteristics of a centrifugal pump curve to trigger the low pressure ‘switch-on’ and high pressure ‘switch-off’ conditions as set by the pump controls, see Figure 6.6.

This style of pump control can create undesirable effects in the distribution pipework and in the electrical system of a modern commercial building. These include:

- Varying system operating pressures can lead to fluctuation in flows at the system outlets and large pressure surges within the system. This could be hazardous when trying to control hot and cold services, particularly in buildings with showers.
- Switchgear continually stops and re-starts pumps, particularly at low flow conditions.
- Pressure switches and contactors wear quickly due to the high number of starts and stops.

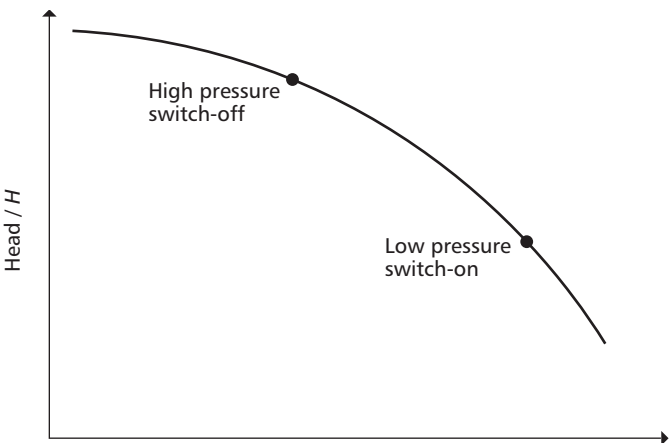


Figure 6.6 Pump characteristic for fixed speed booster set

- Large gas-filled expansion vessels are required to reduce the number of pump start/stops and to alleviate possible pressure surges.
- High start-up currents from the motors can draw down supply line voltages which may create problems for other electrical services in the network.
- Pumps starting and stopping quickly can create problems with pipework vibration and system noise.
- In tall buildings, or large system layouts, many tons of water may have to be started and also stopped quickly. Under certain conditions this can lead to pressure surges in parts of the system.

6.5.5 Variable speed booster sets

The benefits of using variable speed pumps on cold water booster pump sets include the following:

- The system pressure within the pipework is more evenly controlled.
- Hydraulic stress is minimised, leading to a longer operating life of the distribution pipework and associated fittings.
- Electrical energy consumption is reduced in comparison with the same pump size(s) fitted with fixed speed motors.
- ‘Soft’ start and stop eliminates start-up surge currents in the electrical supply system.
- Discharge pressure switches and motor contactors are not required, which reduces both operational noise and mechanical wear within the control panel switch gear.

On a system with several pumps, when the first and second pumps have reached full speed, the third is brought in, and the speed of the first two pumps reduced to re-balance the system pressure. This cascade method of operation would continue for as many pumps as were required.

6.5.5.1 Control of variable speed booster sets

The control system can be considered in two parts:

- control of the pumps
- monitoring and management of the system.

Control of the pumps

When a tap or other outlet is opened the stored system pipe pressure will gradually drop. The rate of pressure drop will be determined by the size of the expansion vessel(s) fitted in the discharge pipe. The electrical signal from the pressure transducer (positioned in the discharge manifold) will show that the system pressure has dropped to just below the system set pressure, which causes the controller to start the lead pump.

The lead pump will speed up until the pressure transducer indicates that the pressure has been restored to its original

set point. If the frequency converter fitted to run the pump motor reaches full operational output (100%) and the demand for water increases beyond the capacity of the lead pump, then the pressure will again begin to drop below the set point. The pump controller will then start up the second pump unit. The speed of the lead pump will be reduced to match that of the second pump at a level required to maintain the set-point pressure in the system. If there is further demand for water, the speed of both pumps will increase towards their full operating speed.

This is illustrated in the pressure/flow diagrams shown in Figure 6.7 for a three-pump system.

Monitoring and management of the pumps

The pump motor starters/circuit breakers and controls should be enclosed within an electrical control panel. The front of the panel should include the mains isolator switch.

For multiple-pump systems, the controller should provide automatic duty rotation of the pumps and provision for timed changeover to ensure that individual pumps do not run for excessively long periods.

The control panel should have a visual display indicating key system failure conditions and the following operational functions:

- run-on delay before pump stop
- low-water cut-out to prevent the shaft seals in the pumps running dry
- visual display of the system set pressure

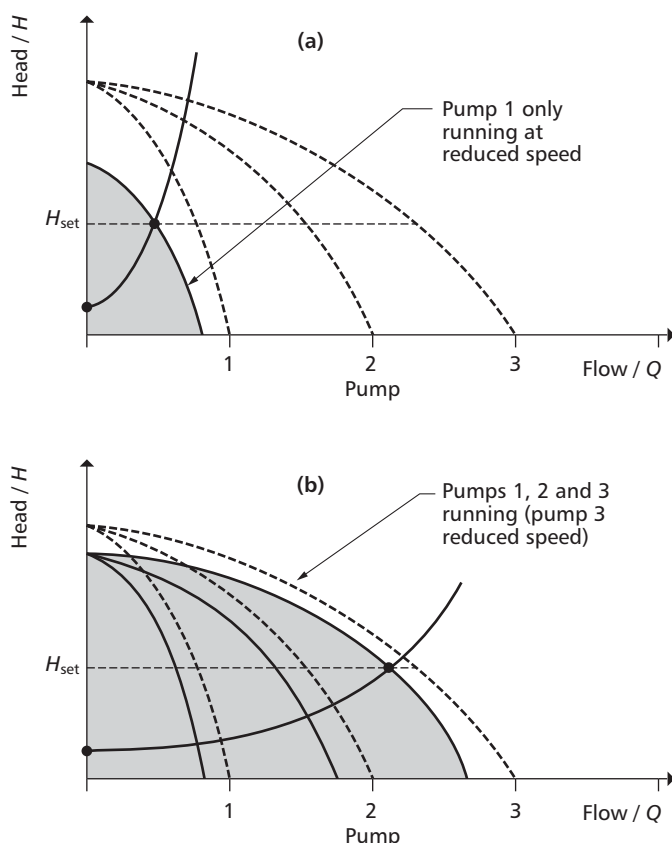


Figure 6.7 Performance flow and pressure graphs for a three-pump system; (a) one pump operating, (b) three pumps operating

- visual display of individual pump function
- visual display of individual pump fault
- visual display of discharge pressure sensor fault
- visual display for low water level.

On small buildings it is more common to provide a reduced level of visual indication in order to reduce the cost of the control panel. In such cases visual indication of 'pump running' and common faults are usually all that is required.

6.5.5.2 Number of pumps

A two-pump system creates minimum back-up and ensures that the building can continue to function in the event of a single pump failure.

Generally three-pump arrangements give an additional level of design security in that the system will maintain a much higher proportion of design flow in the event of a single pump failure.

Problems have occurred where it has been assumed that very large pumps can be used with variable speed drive (VSD) without any consideration of the consequences of delivering a small but prolonged flow within the system during times of low demand. In extreme cases pumps have overheated excessively and transferred heat to the water being conveyed. Therefore when selecting the number of pumps, the minimum recommended flow rate of each pump should be considered and where necessary the use of a small 'jockey' (lead) pump should be considered.

On large volume systems a greater number of pumps will ensure the following benefits to the contractors, end-users and maintenance support teams:

- For systems with wide flow variation, the pump controller can minimise energy consumption by operating each pump closer to its peak efficiency.
- Higher levels of redundancy allows more time to repair or replace a pump in the event of pump failure
- Smaller pumps, non-return valves and pump isolating valves are easier to maintain and repair.

As a rule, the maximum hydraulic output required in commercial buildings is rarely so large as to need more than a total of six pumps.

6.5.6 Switchgear for booster sets

Fixed speed motors up to and including 4 kW are switched 'direct-on-line' using motor-rated contactors with thermal and magnetic trips to provide motor protection. Fixed speed motors above 4 kW may have soft start or 'star-delta' starters with thermal trips for motor protection.

Motors for variable speed drives usually incorporate built-in motor protection.

Circuit breaker(s) may be included to protect the control circuits. A disconnect switch interlocking with the front panel door should also be incorporated.

6.5.7 Vibration isolation

Generally, if the pump base plate is mounted on a flat solid surface, this is sufficient to minimise vibration and avoid pipework movement.

In more sensitive building environments, or where plant rooms are located close to living facilities, then the installation of anti-vibration mountings may be considered in order to minimise the transmission of vibration and noise through the structure when pumps are activated. Inertia bases with suitably sized spring mounts, which must be anchored to the structure, are typically required to meet these requirements.

The suction and discharge pipes should have anti-vibration couplings fitted between the flanged ends of the pump set manifolds and the system pipework to minimise transmission of vibration from the pump set to the system pipework.

6.5.8 Valves

Each pump, break tank and the terminating suction and discharge pipework must be fitted with suitably sized isolation valves.

A non-return valve must be fitted to each pump discharge to prevent short-circuit cycling within the pump set. The non-return valves should, however, be fitted on the suction side of each pump in low suction pressure applications.

Isolating stop valves and drain valves must be fitted to the expansion pressure vessel(s) fitted on the discharge pipe work.

6.5.9 Cold water boosting in high-rise buildings

For all buildings above 10 m (2 storeys) there is a risk of a vacuum occurring in the top of the riser pipe(s) of the building, see Figure 6.8.

This situation can occur when the water supply to the building is interrupted as a result of:

- electrical failure of the booster set controls
- interruption of the water supply to the water break tank supplying the booster pump set
- loss of prime due to air ingress into the pipework supplying water to the booster pump set.

The building occupants will continue to draw water, as they will be unaware of the loss of the pumped water supply. The static pressure of the water in the riser pipe(s) will allow water to escape through taps at the lower levels. In modern buildings, it is common practice to place non-return valves (check valves) on each floor or individual apartment to prevent the risk of drawing contaminated water back from a consumer's outlet(s) into the main riser pipe(s). This also means that air cannot enter the riser pipe to replace the water that is escaping through the taps and outlets lower down in the building.

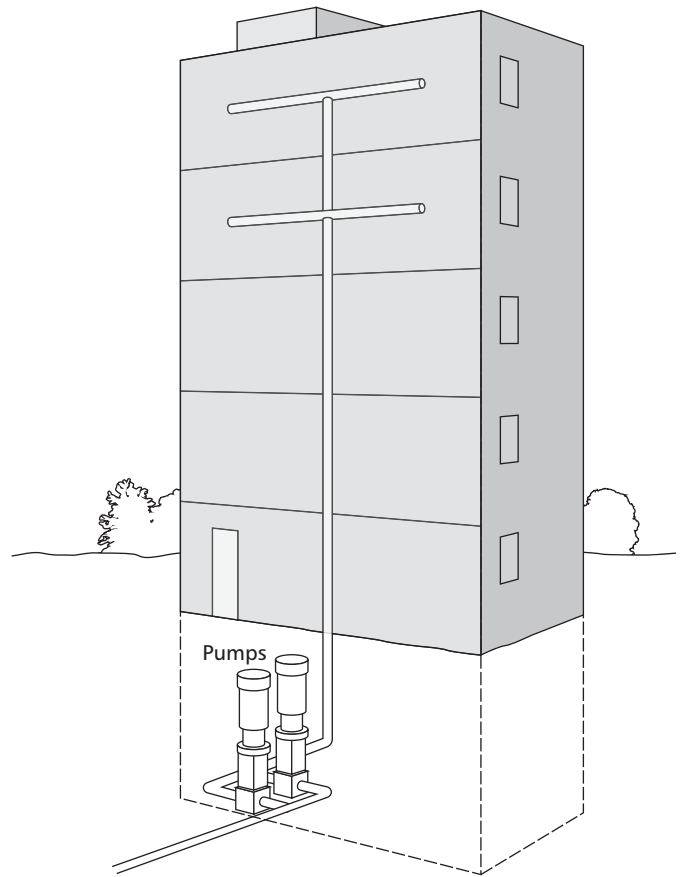


Figure 6.8 Booster set and riser configuration in a high-rise building

The water column will then collapse, resulting in the creation of a partial vacuum in the upper part of the riser pipe(s). The partial vacuum is actually water vapour 'stretched out' to fill the space left by the liquid water being drawn off. When the water pressure in the riser pipe is restored there is the risk of creating a pressure surge, see section 6.4.2.

6.5.9.1 Pressure reducing valves

Pressure reducing valves (PRVs) will normally be incorporated on each floor (or apartment) to limit the pressure to around 3 bar per floor/apartment. These valves will achieve this function even with relatively large pressure drops across the valve mechanism (e.g. 20 bar to 3 bar). However, if any of the PRVs were to fail in service then the high pressure water could become available in the consumer's pipework.

Consideration should be given to 'zoning' the building by providing the total flow through several riser pipes, each serving a different 'pressure zones'. This reduces the risk of developing high pump pressure within system pipework and fittings in the lower levels of the building.

6.5.9.2 Pressure zoning

In order to achieve zoning the following are required and this needs to be considered at design stage:

- a separate riser pipe for each pressure zone
- a separate pump set for each pressure zone.

Pressure zoning in a high-rise building is illustrated in Figure 6.9

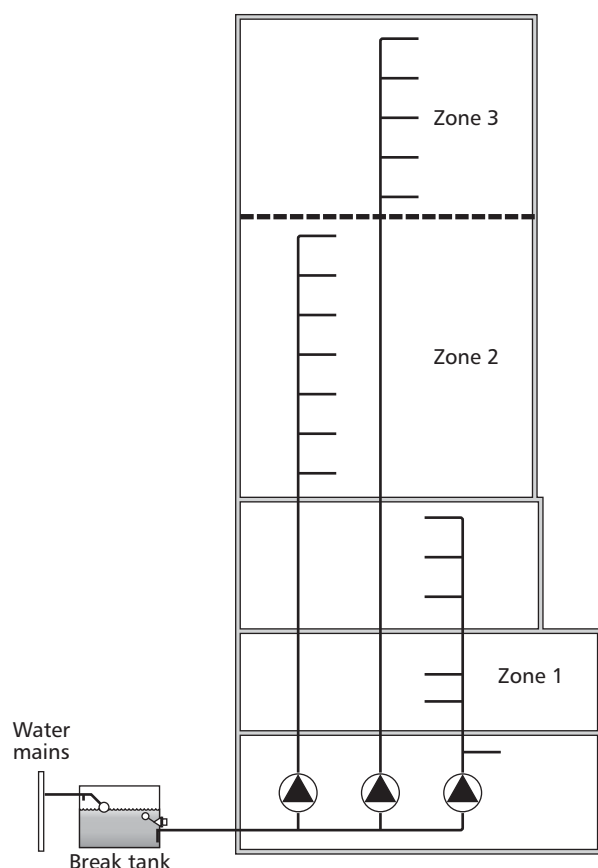


Figure 6.9 Pressure zoning in a high-rise building

Pressure zoning is particularly appropriate in ‘multi-rise’ developments where different risers end at different heights. In this situation, it is not necessary to provide a separate booster set for each high-rise building, but just a separate pump set for each pressure zone.

For a building with, say, 40 floors, the developed pressure from the booster pump set must be large enough to reach the taps/outlets on the 40th floor. This would require a developed pressure of least 12 bar for a building of this height. Added to this would be an exit pressure on the top floor of 3 bar plus an estimated 2 bar to account for friction losses in the system pipework. The total developed pressure at the pump set is therefore approximately 17 bar.

The pump performance curve will have to be capable of developing a higher pressure at the closed valve condition in order to satisfy the duty pressure of 17 bar. This might require another 3 bar (or more, depending on the choice of pump), over and above the duty point pressure. Assuming that the automatic pump controls have been overridden by manual operation, the pressure on the pressure reducing valves on the lower floors could be in excess of 20 bar.

Dividing the building into smaller pressure zones significantly reduces the reliance on individual PRVs for protection against high pressures. In this situation, the individual PRVs function more as hydraulic balancing valves rather than as high pressure reduction valves.

Example

Consider the 40 storey building discussed above. For the first 3 storeys, the booster pump needs to provide:

- 1 bar for the building height (3 floors)
- 3 bar potential exit pressure for each floor
- 1 bar friction loss in the distribution pipe
- 2 bar for pump closed valve pressure over and above the set pressure (this value increases proportionally for taller buildings, so the pumps become proportionally larger).

Therefore, for the first 3 stories this gives a maximum system pressure of 7 bar.

For a building of 40 storeys, 13 packaged booster pump sets would be required to achieve zoning within these narrow pressure limits. Economically, this may unacceptable so compromises on pressure limiting will need to be considered.

For the largest and tallest of commercial buildings pressure zoning could be considered for groups of floors. There are no specific rules regarding this design issue, so the following is offered as a guide to the maximum system pressure for groups of floors:

- groups of 6 floors: 8 bar
- groups of 9 floors: 9 bar
- groups of 12 floors: 10 bar.

6.6 HWS circulation

Small circulation pumps made of bronze or stainless steel are commonly found in the return pipework of circulation loops for stored hot water cylinders located in the plant rooms of commercial buildings. Some light commercial and perhaps large domestic systems may also benefit from the installation of an HWS return loop and small recirculation pump. Hot water storage and pumped circulation is not generally relevant where direct or instantaneous water heating is employed.

The main reasons for circulating hot water in commercial buildings include the following:

- to maintain a quick response time for the hot water
- to reduce the quantity of cold water wasted to drain
- to maintain sufficient temperature in the water contained in the pipework to prevent the growth of harmful microorganisms such as *Legionella*.

The amount of water that requires to be circulated in the pipework is generally quite small and consequently relatively small pumps, such as glandless circulation pumps, are commonly employed. The pumped flow is calculated based on the heat losses through the walls of the flow and return pipework. The heat loss can be estimated based on:

- the pipe diameter
- the pipe material and level of insulation
- the minimum expected ambient temperature.

Having established the total heat loss from the pipework, the pump flow is calculated using the formula:

$$q_v = \frac{\Phi_p}{c_p \times \Delta\theta} \quad (6.12)$$

where q_v is the volume flow rate of water ($\text{litre}\cdot\text{s}^{-1}$), Φ_p is the heat loss from the pipework (kW), c_p is the specific heat capacity of water ($\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$) and $\Delta\theta$ is the temperature difference between the flow and return (K).

The friction losses in the flow and return pipes can be calculated by the methods shown in chapter 3.

Position of pump

Small pumps are typically installed on the return branch of the circulation system. This avoids any conflict between the capacity of the relatively small pump and the much larger 'peak flow' demand through the flow branch. Being installed on the return, the pump is also subject to lower hot water temperatures, the deposition of calcium on the pump bearings, shafts and impellers.

In some hard water areas where water softening has not been employed, small circulation pumps have been known to seize-up completely within a few months of initial operation. Therefore try to ensure that:

- the hot water temperature remains within accepted norms (typically 65°C max. in the hot water cylinder)
- water softening is used in the water is particularly hard
- pumps are positioned on the return pipework.

In most commercial systems the water pressure will be typically maintained at around 3 bar by a cold water booster pump set. This ensures that any oxygen and nitrogen bubbles in the water remain compressed and are therefore unlikely to cause air locks in the system pipework and, in particular, in the pump suction.

On larger systems, duplicate HWS pumps should be provided, together with alternating the duty pump to minimise stagnation and the risk of *Legionella*. HWS pump sets should be connected to the pump control panel via the building management system.

It is good practice to position HWS circulation pumps in a vertical section of pipe such that they pump 'upwards', see Figure 6.10. This means that any gas bubbles can pass through the pump casing and back into the HWS cylinder. This is particularly important in low pressure hot water systems such as:

- domestic open vent systems
- mains fed water systems (mains pressures may fluctuate)
- pipework systems with long runs, where the system pressure may drop towards the end of the run allowing air to be drawn into the return branch of the system.

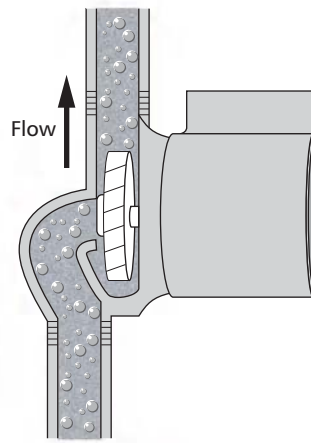


Figure 6.10 Preferred position for HWS pumps

Pumps fitted with shaft seals

In systems where calcium deposits cannot be reduced, consideration may be given to selecting slightly larger bronze bodied pumps with a mechanical shaft seal. This seal will wear and eventually leak. Therefore pumps fitted with shaft seals should be located in plant rooms where the eventual shaft seal leakage will not cause a problem.

6.7 Sewage/foul water pumping

Sewage pumps and/or pumping stations will need to be considered if there is insufficient gradient for gravity assisted sewage runoff or if the building's sewage discharge pipes are below the level of the main sewer drain.

For all sewage pumping systems a collection sump will be required. The size and arrangement of a wastewater pumping station will depend on a number of factors:

Common types of wastewater pumps used in sewage pumping systems include the following:

- self-contained single toilet macerator units for dwellings
- surface mounted pump chambers and pump units (dry well) installations.
- buried sumps with vortex impeller pump(s) mounted on guide rails.
- buried sumps with macerator/grinder pumps with a vortex impeller mounted on guide rails.
- buried sumps with channel impeller pump(s) mounted on guide rails.

Although other types are available the above are the most common arrangements installed in commercial buildings.

The sewage or foul water drainage systems should not be used for transporting:

- industrial chemicals such as acids, alkalis etc.
- runoffs from industrial cleaning or painting processes

- aggregates and cement type products from building sites
- petrochemical products and oils
- grease and food products.

Ideally these products should be filtered and trapped, or chemically removed, from the wastewater before they can enter into the main sewage system.

A common problem in commercial systems is waste products from kitchens, restaurants and coffee shops. In some cases simple dosing with an appropriate chemical agent will break down some substances so they do not congeal and risk clogging parts of the plumbing system. See chapter 4 for further details.

In other cases such as the production of food grease it should be trapped and dealt with in a separate system other than the wastewater drain. Greases can and do congeal in both pipes, pumps and sumps.

6.7.1 Types of sewage pump

6.7.1.1 Single toilet macerator units for dwellings

Domestic style macerators are designed to be fitted behind a single WC, see Figure 6.11. The macerator is powerful enough to break up human faecal deposits so that the discharge pipework can then be relatively small bore (e.g. 22 mm diameter). This allows for small conveniently sized discharge pipework to be run around the property to rejoin the larger 100 mm pipework that runs to the sewer drain.

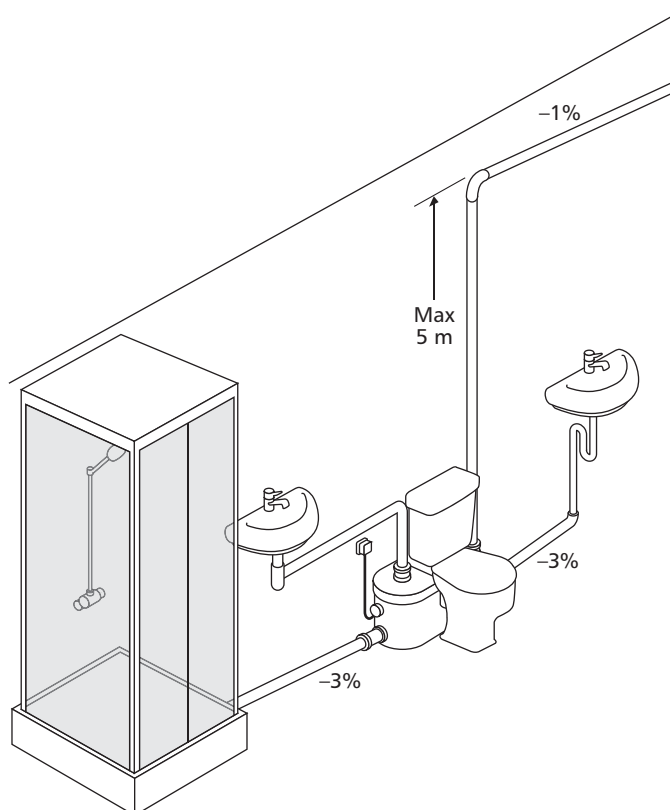


Figure 6.11 Domestic WC macerator

This type of unit become clogged if any solid materials are dropped into the WC. Even relatively small items such as cotton buds can jam the rotating parts of the macerator. These units are only intended for increasing the toilet facilities in existing domestic properties and should not be considered for commercial properties.

6.7.1.2 Surface mounted pump chambers and dry well installations

If the space around a building is limited (as is often the case with inner city buildings) then an external buried pumping station may be impracticable. An alternative approach is to consider using a basement area to facilitate a 'dry well' collection tank and associated pump unit(s), see Figure 6.12.

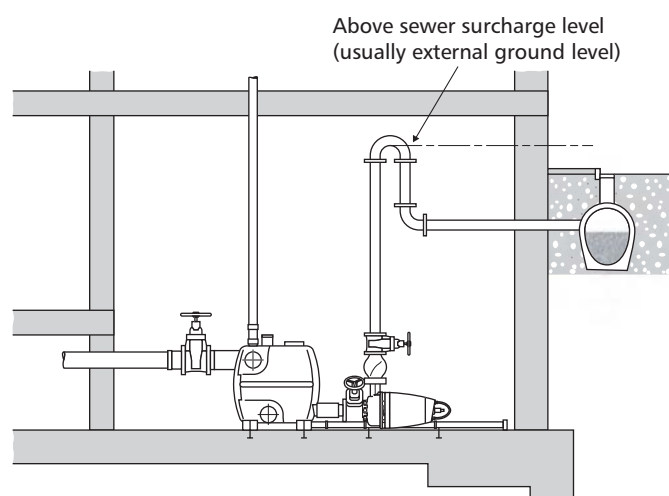


Figure 6.12 Dry well installation

Small dry well pumps have impeller clearances as small as 40–50 mm. Therefore any non-faecal solid materials may quickly become jammed. Therefore such systems should only be installed where the building occupants can be trusted to use the toilet facilities responsibly and refrain from using the WC to dispose of items such as nappies, condoms, tampons, clothing, hypodermic needles and other solid objects.

Due to the limitations on space many dry well collection chambers may be too small to give effective 24-hour storage. It is always desirable to consider providing some additional storage capacity to cover for:

- pump(s) becoming jammed
- pump motor failure due to wear
- electrical system failure.

Note: the discharge pipe should pump over the storm water flood level before discharging into the sewer.

6.7.1.3 Buried sump pumps with vortex style impellers mounted on guide rails

These systems are the more common systems fitted in commercial buildings, see Figure 6.13. They also have the advantage of having a 'wet well' sump system designed to cover a number of future requirements:

- peak inflows caused by excessive use or rainwater overflow flooding

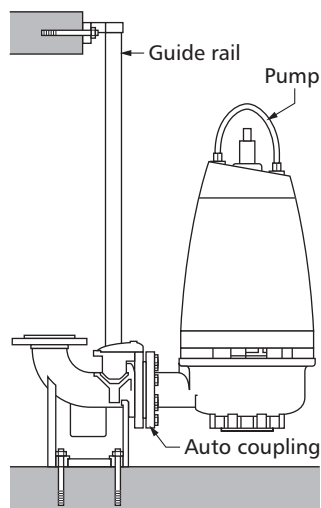


Figure 6.13 Buried sump pump with vortex type impellers

- at least 24 hours' business coverage in event of system failure
- reduced risk of odor during operation
- reduced risk of odor during maintenance
- access to building is not required for pump maintenance or replacement.

The size of wet well pumps can be larger than typical dry well installations as the collection sumps are correspondingly larger. This will also allow for designing the systems with larger vortex impeller clearances of 65 mm, 80 mm or even up to 100 mm.

The larger the pump internal clearance and the larger the discharge pipe size, the lower the risk of clogging or the pump jamming due to system misuse. However, too large a pump may create too great a flow rate into the main sewer. The water utility company should be consulted to determine if there are any maximum flow limits.

Buried sump with macerator/grinder pump

In some installations there may be a long distance between the pump station/sump and the main sewer pipe and it may be difficult to find the appropriate size of pump to handle the solids content and yet maintain the correct flow velocity. In these situations cutter/grinder pumps are often considered.

The purpose of the cutter is to reduce the sewage solids so that they can be pumped through smaller bore pipework (typically 40–50 mm). This also allows for the impeller shape to be designed for a low flow/high pressure characteristic to meet the increased friction losses through the use of smaller bore pipe.

Cutter pumps are more powerful than the domestic-type units and can tolerate pumping some non-feacal material. However, the cutter blades will quickly become worn if required to break-up any cloth/fibre materials and the pumps will require a higher level of maintenance if subjected to such treatment.

Externally buried sump with channel impeller pump

For large flow systems the pump impellers will be single channel impeller style. The solids clearance of such impellers typically starts at 80 mm and can go to much larger clearances although the number of channels (two or three) may increase to maintain overall hydraulic stability.

It is less common to find these larger pump sizes installed in commercial building sump systems as the discharge flows are likely to reflect the flow volumes of many combined systems. These larger pump sizes are more commonly found in the main sewer system to act as transfer pumps between pump stations (owned by utility companies) and water sewage treatment plants.

6.7.2 Sizing sewage pumps

The pump size will usually be based on an average design flow derived from the total of all the possible discharge flows. The total pump head will be determined from the friction loss in the discharge pipe, based on this average flow rate, and the static head from the low level stop float position in the collection sump to the sewer main height.

Example

The inflows to a typical small system wastewater sump are as follows:

- 2 WCs: 3.6 litre/s
- 1 bathtub: 0.9 litre/s
- 2 showers: 0.8 litre/s
- 2 wash basins: 0.6 litre/s
- 2 kitchen sinks: 1.2 litre/s
- 2 floor drains (75 mm): 1.8 litre/s
- 1 washing machine: 0.6 litre/s
- 1 dishwasher: 0.6 litre/s

This gives a total maximum inflow of 10.1 litre/s.

This total figure will be used by a designer to determine an average system discharge flow which, in this example, is likely to be in the region of 1.8–2.0 litre/s.

In some system designs a higher peak flow may be required to cover for emergency sump flooding. This may require several pumps to be fitted to assist in the event of such an occurrence. The use of VSDs may also be considered in order to 'de-rate' the pump size during normal system function.

6.8 Wastewater pumping stations

6.8.1 Basic design

Poor pumping station design may lead to pump malfunction, uneconomical pumping and frequent need for pumping station service and clean-out. Modern sewage

pumping stations are designed for pumping of unscreened sewage, and the design criteria for these will differ from those used for clean water.

6.8.2 Wet well volume and surface area

If the wet well volume is too large, this may lead to accumulation of sludge in the well, whereas too small a volume will lead to frequent starting and stopping of the pumps. Modern submersible pumps, with a higher starting frequency, help lead to smaller and more efficient pumping station design. The effective sump volume is the volume of water between the pump start and stop level.

In a good design the start and stop levels should be relatively close to each other for the following reasons:

- Pump starting frequency is high enough to prevent sludge and impurities from settling onto the well floor.
- Pumping station inlet should stay low relative to the liquid level in the wet well. A guide for the effective volume height in small pumping stations is approx. 1 m, and 2 m in larger pumping stations.

The effective volume can be estimated from the wet well surface area, which may be obtained from the following equation:

$$A_w = Q / 20 \quad (6.13)$$

where A_w is the wet well surface area (m^2) and Q is the pumping station total flow rate (litre/s).

For small pumping station flow rates, the surface area will be limited by the physical dimensions of the pumps when submersible pumps are used. The surface area will then be larger than obtained with the above equation.

6.8.3 Pumping station inlet pipe

The location and size of the pumping pipe is important for the function of the pumping station. An inlet pipe located too high in relation to the liquid surface, or with a high flow velocity may cause entrainment of air and the formation of eddies in the water when splashing down into the well. Air mixed into sewage water has a tendency to remain because air bubbles adhere to the solid particles present. Therefore even a separate water 'calming chamber' may not alleviate this situation.

Inlet fall height should always be minimised and should not exceed 1 m with the water level down, whether or not the pumping station has a separate calming chamber. The effect of a high inlet fall height cannot be effectively alleviated with baffles. Air entrained in the water has a tendency to remain inside the pump impeller, where centrifugal forces will cause the air to accumulate around the impeller hub. This will lead to a lowered pump performance, lower efficiency, and risk of cavitation and pump vibration. If the amount of air entrapment continues to increase then the pump will lose prime and will cease to pump altogether. Air is commonly a problem for pumps drawing directly from aeration basins in treatment plants because of the high dissolved content of

air. If a pump is placed in an aeration basin it should be placed as low as possible, with the suction pipe near the bottom

Location of the inlet pipe should be as remote as possible from the pump inlet. Figure 6.14 shows configurations that should be avoided. Flow velocity at the inlet should be no greater than 1.2 m/s to reduce the risk of forming eddies in the wet well.

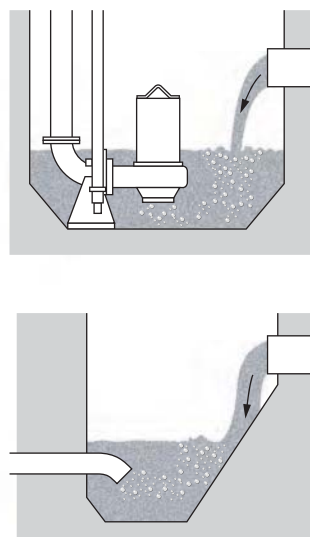


Figure 6.14 Examples of air entrainment due to incorrect inlet pipe configurations

6.8.4 Wet well floor shape

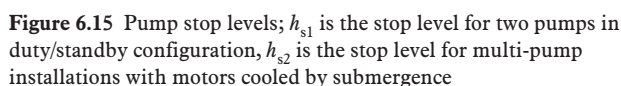
A good floor design prevents sedimentation and will also assist in the prevention of scum formation and the accumulation of flotsam on the surface. All corners should be benched to a minimum angle of 45° ; in small pumping station the bench angle may be as high as 60° . The angle may be smaller, if the section is flushed by an incoming flow. The overall bottom area should be minimised and the liquid volume below pump stop level should be kept to a minimum.

By minimising the bottom area and the residual volume, the flow velocities near the pump inlets will increase, flushing out any settling sludge. A surface area which is decreasing with the falling water level will also lead to less accumulation of surface materials.

6.8.5 Pump stop levels

The pump start and stop levels are specified at the design stage. They should always be checked for function and adjusted at commissioning in order to secure good operation. The stop level should be as low as possible, so that the flow velocity increases toward the end of the working cycle. The stop level is set by the need to ensure sufficient motor cooling (by means of submergence) or by the level when surface air may be sucked down into the pump inlet. If designing to a 'vortex level' then this should be established by test trial during pump station commissioning.

In pumping stations with two submersible pumps in duty/standby configuration, see Figure 6.15, the stop level can normally be set below the top of motor even if the motor is cooled primarily by being submerged. Short



Identical pumps are selected so that each pump is able to cope with the total pumping station flow on its own and the risk of the liquid level remaining for long near the stop level is slight. Most submersible pump designs incorporate thermal protection to prevent overheating and stop the pump if cooling is inadequate. In pumping stations with multiple submersible pumps running under varying conditions, the stop level must be set so that the pump motors always have enough submergence for adequate cooling. Pumps with cooling water jackets or other means of heat dissipation, independent of submergence, are preferred in such installations.

A provisional pump stop level height can be calculated using the following equation:

$$h_s = 0.04 Q + 0.2 \quad (6.14)$$

where h_s is the stop level height (m) and Q is the pump flow rate (litre/s).



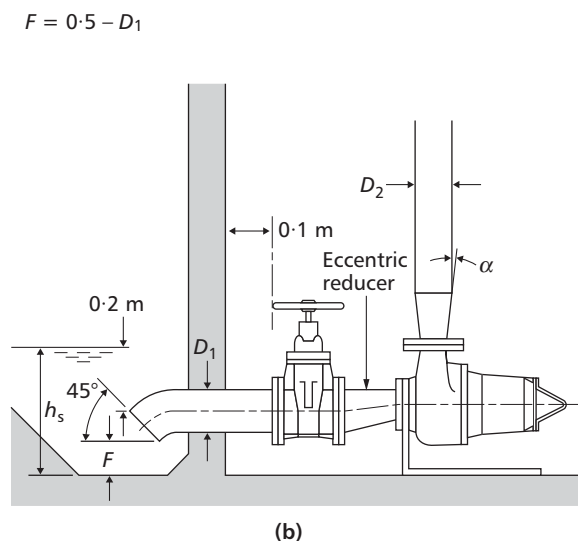
In pumping stations with several different stop levels, such as in frequency-controlled installations, it is important to program the control sequence to pump down to the lowest stop level at least once per day to clean out the bottom of the sump.

6.8.6 Pump start levels

In pumping stations with dry-installed pumps the starting levels must be set above the pump casing in order to ensure that the pump casing fills up and the pump starts pumping.

6.8.7 Suction pipe dimension and design (dry well)

A downward facing suction exerts a cleansing flow on the pumping station floor, and is less prone to suck air from the surface. In vertical pumps the suction pipe will have to turn through 90° to reach the pump suction cover. The bend before the pump suction inlet is crucial for the



function of the pump, since it causes the flow to be irregular. Too sharp a bend may cause impeller cavitation, lower pump efficiency and vibration. If the pump suction inlet is smaller than the suction pipe, a reducing bend should be used, minimising the interference. The contraction of the straight inlet pipe to a horizontal pump should be eccentric so as to avoid air from collecting and blocking the impeller.

6.8.8 Pumping station internal pipework

The internal pressure pipework in a pumping station should be selected for a flow velocity of 2–3 m/s. BS EN 12056-4⁽³⁾ gives 0.7 m/s as the minimum velocity. If the sewage contains sand the flow velocity must be at least 2 m/s in order for the sand to be carried with the flow out of the pump. In frequency-controlled installations this requirement may lead to problems at lower pump speeds. Ideally the pipework diameter should be at least 100 mm, but, on small commercial building installations, pipes as small as 40 mm may be used (with grinder/macerator pumps). The size of the discharge pipe will be intrinsically linked to the pump size in order to ensure minimum cleansing velocities are maintained. The smaller the pump size the smaller the pipe size and the greater the risk of clogging from any fibrous contaminants in the sewage waste.

For vertical dry-installed pumps and submersible vortex pumps the check valve should be installed as far away as possible from the pump in order to alleviate possible problems with air in the pump at start-up. If the check valve(s) are mounted in the horizontal pipe run at or near the surface then care should be taken to ensure that the water volume in the 'vertical' pipe is sufficiently small

that, if it were to drain back, it could not restart the pump on its lowest start level.

6.8.9 Odor problems in pumping stations

A sewage pumping station may create odor problems in its immediate environment. Many factors are involved, such as the location of the pumping station, sewage quality, wet well dimensions and design. If the pumping station is fed by another, remote pumping station, the sewage transfer time between the pumping stations may be so extensive that the sewage turns septic by anaerobic action. Septic sewage produces hydrogen sulphide (H_2S) that, apart from being toxic, also creates a typical foul odor.

The occurrence of odor problems is practically impossible to predict. Where they do occur the following actions may help to alleviate the problem:

- lowering the start and stop levels in order to cut the retention time in the wet well and prevent sludge from forming
- installing a submerged inlet bend in the wet well, in order to convey the incoming sewage below the surface, thus preventing aerosols from forming
- installing air filters in the wet well ventilators
- dosing the sewer upstream from the pumping station with odor-preventing chemicals.

6.8.10 Pumping station design

Wet well design will depend on pumping station size and flow volume. Figures 6.17 to 20 show examples of wet well design for various cases and pumping station sizes.

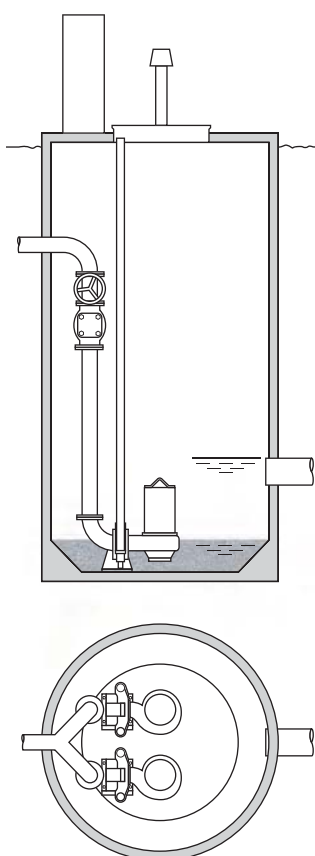


Figure 6.17 Pumping station design for submersible pumps and small flows (4–50 litre/s)
Note: When pumping stations are located in or close to the building, the sump vent pipe should be extended to a suitable elevated termination point to prevent odour nuisance.

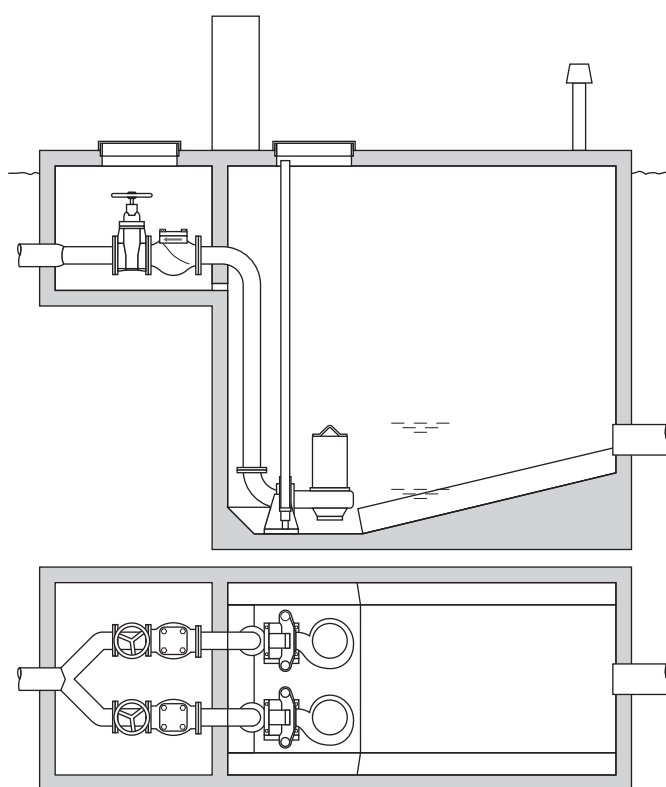


Figure 6.18 Pumping station design for two submersible pumps and moderate flows (50–2000 litre/s)

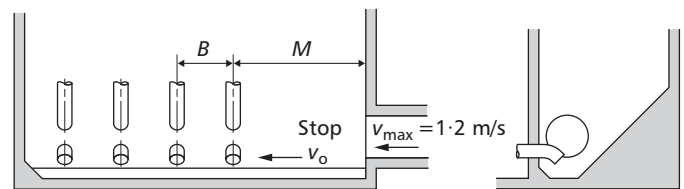
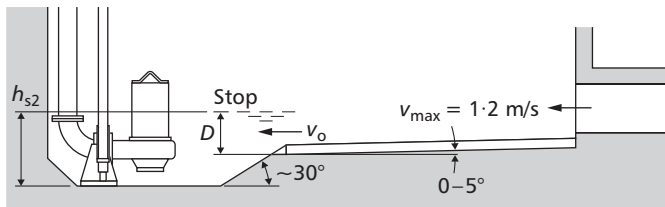


Figure 6.20 Wet well design for pumping station with multiple dry-installed pumps

For larger pumps, the net positive suction head (NPSH) safety margin may not be met for pumps mounted in a vertical position, whereas a horizontal pump may be acceptable. All possible pump duty points must be considered when performing NPSH calculations, particularly for installations where more than one pump is being operated.

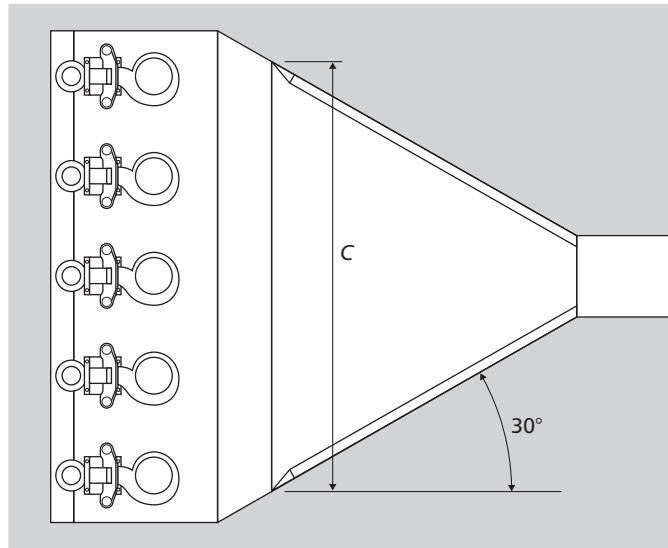


Figure 6.19 Pumping station design for several submersible pumps and large flows

Figure 6.17 shows a design for submersible pumps and small flows (4–50 litre/s). The preferred cross section for small pumping stations is circular, which minimises liquid surface area and avoids corners where sludge could accumulate. The minimum diameter is 1.5–2 m to facilitate service access.

The design shown in Figure 6.18 is suitable for larger flows (50–2000 litre/s). The elongated wet well is an important feature that places the inlet pipe away from the pumps and prevents the build-up of sludge on the wet well floor.

A design for pumping stations with multiple submersible pumps and large flows is shown in Figure 6.19. If the pumps rely on being submerged for cooling, the stop level (h_{s2}) is chosen accordingly.

Figure 6.20 shows a wet well design for a pumping station with multiple dry-installed pumps. Flow velocity across the suction bends is 0.3–0.4 m/s with the liquid at stop level. Pump internal distance 'B' can be selected as for submersible pumps whereas the distance 'M' should be selected according to the fall height and should ensure an even flow at the suction inlets.

6.8.11 Dry-installed pump positions

For dry installation, most manufacturers can offer pumps for both vertical and horizontal installation. Usually a pump in a horizontal position offers advantages, such as:

- simplified piping with less bends.
- suction flow to the impeller is even.
- lower pump position.

6.8.12 Packaged pumping stations

Packaged pumping stations are available for installation on site. The material used is glass-fibre reinforced plastic (GRP) or, for smaller pumping stations, polyethylene (PE), and the stations are manufactured complete with all internal pipework and plumbing components in place. Installation is then reduced to the excavation of the site, laying of a foundation and connecting the station to the incoming sewer and rising. The pump motor power leads and float cables must be connected to the control panel supplied for the purpose.

The pumping station must be vented to prevent the build-up of toxic or explosive gases. If there is risk of freezing, the upper part of the pumping station can be insulated. Packaged pumping stations are fitted with access covers that may be made of aluminium or galvanised steel and molded into the structure. The internal pipework can be either cast iron or thin walled stainless steel with fabricated bends and branches, ductile iron or PVC. Valves are typically cast iron, brass or plastics and are suitable for use in either horizontal or vertical position.

6.9 Rainwater removal and flood protection

As discussed in chapter 4, in any commercial building drainage water and, in some cases rainwater, may need to be pumped away. The need for sump collection chambers and submersible pumps will depend on how much of these naturally occurring waste waters can be taken away by gravity or will absorb underground through a soak-away. Excess rainwater pumping will have to be made through a drainage system separate to the sewer mains in order to avoid potential flooding of the main sewer system.

6.9.1 Rainwater drainage

6.9.1.1 Direct water run-off

The water from the roof areas can be directly channeled using the installed drain pipes. This can then be run to temporary storage cisterns for rainwater harvesting, which have overflow pipes that run to the underground pumping stations or sumps.

6.9.1.2 Drainage water

The grounds of the property can be further drained by installing suitable underground drainage pipes in order to collect and channel the water being absorbed into the soil. These pipes can then be run to temporary storage cisterns for rainwater harvesting, see section 6.9.3, which also have overflow pipes to run to underground pumping stations or sumps.

6.9.2 Design considerations

When pumping to common storm drains there may be limitations imposed by the water utility company or by the organisation responsible for operating the drainage system. Consultation with the relevant organisations should be undertaken to see if such limitations will be imposed. If the potential flow limits are much higher than the estimated flow, then larger drainage systems, pumps, pipes and collection sumps could be considered. It may be possible to consider dealing with potential flood prevention even for storm conditions if the main drainage system will allow the relevant input flow.

For some properties it may be desirable, or essential, to move water away from certain designated critical areas, e.g:

- underground workspaces or basement areas
- critical operating plant such as electrical substations
- wastewater systems or treatment plants
- livestock areas.

Under these conditions, even if the main drainage system is unable to cope with the flow rate, the designer may have to consider the possibility of deliberately flooding a lower risk area in order to protect livestock or essential equipment.

6.9.3 Rainwater harvesting.

Equipping buildings with tanks, pumps and filters to capture rain water off the roof and store it for future use is becoming more common in the UK. Commercial and agricultural use of rainwater is also increasing as metered water costs rise and droughts become more frequent.

Pump types

There are three common pump types used in rainwater harvesting systems:

- *Electro-submersible pump units (single-stage)*: for low pressure requirements to storage cisterns and high level tanks single stage drainage/dewatering sump pumps may be utilised.
- *Electro-submersible pump units (multi-stage)*: for larger water distribution systems with high flow demands and/or high pressure requirements multistage electro-submersible pump units may be preferred. If borehole style submersible pumps are chosen these may also require forced cooling across the submersible motor surface by fitting a flow sleeve.
- *Self priming pumps (surface mounted)*: where tanks are less accessible for fitting a submersible pump unit then a surface mounted pump may be preferred. These units are commonly self priming style pumps with either vortex impellers and priming chamber or possibly internal jet/ejector style units. If a standard centrifugal impeller designed pump is used on a suction lift application then there is always a risk of a loss of water prime in the suction pipe which prevents the pump and system from functioning.

See chapter 5 for further information on rainwater harvesting.

6.10 Fire protection

For detailed guidance on fire protection systems, see CIBSE Guide E: *Fire engineering*.

6.10.1 Fire sprinkler pump sets

In many cases, actual pump specifications will be defined in accordance with relevant European (EN) or British (BS) standards and in accordance with any technical guidelines from relevant professional bodies.

The number of booster pumps supplied will typically be one or two (usually identical) pumps to act as the primary pressure pumps to the fire sprinkler heads within the premises. The exact flow and pressure requirements will be defined in accordance with the relevant rules to determine the number of and style of sprinklers required.

The sprinkler styles and quantity/density of sprinkler positioning will also be defined in accordance with the style of the premises and in line with rules defining the type of hazard classification and the heights involved between the pump locations and the highest sprinkler head. The majority of pump systems may be defined in accordance with pre-defined flows which are set against a respective hazard class and the maximum sprinkler height.

Pump drivers

Pumps will be driven by either an electric motor or a diesel engine. In many large commercial installations, one electrically driven pump and one diesel driven pump may be specified.

Electrically driven pumps are simpler and more cost-effective than a similar pumps driven by diesel engine. The purpose of the diesel driver is to be independent of the electrical system. Current designs also incorporate their own diesel fuel reserves in order to run the diesel engine for a minimum period, typically 90 minutes.

Diesel driven pump units incorporate batteries to energise the starter and the controls. Batteries and battery chargers may be duplicated to provide back-up for starting the diesel engine in the event of a fire.

Jockey pump

The control circuits on the main fire sprinkler pumps will be designed to 'latch-on' to ensure that the pump(s) are kept running in the event of a fire. If the sprinkler network is kept full of water under design pressure leaks will inevitably occur through pipe joints. Eventually this will cause the control system to energise one of the main sprinkler pumps. This is likely to activate associated fire alarms, possibly leading to the building being evacuated and the fire brigade alerted.

To avoid this, a small jockey pump is often provided to maintain the system water pressure. This jockey pump should maintain a pressure higher than the sprinkler operating pressure (at which the main pump(s) are designed to activate). It should, however, be sized small enough not to be able to maintain pressure through any of the individual sprinkler heads.

6.10.2 Hydrant fire systems

Fire hydrants are the means by which the fire brigade will draw water from the utility water supplies for firefighting purposes.

In commercial buildings additional private fire hydrants may be required. This is usually determined by the size and layout of the property and the proximity of the nearest water utility hydrant, for example:

- if the building is tall
- if the property is extensive
- if there are large storage yards or workshops
- if the fire hazard is defined as high
- if the nearest water utility hydrant is a considerable distance from the property, thereby limiting the fire brigade's ability to fight a fire.

Large properties and, in particular, high-rise properties may require hydrants throughout the building. In order to generate sufficient water pressures to the fire fighting hoses 'fire hydrant pump sets' will be required.

Fire hydrant pump sets follow similar design layout rules and pump control philosophy to those used for fire sprinkler systems.

Design data for sizing fire hydrant systems will be found in BS 5306-1⁽⁴⁾. Systems may incorporate two main pumps and a jockey pump unit. The jockey pump is provided to take account of small leaks in the pipework. The two main pumps provide mutual back-up in the event of failure of

either one of the pumps. In many cases one pump will be electrically driven and the other pump will be driven by a diesel engine.

6.10.3 Sump pumps in lift shafts

Any lifts in the building are likely to be controlled so as to descend towards the ground floor in the event of a fire or fire alarm.

If there is any water-based firefighting capability in the building, such as a pressurised fire sprinkler system, then the booster pumps will be activated in order to produce water flow through the sprinkler heads. Any fire hydrants and hose reels in the building may also be in use in order to help fight the fire.

The lift shaft should be designed and constructed in such a way as to channel any water run-off away from, and thereby prevent possible accumulation of water in the bottom of the shaft(s). However, in extreme circumstances very large volumes of water may be channelled into a lift shaft, for example:

- a large number of sprinkler heads have been activated simultaneously
- hose reels and/or hydrant(s) have been opened by accident and then abandoned by the operator(s).

The quantity of water that could accumulate in such situations will depend on the depth of the lift shaft below the level of the ground floor. In extreme circumstances it is possible that the lift shaft may fill with water which could then:

- compromise the switchgear used to operate the lift(s)
- produce a water cushion under the lift, making it difficult for the lift(s) to achieve the correct level to allow the doors to open and let the passengers out.

As a precaution, one or more emergency sump pumps may be installed at the bottom of the lift shafts. To assist routine maintenance, an alternative robust design would be to locate the pump station outside of the lift pit. The size of these pumps will depend on:

- the size of the sump at the bottom of the lift shaft
- the available power supply for the pumps
- the peak rate at which water is expected to descend into the lift shaft
- the total static lift back to a suitable drain.

Pump designs

Where there is adequate space to fit a standard de-watering sump pump, then this should be considered. The pump and associated pipework should be installed such that any suddenly rising water in the sump will not produce an air lock in the pump when it is required in an emergency.

Where the sump is not big enough to accommodate an electro-submersible sump pump then a surface mounted suction lift (self priming) pump should be considered.

These types are more limited in output due to the constraints of having to pump on a suction lift, typically around 8 m minus the associated frictional resistances in the suction pipework. The operational reliability of these pumps should be considered since the priming chambers on suction lift pumps must be maintained and the water must not be allowed to evaporate.

Whichever type of pump design is chosen the pump(s) must be operated with water for a short period at regular intervals preferably once a month. Any pump which is left in an inoperable condition for long periods of time may stick on its bearings, shaft seal faces or impeller neck ring location. This potential for a pump to stick could prevent the pump from functioning when an emergency situation occurs.

6.11 Water features/fountains and swimming pools

6.11.1 Water features and fountains

There are two types of centrifugal pump installations:

- dry pumps
- electro-submersible pumps.

These are illustrated in Figures 6.21 and 6.22.

The choice between dry or submersible installations is often dependent on external constraints. In most cases it will be necessary to use submersible pumps. The installation of a submersible pump has the following advantages over a dry pump installation:

- quieter operation
- a smaller pump and motor can be used because less pipework is needed
- a separate pump room is not required
- less maintenance is required
- relatively reliable, provided that dry running protection is provided.

However, possible disadvantages include:

- maintenance will need to be carried out by a specialist
- the initial cost of the pump is higher than that of a dry installed pump type.

Corrosion

Materials which can withstand corrosion are essential to prevent deterioration from the effects of chlorine and other water treatment chemicals dissolved in the water. It is recommended that bronze or stainless steel impellers are used. Plastic or composite materials will resist corrosion but they are generally not durable enough when used on pumps which are running for long periods.

Non-metallic impellers in water with solids

Nylon, plastic and composite impellers are best avoided where there is likely to be solids, such as grit, present in the water. Metal impellers (e.g. stainless steel or bronze) will give better lifetimes.

Plant space and location

In most electro-submersible installations the main item of plant is the pump itself. Therefore, the requirement for plant space is minimal, as the pump is usually within the water feature pool.

For dry pump installations, it is advisable to locate the pump and associated equipment as close as possible to the water feature, so as to limit the length of pipe runs and therefore reduce friction losses.

In general, the pump chamber should be well ventilated and there should be adequate access to it. Greater thought for space requirements must be given where water treatment plant is included. The space required will depend on the treatment method adopted. The water treatment plant should be located as close as practicable to the feature.

Variable frequency drives

The use of variable frequency drives (see section 6.2.3) is becoming more common with water features and

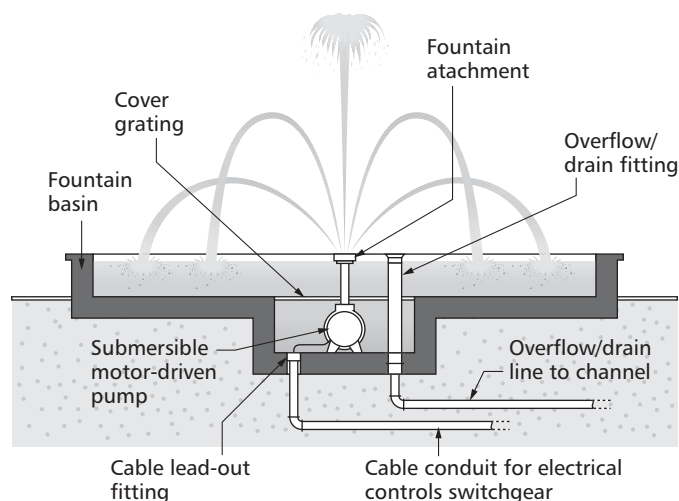


Figure 6.21 Electro-submersible installation for water feature/fountain

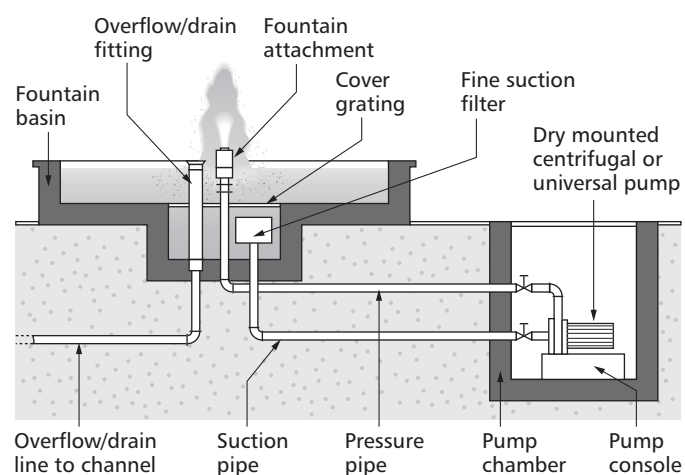


Figure 6.22 Dry pump installation for water feature/fountain

fountains. This allows the designer the latitude to design a water feature with a varied display.

Many small submersible pump have very narrow operating limits if fitted with a frequency drive. If care is not taken very poor reliability will be experienced. The manufacturer should be consulted to determine whether a VAD can be used on the chosen pump motor.

6.11.2 Swimming pools

Only dry installed pump types should be considered for swimming pools because submerged power cables and electric pump motors are not desirable with respect to electrical safety.

The concentration of chlorine and other water treatments present in the pumped pipework will be much higher than those on water features to ensure the health of the bathers. The materials of pump construction will need to be considered carefully in order to ensure a reasonable operating life.

The size of the pool filtration system and water treatment plant will determine the minimum required circulation flow rates for the size of the swimming pool. The respective pressure drops can be calculated or derived in the same way as for boosted water systems. As swimming pools are open to the air then the static lift must be added to the friction losses in the pipework and filtration plant.

Variable frequency drives

Reduced pump performance may be possible during periods when the pool is unoccupied and circulation pumps operating at full output to maintain unnecessary circulation flows will be wasteful of electrical energy.

If the designer can balance the need to maintain the minimum water treatment levels in the pool with a reduced circulation then electrical energy savings can be achieved.

6.12 Geothermal and hydrothermal energy

Geothermal energy is the heat energy in molten magma in the core of the earth. This energy can be harnessed using various technologies.

Hydrothermal energy is the energy in naturally occurring hot water and steam, produced by geothermal energy. Hydrothermal resources can be tapped with existing technologies to produce hot water and space heating. Where water does not occur naturally in geothermal sites, known as 'hot dry rocks', water can be injected and the resulting hot water or steam then extracted and used as hydrothermal energy.

Localised geothermal pump systems

To ensure a reliable supply of hot water in a commercial building by pumping very hot water from underground presents a challenge. Some key design factors that need to be considered include:

- whether to use electro-submersible pumps or pipeline mounted dry-installed pumps
- the suitability of the materials of construction in respect of water quality, temperatures encountered and dissolved gases in the liquid
- the effects on electric motors with respect to the temperature of the pumped water.

Electro-submersible installations

For cooled water systems or for water temperatures of less than 40 °C standard pump technology is suitable. Many standard borehole-type submersible pumps, motors and electric cables are available for such applications. If the water temperatures rise above 40 °C then retrieving water via an 'open pipe' system, deep in the ground, would require specially designed pumping equipment.

Circulation pumps

If the pipes are to be sealed (and buried in the ground) or are to form a continuous liquid-filled loop that is inserted into a borehole then standard surface designed pumps can be considered as circulation pumps. Standard circulation type pumps can tolerate water temperatures up to around 120 °C. This is more than adequate for the majority of system designs.

Note: the pipework must be sealed and pressurised in the same way as a standard low temperature hot water heating system.

References

- 1 *Variable flow pipework systems* CIBSE Knowledge Series KS7 (London: Chartered Institution of Building Services Engineers) (2006)
- 2 *Commissioning variable flow pipework systems* CIBSE Knowledge Series KS9 (London: Chartered Institution of Building Services Engineers) (2007)
- 3 BS EN 12056-4: 2000: *Gravity drainage systems inside buildings. Wastewater lifting plants. Layout and calculation* (London: British Standards Institution) (2006)
- 4 BS 5306-1: 2006: *Code of practice for fire extinguishing installations and equipment on premises. Hose reels and foam inlets* (London: British Standards Institution) (2006)

7 Waste management systems

7.1 Introduction	Summary
7.2 Waste management in context	Waste management legislation, plus the key directives set to reduce waste have been implemented not only to reduce waste, and its environmental impact, but in particular to minimise landfill and encourage recycling of materials.
7.3 Policy, planning and legislation	The emphasise to produce less waste and encourage recycling has led to increased storage periods of municipal waste. If disregarded, this can quickly become a public health hazard, therefore this chapter aims to provide the engineer with the fundamental planning and design principles involved when considering waste management.
7.4 Waste generation and storage	An overview of the main waste streams and legislation has been provided, with particular focus being provided on design guidance, to ensure the engineer has the essential information necessary to consider from concept design up to detailed design stage.
7.5 Design guidance	
7.6 Waste management equipment	
References	It should be noted that waste management within the construction stage is not covered in this chapter.

7.1 Introduction

7.1.1 General

The intention of this chapter is to inform the designer, engineer, architect and developer about the various types of waste management systems that may be required in the development of both new and refurbished buildings. It aims to provide background to current practices in waste management and legislation, policy drivers and the mandatory design standards. It also importantly details the types of collection and storage options for use in different building designs. It should be noted that this chapter provides information only for the design and operational phases of a building development and not the construction phase.

This chapter does not provide the level of detail required to site and plan large scale waste infrastructure, and its focus is on solid waste and therefore does not provide the requirements for liquid waste management, guidance for which may be found in chapter 4.

7.1.2 Sustainable waste management

This chapter concentrates on the requirements for suitable waste management systems in new developments as well as providing information on current practice for collection and the disposal of wastes.

The management of waste and resources is a key theme for sustainable development. The most commonly used working definition is:

‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.’ (*Our Common Future* — *World Commission on Environment and Development*⁽¹⁾)

The principal objective of sustainable waste management is to reduce the amount of waste produced, as well as to use material resources more efficiently. Sustainability objectives and design guidance for any new development should be developed based on best practice guidance along with policy and legislation requirements.

The objectives and targets for sustainable waste management apply to the following three key development stages:

- design phase
- construction phase
- operational phase.

Where waste is generated, it should be managed in accordance with the national waste hierarchy⁽²⁾ (see Figure 7.1) and should form a core element of sustainable development.

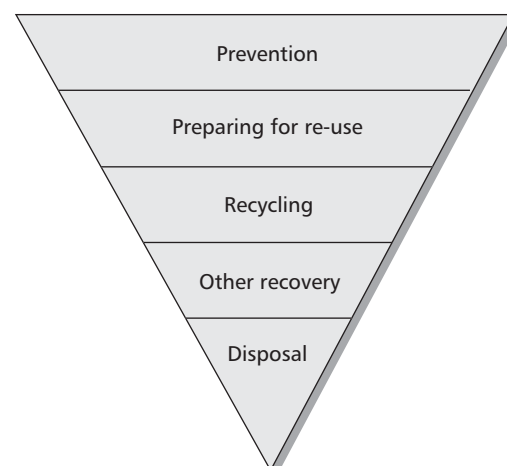


Figure 7.1 The waste heirarchy⁽²⁾

Waste generation associated with construction contributes significantly to overall waste generation in the UK. Operational waste associated with new developments also adds to the national waste burden. Waste and resource management is therefore an integral part of planning sustainable communities.

Many environmental impacts are linked to the goods and services required to sustain a vibrant economy. These impacts occur across the whole life-cycle of a product or service (see Figure 7.2). This is known as a systematic approach to waste management and should be integral to all developments. This approach, known as 'life-cycle thinking', aims to use resources more efficiently and hence reduces waste arising, in order to reduce environmental impacts.

7.1.3 Development life cycle

Effective planning and design is a fundamental requirement for successful resource and waste management. An integrated planning approach to procurement and waste management at the design stage of a development project will reduce the volume of materials disposed of to landfill. This can bring significant benefits in terms of resource efficiency, environmental performance (e.g. reduction of carbon dioxide emissions), risk reduction, market positioning and ultimately result in cost savings.

In terms of the built environment, sustainable resource and waste management should consider the whole development life cycle as shown in Figure 7.3.

7.1.4 Sustainable consumption and production

Waste management plays a central role in delivering progress on sustainable consumption and production (SCP). Reduction in commercial and industrial waste generation will reduce the impact of production through reducing resource use, energy consumption and carbon emissions, and reduce the environmental and economic impacts of waste management. Reduction in municipal

waste generation is indicative of more sustainable consumption; products are used more efficiently and retained within the economy for longer.

Producing a strategy sets out a vision identifying a series of strategic outcomes and associated actions to be delivered in order to progress the SCP agenda. The SCP action plan aims to ensure that the project being undertaken uses its resources more sustainably and has a thriving 'environmental technologies and services' (ETS) sector. The SCP action plan will act as a 'living' document that will play a key role in supporting the delivery of the strategic aims identified and adapt to any required changes in a prolific manner.

7.2 Waste management in context

7.2.1 Introduction

This section sets the scene for waste management. It provides an overview of sustainable waste management practice and details where waste can be reduced through the various development phases. Explanation regarding the differing waste sectors and waste types is also provided.

The UK has made considerable progress in addressing its waste management agenda over the last 15 years. Recycling and composting initiatives have quadrupled since 1996–7 and there has been uptake of both regional and local waste management strategies for municipal waste, which has lead to all local authorities providing a collection for two thirds of the recycle stream, as a minimum.

Waste Management Strategy for England⁽³⁾ was released in 2000 and further updated in 2007. It aims not only to increase landfill diversion rates for municipal solid waste (MSW) but also for commercial and industrial (C&I) and construction, demolition and excavation wastes (C,D&E).

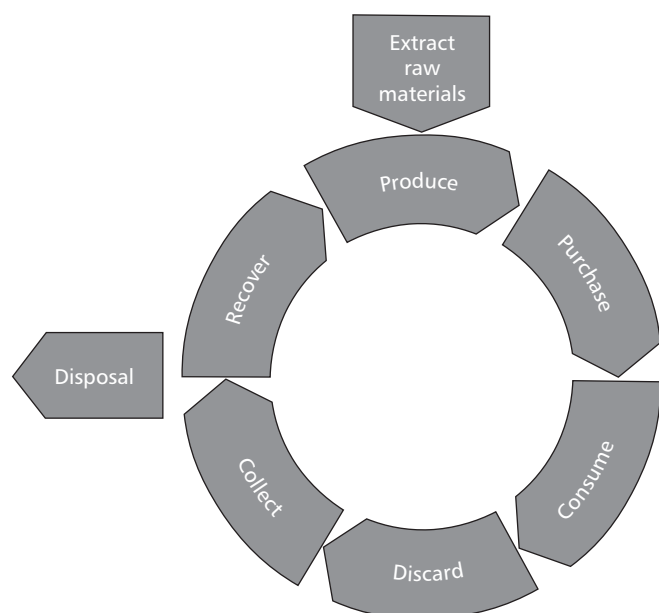


Figure 7.2 Product life cycle⁽³⁾

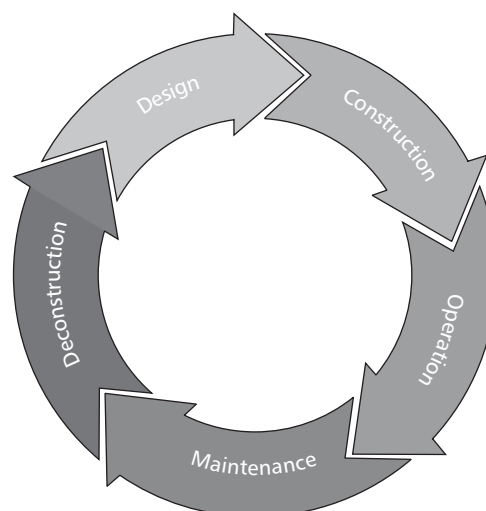


Figure 7.3 Development life cycle

7.2.2 UK recycling statistics

The municipal waste stream is monitored through WasteDataFlow⁽⁴⁾, which is provided through a joint initiative by DEFRA and the Environment Agency. For C&I and C, D&E wastes there are periodic reviews carried out on a regional basis but no single monitoring tool which provides updated waste statistics for the UK on an annual basis.

Domestic waste includes household bin waste and also waste from civic amenity sites, other household collections and recycling sites. Between 2003–4 and 2007–8 household waste per person increased by just 0.9%, with each person generating about half a tonne on average.

The amount of waste recycled or composted has increased, and accounted for 34.5% of household waste in 2007–8, see Figure 7.5. There has been a year-on-year decrease in the amount of non-recycled waste per person over the last six years and is now at the lowest level since estimates were first made in 1983–4. Most of this waste goes to landfill.

In 2007 in the UK, around 73 million tonnes of waste were disposed of in landfill sites, see Figure 7.6. This includes waste produced by households, commerce and industry and construction and demolition. This is a decrease of 19.5 per cent since 2002 when 91 million tonnes of waste were disposed of in landfill sites.

In 2006/7 local authorities reported that around 8.0 million tonnes of household waste (31% of total household waste) was diverted for recycling or composting through schemes run by local authorities or organisations working in partnership with them. Progress is on track towards meeting the Waste Strategy 2007⁽³⁾ target to recycle/compost 40% of household waste.

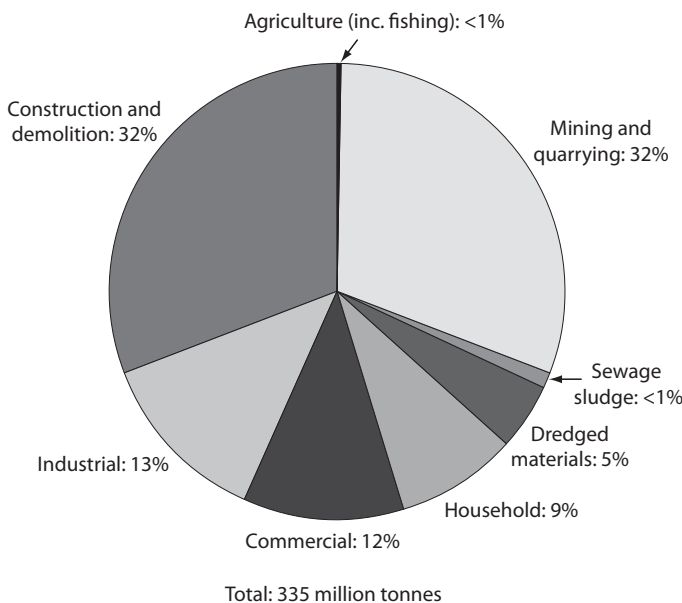


Figure 7.4 Total annual waste by sector for 2004 (source: DEFRA, ODPM, Environmental Agency, Water UK)

7.3 Policy, planning and legislation

7.3.1 Introduction

This section sets out the key policy, planning and legislative drivers for waste management practices. These stem from both European and national drivers and have an impact on the subregional and local levels. It also provides design guidance, which in essence sets targets through the three phases of a development (see section 7.2) to reduce environmental impact on resources and climate change.

7.3.2 Policy and legislation

The following documents cover essential legislation and commonly accepted standards for drainage design. However, this list should not be regarded as exhaustive.

Legislation includes the following:

- Waste Framework Directive (2008/98/EC)⁽⁵⁾
- Landfill Directive (1999/31/EEC)⁽⁶⁾
- Waste Incineration Directive (WID) 2000/76/EC⁽⁷⁾

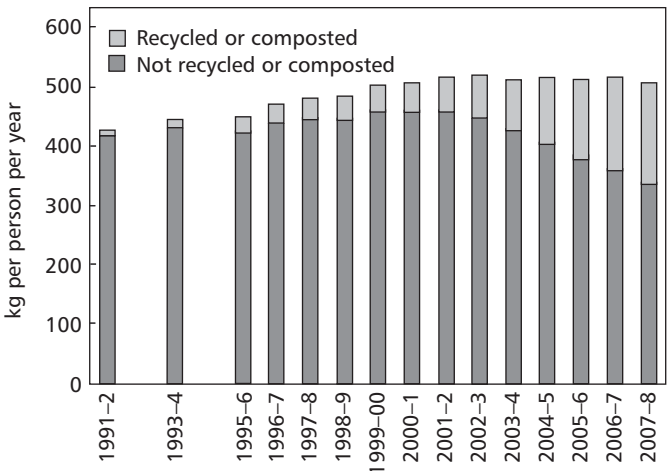


Figure 7.5 Household waste per person 1991–2 to 2007–8 (source: DEFRA, English Heritage, Scottish Environmental Protection Agency, Welsh Assembly Government)

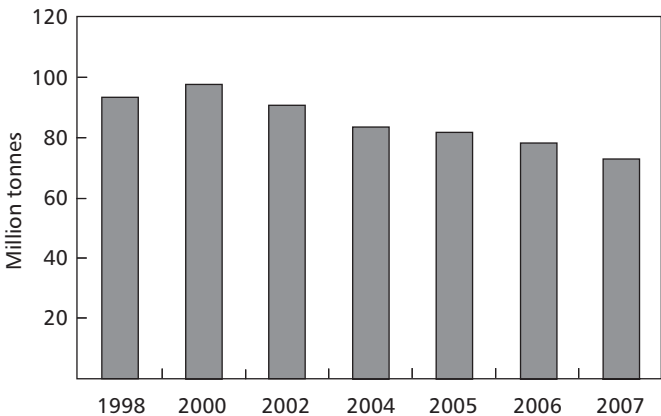


Figure 7.6 Total waste from all sectors landfilled 1998–2007 (source: DEFRA)

- Directive on Integrated Pollution Prevention and Control (IPPC) (2008/1/EC)⁽⁸⁾ (supersedes earlier IPPC Directive 96/91/EC⁽⁹⁾)
- Directive on Packaging and Packaging Waste (94/62/EC)⁽¹⁰⁾
- Directive on the disposal of PCBs and PCTs (96/59/EC)⁽¹¹⁾
- Landfill (England and Wales) Regulations 2002 (as amended)⁽¹²⁾
- The Building Regulations: Part H6: Solid waste storage
- Hazardous Waste Regulations 2005 and List of Waste Regulations 2005
- Waste Electrical and Electronic Equipment Regulations 2004
- Animal By-Products Regulations 2005
- Landfill (England and Wales) Regulations 2002
- European Regulation on ozone depleting substances
- Environmental Protection Act 1990 (Part II)
- Clean Neighbourhoods and Environment Act 2005 Section 54
- Public Health Act 1984
- Waste and Emissions Trading Act 2003
- Environment Protection Act 1990 (duty of care).

7.3.3 Planning requirements

Planning plays a pivotal role in delivering change in the way waste is managed, particularly in the development of new build facilities.

When planning for municipal waste storage in a residential area it is essential to communicate with the local authority (LA) in the region, prior to the design phase. This may require contacting more than one department or authority and it is recommended that, as a minimum, the following departments should be consulted:

- *cleansing*: for information on waste container types, access for collection, frequency of collection, special treatments (compaction, baling etc.) and recycling facilities
- *building control*: for guidance on solid waste storage and built-in equipment, e.g. waste chutes and hoppers
- *environmental health*: for information on health and safety, public health and food hygiene.

In all instances the LA provides for the collection of recyclate and residual waste from the doorstep. It will provide specific strategic information regarding collection schedules and will also in many cases be able to provide a design guide. This would provide information on the size of vehicles used for collection and the types of bins, which have been issued in accordance with the waste strategy.

At an early stage in the development of any building project, consultation needs to take place with the client with a view to producing an outline brief covering waste management so that approval can be obtained from the relevant local authorities and the necessary facilities incorporated into the architect's overall design. Topics for initial discussion with the client should include, but are not limited to, the following:

- waste generation and composition depending on the type of building
- types of storage containers required
- room allocation for storage depending on the type of building
- segregation of waste for recycling
- consideration of volume reduction, using such methods as compacting, baling and shredding.

The outcome of initial discussions with the local authorities and client needs to be reported to the architect and other relevant members of the design team to enable the necessary space and access requirements to be incorporated into the initial design concept. There is one significant piece of specific planning policy for waste management, which is Planning Policy Statement 10: *Planning for Sustainable Waste Management*⁽²⁾.

Planning and climate change — Supplement to Planning Policy Statement 1⁽¹³⁾ and Planning Policy Statement 22: *Renewable energy*⁽¹⁴⁾ are additional planning policy documents relating to the use of waste in reducing carbon emissions and the impact of climate change.

Local Development Frameworks

Each local and unitary authority is required to produce a portfolio of local development documents (LDDs). Together, the LDDs comprise of the local development framework (LDF) and determine the spatial planning strategy for the area. Local development frameworks must reflect this central role and will continue to be supported by the contextual framework of sub-regional waste local plans.

7.3.4 Design guidance

Building Regulations 2000: Solid waste storage

Building Regulations⁽¹⁵⁾ Part H deals with drainage and waste disposal. Regulation H6, concerns solid waste storage; in particular, that it is:

- designed and sited so as not to be prejudicial to health
- of sufficient area having regard to the requirements of the waste collection authority for the number and size of receptacles
- sited so as to be accessible for use by people in the building and of ready access for removal to the collection point specified by the waste collection authority.

The efficacy of a refuse storage system is dependent on its capacity and the ease of removal in relation to the

collection service provided by the waste collection authority. The waste collection authority has powers under Section 46 (Receptacles for household waste) and Section 47 (Receptacles for commercial or industrial waste) of the Environmental Protection Act 1990⁽¹⁶⁾ to specify the type and number of receptacles to be used and the location where the waste should be placed for collection.

Building Regulations Approved Document H⁽¹⁷⁾ provides detailed guidance on meeting the requirements of the Regulations.

BS 5906: Waste management in buildings

BS 5906⁽¹⁸⁾ provides recommendations for methods of storage and on-site treatment of solid waste from residential and commercial buildings and hospitals, with the exception of medical waste.

It recognises that, at an early stage in design, it is essential that agreement is reached between the designers and appropriate authorities, particularly with respect to:

- the methods of storage, segregation, on-site treatment and collection of waste, including recyclable material, to be used for the form of layout and building density adopted
- a designated location for waste including recyclable material storage, segregation and treatment areas to be provided and means of access to them for waste collection staff and vehicles
- the storage capacity to be provided with allowance for the frequency of collection specified by the collection authority, the volume and nature of waste including recyclable material expected and the size and type of containers to be used
- the responsibility for cleansing and maintenance of storage facilities
- environmental aspects, e.g. air pollution, indoor air quality, noise control, and litter abatement
- the discharge of waste into sewers (e.g. food waste disposers)
- means of escape and firefighting arrangements in waste and recyclable material storage and collection areas
- appropriate arrangements for older persons and persons with disabilities.

7.3.5 Site waste management plans

The site waste management plan (SWMP) provides an opportunity to ensure that the client, principal contractors and subcontractors are aware of the relevant site waste management requirements and best practices, and that these requirements are implemented under the Environmental Protection (Duty of Care) Regulations 1991⁽¹⁹⁾. WRAP* guidance should be consulted during the preparation of SWMPs.

* Waste Resource Action Plan (<http://www.wrap.org.uk>)

7.3.6 Benchmark guidance

Code for Sustainable Homes

The existing benchmark for environmentally responsible construction in the UK is *Code for Sustainable Homes: Setting the standard in sustainability for new homes*⁽²⁰⁾ (CfSH), published in February 2008. The CfSH is a standard for key elements in the design and construction process, which affect the sustainability of new homes. The CfSH measures the overall sustainability of a home by rating the home against a range of design categories that include energy, water and materials.

The waste performance of homes is also rated within the CfSH and it provides an important set of principles to consider when specifying the sustainability and waste objectives of a development. Although in the short-term compliance with the CfSH is voluntary, home builders are encouraged to follow CfSH principles as the government is considering making assessment under the Code standards mandatory in the future.

The Code uses a sustainability rating system, indicated by stars, to indicate the overall sustainability performance of a home. A home can achieve a sustainability rating from one to six stars depending on the extent to which it has achieved Code standards. One star is the entry level, which is above the level of the Building Regulations; six stars is the highest level, reflecting exemplar development in sustainability terms.

Building Research Environmental Assessment method (BREEAM)

In the UK, the operation of buildings accounts for approximately 50% of primary energy use, and hence CO₂ production, whilst extraction and production of building materials account for approximately a further 10% of primary energy use. In addition, natural environments are damaged and the extraction of materials and release of toxic chemicals through some production processes pose health risks.

BREEAM is a system for assessing the range of environmental impacts associated with buildings. The assessment method exists to help determine the environmental qualities of building projects. BREEAM awards 'credits' for meeting different environmental targets. These are summarised on a certificate which the client can display in the building or use in publicity material.

For some building types a summary of performance is expressed as a single rating of 'fair', 'good', 'very good', or 'excellent', based on the distribution of credits. As well as raising awareness of the impact buildings have on the environment, the scheme also encourages environmental improvement in the building being assessed.

BREEAM is used by various organisations primarily to demonstrate their commitment to reducing the impact that their buildings and processes have on the environment during design, construction and operation. Users of BREEAM include:

- building developers

- building owners
- architects
- building services engineers
- construction contractors
- Private Finance Initiative (PFI) contractors
- public sectors developers.

7.4 Waste generation and storage

7.4.1 Potential material streams

Waste is classified as being either hazardous or non-hazardous. However, if a material or item is classed as hazardous it does not mean that it, or its components, cannot be recycled; an example would be white goods.

The practicality of implementing recycling schemes is dependant upon local and regional access to processing and treatment plants. For any type of building there are characteristic waste streams. These include, but are not limited to those shown in Table 7.1.

Table 7.1 Waste items and materials that can be recycled

Material/item	Potential for recycling/reuse	Hazardous waste
Paper (includes newspapers and magazines)	●	
Cardboard	●	
Plastic	●	
Cans/tins	●	
Glass	●	
Wood	●	
White goods	●	●
Food and green waste	●	
Mobiles	●	●
Jet ink cartridges	● ^[1]	
Oils (food and motor)	●	● ^[2]
Furniture	●	
Plasterboard	●	
Segregated construction and demolition waste	●	● ^[3]
Excavation spoils and aggregates	●	● ^[3]
Chemicals	●	●
WEEE (waste electronic and electrical equipment)	●	●
Batteries	●	●
Florescence tubes		●
Tyres		●
Asbestos		●
Clothes and textiles	●	

Notes: [1] refilled cartridges, [2] motor oil; [3] potentially hazardous

When dealing with any type of waste, reference should be made to the Lists of Wastes Regulations 2005^(21–23) which brings the European Waste Catalogue⁽²⁴⁾ into law in England and Wales. The list has over 800 codes for all hazardous and non-hazardous wastes. This relates directly to the treatment or disposal processes, i.e. whether the material can be recycled or not. Under duty of care, these codes are used for the transportation of wastes and also form part of the regulatory site waste management licence conditions for any site accepting or releasing waste.

7.4.2 Waste generation

Over half of the waste in the UK is generated through three sectors; these are:

- municipal solid waste (MSW): waste and recycling from domestic properties;
- commercial and industrial (C&I) waste: all public sector, commercial and industrial wastes
- construction, demolition and excavation (C,D&E) waste: all waste generated through the construction industry; this covers new-build, retrofit and site clean-up.

Under Section 54 of the Clean Neighbourhoods and Environment Act 2005⁽²⁵⁾, the introduction of the Site Waste Management Plan Regulations 2008 ensures that developments over the threshold of £300 000 actively reduce, monitor and ensure legal compliance in managing the waste streams whilst on site. The site waste management plan (SWMP) provides an opportunity to ensure that the client, principal contractors and sub-contractors are aware of the relevant site waste management requirements and best practices, and that these requirements are implemented under the Duty of Care Regulations⁽¹⁹⁾. The WRAP guidance should be consulted during the preparation of SWMPs.

7.4.3 Quantities of waste

Estimates for quantities of solid waste generated from various types of buildings are given in BS 5906⁽¹⁸⁾. Table 7.2 indicates the average volume of waste generated per week.

The storage requirements for shops, hotels or offices can be calculated either by the amount of sales area involved or by the number of residents or employees. The sales area figure is multiplied by either the number of trading days or the output per head for hotels and offices (multiplied by seven for hotels and usually five for offices, being the normal working weeks).

The composition of solid waste will vary considerably depending on its source and the figures provided in Table 7.2 should only be used as a general indication to be supplemented by information obtained from similar facilities where possible.

7.4.4 Composition of waste

The compositional breakdown of waste is linked to the sector from where it was generated. Figures 7.7 and 7.8

Table 7.2 Waste volumes generated per week from various outlets (source: BS 5906⁽¹⁸⁾)

Type of user	Waste volume per week / m ³	Basis of waste volume
Residential	0.1	per house or flat (2 persons)
Office	0.05	per person or per 10 m ² floor area
Hotel		
— 4/5 star	0.35	per bed
— 2/3 star	0.25	per bed
— 1 star/B&B	0.12	per bed
Restaurant	0.075	per cover (dining)
Fast food outlet	0.075	per cover (dining)
	0.005	per sale
Major shopping centre	0.01	per m ² sales area
Large supermarket	0.025	per m ² sales area
Small super market	0.01	per m ² sales area
Hospital (excluding clinical waste)	0.15	per bed
Industrial unit	0.05	per m ² of floor area

show the compositional analysis of municipal solid waste and commercial and industrial waste.

It is important first to assess the requirement for waste storage in relation to the function of the building. This will then inform the specific type of waste collection and storage design required within the development.

All major developments or additions to such developments, which are either privately owned or open to the public, should provide recycling and waste disposal storage areas within their design.

To meet the national targets for recycling of MSW, the local authorities will continue to promote public awareness and opportunities for recycling. The provision of appropriate storage and separation facilities in new housing developments will help to support these efforts.

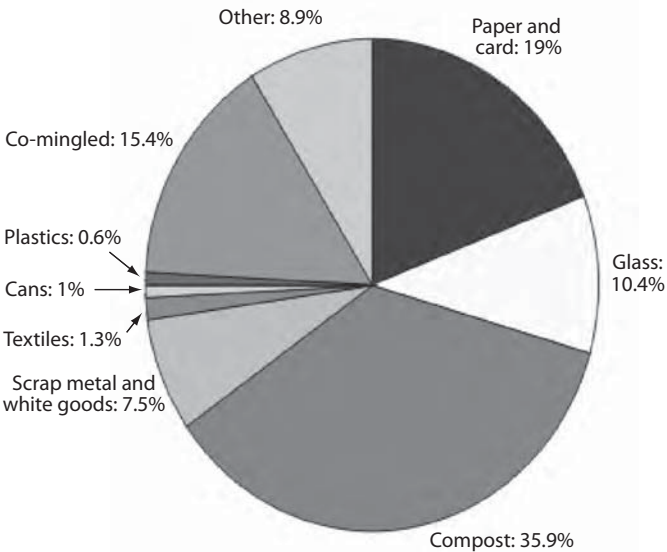


Figure 7.7 Materials collected from household sources in England for recycling in 2006–7 (source: DEFRA)

7.4.5 Storage options for various building uses

7.4.5.1 Storage of waste facilities

There are a number of ways in which waste can be stored both for recycling and residual collection. It is important to understand the links between waste generation, space requirements and the collection schedule in any building design.

Waste generation and composition is linked intrinsically to the building use. The collection schedule will be informed by the waste generation and the available space allocated within the building design.

Recycling storage

Space must be provided for the collection, separation, and temporary storage of recyclable materials within all new developments or re-developments with six or fewer dwelling units. Communal space must be provided for developments over six units. Space designated for recycling should be located so it is at least as convenient as the location where refuse is collected. Space designated for recycling must be identified on plans submitted for planning permission.

Minimum space requirements for recycling

The minimum amount of recycling space required is determined by multiplying the gross floor area (m²) by 0.0025 (if result is less than 1 m² then the minimum is one square metre). The floor area must include all areas serving or accessory to the dwelling, such as corridors, common areas etc. Gardens, courtyards shared gardens and similar areas are excluded. For developments over six units the minimum amount of recycling space required is determined by multiplying the gross floor areas (m²) assigned to each use within the building.

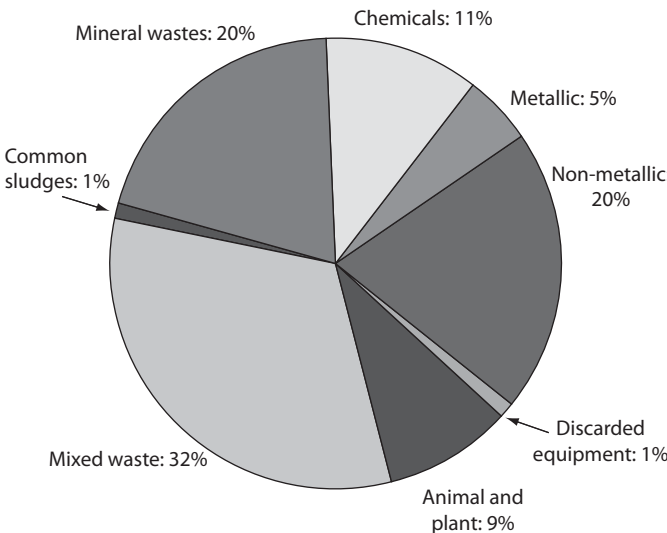


Figure 7.8 Composition of commercial and industrial waste for 2002–3 (source: Environment Agency Commercial and Industrial Waste Survey 2002–3)

Community recycling areas should be:

- secured from vandalism
- accessible without the need to enter the building or climb any steps*
- not more than ten metres from collection vehicle access point*.

Recycling banks

Recycling banks should, as a minimum, be provided for paper, cardboard, (brown and green) glass, tins and cans, and plastic.

The banks must be lockable and have appropriate apertures to receive the materials to be recycled. Typical dimensions are given in Table 7.3.

Table 7.3 Recycling banks — typical dimensions

Volume / litre	Dimension / m		
	Width	Depth	Height
240	574	722	1061
360	625	850	1095
1280	1280	1000	1470

7.4.5.2 Municipal waste

The collection schedule is pre-determined through the local authority waste management contract. Consultation with the local authority at an early stage of the design should indicate the areas where separation is either required or may be desirable for a residential housing development.

Most local authorities provide waste design guidelines that provide details of the size and number of storage bins for a particular residential area. This provides information upon level of segregation of the recycle, e.g. segregated into separate bags or bins, or placed in one container. It also importantly provides information regarding the vehicle types likely to be used for collection, so that suitable access and turning areas may be planned during the design phase.

Bulky items and hazardous wastes can be taken to household waste recycling centres (HWRCs), provided by local authorities. A designated area must be provided for the provision of bulky waste to be discarded/stored prior to collection. All high-rise (residential) developments of approximately 25 units and over are required to be provided with separate covered accommodation for the storage of discarded bulky items, such as furniture, white goods etc.

Storage point location

(a) Single houses

- Residents should not have to move more than 30 m to any designated storage area within the boundary of the property.

* for buildings without on-site caretakers

- Any designated storage area within the boundaries of the property should not be more than 30 m distance from the collection point.
- The storage point should be located in a well ventilated area.
- Waste should not have to be moved through a building to reach the collection point.
- The collection point should be easily accessible to the occupier.
- The collection point should be housed within the designated area or structure as appropriate.

(b) Flats and apartments

- Temporary storage of waste does not tend to occur in flats due to the lack of space. Waste is normally transferred to the point of collection, which is the communal storage facility.
- Provision of a number of transit options should be available.
- Collection crews should not have to move bins over a distance greater than 10 m.
- An assessment should be made in terms of user convenience, health and safety, and risk of environmental harm.

Storage areas must be provided at ground level at convenient points located throughout the development on the basis of one store for every 75 units of accommodation. Each store should be approx 7.5 m² in floor area to normal storey height, and fitted with double doors providing a clear opening of width 1830 mm and height 1830 mm.

7.4.5.3 Commercial waste

The collection schedule is arranged directly through a private waste management contractor and scheduled collections are negotiated during contract agreement.

There should be a separate hazardous waste storage area provided for in all commercial buildings or, at the least, an area which can be adopted as such. Recommended floor space requirements for waste storage for commercial applications are given in Table 7.4.

As a minimum, the developer must provide the external storage space required to accommodate the required external waste containers. Minimum storage requirements

Table 7.4 Floor space required for waste storage for commercial applications (source: Westminster City Council)

Type of development	Facility type	Facility size*	Contents of facility
Supermarket/retail	Bulk containers	20 m × 10 m	All materials
High density residential	1100 litre bulk container	10 m × 5 m	All materials
Sports/community centre	1100 litre and bulk containers	10 m × 5 m	All materials
Public house car park	1100 litre and bulk containers	10 m × 5 m	All materials

* Plus space for access by collection vehicle

Table 7.5 Recommended storage capacity commercial (source: Westminster City Council)

Type of commercial development	Waste storage capacity	Fraction of total capacity for storage of recyclables
Offices	2600 litres per 1000 m ² of gross floor area	One third (minimum)
Retail	5000 litres per 1000 m ² of gross floor area	One third (minimum)
Restaurants/fast food outlets	1500 litres per 20 dining spaces	Variable
Hotels	5000 litres per 20 dining spaces	Variable

are suggested in the RECAP* *Waste Management Design Guide*⁽²⁶⁾, see Table 7.5.

Storage point location

The following provides a number of points that should be considered prior to finalising the location of a storage point. It is recommended that this detail is checked with the local authority for clarity:

- All waste receptacles must be stored within the development and off the highway and public land.
- Development proposals must show how the waste storage area is accessed and where the waste receptacles will be placed to facilitate emptying.
- If bins need to be placed on the highway to facilitate emptying they should be placed in an area that does not impede access or cause a hazard to pedestrians and other highway users.
- Development proposals must show how it is intended to accommodate the waste arising from any commercial premises (and must be separate from waste generated from any residential properties occupying the same site).
- A management plan must show how the proposals ensure that waste is stored securely to prevent: (1) other businesses or persons depositing their waste, (2) people (such as rough sleepers) gaining physical access into the bins/skips and (3) how waste will be contained to prevent litter nuisance.
- Consideration should be given to providing containers that have lockable lids.
- In accordance with Building Regulations Approved Document H⁽¹⁷⁾, waste storage areas should have an impervious floor, and provision for washing down and draining the floor into a system suitable for receiving effluent.
- The development may be subject to planning conditions that limit the times for servicing if it is close to or includes residential accommodation.

7.4.5.4 Food waste

In order to further reduce the amount of biological municipal waste, i.e. biodegradable material which breaks

down to release greenhouse gases, being sent to landfill many local authorities are starting to provide a food waste collection service.

The Animal By-Products Regulations 2003⁽²⁷⁾ place controls on the collection, handling, transport, storage and disposal of animal by-products. 'Animal by-products' includes catering waste, former foodstuff and other animal waste. The aim of the Regulations is to control risks, including disease, to both animals and the public.

Animal by-product waste that is required to be kept separate from general waste, under the Regulations, must be allocated a designated storage area. The local authority requires to be consulted in order to approve areas that are designated for storage of catering wastes, should this prove appropriate.

7.4.5.5 Storage containers

There is a large variety of container types and models available, ranging from dust and litter bins to waste handling systems. These include:

- waste paper bins (for internal or external use)
- plastic or paper sacks (attached to metal frames or as bin liners)
- dustbins
- containers (circular and rectangular)
- skips (open or closed)
- bulk containers (open or closed).

The selection of containers at various stages of the transport of solid waste materials will depend on several factors:

- waste composition
- waste generation
- handling method
- transport facilities
- volume reduction equipment
- capital, life cycle and maintenance costs.

In addition to the above, health, safety and environmental factors should also be considered.

Table 7.6 shows the recommended capacities of waste containers for residential and commercial applications.

Table 7.6 Recommended waste container capacity for residential and commercial applications

Type of development	Container type	Container size
Residential	Bags	10 litres
	Boxes	30–55 litres
	Composting units	55 litres
Commercial (all sectors)	'Wheelie' bin (1100 litres*)	Width: 1265 mm Depth: 986 mm Height: 1404 mm

* Recycling in Cambridgeshire and Peterborough

* Capacities range from 750–1100 litres

7.4.5.6 Estimation of waste volume from residential apartments

In estimating the waste generation during operation of the proposed development, consideration has been given to guidance and benchmarks set out in BS 5906⁽¹⁸⁾ and Institute of Civil Engineers' *Planning for Resource Sustainable Communities: Waste Infrastructure and Management*⁽²⁸⁾.

In order to calculate the amount of containers required for a given number of apartments, the following formula⁽²⁹⁾ can be used as a rule of thumb:

$$V = 150 N p \quad (7.1)$$

where V is the volume of waste generated from the building (litre), N is the number of apartments in the building and p is the percentage of the total of a particular type of waste (%) (see Table 7.7).

Dividing the total volume generated by the capacity of a single bin gives the number of bins required.

This method is illustrated in Table 7.7 by means of an example.

The volumes of recyclable waste types will inevitably increase in future with the inclusion of clear, brown and green glass, as well as plastic containers, thereby affecting the percentages.

7.4.6 Waste collection and logistics

For apartment blocks, it is unlikely that there will be space for temporary storage immediately outside each apartment. Waste from individual apartments will need to be transported to a communal storage facility to await collection. Some options for such transit are given in Table 7.8^(26,30).

There are two potential waste management collection strategies for adoption in any building use. These are as follows:

- (1) The waste is segregated through the provision of separate storage bins. It relies upon the people who work in the building/sector to undertake this practice manually. The contractual arrangement for this type of process would require a multi-material collection strategy and storage bins would be required for individual recycle materials.

Table 7.7 Example of calculation of volume of waste from an apartment block

Waste type	Percentage of total waste (%)	Number of apartments (N)	Volume of waste generated (V)	Number of 1100 litre eurobins required*
Waste	65	95	$95 \times 150 \times 0.65 = 9262.5$	$9262.5/1100 = 8.4$
Paper	20	95	$95 \times 150 \times 0.20 = 2850$	$2850/1100 = 2.6$
Glass	10	95	$95 \times 150 \times 0.10 = 1425$	$1425/1100 = 1.3$
Cans	5	95	$95 \times 150 \times 0.05 = 712.5$	$712.5/1100 = 0.65$
Total	100			13

* Divide by 240 for 240 litre 'wheelie' bins

Table 7.8 Potential options for the transit of waste to communal storage facilities (source: *RECAP Waste Management Design Guide*⁽²⁶⁾)

Option	Description
Transit by resident	In low-rise blocks (i.e. up to 4 floors) residents typically transfer their waste to communal compounds, within which are located a number of bins to receive the waste. Residents should not have to transfer waste more than 30 m (including vertical distance). Best practice is to install bins allowing segregation of recyclable material from residual waste.
Transfer chutes	In high-rise blocks (i.e. more than 4 floors), waste chutes may be provided. The chutes convey the waste by gravity to a communal storage point. This may be a compactor, skip or large bin. Specifications for refuse chutes are given in BS 1703 ⁽³⁰⁾ .
Transit by building management	Residents deposit their waste, in bags, outside their door from where it is collected by the building management team. Service lifts should be provided.

- (2) The waste is not segregated on site but is collected by a waste management contractor who then transports it to a segregation site. The waste is then processed to provide both recycles and residual waste.

Strategy 1 is preferred and widely accepted as the norm. It also increases the social impact of embedding recycling into daily life for all.

Collection of containers

There are two options for the collection of containers:

- containers are collected directly from the building's container area/store
- containers are moved to a convenient collection point.

In both cases, the following points should be noted:

- It is the responsibility of the management company to allow the collection crews access to the container stores/collection point on collection day and to ensure that access is not restricted, e.g. by parked cars.
- The collection vehicle should be able to approach to within a maximum distance of 8 m of the bin store/agreed collection point.

- The gradient of a slope that containers need to be moved over should not exceed 1:12.
- Surfaces that containers need to be moved over should be of a smooth, continuous finish and free from steps or other obstacles. Any steps should incorporate a drop-kerb.
- Following collection, containers should be returned to storage areas as promptly as possible. There should be clear responsibility for who carries out this task (i.e. management company, caretaker, waste contractor etc.).
- Plans should be included that show the proposed route of the collection vehicle around the site, including access to the proposed collection points.

The access roads that the waste collection vehicles will be required to use must be constructed to withstand a gross vehicle weight of 22.5 tonnes and axle loading of 11.5 tonnes. A fully laden collection vehicles weighs approximately 32 tonnes. Manhole covers, gratings etc., situated in the road must also be capable of withstanding the loads indicated.

The access roads must be a minimum of 4 metres in width and the layout should permit the vehicle to travel in a forward direction. If reversing is unavoidable (e.g. if the site cannot accommodate a turning circle) then BS 5906⁽¹⁸⁾ recommends that the reversing distance should not exceed 12 m. Vehicles should not reverse into the development from a major road, and should always exit the development onto a major road in forward gear. If the access roads are also used by pedestrians, a raised footpath must also be provided. Generous allowances (at least 1 metre) should be included when considering the width of access roads, gateways etc. Additional allowances will be required if vehicles are required to approach from an angle.

Consideration should be given to the provision of areas for turning the waste collection vehicle within a development by means of ‘hammerheads’ etc. Appropriate measures must be taken to control unauthorised parking of vehicles that could inhibit access by the waste collection vehicle and operatives. Vehicle access and turning circles, and the length, width, height and weight of the vehicles need to be considered at the design stage, see Figure 7.9 and Table 7.9.

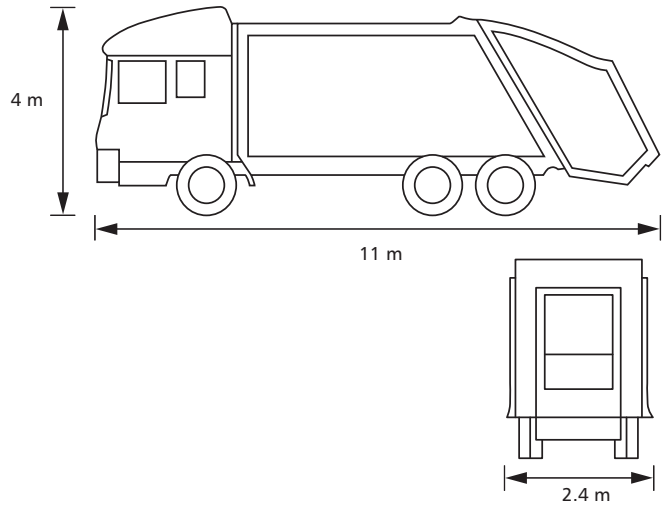


Figure 7.9 Dimensions of a typical waste collection vehicle⁽²⁶⁾

Table 7.9 Specification for a typical waste collection vehicles⁽²⁶⁾

Dimension	Value
Overall length	11 m
Overall length (whilst loading)	13.1 m
Overall width (whilst loading)	2.5 m
Overall height	4 m
Operating height (including top loader arms)	6.3 m
Turning circle between kerbs	17.88 m
Turning circle between walls	21.9 m
Gross vehicle weight	26 tonnes

BS 5906⁽¹⁸⁾ requires a minimum street width of 5 m for waste vehicles. It is also a requirement that collection crews should not have to carry individual waste containers or move wheeled containers more than 25 m. The passage to the collection vehicle should be free of steps where possible but should not exceed any more than three. In all cases the gradient should not exceed 1:12.

7.4.7 Sector-specific waste considerations

The waste management requirements for different sites will vary according to the building use. It should be noted that with any building design, as a minimum, the provision of storage for both at least 50% recyclates and 50% residual waste should be provided.

A summary of some specific considerations for a number of sectors are given in Table 7.10. Note that this list is not exhaustive.

7.4.8 Hazardous waste

7.4.8.1 Clinical waste

In a development comprising of a medical centre, dental surgery, veterinary surgery, old people’s home, nursing home, home or day centre for the disabled or handicapped, separate storage for clinical waste will need to be considered. Clinical waste includes anything containing bodily fluids or tissue (such as bandages, plasters, incontinence pads etc.), discarded drugs, needles, body parts, dead pets etc. Clinical waste must be stored separately from all other waste. Normally clinical waste is sealed inside yellow, coded bags. ‘Sharps’ (including needles or surgical implements) are stored in special boxes. Collection of clinical waste is always made separately from normal waste collections. For detailed guidance on clinical waste, see Health Technical Memorandum HTM 07-01: *Safe management of healthcare waste*⁽³¹⁾.

Table 7.11 provides estimates for quantities and composition of differing types of clinical waste. However, these should be cross referenced with the appropriate Health Technical Memorandum for the various National Health Service facilities.

Table 7.10 Summary of waste considerations for specific sectors

Sector	Waste considerations
Retail	- Waste contracts for all waste streams need to be in place prior to the occupancy of retail units. - Contracts will either be directly managed with the individual stores or if located in a managed shopping centre may be administered through the building occupancy rates by the landlord. - The above will also determine the collection schedules and the required storage areas. - Specialist waste streams such as waste cooking oil must be accommodated. - Some retailers return their waste to source using their own supply chain, known as 'back-hauling'. - Location of skips/bins should be considered for major shop fit-outs and segregation of material through this process for recycling should be adhered to. - Provision for food/catering waste should be provided. - A separate storage area for any hazardous waste should be provided or at least an area which can be adopted as such.
Offices/financial institutions	- Offices typically produce large quantities of waste paper; this should either be stored on site ready for collection or collected from each office floor by a specialist contractor. - Compaction skips (cardboard and residual waste) are generally used for the storage of waste from larger office buildings where the space requirements are limited. - A separate storage area for any hazardous waste should be provided or at least an area which can be adopted as such. - The above should not limit the level of waste segregation provided.
Health care	- Consideration should be given to whether on or off-site incineration is the most appropriate solution for anatomical waste. - Clinical waste containers should be kept in a secure compound. - For laboratories producing hazardous (radioactive or chemical waste etc.) a risk assessment should be carried out to determine whether on-site storage and treatment of such waste is preferable to transport of untreated waste by road, rail etc.
Education	- Waste contracts for all waste streams need to be in place prior to occupancy. - Specialist waste streams such as waste cooking oil must be accommodated for. - Storage of recycling and residual waste bins need to be located appropriately to allow for ease of collection access. - A separate storage area for any hazardous waste should be provided or at least an area which can be adopted as such.
Entertainment	- Consideration should be given to how best to incorporate the operational waste handling strategy for large venues into the concept and subsequent design stages. - This could potentially include automated waste systems, local waste holding areas and the use of public transport vehicles to remove waste. - Provision for food/catering waste should be provided. - A high level of glass and cans would be expected from this sector. - A separate storage area for any hazardous waste should be provided or at least an area which can be adopted as such.
Hotels	- Waste facilities should be designed to accommodate the retail/catering functions associated with larger venues. - Specialist waste streams such as waste cooking oil must be accommodated for. - A separate storage area for any hazardous waste should be provided or at least an area which can be adopted as such. - Provision for food/catering waste should be provided. - The volume of waste generated by hotels can vary dependant upon the operator's star rating.

Table 7.11 Typical quantities of clinical waste from healthcare facilities

Department	Quantity for stated facility type									
	kg per available bed		kg per occupied bed		kg per bed day		kg per FCE*		kg per m ²	
	M	UC	M	UC	M	UC	M	UC	M	UC
Acute	593	502	710	606	2	1.7	6.4	5.3	5.23	4.33
Teaching	919	802	1071	894	3	2.63	11.1	8.8	5.57	4.77
Specialist	885	710	1119	950	3.1	2.53	10.2	6.9	5.33	4
Mental health	136	85	150	94	0.83	0.37	32.1	13.4	1.5	1
Multi-service	465	395	558	470	1.63	1.4	6.6	5.3	4.03	3.27
Community	270	184	306	217	1.17	0.87	29.1	19.1	2.07	1.37
Primary Care Trust	440	368	545	424	1.2	0.7	27	14.3	2.2	1.6
Ambulance	—	—	—	—	—	—	—	—	0.37	0.13

* Finished consultant episode

7.4.8.2 Hazardous solid and liquid wastes

This group of waste materials includes all items that require separation from the household or commercial waste materials normally dealt with at local authority landfill sites. Also excluded from this group are gaseous wastes and those waste materials that have the potential for recycling. There are many types of hazardous wastes but they can generally be grouped under one of the following headings:

- clinical waste (see section 7.4.8.1)
- toxic waste
- radioactive waste.

At the earliest stage in the design of facilities that are likely to have waste products outside those considered as household or commercial waste, it is important that information on the scope and likely quantities are obtained from the client. Hazardous waste is generated by most businesses and includes items such as:

- fluorescent tubes
- computer monitors
- solvents
- asbestos
- chemical wastes
- healthcare wastes
- electrical equipment containing hazardous components such as cathode ray tubes or lead solder
- lead-acid batteries
- oily sludge
- pesticides

Once the types of hazardous wastes are identified, contact should be made with the local authority for guidance on procedures required to meet the relevant regulations and to comply with the Hazardous Waste Regulations 2005⁽³²⁻³⁴⁾. In many cases, specialist advice can be obtained from the Health and Safety Executive and trade organisations.

Where hazardous or liquid wastes are expected to be produced on a site, it is essential that the local authority be contacted at the earliest opportunity to discuss acceptable methods of disposal. Such premises must be registered with the Environment Agency before any hazardous waste is permitted to leave the premises.

Liquid wastes vary but may be grouped as follows:

- oils
- solvents
- chemicals
- sewage
- organic materials
- industrial slurries.

In most circumstances landfill sites are licensed to receive these types of liquid waste but, even in these cases, special

handling procedures will probably be required. Many infectious, flammable, or toxic wastes need special treatment such as incineration. This should only be carried out in incinerators specifically designed for that material as incorrect combustion can lead to unacceptable emissions into the atmosphere.

Where hazardous materials are identified that cannot be accepted by the local authority, specialist contractors should be contacted who can advise on the method of storage and collection.

In general, infected hospital waste and similar materials from research institutions should be incinerated on the site where they are produced. This will reduce the possibility of pathogens etc. escaping. For highly infectious materials, the incinerator is usually built as part of the hospital or research building, the whole of which is under negative pressure to prevent air escaping except via special filters. In such cases, air locks and interlocking devices may be necessary to enable the incinerator to operate without risk of pathogen escape.

Hazardous solid wastes, such as asbestos and chemical substances, need to be clearly identified as special methods of handling, storage, and disposal will be required. Early contact with the local authority and specialist disposal contractors should be made so that the necessary procedures can be incorporated into the design of the building.

Where radioactive wastes are expected, early discussions with the Health and Safety Executive (HSE) and Her Majesty's Inspectorate of Pollution (HMIP) are required.

Even where the local landfill site will accept liquid wastes it may be possible for them to be profitably recycled and therefore early discussion with an appropriate specialist disposal contractor should be carried out. On-site treatment and recovery of certain wastes may also be possible, but this is beyond the scope of this Guide.

Where significant quantities of wastes such as solvents are disposed of during industrial processes, it may be worth considering a fixed pipeline system discharging to a storage vessel for tanker collection, thus considerably reducing handling and the risk of fire.

A large proportion of the hazardous wastes produced in the UK are now dealt with by private contractors. Advice can be obtained from the Institute of Waste Management and the National Association of Waste Disposal Contractors.

7.5 Design guidance

7.5.1 Design principles

Waste facilities should provide adequate storage and sufficient space. Containers should be accommodated to enable efficient management of waste. Waste storage areas should be located in a position that provides easy and safe access for both waste producers and collectors.

Special consideration needs to be provided to access and ease of use for older persons, persons of short stature and people with disabilities. Facilities should be designed so as to minimise the potential for nuisance to occupants and neighbouring premises. The waste storage area should be maintained to the highest hygiene standards, and be clearly designated as a waste storage area through the use of signage and/or floor markings.

In order to provide adequate means of storage, collection facilities fundamental to the removal of all solid waste and recycling targets, it is recommended that any proposed plans are discussed and consulted between all relevant local authorities prior to the design for storage and collection facilities. These include planning, building control, highways, waste collection and environmental health, as well as liaising with the fire brigade and of course the client, architect and independent contractors.

The key stages in the design of waste facilities are:

- assessment of quantities and composition of the waste
- calculation of waste container requirements
- consideration of appropriate legislation
- consultation with the relevant authorities
- undertake detailed design.

Important issues to consider in the design are as follows:

- access (both pedestrian and vehicular)
- storage, collection and separation
- transport
- equipment (i.e. containers, waste chutes, pneumatic systems etc.)

- volume reduction (e.g. compactors, shredders, balers)
- hazardous and liquid wastes
- health, safety and environmental considerations
- capital and running costs
- adequate drainage cleaning facilities.

7.5.2 Design considerations for waste storage areas

Table 7.12 identifies some design considerations based on the requirements of BS 476-21⁽³⁵⁾ and the *RECAP Waste Management Design Guide*⁽²⁶⁾.

7.6 Waste management equipment

7.6.1 Introduction

There are many different types of waste equipment used for the collection and storage of waste and recyclates. The options range from the technically advanced, such as automated waste systems, to the simple 'wheelie' bin. The relevancy of each option should be assessed in relation to the use of the building development and type of waste produced. For example, an automated waste system would not be appropriate for a building design to be occupied by a company that produces a high volume of liquid waste.

Table 7.12 Design for waste storage areas (sources: *RECAP Waste Management Design Guide*⁽²⁶⁾ and BS 5906⁽¹⁸⁾)

Feature	Design considerations
Walls and roofs	Should be made of a non-combustible, robust, secure and impervious material with a fire resistance of 1 hour (as tested in accordance with BS 476-21 ⁽³⁵⁾).
Floors	Should be made from a hard impervious material with a smooth finish and a minimum thickness of 100 mm. There should not be any steps or projections present at the entrance.
Doors	Width should be 1.8–2 m (minimum) and be made of steel or of some other material with a fire resistance of 30 minutes (as tested in accordance with BS 476-22 ⁽³⁵⁾). Doors should be self-closing except where they communicate directly with the outside air. They should be hung so that hinges are not damaged where the doors are allowed to swing wide. They should be capable of being opened both from the inside and outside to prevent the risk of individual users becoming trapped.
Door frames	Should be metal, hardwood or metal clad softwood. Door frames should also be situated in the external wall and rebated into the reveals of the opening.
Junctions of walls with floor	Should be coved with the coving formed to prevent damage to the walls from the containers in accordance with BS 1703 ⁽³⁰⁾ .
Drainage	Should be via a trapped gully connecting to the foul sewer. Floors should have an appropriate fall towards the drainage point.
Ventilation	Areas for ventilation should be situated as near to the top and bottom of the container as possible, with the total ventilation area not less than 0.2 m ² .
Lighting	Should be provided by bulkhead fittings within the storage compound with housings rated to IP65 in BS EN 60529 ⁽⁴³⁾ . Luminaires should be low energy light fittings and switching should be via proximity detector or time switch.
Cleansing	A hose union tap with water supply should be provided within the compound.
Access paths	Should be a minimum of 2 m wide with a hard finished surface.

7.6.2 Bins

Bins are required for storage both internally and externally.

7.6.2.1 Internal storage

Two-way recycling lockers

To encourage recycling at home, the Royal Borough of Kensington has introduced a built-in recycling system for multi-occupancy blocks of flats. This involves two-way waste and recycling lockers whereby one door opens into the flat and the other, locked, door opens into the corridor. The collection team removes the filled bags from the lockers, using the locker keys, and returns any containers or re-useable bags to the locker after emptying.

Indoor kitchen caddy for organic waste

Kitchen waste can be placed into a 5.5 litre compost bin, which is supplied with an activated carbon filter.

7.6.2.2 External storage

Eurobins and wheeled bins

Eurobins and wheeled bins are manufactured in a range of sizes and colours, see Figure 7.10.

As the waste industry changes, operators are considering the way they charge for their services. Some waste management companies are moving to a pay-by-weight

collection regime using collection vehicles that incorporate on-board weighing equipment. The bins contain an electronic chip that generates a unique identifier. The benefits of this system are that tonnage calculations can be provided for each customer on a commercial collection scheme. It also avoids the customer from having to pay the full price for emptying a half empty bin.

7.6.3 Skips

Skips are widely available in various sizes. Some examples are given in Table 7.13.

Table 7.13 Dimensions of typical skips (source: Grundon Waste Management Ltd. (<http://www.grundon.com>))

Volume / m ³	Dimensions / m			
	Length	Width	Height	Loading height
4.5	3531	1880	1092	940
9.0	3962	1880	1727	1270
15.0	4572	1880	2134	1321

7.6.4 Compactors

Compactors are generally chosen for those building uses which have very limited amount of room in which to store waste. They also reduce the collection frequency. Compaction can reduce odours if it is an enclosed system. If a compactor is used for residual waste the waste contractor should be taking the waste through a further sorting process to remove the recycle material.

Types of compactor include the following.

Wheeled bin compactors

These are suitable for 1100 litre wheeled containers and achieve effective volume reduction (typically 3:1 to 4:1) whilst maintaining acceptable container weights for handling and disposal. They may be installed either inside or outside and can be operated by one person. They can be used with food waste provided that they comply with food handling regulations.

Typical dimensions:

- Width: 1850 mm (2000 mm for access)
- Depth: 1240 mm (2000 mm for access)
- Height: 2500 mm
- Maximum container load: 440 kg

Portable compactors

Portable compactors can reduce waste volumes by up to 5:1, depending on waste material type. However, for residual waste, a ratio of 3:1 to 4:1 is more likely to be achieved.

Typical dimensions:

- Width: 1865 mm

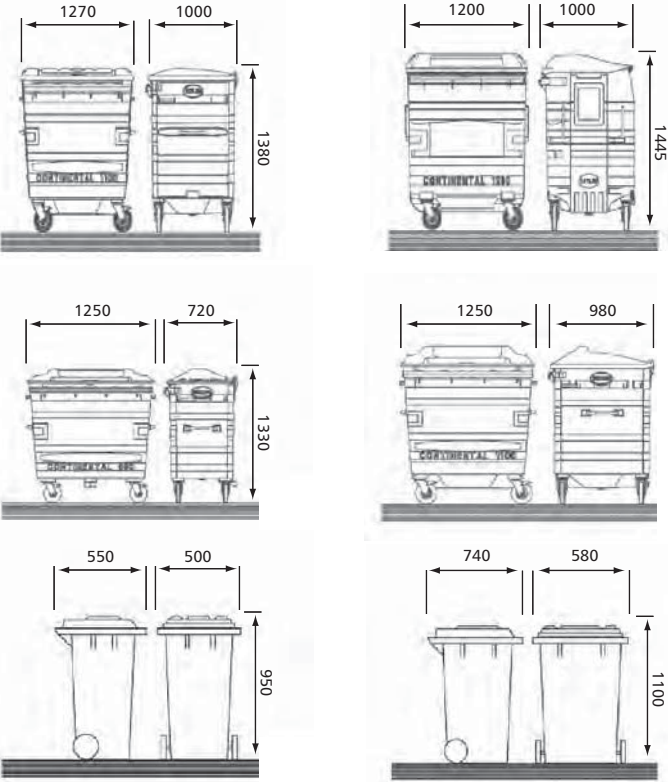


Figure 7.10 (a) 660 and 770 litre eurobins, (b) 660 and 1100 litre recycling eurobins for glass, (c) 240 and 450 litre eurobins for household waste

- Length: 4000 mm
- Height: 2300 mm
- Container volume: 6.3 m³
- Weight: 2.9 tonnes.

A 415 V, 3-phase electrical supply may be required for compactors of this type.

Static compactor with rear end loader

Compactors of this type are used in conjunction with portable containers ranging from 10–30 m³.

7.6.5 Balers

Balers can produce bales from 50–500 kg and are designed to bale materials such as cardboard, plastics, textiles. They can achieve a weight reduction of up to 90%, depending upon the material.

Multiple chamber balers allow for the baling of different types of material at the same time.

Dimensions and other information for typical vertical and horizontal balers are given in Table 7.14.

Table 7.14 Dimensions of typical balers

Item	Baler type	
	Vertical	Horizontal
Dimensions:		
— width	830 mm	1500 mm
— length	850 mm	6725 mm
— length (with door open)	1600 mm	—
— height	2250 mm	1316 mm
Baling pressure	3 tons	50 tons
Bale dimensions	500 × 700 × 500 mm	1000 × 900 × 1400 mm
Bale weight:	25–60 kg	500 kg
Cycle time:	40 s	45 s
Electrical supply	13 A, 240 V	3-phase, 63 A, 15 kW

7.6.6 Water and drainage design in refuse bin stores

If left untreated, refuse bin rooms and refuse chutes can become a hazard to public health. As a result, unpleasant foul odours can quickly collect in and around the vicinity of the building. To facilitate periodic cleansing within the refuse bin store a water supply and drainage point is necessary.

7.6.6.1 Drainage design process

Refuse storage areas should have provision for washing down and draining the floor into the foul water drainage system. The selection of the floor gully within the refuse bin store area is the responsibility of the public health engineer. Proximity of the gully to the source of water is vital, as well as the gradient of the ground floor slab, so that any water discharging on any floor will naturally flow towards the gully. To ensure the correct gully is selected,

the designer will require to review and consider the following.

7.6.6.2 Building Regulations and Standards

All above and below ground drainage systems must comply with local Building Regulations and Standards. Effectively, it a requirement that a trapped floor gully should be specified to prevent foul odours entering or be noticeable in or around the building. Consideration should also be given to ensure the gully selected incorporates a trap that maintains an adequate seal even during periods of disuse, i.e. measures should be implemented to ensure the trap does not dry out.

7.6.6.3 Floor make-up and finish

The designer should also liaise with the structural engineer early in the design process to ascertain the depth and make-up of the ground floor slab and structural elements, such as foundations etc., as this may affect the type of gully body selected or location. In addition, liaison with the external ground works team will be required to ensure the manhole cover and frame in near proximity to the refuse store has considered the total weight of the waste disposal vehicle.

7.6.6.4 Cover classification

The full load characteristics of the bins should be considered early in the design stage in respect to the expectant weight loads imposed on the gully grating, body, the below ground drainage pipework, as well as manhole covers and gratings. An assessment reviewing the weight characteristics of the number of bins stored and the number that could potentially be manoeuvred at any one time in and around the refuse area, including the waste disposal vehicles should also be factored. For further details refer to chapter 4, section 4.3.8.6.

7.6.6.5 Flow rate

Finally, an assessment should be carried out by the designer to ascertain the total discharge of water (litre/s) that will flow into the gully at any one time. The number and location of floor gullies must be considered based on anticipated volume and proximity.

Each scenario will be different, although the main factors to consider are:

- the overall area of the refuse store
- whether the area is sheltered or unsheltered
- the number of bins being washed at any time
- the size of gully body, grating and outlet
- the diameter of below-ground drainage pipework.

The flow rate will mainly be determined by the overall volume and frequency of water usage to wash the areas down.

7.6.6.6 Water supply design process

The public health engineer must ensure the hose union tap located within the refuse bin store cannot cause any backflow contamination into the wholesome drinking water supply. The designer should assess and review the various water supply alternatives to wholesome water, as well as ensure the correct method of backflow prevention is selected by considering the following:

- *Water Regulations:* the Water Regulations govern the safe water supply and installation within all buildings. Backflow prevention is ultimately the responsibility of the public health engineer to ensure the water supply is not contaminated or contravenes the water regulations. A risk assessment is necessary to ascertain the type of backflow prevention required, which is dependent upon if the fluid category, (refer to chapter 2, Table 2.2, for description of fluid categories).
- *Backflow prevention:* Table 6.1e of the WRAS *Water Regulations Guide*⁽³⁸⁾ provides examples of water installations within various scenarios. This table states that all non-domestic hose union taps, in particular located within a refuse bin store. Hose union taps used in bin store areas serving domestic premises, such as a block of flats, are regarded as a fluid category 3 risk, unless a risk assessment, taking into account specific circumstances, indicates that a higher level of backflow protection is required. For example, fluid category three backflow protection of the hose union tap is permitted by a double check valve. Hose union taps located within the bin store pose a health risk as they could be used to wash down bins or come into contact with substances that may contaminate the wholesome drinking water supply. To prevent backflow prevention for this risk requires a Type AA unrestricted air gap, effectively, the water must be supplied by a separate break cistern and not be connected direct to the main cold water supply. A packaged break tank, complete with a boosted cold water supply, can be installed to assist where pressure may become a problem.
- *Alternative supplies (rainwater harvesting, greywater etc):* Before selecting the necessary backflow requirement that could be expensive to the client, the public health engineer should also consider alternative water sources that may be in use elsewhere in the building that could be utilised. For example, a rainwater harvesting system can provide a type AA air gap, see chapter 5, section 5.4.

7.6.6.7 Location

In addition, the designer should also carefully consider the location of the hose union tap and associated pipework in respect to frost protection and vandalism. Refuse bin stores will be unheated and therefore will require all pipework to be insulated and/or trace heated to provide adequate protection. The store itself should be locked or supervised. However a risk assessment should be undertaken to take into account acts of vandalism, misuse or waste of water.

7.6.6.8 Cleaning of refuse chute and wheeled waste container

The designer should also consider the operation and maintenance of the building when it is occupied. Specialist licensed companies can provide a service to periodically wash wheeled waste containers, as well as refuse chute cleaning. However, consideration to the types of detergents used in respect of both the water supply and the discharge to foul and surface water drainage systems.

The Environment Agency has published guidance on the cleaning of waste containers⁽³⁹⁾.

7.6.7 Chutes

Chute systems have become the standard means of transporting domestic waste from dwellings with four or more storeys and they are covered in detail in BS 5906⁽¹⁸⁾, including their construction and requirements for containers. Chutes can be fitted either inside or outside the building. Building Regulation Approved Document H⁽¹⁷⁾, section H6, recommends the installation of a communal waste chute in any residential apartment block of four or more floors in order to remove household rubbish and contain it within a storage area. A designated area/room must be included on each floor with accessible hoppers and be situated within 30 metres of each apartment, which is the maximum permissible distance the occupier should need to walk carrying a waste container.

A minimum diameter of 450 mm is recommended for chutes, which must be vertical to the point of discharge over the waste collection container. Table 7.15 provides a guide to the size of chute required to serve various numbers of apartments.

Careful consideration needs to be given towards the position and location of a waste chute in terms of:

- total number of apartments (in order to calculate volume of waste being discharged)
- user and collection vehicle access
- ability/need to segregate recyclable materials and residual waste
- building layout regarding potential noise nuisance, hygiene and fire risk.

Chute linings are normally prefabricated from concrete, although they can be manufactured in steel or clay, which provides a lightweight alternative that can be positioned more quickly and easily. Installation of concrete chutes requires the assistance of a crane, resulting in longer installation times. Either option should provide a fire resistance of 1 hour and have a minimum diameter of 450 mm. They must be installed vertically and the inner

Table 7.15 Chute diameters for various numbers of apartments

Diameter / mm	Plastic sack capacity / litres	Number of apartments per chute
450	10–15	0–20
500	30	31–40
550	30	31–04
600	40–50	40+
800	40–50	40+

surface should be as smooth as possible to avoid any future snagging or blockages within the chute. Changes in direction are not recommended but, if required, the angle should not be less than 60° . BS 1703⁽³⁰⁾ recommends that the waste chute should be ventilated to atmosphere by means of an opening of 0.035 m^2 cross sectional area, and that the foul air must be dispersed well away from any windows.

The chute must be located in a central position, no more than 30 metres horizontal distance from each dwelling and be sited well away from any habitable rooms⁽³⁰⁾. Access to the chute should be separated from the rest of the building within its own fire resisting compartment or open air balcony, and not be located within protected stairways or lobbies plus provision for permanent ventilation openings to a minimum of 0.2 m^2 or at least 6 air changes per hour.

A fire door must be installed to provide 1 hour of fire protection, as well as a minimum mass per unit area of 25 kg/m^2 or a minimum sound reduction index of 29 dB ⁽⁴⁰⁾. The hopper access to the communal chute should be located within its own room and should only be accessible via from the open air or by a protected lobby⁽⁴¹⁾. If there is no alternative other than to locate a waste chute adjacent to an apartment, the mass per unit area of the separating wall must conform to the following⁽⁴²⁾:

- habitable room or kitchen: 1320 kg/m^2 (minimum)
- non-habitable room: 220 kg/m^2 .

The hopper door must be self-closing and sealing having a $1\frac{1}{2}$ -hour fire rating and a smoke seal⁽³⁵⁾. The hopper should be installed 750 mm from finished floor level with the minimum opening dimensions size of 250 mm high by 350 mm wide. Access points should also be considered for rodding purposes in order to remove any blockages or obstructions in the chute. An automatic mechanical 1-hour fire door at the base of chute, operated on the breakage of a 70°C fusible link in the event of a fire occurring, is recommended.

A typical communal chute system is shown in Figure 7.11.

7.6.7.1 Health and safety considerations

Various problems have arisen from the use of chutes, including:

- inability of chutes to accommodate bulky items
- increased risk of fire
- difficulties in cleaning.

In order to provide facilities for disposal of bulk items which are too large to enter the chute, it is recommended that separate storage space be provided at ground level at a rate of at least $0.3 \text{ m}^2/\text{person}$ (with a minimum total area of 10 m^2) with a clear height of not less than 2.3 m. These spaces should be kept locked and only be accessible by the caretaking team.

A water supply should be provided near the top hopper on each chute to enable the shaft to be washed down and to deal with minor chute or container fires.

Some chute systems are provided with automatic chute cleaning systems, disinfectant and sanitising units,

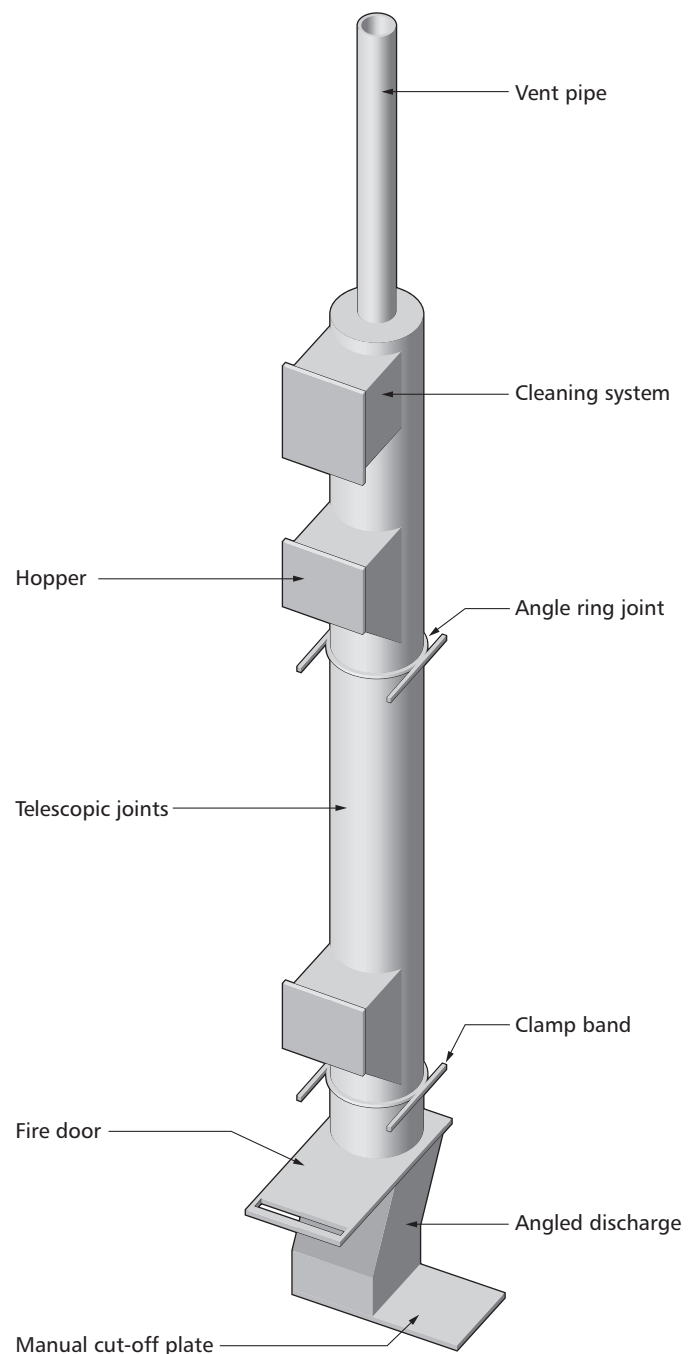


Figure 7.11 Typical communal refuse chute system (courtesy of Evac AG)

electrical interlocks, foul air exhaust fans, sound deadening and fire control equipment.

Chutes may be cleaned manually by means of stiff nylon brushes attached to a cylindrical housing. This is lowered and raised using a high-geared winch (with a ratchet mechanism for operator safety). The nylon brushes scrape the internal surface clean as they move down and up the chute.

7.6.7.2 Fire protection

Chute sprinkler systems

Where provided, the systems should be designed for a minimum of 8.2 mm/min over the most remote 186 m^2 (increase by 30% for dry pipe systems) of floor area with the protection area per sprinkler not to exceed 12 m^2 .

Internal, as well as external, protection also should be considered depending upon specific equipment design, ceiling heights, and accessibility for manual firefighting.

Where the design area consists of a building service chute supplied by a separate riser, the maximum number of sprinklers that needs to be calculated is three each with a minimum discharge of 57 litre/min.

Gravity chutes should be protected internally by automatic sprinklers. This protection requires that a sprinkler be installed at or above the top service opening of the chute.

Automatic sprinklers installed in gravity chute service openings should be recessed out of the chute area through which the material travels. In addition, a sprinkler should be installed within the chute at alternate floor levels in buildings over two stories in height, with a mandatory sprinkler located at the lowest service level.

Gravity pneumatic waste/linen conveying systems

Where material is to be stored at the bottom of the chute automatic sprinklers should be installed below the last service door on the chute.

All chute-fed compactors should have an automatic special fine-water spray sprinkler with a minimum 13 mm orifice installed in the hopper of the compactor. Sprinklers should be ordinary temperature-rated sprinklers.

A cycling (on-off), self-actuating, snap-action, heat-actuated sprinkler may be used, or the sprinkler may be controlled by a temperature sensor operating a solenoid valve. Hand-fed compactors located within a building and not operated in conjunction with a chute do not need an automatic sprinkler in the hopper.

7.6.8 Food waste disposal

A food waste disposer (FWD) is an electro-mechanical device installed within the above-ground drainage pipework from the kitchen sink. The FWD is flushed with water whilst spinning food waste onto an abrasive ring, reducing the waste to particles approximately 2 mm in diameter. These fine particles are then discharged and disposed of into the drainage system. The FWD grinds the food waste and can be sufficiently powerful to reduce and remove glass, stones and metal particles. The FWD reduces the volume of food waste collected directly from the premises. The cold water used for flushing combines fat onto the other particles avoiding deposition on sewer walls, as well as cooling the electric motor within the device.

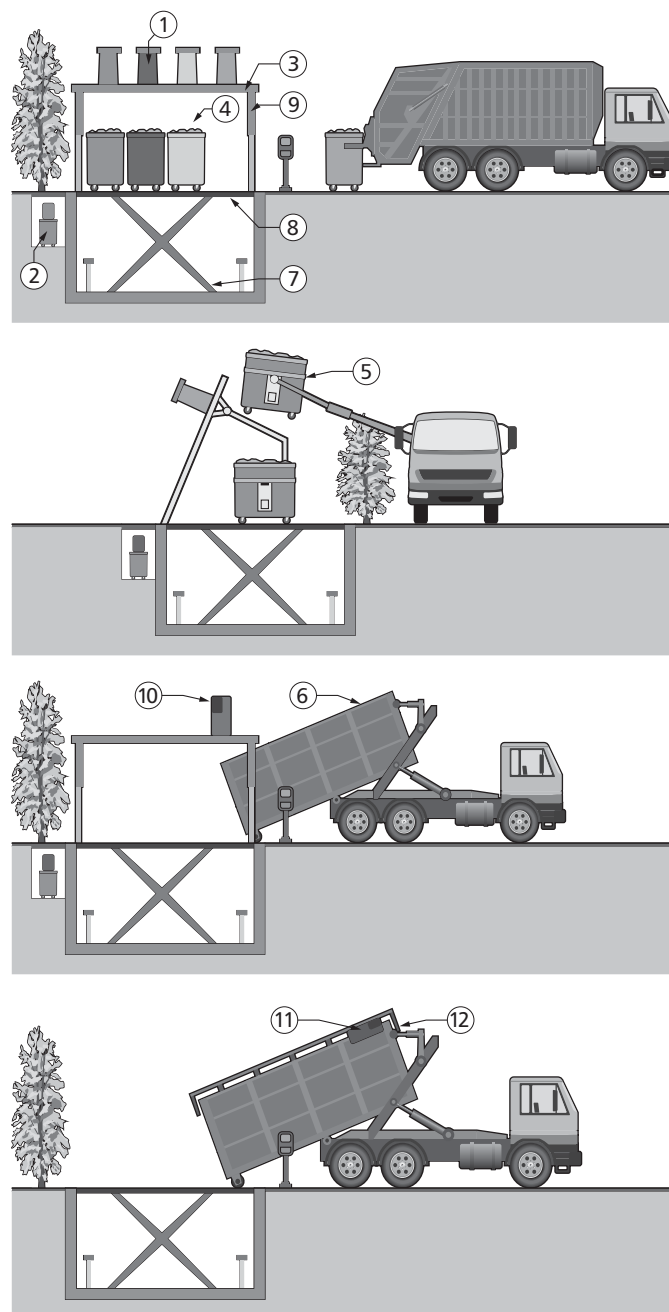
Within commercial kitchens an FWD is usually installed as standard. In addition, commercial kitchens require grease traps to be installed and maintained to ensure that grease generated from food waste does not enter the drainage system, see section 7.4.5.4 and chapter 4.

Special macerator units are available for dealing with organic materials from research institutions and hospitals. Individual macerator units or central macerator systems

discharging directly to the foul drainage system can also be used to deal with sanitary towels.

7.6.9 Underground refuse systems

Underground recycling and refuse systems are available for the storage of standard UK refuse and recycling containers in a secure and discrete underground concrete enclosure, pending waste collection. Various configurations are shown in Figure 7.12.



Key:

- 1 Fibreglass funnel, 2 Equipment space, 3 Top enclosure platform,
- 4 Waste bin (max.1700 litre), 5 Waste bin (max. 3800 litre),
- 6 7 m³ wheeled waste compactor, 7 Scissor lift, 8 Loading platform, 9 Top closure and loading platform, 10 Steel funnels with rotating openings, 11 Retrievable steel funnels with rotating openings, 12 Side flaps

Figure 7.12 Below-ground waste storage systems

To present the bins for emptying, the collection operatives elevate the system platform via a secure low voltage electrical control panel. This raises the underground platform and presents the containers at surface level. Bin emptying is conducted in the normal manner without the need for specialist lifting attachments on the collection vehicles. The empty containers are then replaced on the raised platform, and the platform lowered to its normal secure position.

The container is located underground in a concrete shaft with an above ground section, which is a normal 'litter bin' sized container and therefore fits into the streetscape. The disposal columns can be supplied in different sizes and colours with a slot for paper or a hopper for refuse. The underground refuse system allows more material to be stored than an above ground system and is concealed.

Vermin and animals are not attracted and odour is minimised due to the underground container.

7.6.10 Automated waste systems

An automated waste collection system transports waste from each floor of the building or complex of buildings pneumatically through a set of tubes. Waste can be deposited within a building into a hopper and outside a building into a litter bin sized disposal funnel from where it is sucked horizontally or vertically into a pipeline system towards the central waste collection point.

There are two types of central waste collection points: above-ground and underground. For the above-ground storage a standard refuse collection vehicle can be used whereas underground storage requires a modified refuse collection vehicle that sucks the waste out of the storage containers.

The above-ground system is mainly used within the building and the underground system can also be used outside the building, e.g. in historic or modern city centres (i.e. narrow or car-free streets). Vacuum waste transport is appropriate for high-rise buildings, offices, hotels, hospitals, airports etc.

In this system, the tubes terminate in a small above ground waste room, either inside or outside a building, and deposit the waste into either a container or a compactor. The waste is emptied into a hopper from where it is sucked into the pipeline system. From the central waste collection point it can then be collected by a conventional refuse collection vehicle, see Figure 7.13.

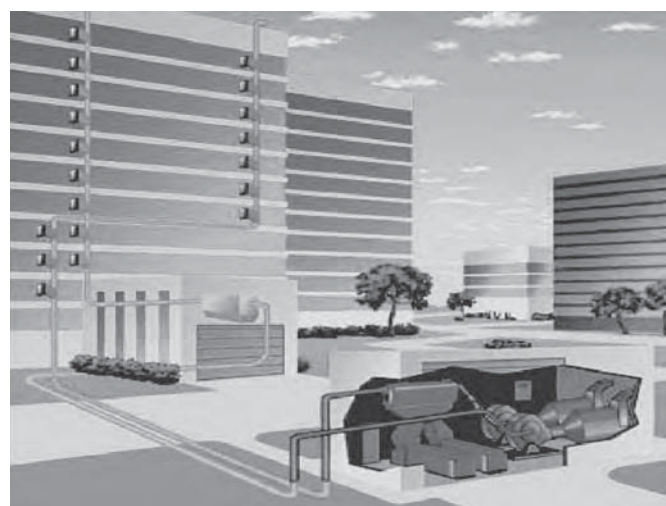


Figure 7.13 Vacuum waste disposal system (courtesy of Evac AG)

Through installing another pipe, the system can also be used for recycle. An additional hopper per type of waste is installed ideally next to the one for waste. Each type of waste is pumped into another waste room where it can be collected by its own type of collection vehicle. This kind of system is successfully used by hospitals to collect waste and laundry.

Alternatively, if extra pipework is not installed, the waste can be segregated at source into different coloured bags and they can be sorted on a conveyor in a waste handling facility using an optical scanner and conveyor system.

Mobile vacuum system

In the system shown in Figure 7.14, waste is deposited in a column where it drops, either by gravity or vacuum, into a container/compactor or an interim smaller sized box.

If it drops directly into a container/compactor it is regularly emptied by a vacuum truck sucking the waste out of the container. The driver of the vacuum truck manages the emptying process by connecting to the docking point.

If the waste drops into an interim box, all the columns are connected to the central waste collection station and are automatically emptied at regular intervals. This is achieved by creating a vacuum in the network of pipes, thereby sucking the waste vertically or horizontally to the central waste collection station. The central waste collection station is located underground and comprises a container or compactor from which the waste is sucked out by the specially equipped collection vehicle.

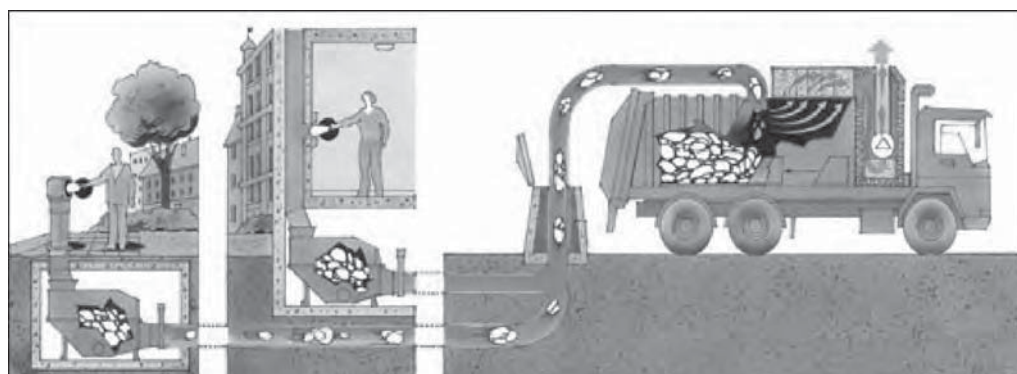


Figure 7.14 Mobile vacuum waste system (courtesy of Evac AG)



Figure 7.15 Fully enclosed vacuum waste system (courtesy of Evac AG)

Fully enclosed vacuum system

A fully enclosed vacuum system has been developed, which dispenses completely with potentially foul-smelling, dirty, refuse collection rooms and containers in the streets, see Figure 7.15.

The system can be used for recycling without installing additional pipes to the system by providing a separate hopper/disposal column for each category of waste. The control system opens and closes the valves of the main vacuum pipe depending on which type of waste is going to be transported into its separate container at the central waste collection point. The collection vehicle then empties the various categories separately.

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8 Gaseous piped services

8.1 Gas fuels	Summary This chapter provides guidance on the design of piped systems for gas fuels (including pipe sizing), compressed air, medical gases (including surgical and medical air) and vacuum (medical and non-medical). It takes into account the recent changes to legislation and also provides guidance on sustainability issues required to be incorporated in the design of these systems.
8.2 Non-medical compressed air	
8.3 Medical gases	
8.4 Medical vacuum	
8.5 Non-medical vacuum	
8.6 Medical pipework installation	
References	

8.1 Gas fuels

8.1.1 Design principles, standards and codes of practice

The designer has a responsibility to ensure that the design complies with current gas regulations. It is the installer’s responsibility not to complete the installation if the design does not comply with the regulations.

Codes of practice represent a standard of good practice and do not confer immunity from statutory requirements. It should further be remembered that it is not always sufficient to quote a standard without qualification — a specific grade or category of product must be added where alternatives are available. Relevant standards are listed at the end of this chapter.

The designer should have understanding and appreciation of the properties of natural gas and LPG as these are the prime gas fuels used in industry. Gases can be arranged into three families according to their Wobbe number (an index used to compare the combustion energy output of different composition fuel gases in an appliance), see Table 8.1. Some basic data for gas fuels are given in Table 8.2.

Table 8.1 Gas fuel families

Family	Gas type	Approx. Wobbe number
1st	Manufactured (town gas)	24–29
2nd	Natural	48–53
3rd	LPG	72–87

8.1.2 Natural gas

Gas pressure in the regional grid network ranges from 7 bar (high pressure) to 30 mbar, arriving at the building property at around 21 mbar. Pressures less than 75 mbar are regarded as low pressure.

To design a full system, the gas input installation requirements need be known, rather than gas output rates, in order to size pipework correctly.

At the planning stage, discussions on loads and periods of usage should be held with the gas supplier or meter asset manager (MAM) to confirm the availability of gas. The designer should also obtain information on the meter installation. This is of particular importance where extreme pressure and load factor fluctuations are expected so that the correct meter can be specified, e.g. high flow rates with on/off control.

The design should take into account the maximum flow of gas at a pressure and velocity to minimise adverse impacts whilst satisfying equipment and plant loads. An allowance

Table 8.2 Fuel gases: basic data (source: *Plumbing and Engineering Services Design Guide*⁽¹⁾)

Item	Natural gas	Synthetic natural gas	Methane
Calorific value (MJ/m ³)	39.70	38	37
Calorific value (Btu/ft ³)	1040	1000	995
Specific gravity	0.57–0.58	0.555	0.56
Wobbe No. (MJ/m ³)	52.12	51	49.44
Air/gas volume ratio for combustion	10	10	9.60
Flame speed (m/s)	0.36	0.36	0.36
Ignition temperature (°C)	704	704	704

should also be made for any possible increase in the future load. This should be based on a project-by-project approach and discussed at the beginning of the design stage with the client.

8.1.3 Pipework design

8.1.3.1 Gas pressure

Systems within a building envelope will be designed for a gas pressure of around 21 mbar. Outside the building, but within the property boundary, pressures can be higher and overpressure protection will be required to address the transition pressure. This is in addition to the pressure regulator.

Where gas is supplied from a booster or compressor at above 21 mbar, the total allowable pressure drop should not exceed 10% of the pressure drop at the booster outlet. The total allowable pressure loss in the system may be increased by considering the increase in pressure caused by rises in the system.

The pressure drop through a pipework system should not exceed the values given in Table 8.3.

Table 8.3 Maximum allowable pressure drop

Gas family and type	Operating pressure	Maximum design pressure drop at design flow
2nd: Natural gas	≤ 25 mbar	1.0 mbar
	> 25 mbar	10% of operating pressure
3rd: LPG (propane)	≤ 42 mbar	2.5 mbar
	> 42 mbar	10% of operating pressure
3rd: LPG (butane)	≤ 33 mbar	2.5 mbar
	> 33 mbar	10% of operating pressure

8.1.3.2 Gas velocity

To avoid excessive erosion of pipework the velocity of gas at maximum flow should not exceed 20 m/s in an unfiltered piping system and 40 m/s where a filter of >0 to ≤ 200 micron is fitted.

Filters limit the size of dirt particles entering parts of an installation and may be used to protect the controls. Where filters are fitted, pressure test points should be provided at the filter inlet and outlet to measure their performance.

8.1.3.3 Gas pipework sizing

Basically, three parameters determine the sizing of pipework:

- flow
- pressure drop
- velocity.

The gas demand is assessed from the input rating of the appliance(s) to be served together, with the calorific value of the gas. Installation design more commonly associated with building services include commercial kitchens, domestic heating plant, laboratories and below ground reticulation within a property boundary.

Hand calculations and tables may be useful for small systems but for large, complex installations, computer software programs are more appropriate. Most computer programs are based on the 'general flow' equation. Regardless of the design approach it is important to stay within the parameters of the recommended velocity and pressure drops.

Note: when sizing a gas piping system, the output of the appliance as given by a manufacturer may be at 85–90% efficiency. The gas supply *must* be sized for 100% full input duty.

Pole's equation offers an adequate approximation for residential and most commercial buildings for pipe diameters less than 100 mm. Errors can be marginalised if pipe sizes are limited to a maximum of 100 mm diameter.

Large commercial systems should be sized using IGEM/UP/2⁽²⁾ and systems in dwellings should be based on BS 6891⁽³⁾.

Pole's equation:

$$Q = 0.0071 \sqrt{\frac{d^5 h}{s l}} \quad (8.1)$$

where Q is the flow of gas (m³/h), d is the internal diameter of the pipe (mm), h is the pressure drop (mbar), s is the specific gravity of the gas and l is the length of the pipe (m).

By transformation of Pole's equation and limiting acceptable pressure loss (h) to 1 mbar (see Table 8.3), the correct pipe diameter can be confirmed by trial and error. The internal diameter will vary depending on material selection.

Example

Consider a gas heater rated at 1200 MJ/h (input). The calorific value for natural gas is 39.7 MJ/m³. The required flow of gas is obtained by dividing the input rating by the calorific value of the fuel:

$$Q = 1200/39.7 = 30.22 \text{ m}^3/\text{h}$$

The gas heater is located 9 m away from the incoming gas regulator. A pipe diameter is 42 mm (inside diameter 39.6 mm) is initially selected. Pole's equation (rearranged) is used to check that the selected pipe size will provide a sufficient supply of gas.

Rearranging Pole's equation:

$$h = \frac{Q^2 s l}{d^5 (0.0071)^2}$$

Hence, for 42 mm (nominal) pipe diameter (i.e. 39.6 mm inside diameter):

$$h = \frac{30.22^2 \times 0.58 \times 9}{39.6^5 (0.0071)^2} = 0.97$$

At 0.97 mbar, the pressure drop is less than the maximum (i.e. 1 mbar). Therefore the selected pipe size is correct.

Changes in height

The pressure gain due to increase in height can be calculated as:

$$\Delta P = g(\rho_{\text{air}} - \rho_{\text{gas}}) \quad (8.2)$$

$$= 9.81 \times (1.2 - 0.7) = 4.9 \text{ Pa/m}$$

where ΔP is the pressure gain per metre rise (Pa/m), g is the acceleration due to gravity (m/s^2), ρ_{air} is the density of air (kg/m^3) and ρ_{gas} is the density of the gas (kg/m^3).

Therefore a pressure gain of 0.5 mbar per 10 m increase in height can be applied, although this will only produce a significant effect in high-rise applications.

Pipes, fittings and components must comply with British Standards and other relevant gas specifications where appropriate.

Equivalent length of pipework for fittings resistance

When calculating pressure losses, allowances for pressure losses through fittings should be made. These will vary with the materials used. The equivalent lengths for fittings and valves (in metres) of various materials and diameters are given in Table 8.4. Pipework materials not shown in the information below should be retrieved from the manufacturer.

Table 8.4 Equivalent lengths for fittings (source: *Plumbing and Engineering Services Design Guide*⁽¹⁾)

Nominal pipe size (mm)		Approximate additional length to be allowed (m)		
Cast iron or mild steel	Stainless steel or copper	Elbows	Tees	90 bends
Up to 25	Up to 28	0.5	0.5	0.3
32 to 40	35 to 42	1.0	1.0	0.3
50	54	1.5	1.5	0.5
80	76	2.5	2.5	1.0

Table 8.5 Pipe sizing table for natural gas in steel pipe (source: *Plumbing and Engineering Services Design Guide*⁽¹⁾)

Nominal diam. (m)	Wall thickness (m)	Inside diam. (m)	Discharge rate ($\text{m}^3\cdot\text{h}^{-1}$) for stated total (i.e. actual plus equivalent) length of pipe (m)									
			3	6	9	12	15	20	25	30	40	50
8	2.3	8.70	1.201	0.849	0.693	0.600	0.537	0.465	0.416	0.379	0.329	0.294
10	2.3	12.20	2.798	1.978	1.615	1.399	1.251	1.083	0.969	0.884	0.766	0.685
15	2.6	15.90	5.425	3.836	3.132	2.712	2.426	2.101	1.879	1.715	1.485	1.329
20	2.6	21.40	11.402	8.063	6.583	5.701	5.099	4.416	3.950	3.605	3.122	2.793
25	3.2	27.00	20.388	14.417	11.771	10.194	9.118	7.896	7.062	6.447	5.583	4.994
32	3.2	35.70	40.987	28.982	26.664	20.493	18.330	15.874	14.198	12.961	11.224	10.039
40	3.2	41.60	60.078	42.481	34.686	30.039	26.867	23.268	20.811	18.998	16.453	14.716
50	3.6	52.60	108.006	76.371	62.357	54.003	48.301	41.830	37.414	34.154	29.578	26.455
65	3.6	68.20	206.749	146.194	119.366	103.374	92.461	80.073	71.620	65.379	56.620	50.643
80	4.0	80.10	309.075	218.549	178.445	154.537	138.222	119.704	107.067	97.738	84.281	75.707
100	4.5	104.30	597.990	422.843	343.250	298.995	267.429	231.600	207.150	189.101	163.766	146.477
125	5.0	128.70	1011.966	715.179	583.941	505.708	452.319	391.719	350.364	319.838	276.987	247.745
150	5.0	154.10	1586.683	1121.954	916.072	793.341	709.586	614.519	549.643	501.753	434.531	388.656

Notes:

- (1) Discharge rate for gas of relative density 0.6 in medium steel pipe for differential pressure of 1 mb between ends.
- (2) Large commercial systems should be sized using IGEM/UP/2⁽²⁾ and systems in dwellings should be based on BS 6891⁽³⁾.

Table 8.6 Pipe sizing table for natural gas in copper pipe (source: *Plumbing and Engineering Services Design Guide*⁽¹⁾)

Nominal diam. (m)	Wall thickness (m)	Inside diam. (m)	Discharge rate ($\text{m}^3\cdot\text{h}^{-1}$) for stated total (i.e. actual plus equivalent) length of pipe (m)									
			3	6	9	12	15	20	25	30	40	50
6	0.8	4.36	0.213	0.151	0.123	0.106	0.095	0.082	0.074	0.067	0.058	0.052
8	0.8	6.36	0.549	0.388	0.317	0.274	0.245	0.212	0.190	0.173	0.150	0.130
10	0.8	8.36	1.087	0.769	0.627	0.543	0.486	0.421	0.376	0.343	0.297	0.266
12	0.8	10.36	1.859	1.314	1.073	0.929	0.831	0.720	0.644	0.588	0.509	0.455
15	1.0	12.96	3.244	2.301	1.879	1.627	1.455	1.260	1.127	1.029	0.891	0.797
22	1.2	19.55	9.096	6.431	5.251	4.548	4.067	3.520	3.150	2.876	2.491	2.228
28	1.2	25.55	17.760	12.558	10.254	8.880	7.942	6.878	6.152	5.616	4.863	4.350
35	1.5	31.94	31.032	21.943	17.916	15.516	13.878	12.018	10.750	9.813	8.498	7.601
42	1.5	38.94	50.929	36.012	29.404	25.464	22.776	19.725	17.642	16.105	13.947	12.475
54	2.0	49.94	94.864	67.079	54.770	47.432	42.424	36.740	32.862	29.998	25.979	23.237
66.7	2.0	62.63	167.085	118.147	96.467	83.542	74.723	64.712	57.880	52.837	45.758	40.927
76.1	2.0	72.03	237.010	167.591	136.837	118.505	105.994	91.793	82.102	74.949	64.907	58.055
108.0	2.5	102.93	578.547	409.094	334.024	289.273	258.734	224.070	200.414	182.952	158.441	141.714

Notes:

- (1) Discharge rate for gas of relative density 0.6 in medium steel pipe for differential pressure of 1 mb between ends.
- (2) Large commercial systems should be sized using IGEM/UP/2⁽²⁾ and systems in dwellings should be based on BS 6891⁽³⁾.

8.1.3.4 Simultaneous demands

It is not possible to give any general method of determining the diversity of use appropriate to a number of gas appliances connected within a building. When undertaking the gas consumption for a commercial kitchen, an assessment must be made of the number of appliances appropriate to the preparation of each meal, which may amount to as much as 80 per cent of the total connected. Obviously in the case of gas boiler plant, allowance must be made for the full connected gas rate to operate at the same time, unless a proportion of the plant is specifically allocated as standby.

Operational variances dictated by local controls can cause problems even in buildings of similar a size. Load fluctuations can be affected by:

- time of day
- type of operation (commercial, residential, industry)
- occupancy loads
- orientation (possible heat gain)
- physical construction.

Load factor and diversity

The load factor is the average hourly rate of gas distribution divided by the maximum potential hourly rate of gas distribution.

Diversity is different from load factor because it is the relationship between aggregate and maximum demand for each individual consumer. Thus:

$$\text{Diversity factor} = \frac{\text{Potential maximum hourly demand}}{\text{Actual hourly demand}} \quad (8.3)$$

For example, 1000 consumers on a housing estate have a potential demand of 5.5 m³/h each. The gas network has been designed to supply 5500 m³/h but the actual maximum demands on the main proves to be 1375 m³/h. Therefore the diversity factor = 5500/1375 = 4 (or 0.25).

From this it can be appreciated that the diversity factor should be taken into consideration. This requires a sound professional judgment to prevent large pressure fluctuations in the network.

Another example is laboratory gas points; these may be considered as falling into one of the following categories:

- (a) Those serving major apparatus such as furnaces, glass-blowing benches, etc., which are likely to be in use simultaneously and in addition to normal bench points.
- (b) Those situated in teaching laboratories where despite an apparent excess of points, a large proportion may be in use during examination periods, etc.
- (c) Those situated in research laboratories where convenience rather than demand dictates.

For simultaneous gas demand for laboratory bunsen burners, see Table 8.7.

8.1.3.5 Kitchen equipment

For kitchen equipment approximate rates of gas discharge are quoted in Table 8.8 but should be confirmed from manufacturers' data for specific applications. Service

Table 8.7 Usage of laboratory bunsen burners

Number of burners connected	Predicted number of burners in use	
	In any one laboratory	In a group of laboratories
1	1	—
2	2	—
3	3	—
4	4	—
5	4	4
6	—	5
10	—	6
15	—	6
20	—	6
25	—	8
30	—	9
40	—	12
50	—	13
60	—	15
100	—	20

Table 8.8 Approximate gas consumption figures for various typical appliances

Appliance	Gas consumption	
	m ³ /h	litre/s
Boiling pan:		
— 50 litre	2.5	0.7
— 100 litre	3.4	0.95
— 150 litre	4.3	1.2
— 200 litre	5.0	1.4
Hot cupboard		
— 1200 mm	1.0	0.28
— 1800 mm	2.7	0.75
	3.0	0.85
Oven:		
— steaming	2.9	0.8
— two-tier roasting	1.5	0.4
— double range	6.0	0.24
— roasting	0.7	0.47
Gas cooker	2.2	0.6
Drying cupboard	0.15	0.04
Gas iron heater	0.15	0.04
Washing machine	0.6	0.15
Tumble dryer	1.5	0.42
Wash boiler	0.83–1.4	0.23–0.4
Bunsen burner:		
— small (school type)	0.07	0.02
— large (laboratory type)	0.3	0.08
Glue kettle	0.3	0.08
Forge	0.85	0.23
Brazing hearth	1.7	0.47

Note: these values are approximate; manufacturers' literature should be referred to for full design calculations

Table 8.9 Approximate connected natural gas load for 'all-gas' kitchens

User	Connected gas rate (litre/s) for stated number of meals served								
	50	100	200	300 to 400	500 to 600	700 to 800	900 to 1000	1250	1500
Restaurants*	2.4	4.4	7.3	11.2	15.7	20.8	25.4	—	—
Institutions†	2.7	5.6	9.3	12.8	18.3	24.3	30.7	33.4	41.1

* Includes hotels and restaurants serving breakfast, lunch and dinner. Also public cafeterias serving lunch plus snack only.

† Includes holiday camps and hospitals serving breakfast, lunch and dinner. Also private canteens serving lunch plus snacks only.

intakes to kitchens having all gas or some gas appliances may be estimated from the data listed in Table 8.9. In both cases the gas rate quoted is for all equipment in full use.

8.1.3.6 Design considerations:

The designer should avoid locating consumer piping where a leakage could be hazardous due to the build-up of gas.

It should also not be placed in any location where it could prejudice egress from a building in an emergency, or interfere with any emergency response.

Pressure regulators

Where gas pressure regulators are installed they should:

- provide and maintain adequate control of the operating pressure to all parts of the gas installation that they are intended to control
- be positioned in a safe location and be readily accessible for maintenance and adjustment
- be rated for the working pressure of that part; where any part of the gas installation is incapable of withstanding the inlet pressure to its gas pressure regulator, it should be provided with over-pressure protection.

Adequate pressure test points should be provided to ensure all parts of the gas installation can be safely tested and commissioned.

Gas ventilation

Gas venting devices should be provided to ensure vented gas discharges freely to a safe location. Spaces containing gas venting devices should either be ventilated to prevent the hazardous accumulation of gas or be free from all potential sources of ignition. Pipework should not be installed within voids in cavity or partition walls except where such voids are designed and built to be ventilated ducts.

Pressure-raising devices

Gas pressure raising devices must not adversely affect either the gas supply or the gas installation.

Adjacent services

Other services should be installed to be at least 25 mm clear of gas installation pipes after all coverings are applied.

Electrical bonding and connections

Installation pipes should be electrically bonded to other nearby services and/or the consumer's earth terminal, in accordance with the current IEE Wiring Regulations (BS 7671)⁽⁴⁾.

No electrical connection should be made to the gas installation that may cause a hazard to the occupier of the premises or anyone likely to work on the installation pipework.

Pipework identification

Pipework should be generally identified in accordance with BS 1710⁽⁵⁾ and in industrial applications, proprietary bandings should be used incorporating pressure details and source and destination of the service.

Piping carrying gas at a pressure exceeding 75 mbar should be identified in accordance with BS 1710 and should have the normal operating pressure stenciled onto the colour banding.

Where wet gas is supplied, branch connections should only be made into the crown or side of the main. Wet gas mains should have moisture pockets at intervals, complete with a drain valve arrangement. Moisture pockets should be made from tubing of line size, at least 50 mm in diameter.

8.1.3.7 Piping in ducts or above ground

Pipe entries into buildings penetrating structural elements should be made through sleeves sealed to prevent passage of water, vermin and gas, but permitting normal pipe movement. Sealing material should be non-combustible. Pipes passing through partition walls and non-solid floors should be wrapped with protective tape.

Installation pipes should not be fitted in electrical intake chambers, transformer rooms, lift shafts, or in any other location likely to expose the pipes to damage.

Pipes passing through the walls of ducts must be fire-stopped, but such pipes should not be greater than 150 mm nominal bore.

All ducts other than those provided by a ceiling void should have through-ventilation to prevent the accumulation of gases. As minimum provisions for ventilation, one opening at each end of the duct and at each end of every isolated section of duct should be provided.

8.1.3.8 Duct ventilation

Free area openings should be equal to 1/150th of the duct cross-sectional area or 0.05 m², whichever is greater.

Ventilation ducts or sub-atmospheric pressure piped services which are not of all-welded or all-brazed construction should not be installed in the same duct or shaft as gas piping.

Vertical ducts should have an opening at the top to dispel heat or smoke emanating from inside the duct. Gas piping should not normally be installed in an unventilated duct or void. Where this is unavoidable, the pipe should be continuously sleeved throughout the unventilated duct or void. The sleeve must be open at both ends to a ventilated area, or the unventilated duct or void should be filled with granulated inert fill to restrict the volume of any gas accumulation. The fill should be dry, chemically neutral and fire resistant, e.g. crushed slate chippings or dry washed sand.

8.1.3.9 Valves

Welded pipework should have integral flanges or welding ends. Welding should be in accordance with BS 2971⁽⁶⁾. Neoprene rubber gaskets should not be used with flanged gas pipework, due to the possibly detrimental interaction between the gas and the material.

8.1.3.10 Liquid petroleum gas (LPG)

The industry standard operating pressure for propane is 37 mbar and pipes should be sized on a maximum pressure drop from storage vessel second stage regulator to furthest fitting at maximum input load of 2.5 mbar. Consideration should be given when sizing pipework for any future extensions

8.1.4 Buried piping for natural gas and LPG

Buried pipes should not pass under load-bearing foundations of buildings or under load-bearing walls or footings. Pipe routes should avoid running in close proximity to unstable structures and retaining walls, and should avoid areas of recent infill. Where it is not possible to avoid newly in-filled areas, welded steel, polyethylene or ductile iron pipe with locking joints should be used. Avoid proximity to structures with unventilated voids.

Main distribution pipes operating at pressures between 2 and 5 bar should be routed at a minimum distance of 3 m from buildings, except for branches leading into buildings.

8.1.4.1 Polyethylene

The following standards apply to polyethylene (PE) pipe fittings and valves:

- BS EN 1555: Parts 1 and 2⁽⁵⁷⁾: pipes
- BS 5114⁽⁸⁾ and BS EN 1555-3⁽⁷⁾: fittings
- BS EN 1555-4⁽⁷⁾: valves and ancillaries.

Because of its flexibility, buried PE pipe will deform slightly under both earth and other imposed loads. This leads to an increased lateral diameter and a correspondingly reduced vertical diameter. As the pipe takes on an elliptical deformation, its vertical diameter may be reduced as much as 7% depending on the imposed loading; however, flow reduction is no more than 1%.

PE has gained wide acceptance as the material of choice for below-ground installation. If installed above ground, it must not be subjected to prolonged exposure to sunlight unless enclosed within a steel or glass-reinforced plastic (GRP) sleeve.

PE pipe can also be installed in a fully protected purpose-built enclosure, such as a culvert, or enclosed within a duct below ground.

Methods of jointing include:

- butt through fusion
- electrofusion sockets.

Depth and position in ground

Publications such as the Institution of Gas Engineers publications IGE/TD/3: *Distribution mains*⁽⁹⁾ and IGE/TD/4: *Gas services*⁽¹⁰⁾ specify the minimum depth of cover which gas mains and services should be laid in order to minimise the risk of accidental third party damage. Recommended minimum pipe covers are listed in Table 8.10.

Mains and services should be installed at the depths specified in these publications unless other effective precautions are taken to minimise the risk of third party damage.

Where water and gas pipes are run in close proximity underground, a minimum separation radius of not less than 350 mm is recommended, with the water pipe below the gas pipe to minimise risk of odour in water supplies

Table 8.10 Recommended minimum pipe cover

Type of ground covering buried pipe	Minimum depth of cover (m) for stated maximum operating pressure and pipe diameter	
	≤ 75 mbar ≤ 63 mm	> 75 mbar > 63 mm
Carriageways	0.45	0.75
Paths/footways	0.375	0.6
Verges	0.375	0.75
Fields and agricultural land	1.1	1.1
Other private ground	0.375	0.6

due to permeation of gas through the wall of the water pipe, see chapter 13, Figure 13.1.

8.1.4.2 Gas permeation

Pipelines carrying compressed gases over a long distance may deliver slightly less gas due to permeation through the pipe wall. Usually, such losses are small but it may be necessary to distinguish between permeation losses and possible leakage.

The daily volume of gas that will permeate through polyethylene pipe is determined by:

$$q_p = \frac{K A_p \Delta p}{t_p} \quad (8.4)$$

where q_p is the volume of gas (at standard temperature and pressure) permeated through pipe wall (cm^3), K is the permeability constant for the pipe material, A_p is the area of the outside wall of the pipe (m^2), Δp is the pressure difference across the pipe wall (bar), and t_p is the wall thickness (mm).

Values of the permeability constant for various pipe materials are given in Table 8.11.

Table 8.11 Permeability constants for pipework materials

Gas	Permeability constant, K
Methane	85
Carbon monoxide	80
Hydrogen	425

8.1.4.3 Loads on buried pipes

The interaction between the pipe and soil is also dependent on the variation of site soil conditions together with ratio of pipe diameter to wall thickness ('SDR'). The physical weight of the earth is considered the 'dead load' and vehicular traffic is referred to as the 'surcharge load'. Singularly or together, they produce a vertical surface pressure, which is that normally acting on the crown of the pipe. This pressure is used for calculating deflection for comparison with the performance limit of the pipe.

The term 'arching' is used in soil mechanics. It refers to the soil load mass acting on a horizontal plane and is equal to the weight of the soil directly above the plane. If the stiffness of the soil varies within the soil mass above the plane, the soil mass will become redistributed toward the stiffer areas due to internal shear resistance. Generally engineers make the assumption that the earth load on the pipe is equal to the weight of the soil above the pipe and refer to this as the 'geostatic stress' or 'prism load'.

8.1.5 Gas boosters

8.1.5.1 Introduction

This section is intended to highlight a series of points that should be considered when incorporating gas boosters or compressors in a supply system.

Gas booster are usually centrifugal fan machines, and are used to boost gas pressure to approximately 75 mbar.

Compressors are positive displacement machines, and are capable of very high pressure lifts. Therefore greater safety measures are required for boosters due the high pressures involved.

Practical site considerations

Boosters should be installed in clean, dry, accessible and well ventilated areas, with free ventilation being not less than 2% of the floor area of the room. Boosters should not be installed in governor or meter houses.

Ambient temperatures should be limited to 45 °C, by use of a cooling air supply if necessary.

Where boosters are located in special rooms, high- and low-level ventilation should be provided, with high-level ventilation located as high as practically possible. Boosters should be installed on a firm, flat, horizontal surface, with anti-vibration mountings being used where machines cannot be securely fixed to a concrete bed.

Where anti-vibration mountings are used, the use of flexible metallic tubes to inlet and outlet connections should be considered.

Noise attenuation may be necessary, depending upon the siting and type of the boosters. Care should be taken that any attenuation does not affect the ventilation of the unit.

8.1.5.2 Design considerations:

Location of booster within supply network

The location of the booster or compressor within the supply network must be carefully considered, and the possible effects of the gas booster or compressor upon the various appliances in the system assessed.

For the purposes of this section, the effects of a gas booster on an additional, non-boosted supply are assessed.

When the booster or compressor starts, a depression may occur in the gas supply to the booster, causing nuisance shut-down due to the operation of the low pressure cut-off (LPCO) switch or the temporary pressure starvation of the appliances upstream of the booster.

Methods of protection against surge

There are a number of methods available:

- The header pipe to the booster can be enlarged to provide sufficient storage of gas to absorb the surge caused by the booster or compressor starting, i.e. the header acts in a similar manner to a receiver. However, use of this method may result in very large pipework being required.
- A receiver can be located close to the booster to act as a reservoir and absorb the surge caused by the booster starting. This method may cause problems due to plant space requirements, particularly in existing plant rooms.

- The additional supply can be taken from before the meter and routed through a separate meter. As each booster or compressor should have a device fitted to prevent pressure fluctuations at the meter and in the supply mains to conform to the Gas Act 1995⁽¹¹⁾, taking the supply from before the meter should eliminate any problems caused by starting surges. The use of this method may involve problems due to the locating of, and paying for, an extra meter, particularly if the non-boosted supply is an addition to an existing boosted system.

Low-pressure cut-off (LPCO)

All boosters and compressors should have an LPCO switch fitted on their inlet side to prevent reduced or negative pressure at the gas meter, and in the upstream part of the gas supply network.

The pressure switch setting needs to be carefully determined both to provide protection to the supply and to avoid nuisance shutdown of other appliances. The minimum allowable cut-off pressure is 10 mbar for normal low pressure (21 mbar) gas supplies.

Non-return valve

A non-return valve should be fitted to all boosters and compressors having a pressure lift greater than 70 mbar. A non-return valve (NRV) should also be fitted downstream of the meter installation to protect the gas supply system.

Outlet pressure control

Control may be required to maintain a constant outlet pressure or to protect the downstream system against excessive outlet pressure.

Inlet pressure control

All control and protective devices fitted on the inlet side of any booster or compressor should be located between the inlet gas isolating valve and the booster or compressor. No other shut-off valve should be fitted between the machine and its inlet isolating valve.

8.1.6 Statutory and non-statutory guidance

8.1.6.1 Regulations and legislation

Applicable regulations and legislation include the following:

- Gas Act 1995⁽¹¹⁾
- Gas Safety (Installation and Use) Regulations 1998⁽¹²⁾
- Health and Safety at Work etc. Act 1974⁽¹³⁾
- Management of Health and Safety at Work Regulations 1999⁽¹⁴⁾
- Gas Safety (Management) Regulations 1996⁽¹⁵⁾
- Gas Safety (Rights of Entry) Regulations 1996⁽¹⁶⁾

- Gas Safety (Management) Regulations (Northern Ireland) 1997⁽¹⁷⁾
- Gas Safety (Installation and Use) Regulations (Northern Ireland) 2004⁽¹⁸⁾
- The Gas Safety (Installation and Use) Regulations as amended and applied by the Gas Safety (Application) Order (Isle of Man)⁽¹⁹⁾
- The Building Regulations 2010⁽²⁰⁾
- The Building Regulations (Northern Ireland) 2012⁽²¹⁾
- The Building (Scotland) Regulations 2004⁽²²⁾
- Gas Appliances (Safety) Regulations 1995⁽²³⁾
- Pressure Systems and Transportable Gas Containers Regulations 1989⁽²⁴⁾
- Offshore Safety Act 1992⁽²⁵⁾
- Pipelines Safety Regulations 1996⁽²⁶⁾
- Dangerous Substances Explosive Atmosphere Regulations 2002⁽²⁷⁾
- Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995⁽²⁸⁾
- Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (Northern Ireland) 1997⁽²⁹⁾

Present regulations cover only piped gas supplies, not bulk storage. The regulations do not presently cover factories, mines or quarries.

Most importantly, if the installation is not in located in the UK, enquiries should be made about the local equivalents (if any) of the above legislation.

8.1.6.2 Non-statutory guidance

Some very useful documentation for installations in the commercial and industrial sectors include the following:

- *Essential Gas Safety: Domestic*⁽³⁰⁾
- For all gas installations, excluding domestic installations, reference should be made to the Institution of Gas Engineers and Managers (IGEM) IGE/UP series of publications.

Relevant British Standards include the following:

- BS 1179: *Glossary of terms used in the gas industry: Part 6: 1980: Combustion and utilization including installation at consumers' premises*⁽³¹⁾
- BS 9999: 2008: *Code of practice for fire safety in the design, management and use of buildings*⁽³²⁾
- BS 6173: 2009: *Specification for installation and maintenance of gas-fired catering appliances for use in all types of catering establishments (2nd and 3rd family gases)*⁽³³⁾
- BS 6400-1: 2006: *Specification for installation, exchange, relocation and removal of gas meters with a maximum capacity not exceeding 6 m³*⁽³⁴⁾

- BS 6891: 2005+A2: 2008: *Installation of low pressure gas pipework of up to 35 mm (R1 1/4) in domestic premises (2nd family gas). Specification*⁽³⁾
- BS 8313: 1997: *Code of practice for accommodation of building services in ducts*⁽³⁵⁾.

8.2 Non-medical compressed air

8.2.1 Relevant codes of practice and statutory regulations

Non-medical compressed air is primarily used as a source of power to drive, for example, items of machinery or equipment, or controls. Under no circumstances should medical and non-medical gasses be interconnected.

Statutory regulations applicable to compressed air systems exist to protect employees and the general public and are enforced by the Health and Safety Executive. *A code of practice for the installation of compressed air*⁽³⁶⁾ is published by the British Compressed Air Society (BCAS).

In addition, various international (ISO) and British (BSI) standards apply to components of the whole system, and these are given in the relevant following sub-sections.

The whole system should comply with the safety requirements of BS EN ISO 4414: 2010: *Pneumatic fluid power. General rules and safety requirements for systems and their components (CD-ROM)*⁽³⁷⁾ and the Factories Act⁽³⁸⁾. Reference should also be made to the Health and Safety at Work etc. Act 1974⁽¹³⁾ and the Workplace (Health, Safety and Welfare) Regulations 1992⁽³⁹⁾.

8.2.2 Design loadings

8.2.2.1 Operating pressures

For machinery and tools the usual operating pressure is 6 bar (gauge) at the point of use, with a supply mains pressure of 7 bar (gauge).

For sensitive equipment local pressure reduction may be preferred to allow maximum system flexibility. Alternatively, dual systems may be considered with high and low pressures.

8.2.2.2 Maximum and average loadings

For factory or workshop environments guidance should be sought from the owner or users. In the absence of specific data reference should be made to the BCAS *Guide to the selection and installation of compressed air services*⁽³⁶⁾ for consumption rates. Examples of the most common items are given in Table 8.12. For average loadings, usage factors vary from 10 to 50% dependent upon operational use. The BCAS publication gives indications in the absence of client requirements.

Table 8.12 Compressed air requirements for non-medical equipment (source: *Installation Guide — a guide to the selection and installation of compressed air services*⁽³⁶⁾)

Equipment	Maximum consumption (litre/s)	Average pressure requirement (bar)
Air hoist:		
— 0.5 tonne	33	5.5
— 5 tonne	97	5.5
Air motors (per kW)	16 to 22	5.5
Drill:		
— heavy	33	3.5 to 5.5
— medium	8	3.5 to 5.5
Grinder (medium)	23	5.5
Screwdriver	8	3.5 to 5.5
Spray gun	5	0.5 to 10
Controls	0.005 to 0.01	1
Laboratory bench:		
— high pressure	15	5.5
— low pressure	5	1.5
Laboratory equipment		
— de-ionizing plant	1	0.4
— flame photometer	0.4	1.4
— glassware washing machine	3	2.8
— stirrers	0.5	1.5

8.2.2.3 Leakage factors

During lifetime of any installation, some deterioration will take place in the system's air tightness, mainly at point-of-use couplings. A manual adjustment of 5% uplift in the system flow requirements will account for such leakage.

8.2.3 Plant selection

8.2.3.1 Compressors

Principle compressor types are reciprocating, rotary, centrifugal and axial, the ultimate selection depends on power source (i.e. electricity, combustion engine, or turbine) and system characteristics.

Figure 8.1 gives general guidance on approximate capacity and pressure limitations of the above compressor types. Consideration should be given to the use of multiple units to give flexibility of use, stand-by facilities and cascade controls to give economic running costs.

8.2.3.2 Air receivers

The air receiver serves to eliminate pulses from the compressor and to provide a reservoir to cope with temporary demands in excess of the compressor's capacity. The receiver also acts as a cooling device with the resultant effect of precipitating water from the air. Air receivers are covered by BS EN 286-1⁽⁴⁰⁾ and BS EN 1012-1⁽⁴¹⁾. For initial sizing the vessel should have a capacity between 6 and 10 times the compressor volume output. The use of duplicate units should be considered for continuity of supply.

Where large volumes of air over a short period are required, point-of-use sub-receivers may be considered.

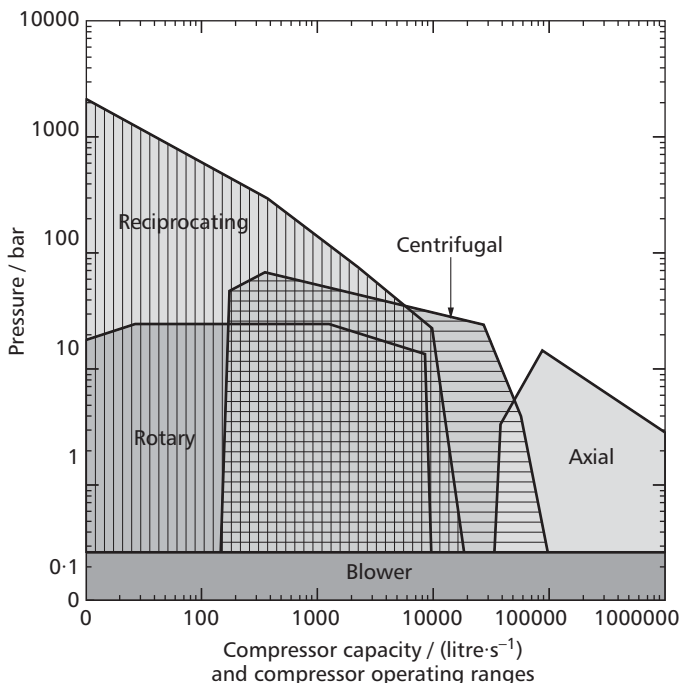


Figure 8.1 Operating ranges for typical compressor types

8.2.3.3 After-coolers, air dryers and desiccant dryers

To achieve an acceptable air quality commensurate with usage, a number of devices are required to eliminate residual water and oil from the air. To ensure this, an after-cooler can be introduced between the compressor and receiver. The after-cooler will lower the air temperature to approximately 10 °C above the cooling medium (either air or water).

For further protection of the pipework and system attachments, the addition of air dryers should be considered.

Where the ambient temperature is expected to remain above 0 °C then a refrigerant or desiccant dryer may be used. A desiccant dryer is essential, where the compressed air is subject to sudden expansion or temperatures of below 0 °C.

8.2.4 System distribution

Ideally, all cooling and condensing should be carried out in a compressed air installation before the air leaves the receiver. However, this is seldom achieved in practice. To ensure effective operation of any compressed air equipment, it is essential to ensure that the mains are installed with an adequate fall to purpose-made drainage points. The general layout of the building will usually dictate the best positions for drainage points but, in general, the main should be given a fall of not less than 1 in 100 in the direction of flow. The maximum distance between drainage points should not exceed 30 m.

Provided care is exercised in the design to prevent excessive pressure drops, it is common to size compressed air mains on a velocity basis. For practical purposes, a reasonable velocity is 6 m·s⁻¹. This is sufficiently low to prevent excessive pressure drops on most systems and to minimise the entrainment of moisture which may collect at the bottom of the pipe.

Consideration should be given to a ring main system within the distribution network to enhance system flexibility and capacity and to reduce the overall velocity and pressure losses due to the pipework. All branches should be taken off the top of the main and drop to a low level with a strainer at the base of the dropper.

The majority of installations require the provision of automatic air traps. Air-binding of traps can occur on initial start-up or where there is the possibility of large quantities of water collecting at the trap. This problem can be eliminated by the use of pressure balance pipes between the main and the trap. A strainer should be installed before each trap.

Airborne water particles will be carried along with the air and these will not be removed by the normal drain points. Therefore, separators should be incorporated in the system to remove airborne water droplets. An in-line separator should be fitted in the main at the point at which it leaves the receiver, as well as at any terminals serving equipment prone to damage.

8.2.5 Materials

Materials for pipework can include steel, copper or specialist thermoplastics. Copper is not normally used for pipe sizes over 25 mm in bore. Selection of the pipe material depends on the cost and pressure requirements. Where a robust system is required, the use of galvanized steel is recommended with thermoplastics being used in less vulnerable areas.

8.2.6 Testing and commissioning

8.2.6.1 Hydraulic testing

After the installation of main and branch air lines and before connection of the dropdown and compressor or air receiver, it is recommended that the system should be tested hydraulically (if necessary with the addition of an anti-corrosion agent) at 1.5 times the continuous rated working pressure for 2 hours. A record should be kept of the date and the pressure of the hydraulic test and be signed by both installer and user. This record should be attached to the pipe system at the point where it joins the compressor or air receiver. After testing, the system should be blown through with low-pressure air.

8.2.6.2 Testing for leakage

Faults in most factory services can be detected easily: e.g. water leaks are visible, an electrical fault will blow a fuse, and a gas leak can be smelt. However, leaks in compressed air lines may not be readily detected and, even if noticed, may in any case be ignored. Therefore, it is recommended that the entire system is tested on commissioning in order to determine the leakage rate. Methods for determining leakage rate are as follows.

Method 1

Determine the volume V (litres) of the air mains downstream of the receiver isolating valve, including all branch and drop pipes. Pressurise the whole system to the

normal operating pressure (P_1) and then shut down the compressor. Close the receiver valve and ensure that all the tools and equipment are isolated. Check the time for the system to leak down to some lower pressure (P_2). Thus, P_1 minus P_2 is the pressure drop (ΔP).

The amount of leakage in litres per second of free air is given by:

$$L = V \Delta P / T \quad (8.5)$$

where L is the leakage (litre·s⁻¹ of free air), V is the volume of the system (litre), ΔP is the pressure drop (bar) and T is the time over which the pressure drop occurs (s).

For example, for $V = 300$ litres, $P_1 = 7$ bar, $P_2 = 6$ bar and $T = 200$ s, the leakage rate is:

$$300 \times (7 - 6) / 200 = 1.5 \text{ litre·s}^{-1}$$

Method 2

This method requires a compressor of known capacity and an accurate pressure gauge, not less than 100 mm in nominal diameter, that has recently been calibrated against a test gauge, and a stopwatch or timer.

Run the compressor with all equipment isolated until the system is charged to operating pressure and has remained at a constant pressure for 1 minute; note the pressure and time, and stop the compressor.

The pressure will fall in the system as a result of air leaks and should be allowed to drop to some suitable point on the pressure gauge scale, approximately 1 bar below the maximum recorded reading. Note the time (t) in seconds for the pressure to fall and restart the compressor. Record the time (T) for the compressor to reach maximum pressure, and stop the compressor immediately it reaches the previously recorded figure.

Repeat at least four times to obtain average values for (T) and (t).

If the compressor flow rate is Q litre·s⁻¹ then amount of air delivered is ($Q \times T$) litres. However, total leakage time is ($T + t$) seconds, so average leakage rate is:

$$L = \frac{Q T}{T + t} \quad (8.6)$$

where Q is the compressor flow rate (litre·s⁻¹), T is the time taken for the compressor to reach maximum pressure (s) and t is the time taken for the pressure to fall and the compressor to restart (s).

Even if the compressor flow rate is not known this method can be used to assess the leakage rate as a percentage of maximum compressor output.

8.3 Medical gases

8.3.1 Introduction

Safety in design is an integral part of the design process and extends to patient safety and those involved in the operation of medical gas pipeline systems.

The main considerations are as follows:

- *Quantity and quality*: these are paramount to a correctly designed system. Flows need to meet the potential demand whilst the liquid or gaseous source needs to meet an appropriate product specification.
- *Continuity and identity of supply*: the former can be achieved by supplying duplex components and by providing additional means to circumvent an event failure, the latter by ensuring that medical equipment can only be connected by gas-specific connectors identified by colour and symbol (refer to HTM 02-01⁽⁴²⁾).

The following elements are covered within the following sections:

- medical gases and their general uses
- safety in design
- pipework system installation (touching on materials and jointing methods, testing and commissioning, storage, production and distribution)
- loadings and gas flows at terminal units
- general fire precautions
- earthing
- hospital information systems (monitoring and alarms are covered within section 8.3.4.7).

The demand for medical gases in healthcare facilities is independent of the size of the facility. This analogy may be extended to the number of medical gas points actually required, as potential savings can be made by rationalising the system design and reducing unnecessary points. Therefore the project team should review the requirements for individual schemes.

In some cases portable point-of-use cylinders may be most appropriate but in large facilities, it may be preferable to install a medical gas pipeline system (MGPS) from a central storage or generation point as it has the following advantages over the former:

- provides a more robust supply than gas cylinders
- reduces the problems associated with portage and storage space
- is inherently safer
- provides for continuity of supply.

Throughout this section, references are made to the Department of Health document *Medical gases: Health Technical Memorandum 02-01: Medical gas pipeline systems*⁽⁴²⁾. The aim here is not to produce a surrogate of

this document but rather to supplement it in such a way that the MGPS design can be approached with a measure of understanding.

8.3.2 Standards and guidance documents

Medical gas technology is evolving on a continuous basis, so whether undertaking a new design from scratch or adding to an existing medical gas pipe system, it is the engineer's responsibility to ensure that he/she has up-to-date guidance information to hand.

The bibliography at the end of this chapter does not claim to be exhaustive but provides a selection of technical guidance material available at the time of publication.

8.3.3 Medical gases and their general uses

The main medical gases and their uses are as follows:

- *Oxygen*: used in general clinical management for resuscitation, surgical and major trauma, shock, and hyperbaric chambers. It is generally supplied as a liquid from a vacuum-insulated evaporator (VIE), liquid cylinders or compressed gas cylinders (or a combination of the above) to supply stand-by and back up capacity.
- *Nitrous oxide*: used as an inhalation anaesthetic and in cryosurgery as a refrigerant.
- *Medical air*: a mixture of oxygen (21%) and nitrogen (79%) (by volume), delivered at 400 kPa. It is used in ventilators and incubators to provide uncontaminated and controlled air flows. Supplied from high quality dried compressed air plant and filtered to remove bacteria.
- *Surgical air*: this a mixture of oxygen (21%) and nitrogen (79%) (by volume), delivered at 700 kPa. It is used as a power source for pneumatic equipment.
- *Nitrous oxide/oxygen*: administered with oxygen 50/50 by volume and used for the relief of procedures which inevitably involve pain.
- *Helium/oxygen*: (also known under the proprietary name of HELIOX21) mixed at a volume ratio of 79/21 and used to treat patients with respiratory or airway obstruction.
- *Vacuum*: vacuums are grouped into three pressure levels: 'low' or 'rough' vacuum at 90 to 125 torr, 'high' vacuum at 1 torr and 'medical' vacuum at 10–15 torr.

Under the Control of Substances Hazardous to Health Regulations 2002⁽⁴³⁾ (COSHH), the control of occupational exposure to waste anaesthetic gas (nitrous oxide) and nebulised agents is a legal requirement. Where nitrous oxide is provided for anaesthetic purposes, scavenging systems are required to be installed⁽⁴²⁾. However, consultation with health care facility managers is necessary to establish the requirements for specific projects.

8.3.4 Design considerations:

The design and performance of a MGPS will be dependent on the following provisions:

- (1) Correct pipe sizing: undersized pipes may not give adequate pressure and flow under peak load, whilst oversized pipes result in a more expensive system.
- (2) Number and location of outlets.
- (3) Flow and pressure required at each of the terminal outlets. In general, design should be such that the pressure drop from the plant/source to any terminal unit does not exceed a 5% as measured at specified test flows⁽⁴²⁾.
- (4) Likely simultaneous usage of the outlets (diversity).
- (5) Safety requirements.
- (6) Total flow.

8.3.4.1 Design loadings

Prior to the sizing of the MGPS, the designer should give full consideration to the following:

- the test flow that is required at each terminal unit for test purposes
- the maximum flow likely to be required at any time in clinical use
- the typical flow required at each terminal
- the sum of the diversified flows in each sub-branch and the total flow to the ward/department
- the sum of the diversified flows in the main branches/risers
- the flow required at the plant.

Given the multitude of variables above it can be seen that the precise prediction of pipeline flow is not possible and it is for this reason that diversified flows are used for the purposes of pipe size selection. Therefore it is important that the designer has an understanding of the function of a particular department. The gas flows required at terminal units in various rooms/areas are shown in Table 8.13.

Separate rooms are recommended for housing the gas control panels and other equipment. The room where gas control panels are kept is known as 'manifold room'. It is preferable that this room is located on the ground floor and should have easy access to delivery vehicles. It should be well ventilated and lit. For ease of handling of cylinders, the floor level should be at a height of one meter from the ground level. A separate room called 'plant room' should be used for the compressors and vacuum pumps. This room should be in close proximity of the manifold room.

Figure 8.2 below illustrates a typical automatic manifold control system and emergency reserve manifold⁽⁴²⁾.

Oil or oil mist and other hazardous material should not contaminate the surrounding atmosphere. No grease, oil or naked flame should be used in the near vicinity and the area should be a 'No Smoking' zone. Oxygen is normally supplied as compressed gas in cylinders at a pressure of

Table 8.13 Gas flow flows required at terminal units (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Service	Location	Nominal pressure / kPa	Flow rate / litre·min ⁻¹		
			Design	Typical	Test
Oxygen	Operating rooms and rooms in which N ₂ O is provided for anaesthetic purposes	400	100 ^(a)	20	100
	All other areas	400	10 ^(c)	6	40
Nitrous oxide	All areas	400	15	6	40
Nitrous oxide/oxygen mixture	LDRP (labour, delivery, recovery, postpartum) rooms	310 ^(b)	275	20	275
	All other areas	400	20	15	40
Medical air (at 400 kPa)	Operating rooms	400	40 ^(c)	40	80
	Critical care areas, neonatal, high dependency units	400	80 ^(c)	80	80
	Other areas	400	20	10 ^(c)	80
Surgical air/nitrogen	Orthopaedic and neurosurgical operating rooms	700	350 ^(d)	350	350
Vacuum	All areas	40 ^(e)	40	40 ^(f)	40
Helium/oxygen mixture	Critical care areas	400	100	40	40

Notes: (a) during oxygen flush in operating and anaesthetic rooms; (b) minimum pressure at 275 litre·min⁻¹; (c) these flows are for certain types of gas-driven ventilators under specific operating conditions, and nebulisers etc; (d) surgical is also used as a power source for tourniquets; (e) 300 mm Hg below atmospheric pressure; (f) maximum, further diversities apply.

approx 1.2 bar. The colour code for oxygen cylinders is a black body with a white neck. In hospitals where the consumption is high and space is available, a liquid oxygen vessel is preferred.

8.3.4.2 Anaesthetic gas scavenging

Where nitrous oxide and anaesthetic agents are available for anaesthetic procedures, an anaesthetic gas scavenging (AGS) terminal unit should be provided. The specification for AGS terminal units is given in BS EN ISO 9170-2⁽⁴⁴⁾.

8.3.4.3 Medical vacuum

Medical vacuum should neither be extended to an infectious diseases unit (IDU) nor provided to such a unit from a central vacuum system⁽⁴²⁾.

8.3.4.4 General fire precautions

Plantrooms, medical gas manifold rooms and internal medical gases cylinder stores require smoke or heat detector heads in accordance with Health Technical Memorandum 05-03, Part B⁽⁴⁵⁾. External stores may also require fire detection systems.

8.3.4.5 Earthing

Medical gas pipelines should not be used for earthing electrical equipment. They should be bonded together and bonded to the local electrical distribution board in accordance with BS 7671⁽⁴⁾. Flexible pipeline connections should be bonded across the fixed points to ensure earth continuity.

8.3.4.6 Terminal units

The connections or probes on terminal units have unique diameters to ensure that only the correct gases can be connected to that apparatus. Refer to BS EN ISO 9170-2⁽⁴⁴⁾ for guidance.

8.3.4.7 Monitoring and alarms

Monitoring and alarm systems are essential to ensure the safe and efficient operation of medical gas systems. The monitoring should provide feedback to let users know that:

- the system is running well
- routine actions are required
- the system has fallen back to the reserve, emergency condition.

Such systems may include pressure sensors, a central monitoring system and repeaters located to allow actions to be easily and efficiently undertaken. Alarms should also be available to the end users downstream of the area valve service unit (AVSU).

The layout for a typical warning and alarm system is shown in Figure 8.3⁽⁴²⁾ below.

8.3.4.8 Hospital information systems

Hospital information systems should be capable of polling networks continuously, whilst scanning all the connected medical devices in the hospital. Any alarm condition should be displayed on the PC as they occur.

The system should support master alarm, area alarm, manifolds, medical compressed air system, medical system.

The basic system should consist of the following:

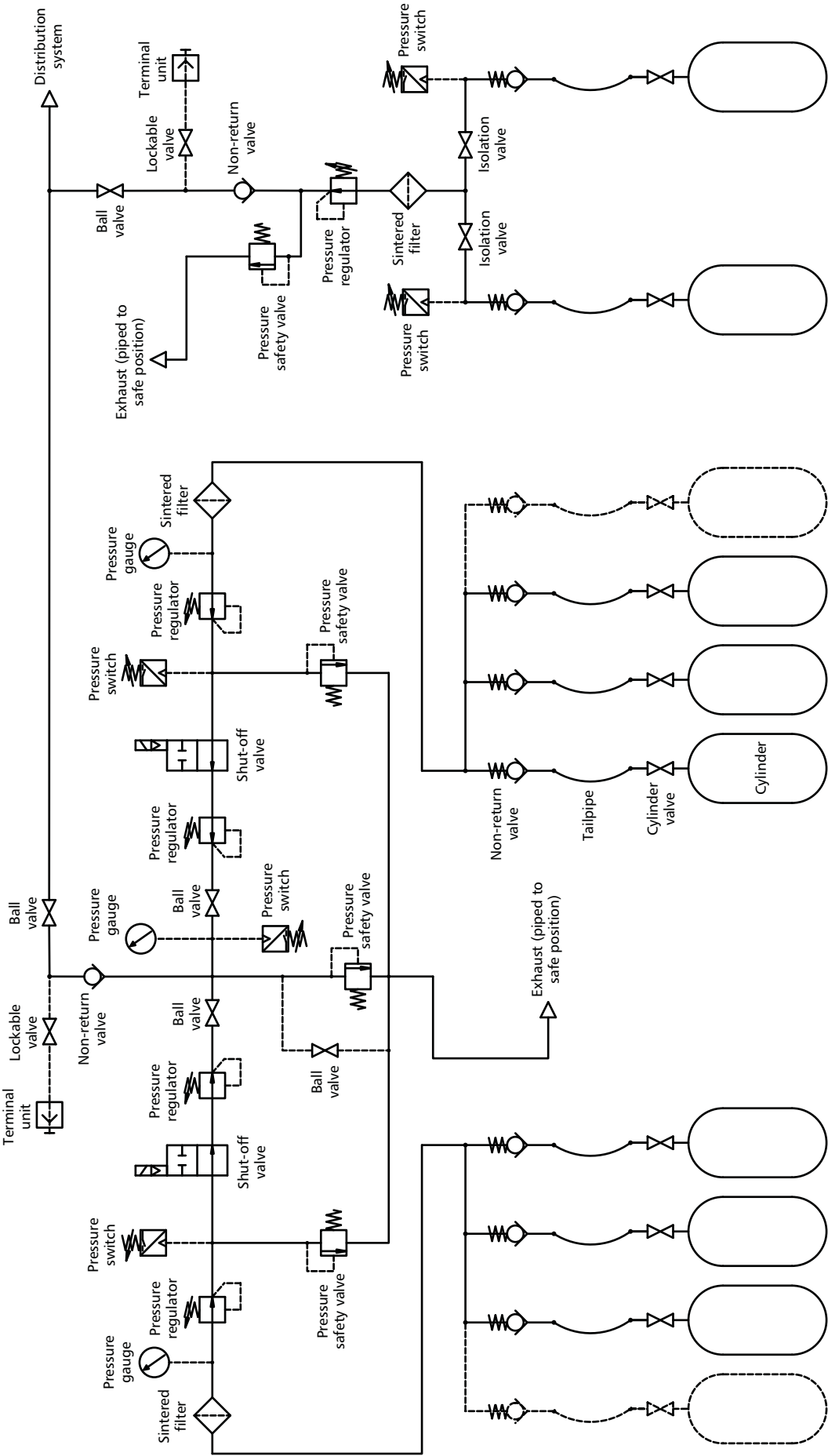


Figure 8.2 Typical automatic manifold control system and emergency reserve manifold (reproduced from HTM 02-01⁽⁴²⁾, Crown copyright)

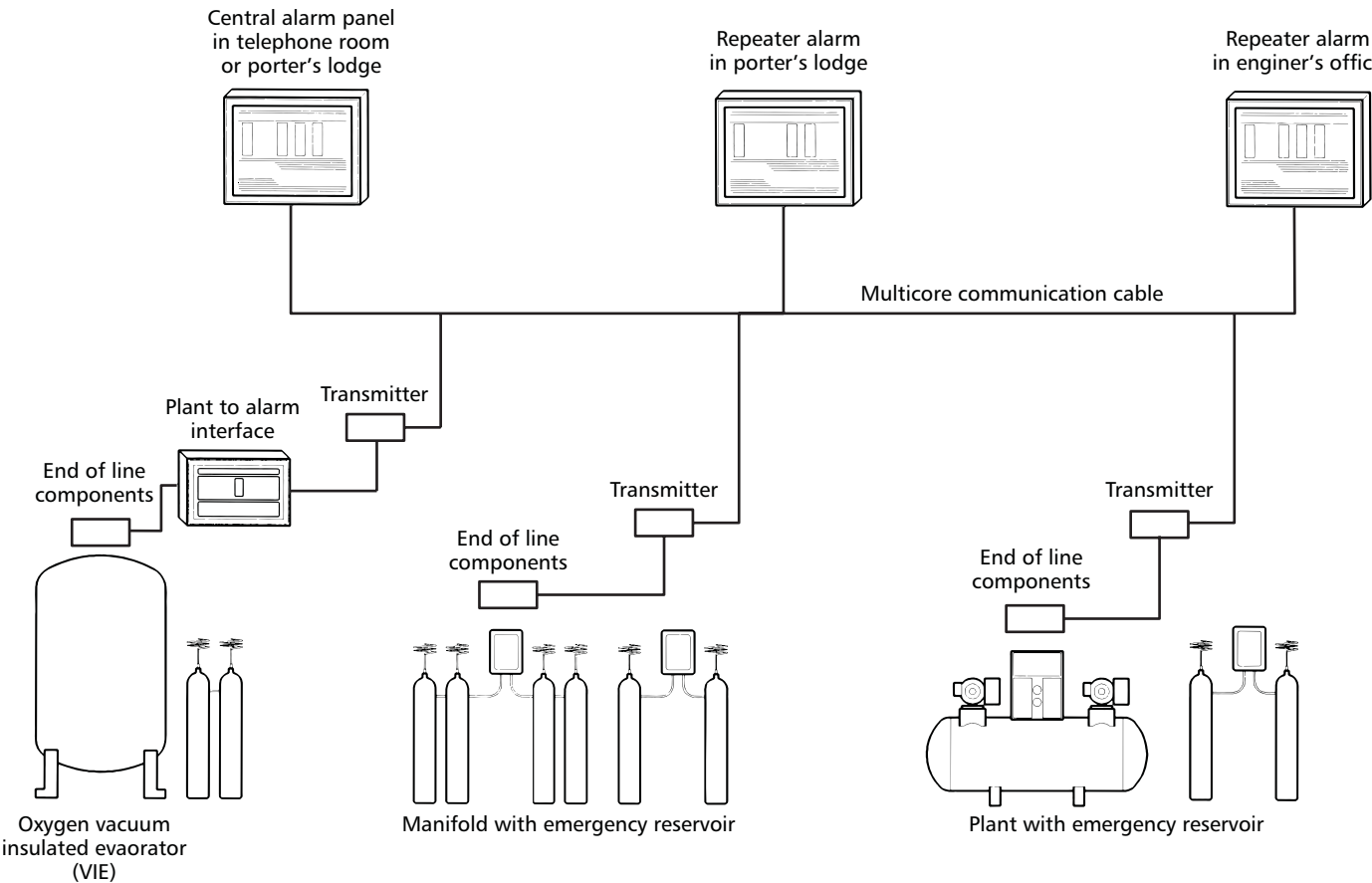


Figure 8.3 Typical warning and alarm system layout⁽⁴²⁾ (courtesy of Shire Controls Ltd.)

- a network interface card in each device
- computer card and hospital information system (HIS) software (computer should be accessible to the hospital's local area network (LAN)).
- the system should be able to access a maximum of 256 devices; each device should be connected in series.

8.3.5 Gas flow

8.3.5.1 Gas flows required at terminal units

When calculating diversified flows, it is the number of bed spaces, treatment spaces or rooms in which the clinical procedure is being performed that is used for the calculation — not the individual number of terminal units since, in many cases, more than one is installed. Therefore the level of diversity applied should be agreed with the health care facility management⁽⁴²⁾.

8.3.5.2 Pressure loss

The actual flow through the system varies with the pressure and temperature. However, the temperature changes within the system are very minor and are considered negligible. Hence the system is regarded as constituting isothermal flow conditions. Appendix G of HTM 02-01⁽⁴²⁾ provides a worked example of a pipeline pressure drop calculation.

8.3.5.3 Valve boxes

Each valve should have an identification bracket bolted directly onto the valve box for the purpose of applying an approved medical gas identification label.

8.3.5.4 Sizing of plant

The central plant should be sized with due allowance for standby equipment. It should be noted that the equipment must be specified clearly as to the volumetric, i.e. in terms of free air or rarified air at the required reduced pressure.

For medical vacuum systems it is normal to have two pumps rated at 75% of the total design flow since the actual demand at any one time will usually be met by one pump.

8.3.6 Guidance for specific medical gases

8.3.6.1 Oxygen

Oxygen is used primarily in ventilators and hyperbaric oxygen chambers. Oxygen should not be used to power ventilators if they are capable of being driven by medical air because of fire risks and costs. Liquid oxygen is likely to be the primary source of oxygen supply and an oxygen manifold from the tanks ('normal' and emergency) or cylinders provided as a standby/secondary reserve source.

To determine the potential daily demand, flows are measured between 8:00 am and 6:00 pm, with all

operating rooms in use and with maximum demand being provided to pipeline outlets. To obtain potential flow results, the engineer would best seek assistance from the facility manager who could investigate a similar working installation. It should *not* be based on the theoretical pipeline design flow conditions⁽⁴²⁾.

By following the above procedure, the appropriate size of the installation and the most suitable and cost-effective method of supplying medical oxygen can be determined.

Design and diversity flows for oxygen are shown in Table 8.14⁽⁴²⁾.

Table 8.14 Oxygen: design and diversified flows (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Department	Design flow rate for each terminal unit (litre/min)	Diversified flow rate, Q (litre/min)
In-patient accommodation (ward units)		
Single 4-bed rooms and treatment room	10	$Q_w = 10 + [(n - 1) 6/4]$
Ward block/department	10	$Q_d = Q_w [1 + (n_w - 1) / 2]$
Accident and emergency (A&E)		
Resuscitation room, per trolley space	100	$Q = 100 + [(n - 1) 6/4]$
Major treatment/plaster room, per trolley space	10	$Q = 10 + [(n - 1) 6/4]$
Post-anaesthesia recovery, per trolley space	10	$Q = 10 + [(n - 1) 6/8]$
Treatment room/cubicle	10	$Q = 10 + [(n - 1) 6/10]$
Operating		
Anaesthetic rooms	100	$Q = \text{no addition made}$
Operating rooms	100	$Q = 100 + (n_t - 1) 10$
Post-anaesthesia recovery		$Q = 10 + (n - 1) 6$
Maternity		
Labour, delivery, recovery and post-partum (LDRP) rooms:		
— mother	10	$Q = 10 + [(n - 1) 6/4]$
— baby	10	$Q = 10 + [(n - 1) 3/2]$
Operating suites:		
— anaesthetist	100	$Q = 100 + (n_s - 1) 6$
— paediatrician	10	$Q = 10 + (n - 1) 3$
Post-anaesthesia recovery	10	$Q = 10 + [(n - 1) 3/4]$
In-patient accommodation:		
— single/multi-bed wards	10	$Q = 10 + [(n - 1) 6/6]$
— nursery, per cot space	10	$Q = 10 + [(n - 1) 3/2]$
— special care baby unit (SCBU)	10	$Q = 10 + (n - 1) 6$
Radiological		
All anaesthetic and procedures rooms	100	$Q = 10 + [(n - 1) 6/3]$
Critical care areas	10	$Q = 10 + [(n - 1) 6] 3/4$
Coronary care unit (CCU)	10	$Q = 10 + [(n - 1) 6] 3/4$
High-dependency unit (HDU)	10	$Q = 10 + [(n - 1) 6] 3/4$
Renal	10	$Q = 10 + [(n - 1) 6/4]$
Continuous positive airway pressure (CPAP) ventilation	75	$Q = 75\ n \times 75\%$
Adult mental illness accommodation		
— electro-convulsive therapy (ECT) room	10	$Q = 10 + [(n - 1) 6/4]$
— post-anaesthesia, per bed space	10	$Q = 10 + [(n - 1) 6/4]$
Adult acute day care accommodation		
— treatment rooms	10	$Q = 10 + [(n - 1) 6/4]$
— post-anaesthesia recovery per bed space	10	$Q = 10 + [(n - 1) 6/4]$
Day patient accommodation	— as ‘In-patient accommodation’ —	
Oral surgery/orthodontic		
— consulting rooms, type 1	10	$Q = 10 + [(n - 1) 6/2]$
— consulting rooms, types 2 and 3	10	$Q = 10 + [(n - 1) 6/3]$
— recovery room, per bed space	10	$Q = 10 + [(n - 1) 6/6]$
Out-patient		
Treatment rooms	10	$Q = 10 + [(n - 1) 6/4]$
Equipment service rooms, sterile services etc.	100	Residual capacity will be adequate without an additional allowance

Notes:

Q = diversified flow for the department; Q_w = diversified flow for the ward; Q_d = diversified flow for the department (comprising two or more wards); n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed (not the individual numbers of terminal units where, in some cases, more than one is installed);

n_s = number of operating suites within the department (anaesthetic room and operating room); n_w = number of wards;

n_t = number of theatres

System configurations

BS EN ISO 7396-1⁽⁴⁶⁾ requires oxygen installations to have three independent supply sources capable of feeding medical oxygen to the pipeline:

- *Primary supply*: the main source of medical oxygen on site.
- *Secondary supply*: capable of providing the total oxygen flow requirement in the event of a primary supply failure.
- *Reserve supply*: capable of meeting the required demand in the event of failure of the primary and secondary supplies, or failure of the upstream distribution pipework.

Plant security and delivery access

Each supply system should be located in a secure fenced compound whilst the gas supplier's requirements for the discharge of the liquid oxygen from the cryogenic tanker in terms of the required clear access should be taken into consideration.

8.3.6.2 Nitrous oxide

When considering flow diversities for the purpose of pipe sizing, each terminal unit should be capable of 15 litre/min and 6 litre/min for the remainder.

Design and diversity flows for nitrous oxide are shown in Table 8.15⁽⁴²⁾.

8.3.6.3 Nitrous oxide/oxygen mixture

Whilst nitrous oxide is mainly for used for anesthetic equipment and occasionally for analgesic purposes, nitrous oxide/oxygen mixture (50/50 by volume) is used for the relief and management of pain.

Although flow would not normally exceed 20 litre/min, all terminal units should be capable of passing 275 litre/min for a 5-second duration to counter initial gasps by the patient.

The diversified flow in delivery rooms is based on 275 litre/min for the first bed space and 6 litre/min for each of the remainder⁽⁴²⁾.

Design and diversity flows for nitrous oxide/oxygen mixture are shown in Table 8.16⁽⁴²⁾.

Table 8.15 Nitrous oxide: design and diversified flows (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Department	Design flow rate for each terminal unit (litre/min)	Diversified flow rate, Q (litre/min)
Accident and emergency (A&E)		
Resuscitation room, per trolley space	10	$Q = 10 + [(n - 1) 6/4]$
Operating	15	$Q = 15 + (n_t - 1) 6$
Maternity		
Operating suites	15	$Q = 15 + (n_s - 1) 6$
Radiological		
All anaesthetic and procedures rooms	15	$Q = 10 + [(n - 1) 6/4]$
Critical care areas	15	$Q = 10 + [(n - 1) 6/4]$
Oral surgery/orthodontic		
Consulting rooms, type 1	10	$Q = 10 + [(n - 1) 6/4]$
Other departments	10	No additional flow included
Equipment service rooms, sterile services etc.	15	No additional flow included

Notes: Q = diversified flow for the department; n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed (not the individual numbers of terminal units where, in some cases, more than one is installed); n_s = number of operating suites within the department (anaesthetic room and operating room); n_t = number of theatres

Table 8.16 Nitrous oxide/oxygen mixture: design and diversified flows (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Department	Design flow rate for each terminal unit (litre/min)	Diversified flow rate, Q (litre/min)
Maternity		
Labour, delivery, recovery and post-partum (LRDP) rooms:		
— <12 LRDP rooms (mother)	275	$Q = 275 + [(n_s - 1) 6/2]$
— >12 LRDP rooms		$Q = (275 \times 2) + [(n_s - 1) 6/2]$
Other areas	20	$Q = 20 + [(n - 1) 10/4]$
Equipment service rooms, sterile services etc.	275	No additional flow included

Notes: Q = diversified flow for the department; n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed (not the individual numbers of terminal units where, in some cases, more than one is installed); n_s = number of operating suites within the department (anaesthetic room and operating room)

8.3.6.4 Medical air

Medical air (sometimes known as 'medical air 400') is supplied at 400 kPa, unlike surgical air which operates at 700 kPa.

It is used to provide power to inhalation equipment. The supply system may be:

- a manifold system,
- a compressor system
- a proportioning system (synthetic air) including an emergency/reserve manifold.

A compressor plant should always be specified where air-powered ventilators are to be used.

Medical air is also used for other equipment such as anesthetic gas mixers, humidifiers and nebulisers. There has been a considerable increase in the use of medical air

to provide power for patient ventilators. The flow rates normally required would not exceed 10 litre/min.

Pneumatically-powered ventilators use up to 80 litre/min free air continuously.

Design and diversity flows for medical air are shown in Table 8.17⁽⁴²⁾.

8.3.6.5 Surgical air

Surgical air is not required in maternity and is only required where surgical tools are to be used. The pressure requirements of surgical tools are between 600 and 700 kPa although distribution is usually at 800 kPa. Flows may vary between 200 and 350 litre/min (STP). Most surgical tools are designed to operate within this pressure range. Higher pressures are likely to cause damage to tools. Inadequate tool performance, however, is likely to result from the lack of flow at the specified pressure.

Table 8.17 Medical air (400 kPa): design and diversified flows (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Department	Design flow rate for each terminal unit (litre/min)	Diversified flow rate, Q (litre/min)
In-patient accommodation (ward units)		
Single 4-bed rooms and treatment room ^[1]	20	$Q_w = 20 + [(n - 1) 10/4]$
Ward block/department	20	$Q_d = Q_w [1 + (n_w - 1)/2]$
Accident and emergency (A&E)		
Resuscitation room, per trolley space	40	$Q = 40 + [(n - 1) 20/4]$
Major treatment/plaster room, per trolley space	40	$Q = 40 + [(n - 1) 20/4]$
Post-anaesthesia recovery, per trolley space	40	$Q = 40 + [(n - 1) 40/4]$
Operating		
Anaesthetic rooms	40	No additional flow included
Operating rooms	40	$Q = 40 + (n_t - 1) 40/4$
Post-anaesthesia recovery	40	$Q = 40 + (n - 1) 10/4$
Maternity		
Labour, delivery, recovery and post-partum (LDRP) rooms:		
— baby ^[2]	40	$Q = 40 + [(n - 1) 40/4]$
Operating suites:		
— anaesthetist	40	$Q = 40 + (n_s - 1) 40/4$
— post-anaesthesia recovery	40	$Q = 40 + (n - 1) 40/4$
Neonatal unit (special care baby unit (SCBU))	40	$Q = 40 n$
Radiological		
All anaesthetic and procedures rooms	40	$Q = 40 + [(n - 1) 40/4]$
Critical care areas^[3]		
	80	$Q = 80 + [(n - 1) 80/2]$
High-dependency unit (HDU)		
	80	$Q = 80 + [(n - 1) 80/2]$
Renal		
	20	$Q = 20 + [(n - 1) 10/4]$
Oral surgery/orthodontic		
Major dental/oral surgery rooms	40	$Q = 40 + [(n - 1) 6/2]$
All other departments		
Treatment rooms	40	No additional flow allowance to be made
Equipment service rooms		
	40	No additional flow included

Notes:

Q = diversified flow for the department; Q_w = diversified flow for the ward; Q_d = diversified flow for the department (comprising two or more wards); n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed (not the individual numbers of terminal units where, in some cases, more than one is installed); n_s = number of operating suites within the department (anaesthetic room and operating room); n_w = number of wards; n_t = number of theatres

[1] It is assumed that a patient will use oxygen in a ward or in the treatment room.

[2] Where two spaces have been provided in an LDRP room, assume only one will require medical air.

[3] The diversified flow is also used for helium/oxygen mixture.

The introduction of synthetic air (from on-site blending of oxygen and nitrogen) leads to the possibility of using nitrogen as the power source for surgical tools. Although, obviously, the designer has to decide on the most cost effective way of providing the necessary pneumatic power, such a system could be considered as part of a back-up arrangement.

Pressure and flow requirements for surgical air are shown in Table 8.18⁽⁴²⁾.

Table 8.18 Pressure and flow requirements for surgical air (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Tool	Pressure / kPa	Flow rate / litre·min ⁻¹
Small air drill	600–700	200
Medullary reaming machine	600–700	350
Oscillatory bone saw	600–700	300
Universal drill	600–700	300
Craniotome	620–750	300

8.4 Medical vacuum

A medical vacuum system can be described as a piped distribution system from a prime mover (generally in the form of an electrically operated pump) terminating in a number of outlet points which give facilities for obtaining a vacuum or a negative pressure service.

The degree of vacuum can be expressed as either an absolute or relative value.

- *barometric pressure*: the pressure of the prevailing atmosphere
- *absolute pressure*: the pressure measured from absolute zero
- *vacuum*: barometric pressure minus atmospheric pressure
- *gauge pressure*: absolute pressure minus barometric pressure.

These degrees of vacuum/pressure are illustrated in Figure 8.4. Absolute pressure is usually referred to as being 30" Hg (i.e. inches of mercury), 1013 mbar, or 760 torr barometer. Barometric pressure is usually referred to as being 14.7 psi (atmospheric pressure), 1013 mbar, or 760 torr.

Specialist vacuum firms always measure the degree of vacuum with atmosphere at 30" Hg or 760 torr and

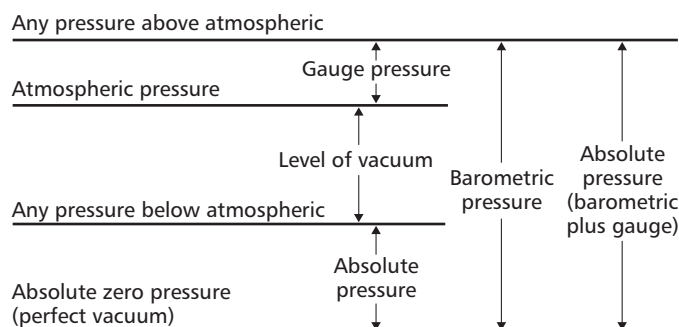


Figure 8.4 Comparison of pressure/vacuum levels

ultimate vacuum as 0, whereas engineers think of vacuum in reverse, whereby atmospheric pressure is 0 and the ultimate vacuum is 760 torr or 30" Hg.

For the purpose of this Guide, 0 will be taken as ultimate vacuum and 30" Hg or 760 torr as atmospheric pressure.

8.4.1 Classification of vacuum

Generally in vacuum technology the pressure levels are divided into three categories:

- *low or rough vacuum*: 90 to 125 torr
- *medium vacuum*: 10 to 15 torr
- *high vacuum*: up to 1 torr.

8.4.2 General design criteria

When selecting the pumps for any system the following factors should be considered:

- initial cost of the installation
- maintenance and servicing cost
- power requirements
- size and space available for the plant.

Table 8.19 gives approximate pipe sizes for vacuum plants.

Table 8.19 Approximate pipe sizes for vacuum

Number of points connected	Pipe size / mm
Up to 24	28
25 to 50	42
50 to 150	54
150 to 200	67
Over 200	76

8.4.3 System calculations

The actual flow through the system varies with the pressure and temperature. However, the temperature changes within the system are very minor and are considered negligible. Hence the system is regarded as constituting isothermal flow conditions.

Sizing can be undertaken using equation 8.7:

$$P_1^2 - P_2^2 = \frac{32 q_m^2 R T}{\pi^2 d^4} \left[\frac{\lambda l}{2d} + \ln \left(\frac{P_1}{P_2} \right) \right] \quad (8.7)$$

where P_1 and P_2 are pressures (kPa), q_m is the mass flow rate ($\text{kg}\cdot\text{s}^{-1}$), R is the gas constant ($\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$), λ is the friction factor, l is pipe length (m) and d is the pipe diameter (mm).

The term involving natural logarithms is often small and can be neglected. Hence this equation can be re-written as:

$$P_1 - P_2 = \frac{64 m^2 R T \lambda l}{\pi^2 d^5} \quad (8.8)$$

A method for calculating pressure drops in pipes is given in CIBSE Guide C⁽⁴⁷⁾: *Reference data*. Specific gravities, densities and dynamic viscosities for medical gases are given in Table 8.20.

Calculation of the flow volume is based upon the standard equation:

$$P V = \text{constant} \quad (8.9)$$

Table 8.20 Vacuum: design and diversified flows (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

Department	Design flow rate for each terminal unit (litre/min)	Diversified flow rate, Q (litre/min)
In-patient accommodation		
Ward unit	40	$Q = 40$
Multiple ward unit	40	$Q_d = 40 + [(n - 1) 40/4]$
Accident and emergency (A&E)		
Resuscitation room, per trolley space	40	$Q = 40 + [(n - 1) 40/4]$
Major treatment/plaster room, per trolley space	40	$Q = 40 + [(n - 1) 40/4]$
Post-anaesthesia recovery, per trolley space	40	$Q = 40 + [(n - 1) 40/4]$
Treatment room/cubicle	40	$Q = 40 + [(n - 1) 40/4]$
Operating		
Anaesthetic rooms	40	No additional flow included
Operating rooms:		
— anaesthetist	40	$Q = 40$
— surgeon	40	$Q = 40$
Operating suites	40	$Q = 80 + [(n_s - 1) 80/2]$
Post-anaesthesia recovery	40	$Q = 40 + [(n - 1) 40/4]$
Maternity		
Labour, delivery, recovery and post-partum (LDRP) rooms:		
— mother	40	$Q = 40 + [(n - 1) 40/4]$
— baby	40	No additional flow included
Operating suites:		
— anaesthetist	40	$Q = 40$
— obstetrician	40	$Q = 40$
Operating suites:		$Q = 80 + [(n_s - 1) 80/2]$
Post-anaesthesia recovery	40	$Q = 40 + [(n - 1) 40/4]$
In-patient accommodation:		
— ward unit comprising single, multi-bed and treatment room	40	$Q = 40$
— multi-ward units	40	$Q = 40 + [(n - 1) 40/4]$
— nursery (cot space)	40	No additional flow included
— special care baby unit (SCBU)	40	$Q = 40 + [(n - 1) 40/4]$
Radiology/diagnostic departments		
All anaesthetic and procedures rooms	40	$Q = 40 + [(n - 1) 40/8]$
Critical care areas	40	$Q = 40 + [(n - 1) 40/4]$
High-dependency unit (HDU)	40	$Q = 40 + [(n - 1) 40/4]$
Renal	40	$Q_d = 40 + [(n - 1) 40/4]$
Adult mental illness accommodation		
— electro-convulsive therapy (ECT) room	40	$Q = 40 + [(n - 1) 40/4]$
— post-anaesthesia, per bed space	40	$Q = 40 + [(n - 1) 40/4]$
Adult acute day care accommodation		
— treatment rooms	40	$Q = 40 + [(n - 1) 40/4]$
— post-anaesthesia recovery per bed space	40	$Q = 40 + [(n - 1) 40/8]$
Day patient accommodation	— as ‘In-patient accommodation’ —	
Oral surgery/orthodontic		
— consulting rooms, type 1	40	Dental vacuum only
— consulting rooms, types 2 and 3	40	Dental vacuum only
— recovery room, per bed space	40	$Q = 40 + [(n - 1) 40/8]$
Out-patient		
Treatment rooms	40	$Q = 40 + [(n - 1) 40/8]$
Equipment service rooms, sterile services etc.	40	Residual capacity will be adequate without an additional allowance

Notes:

Q = diversified flow for the department; Q_d = diversified flow for the department (comprising two or more wards); n = number of beds, treatment spaces or single rooms in which the clinical procedure is being performed (not the individual numbers of terminal units where, in some cases, more than one is installed); n_s = number of operating suites within the department (anaesthetic room and operating room)

where P is the absolute pressure at any given point and V is the volume at that point.

Hence the method of calculation for the flow volume at any point in the system is:

$$P_1 V_1 = P_2 V_2 \quad (8.10)$$

The pipe diameter is calculated using the equation:

$$Q_v = V \times A \quad (8.11)$$

where Q_v is the volumetric flow rate ($\text{m}^3 \cdot \text{s}^{-1}$), V is the velocity ($\text{m} \cdot \text{s}^{-1}$) and A is the cross-sectional area of the pipe (m^2).

Substituting for A in equation 8.11 gives:

$$Q_v = \frac{V \times \pi d^2}{4} \quad (8.13)$$

where d is the pipe diameter (m).

Hence, by rearranging:

$$d = \left(\frac{4 Q_v}{V \times \pi} \right)^{0.5} \quad (8.14)$$

The velocity in the pipeline is normally limited to 25 m/s.

Design and diversified flowrates for vacuum are given in Table 8.21.

8.4.4 Rotary vane pumps

Rotary vane machines are widely used in small-capacity applications as high vacuum devices. Their ease of manufacture provides lower initial costs. Power requirements are also lower due to their high volumetric efficiency. They can provide a high vacuum in a single-stage unit and are quiet in operation. Because few moving parts are involved, they suffer less wear and provide smooth-vibration free running.

The disadvantages of rotary vane pumps are their sensitivity to abrasive carryover and the fact that vapours could be contaminated by the lubrication system. They can only handle liquid carryover in smaller quantities and are mainly used for small capacity dry vacuum systems. They are also prone to discharging quantities of oil with air and specialist servicing is necessary.

8.4.5 Equipment and materials

For lower vacuum systems, gas barrel tube with threaded fittings provides a satisfactory service, but for higher vacuum systems copper tube with capillary fittings has proved to be most suitable and reliable.

In systems where actual liquids are carried over in the system it is necessary to introduce drainage traps to prevent the liquid from entering the pumping mechanism. In multi-storey buildings, the traps are normally located at the base of the risers and the design should be such that the main vacuum lines are still operational when the traps

are emptied. In single storey buildings it is normal to have a trap on each branch.

In medical vacuum systems, certain services may also need bacterial filters. The sizing and location of these filters should be as described in HTM 02-01⁽⁴²⁾. In order to prevent the duty pumps from running continuously it is advisable to install vacuum reservoirs for light loads. The reservoir is sized at approximately at 25% capacity of the design full load and should comply with BS EN 286-1⁽⁴⁰⁾.

A typical vacuum plant, see Figure 8.5, consists of the following components:

- three identical pumps
- a vacuum reservoir with by-pass facilities
- duplex bacteria filters with drainage traps
- non-return valves
- isolating valves
- gauges and pressure switches
- an operating and indicating system
- an exhaust system
- a flow test connection.

For capacities in excess of 500 litre/min, two vessels that can be independently isolated should be installed.

On-site testing must be witnessed by the contractor and a test sheet summarising the important points of each test must be issued to the contractor immediately after the tests have been completed.

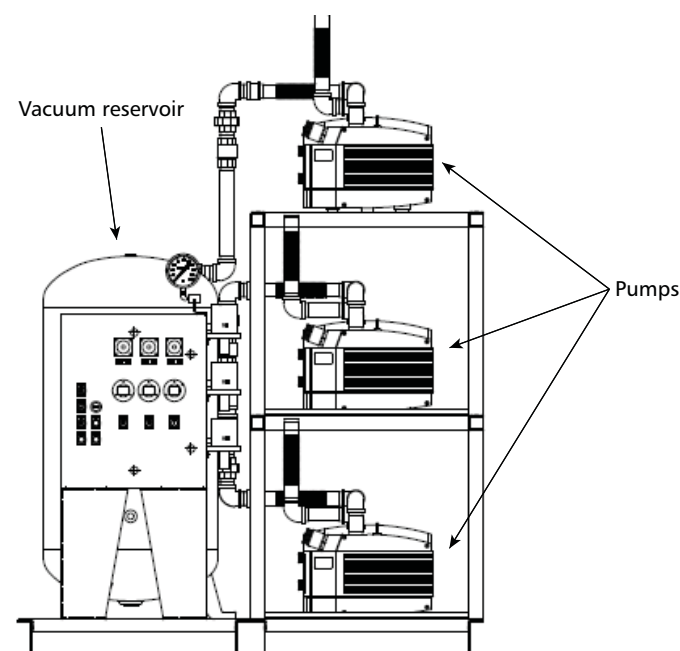


Figure 8.5 Typical triplex vacuum plant

8.5 Non-medical vacuum

It is important to note that a laboratory vacuum system (non-medical) should never be interconnected with any medical vacuum system. There is always the possibility of bacteria being carried from the laboratory systems and finding their way into the medical system and consequently to the patients in the wards or theatres.

Laboratory vacuum systems are generally used for removing air and fluids from waxed tissue and evacuating anaerobic jars.

The guidelines laid down for the classification of volume, system calculations, equipment and materials, testing and commissioning for medical vacuum also apply for non-medical vacuum systems.

8.5.1 General design criteria

The guidelines laid down for the medical vacuum systems also apply for non-medical systems. Non-medical systems serving laboratories in colleges and universities are more critical as the users may demand more accurate control of the line pressures. Large pressure differentials are not acceptable when carrying out long-term experiments.

The central vacuum plant pump should be rated at 100% duty and standby or three pumps at 50% design duty to allow maintenance and servicing of the plant without reduction in the system capacity.

The exhaust gases should be discharged to atmosphere above the roof level away from inlets to other air plants. These should be positioned so as to avoid any risk or ignition in the event of any flammable mixtures being discharged.

8.5.2 Design loadings

For most laboratory applications low- and medium-vacuum pressure levels are normally sufficient. The design flow rates (free air) vary from 0.1 to 0.3 litre·s⁻¹ at each bench inlet.

Note that for dental departments the vacuum service is usually referred to as 'dental suction' and is mainly used for removing saliva and water sprayed on the dentist's drill and the region of drilling. Vacuum service to dental chairs is often provided by local plant and a special characteristic of high flow (approximately 5 litre·s⁻¹ of free air) is required, with outlet to the waste system. The operation of a pipeline pump to produce a vacuum of 0.65 to 0.75 bar absolute pressure has been found adequate.

8.5.3 Simultaneous demands

Diversities for non-medical vacuum services. The distribution pipework should be sized using these diversities and the appropriate flow rates. Diversities for vacuum systems in laboratories are shown in Figure 8.6.

8.5.4 Pathology departments

For pathology departments a vacuum at bench fittings of 0.48 bar absolute pressure is normally adequate, the flow rate being 0.5 litre·s⁻¹ of free air. Bench fittings are often throttled to either 0.1 or 0.34 litre·s⁻¹ to limit the size of the plant required, the basis of determination being to allow 0.5 litre·s⁻¹ for the first fitting connected and 0.1 litre·s⁻¹ for each of the remainder.

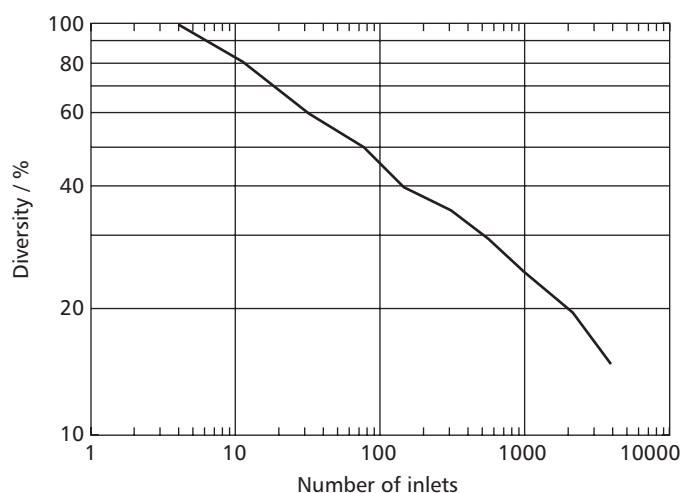


Figure 8.6 Laboratory vacuum system diversity

Pathology laboratory systems may draw-in acid vapours and solvent gases that can damage the vacuum plant. In such cases water-sealed vacuum pumps with casings, impellers and air-vessels designed to cope with these contaminants need to be used. The users should be consulted to confirm the quality of substances likely to be drawn into the system.

If any explosive substances are likely to be entrained in the distribution system then portable or water-jet pumps should be used to evacuate such substances.

8.6 Pipework system installation

8.6.1 Removal of pipework

Cutting out and removing or capping-off existing redundant pipework and equipment should only be undertaken by specialist medical gas contractors and should not be undertaken by general demolition contractors.

8.6.2 Piping and materials

Pipes must be free of grease and contaminants. Manufacturers can supply the specially cleaned and degreased BS EN 1057⁽⁴⁸⁾ copper tube and fittings as necessary on request. The tube is cleaned by a variety of methods including combinations of steam cleaning and drying, shot blasting, solvent degreasing followed by blowing through with medical quality air. Once cleaned and degreased, plastic end caps are fitted to the tube to prevent further contamination before bundling and labeling medical gas pipes. Fittings and valves, (preferably lever-operated ball type) are supplied cleaned and degreased in sealed, similarly labeled plastic bags.

In general, the diameter of pipes tends to reduce from source to end of distribution system. Good system design requires that risers be larger than laterals, and laterals be larger than drops.

Medical gas pipelines should not be routed alongside natural gas pipelines where there is the potential for a

flammable gas mixture to accumulate in the case of a leak⁽⁴²⁾.

Exposed piping should be protected against physical damage, corrosion etc. and not be installed in kitchens, laundries, lift shafts, generator rooms, electrical switch-gear rooms or areas/corridors where movement of equipment may cause physical damage.

The installation and any subsequent modifications to the system should only be carried out by specialist contractors registered to BS EN ISO 9000⁽⁴⁹⁾.

8.6.3 Jointing methods

Copper-to-copper joints should be made by brazing. Brazing filler rods can be used without flux and in the presence of oxygen-free nitrogen, which may be blown through the pipeline during brazing to prevent oxide formation. Alternatively, mechanical joints can be used. Mechanical connections should have comparable structural integrity to brazed fittings in normal operation and in the event of fire.

8.6.4 Labelling and marking

Pipelines should be durably marked with the gas name/symbol at least every 10 m and adjacent to valves, junctions, changes of direction or where it penetrates walls.

A visual check must be made on each pipeline system to ensure that the pipelines are labelled in accordance with the contract specification, and that the terminal unit base blocks are marked in accordance with BS EN ISO 9170-1⁽⁵⁰⁾, as required by HTM 02-01⁽⁴²⁾.

8.6.5 Testing and commissioning

Testing is vital to ensure the integrity of the system through pressure tests, testing for leakage and the like, testing for quality but also to ensure no cross connection takes place. The piped medical gas system is tested over a 2-hour period. The maximum pressure loss should be less than 0.2 kPa for 400 kPa systems and vacuum 0.5 kPa for 700 kPa systems with no allowance made for variation of pressure with temperature.

Both BS EN ISO 7396-1⁽⁴⁶⁾ and HTM 02-01⁽⁴²⁾ give extensive guidance on testing and commissioning to be followed by the installer.

8.6.6 Cross-connection

Before the tests are performed, any links between systems should be removed and all pipelines should be at atmospheric pressure with all AVSUS (area valve service units) open. All systems must be checked to ensure that there is no cross-connection between pipelines for different gases and vacuum. The tests should not commence until all installations are complete and plant operational.

8.6.7 Filling with medical air

There can be extended periods between the installation, testing and operational phases. All medical gas pipe systems should therefore be left filled with medical air at pipeline distribution pressure until they are filled with the specific working gas shortly before use. The medical vacuum pipeline need not be maintained under vacuum.

8.6.8 Storage, production and distribution

The sizing of the storage/production facility for any of the services below should be based on estimated usage and frequency of delivery by the chosen supplier. Whilst some published guidance is available, ultimately it should be defined by hospital management in consultation with the equipment manufacturer and the gas supplier.

Possible sources include the following:

- gas in cylinders
- non-cryogenic liquid in cylinders
- cryogenic liquid in mobile vessels
- cryogenic liquid in stationary vessels
- an air compressor system
- a proportioning system
- a vacuum system.

A typical liquid cylinder manifold installation with cylinder back-up is illustrated in Figure 8.7⁽⁴²⁾.

For each supply there should be three sources: primary, secondary and reserve. Once the primary supply is exhausted, or being maintained, the secondary supply is automatically activated. The third (emergency) supply is for emergency use only and should be connected after the main isolating valve. For all services except surgical air an emergency inlet point should be provided, again after the main isolating valve. Layouts and suitable valve arrangements are given in BS EN ISO 7396-1⁽⁴⁶⁾.

All inlet and outlet points should be gas-specific, typically by using non-interchangeable screw threads.

Except for air, pressure relief should be vented to a safe place outside the building. As with all medical gas pipelines, care should be taken that air from the compressor system is used only for the purpose(s) for which it is designated.

Air for breathing should have the three sources made-up from a selection of the following: a compressor unit, a single cylinder bank or a proportioning unit. All sources should be treated separately and not rely on a component of another system. For example, where compressors make-up more than one source, the system should have at least two conditioning systems to ensure there is not a shared point of failure.

Air for surgical tools requires only two sources as, in emergencies, portable equipment is provided.

Receivers should comply with BS EN 286-1⁽⁴⁰⁾, valved to allow individual maintenance and with individual shut off

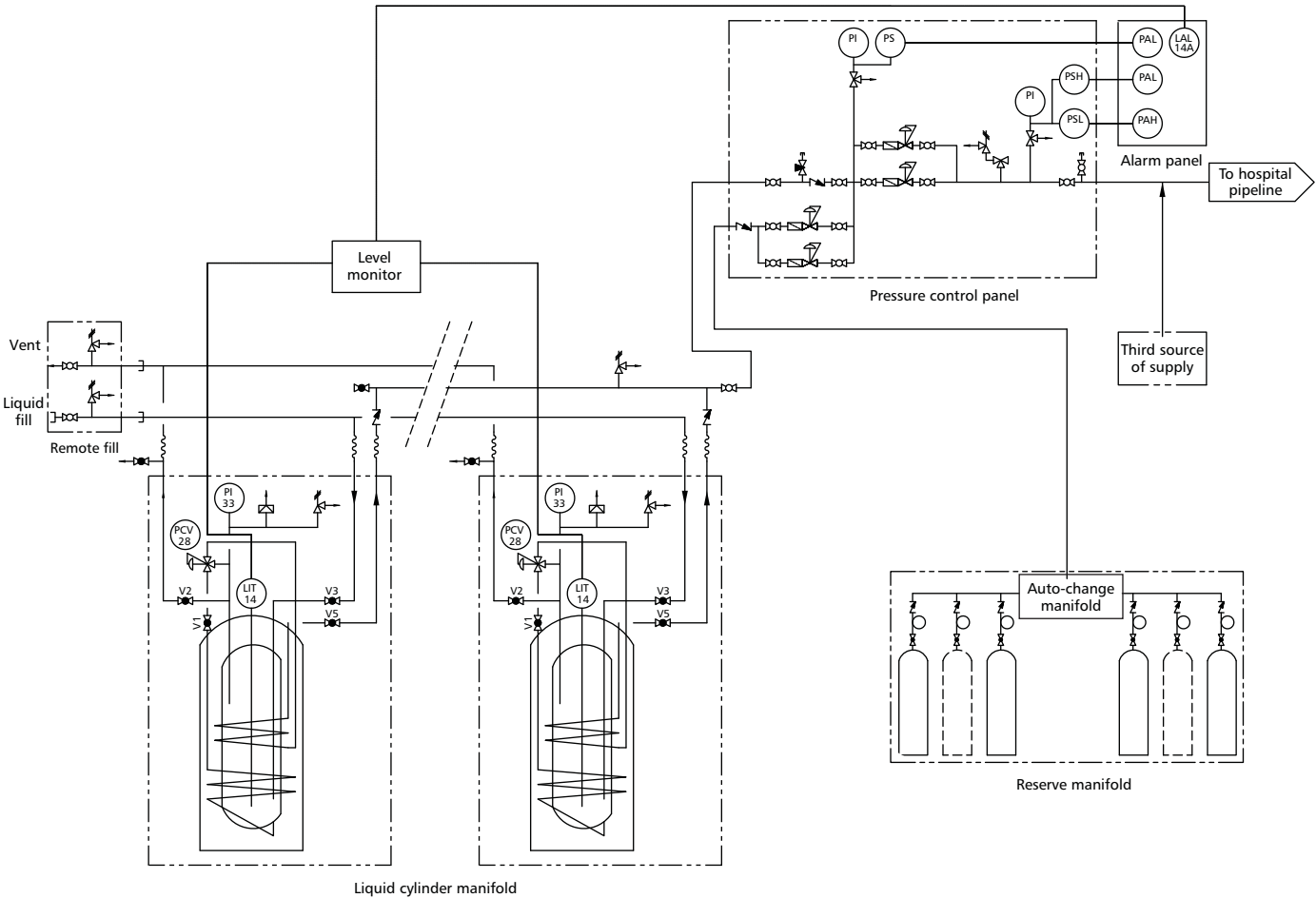


Figure 8.7 Typical liquid cylinder manifold installation with cylinder back-up (reproduced from HTM 02-01⁽⁴²⁾; Crown copyright)

valves, automatic drains, pressure gauges and pressure relief valves.

Air intakes should be away from possible sources of contamination such as engine exhausts, ventilation exhausts, vacuum systems and the like. It should also be fitted with a filter to prevent the ingress of dirt and insects etc.

Connection between compressors and the pipeline should be flexible to prevent vibration transmission.

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9 Steam and condensate

9.1	Introduction
9.2	Boilerhouse
9.3	Flow metering
9.4	Steam distribution
9.5	Steam trapping and air venting
9.6	Control of steam pressure
9.7	Pipeline ancillaries
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Summary

Steam for humidification in air conditioning systems, sterilization in health care and associated industries, hot water generation via plate heat exchangers (PHE) and cooling through absorption chillers are common modern day applications. This chapter provides an overview of the design and operation of steam systems. Key considerations explored within the chapter include boilers and boiler house design, steam distribution, flow metering, steam trapping and air venting, control of steam pressure, valves, condensate removal and recovery, and flash steam. Worked examples of calculations are provided, with extensive diagrams to assist the engineer.

9.1 Introduction

9.1.1 General

The use of steam in building services is often overlooked on the assumption that there is no place for it in a modern system. It is true that steam as a means of directly heating a building is less common but its unique properties mean that it is very much a fluid for the 21st century. These unique properties are:

- **Sterility:** steam itself is a sterile medium and is used extensively as part of the process of product sterilisation in healthcare and the food, beverage and pharmaceutical industries. This sterility is an important benefit of using steam to provide humidification in an air conditioning system.
- **High heat content:** a high heat content means smaller pipes are required to transmit a given amount of heat compared to, say, a water-based system.
- **High heat transfer value:** when steam gives up its heat, this change of state from a gas to liquid results in a very high heat transfer rate. With steam, the heat is transferred at a constant primary temperature, which means that there are no hot or cold spots in the heat exchanger. The high heat transfer rate means heat exchangers can be smaller in size, saving valuable plantroom floor area.
- **Ease of distribution:** no pumps are required to move the steam around the pipework system. This avoids the need for complex system balancing. Control of flow (which in turn controls pressure, temperature or humidity etc.) is achieved using 2-port valves only.

- **Flexibility:** A single steam supply to a plantroom can provide the means to heat, cool (through absorption chillers) and humidify. Multi-fuel use can be easily accommodated. The flexibility of steam distribution systems means that the system can be modified without creating balancing problems. Steam storage enables energy to be stored to cope with peak loads.

9.1.2 Overview of a typical steam and condensate system

A basic steam and condensate system is shown in Figure 9.1

Mains cold water is passed through a softening plant to the boiler feedwater storage tank, to which condensate is also returned. The tank is usually fitted at high level and is heated to at least 85 °C to drive off oxygen, hence reducing possible corrosion. Water treatment chemicals are added to the tank, or the feedwater leaving it, to reduce scale formation and corrosion of the system.

Water from the tank is pressurised by the boiler feedwater pump and enters the boiler through a check valve. Level controls on the boiler maintain the required water level in the boiler and switch off the burner if low water level is sensed.

As the water is evaporated in the boiler the concentration of dissolved solids in the boiler increases and, to control the concentration, a controlled amount of water is 'blown down' from the boiler. Heat energy from this blowdown water is recovered and used to heat the boiler feedwater. The cooler blowdown water then enters a blowdown vessel where it is cooled before being discharged to waste.

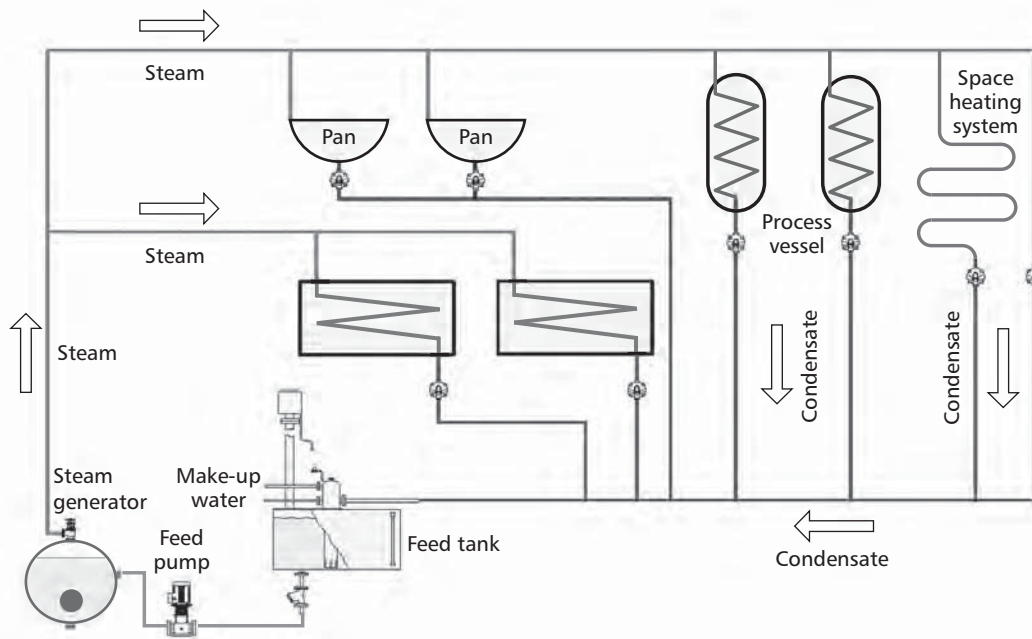


Figure 9.1 Schematic of a basic steam and condensate system

Periodic blowdown from the bottom of the boiler is carried out to remove any dirt that may have gathered. This blowdown is taken direct to the blowdown vessel.

Steam is generated and distributed at high pressure and generally used at low pressure.

Within the steam-using equipment, the steam condenses and transfers heat to a secondary medium. A steam trap is needed to 'trap' the steam but release the condensate formed. This condensate is a valuable source of both heat and treated water, so is recycled to the boiler feed tank.

9.1.3 Properties of steam

Steam tables are used to determine the key properties of steam, see CIBSE Guide C⁽¹⁾, chapter 2.

Steam flows in a pipe due to the change in volume as it condenses in the heat exchange process and forms condensate. Steam does not require a circulating pump.

Steam tables show that the heat content of condensate changes with its pressure. For example, when condensate at 10 bar (gauge) passes through a steam trap to atmospheric pressure, its heat content reduces from 782 kJ/kg to 419 kJ/kg. The difference in heat content is the result of evaporation of some of the low-pressure condensate to produce 'flash' steam, which can be recovered and used elsewhere.

Example

1000 kg/h of condensate at 10 bar(g) passes through a steam trap to atmospheric pressure. How much flash steam will be produced?

Enthalpy of water at 10 bar(g) = 782 kJ/kg

Enthalpy of water at 0 bar(g) = 419 kJ/kg

Heat available to produce flash steam at 0 bar(g) is:
 $(782 - 419) = 363 \text{ kJ/kg}$.

To evaporate 1 kg of condensate at 0 bar(g) into steam requires 2257 kJ. Therefore, 363 kJ will produce $(363/2257) = 0.16 \text{ kg}$ of flash steam per kg of condensate.

From 1000 kg/h of condensate, 160 kg/h of flash steam will be produced. The pipe after the steam trap will therefore be carrying 840 kg/h of condensate and 160 kg/h of flash steam.

9.1.4 Classification of steam and steam quality

9.1.4.1 Dry saturated steam

Steam with a temperature equal to the boiling point of water at that pressure and containing no water particles is known as dry saturated steam (i.e. the water from which it is produced has been saturated with heat energy) and its properties are those in the steam tables.

9.1.4.2 Wet steam

In practice, because of turbulence and splashing in a boiler the steam space above the water will contain a mixture of steam and water particles. The mixture leaving the boiler is known as wet steam. Wet steam can also result from steam picking-up condensate particles in pipework. If the water content of the mixture is 5% by mass, the steam is said to be 95% dry and has a dryness fraction of 0.95.

Because of the water content, the heat energy within wet steam is less than that of dry saturated steam. Importantly, the enthalpy of evaporation (the normal usable energy content of steam) is less, so the heat output of plant can be affected.

Example

Steam at 7 bar(g) has a dryness fraction of 0.96. In the condensation process, how much heat energy is transferred compared to that of dry saturated steam?

Enthalpy of dry steam at 7 bar(g) = 2047 kJ/kg

Enthalpy of 96%-dry steam = $2047 \times 0.96 = 1965 \text{ kJ/kg}$

Water particles in wet steam can also cause erosion of pipes and fittings. To dry the steam it is usual to fit a steam separator after the boiler crown valve. Separators may also be fitted before steam flow meters and pressure reducing valves.

Steam pipes should also be regularly drained to prevent the build-up of condensate and hence steam picking-up the water.

9.1.4.3 Superheated steam

Superheated steam is rarely used for heating applications because it must lose its degree of superheat by cooling before it reaches saturation temperature, when it condenses and gives up its enthalpy of evaporation. The time taken whilst cooling takes place reduces the heat output of plant.

Superheat is also to be avoided where steam is used for sterilisation.

9.1.5 Steam consumption

When steam condenses it is the enthalpy of evaporation (kJ/kg) that is transferred from the steam to the secondary medium across the heating surface. This value is used to convert the heat energy required (kJ/s), to the flow rate of steam (kg/h) required to provide this energy.

Example

An air heater is rated at 200 kW (200 kJ/s) when supplied with steam at 4 bar(g). How much steam does the heater require to satisfy this demand? What will be the condensate flow rate leaving the heater?

$$\text{Steam flow required} = \frac{\text{Energy required (kJ/s)}}{\text{Enthalpy of evaporation (kJ/kg)}}$$

Enthalpy of evaporation at 4 bar(g) = 2108 kJ/kg

Therefore, steam flow rate required
 $= 200/2108 = 0.095 \text{ kg/s}$ or 341 kg/h.

Condensate flow rate will be the same as the steam flow rate, 341 kg/h.

9.2 Boilerhouse

9.2.1 Introduction

See CIBSE Guide B, chapter 1⁽²⁾, for a description of the types of boiler used to produce steam.

A typical steam boiler house and associated plant is shown in Figure 9.2 (page 9-4).

The objectives of a steam boiler are to:

- release the energy in the fuel as efficiently as possible
- transfer the released energy to the water, and to generate steam, as efficiently as possible
- separate the steam from the water for export to the plant, where the energy can be transferred to the process as efficiently as possible.

Modern steam boilers are available to suit both large and small applications. Generally, where more than one boiler is required to meet the demand, it becomes economically viable to house the boiler plant in a centralised location, as installation and operating costs can be significantly lower than with decentralised plant.

9.2.2 Design of steam header and off-takes

When two or more boilers are fitted in parallel, the pressure drop in the steam off-takes to the common header should be as near equal as possible (within 0.1 bar). This will prevent one boiler being more heavily loaded than the other and will minimise carryover and help to prevent overload and boiler lock-out. Figure 9.3 shows the recommended layout.

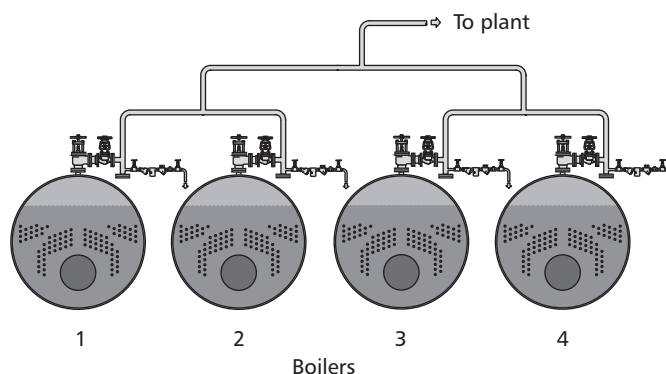


Figure 9.3 Recommended design of off-takes for multiple steam boilers (courtesy of Spirax-Sarco)

9.2.3 Steam quality

Boiler overloading, poor control of boiler water total dissolved solids (TDS), or contamination of boiler feed-water will result in wet steam being discharged from the boiler. To dry the steam, a separator fitted in the off-take from the boiler, as near as possible to the boiler, is recommended.

Separators work by forcing the steam to rapidly change direction. This results in the much denser water particles being separated from the steam due to their inertia, and then encouraged to gravitate to the bottom of the separator body, where they collect and drain away via a steam trap.

9.2.4 Warm-up of steam system

It is essential that when a boiler is brought on-line, it is done in a slow, safe and controlled manner to avoid:

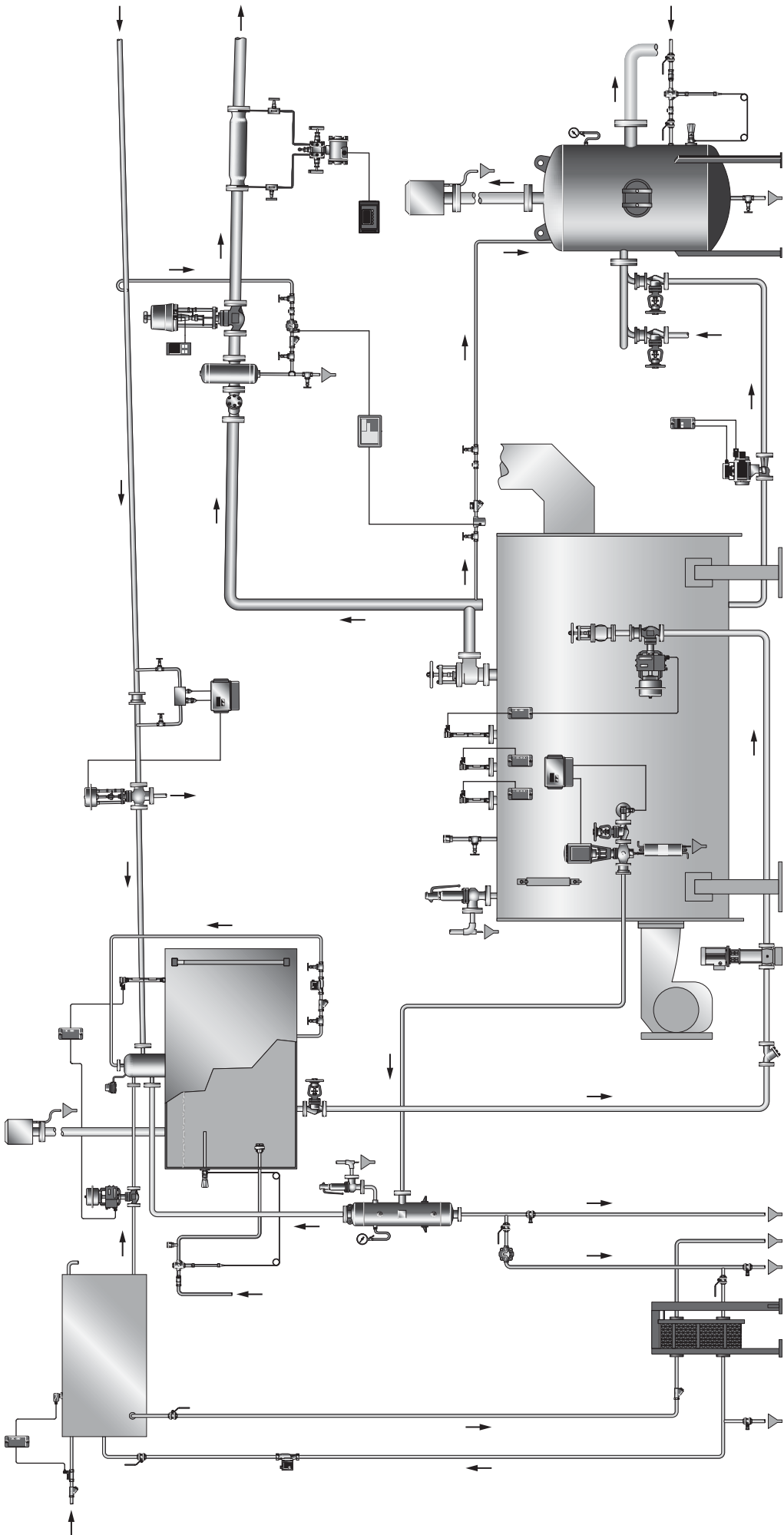


Figure 9.2 Typical packaged shell boiler and associated plant (courtesy of Spirax-Sarco)

- *Waterhammer*: where large quantities of condensate lie inside the pipe and are then pushed forwards or sucked back along the pipe at high velocity. This can result in damage when the water impacts with an obstruction in the pipe, e.g. a control valve.
- *Thermal shock*: where the pipework is being heated so rapidly that the expansion is uncontrolled, setting up stresses in the pipework and causing large movement on the pipe supports.
- *Priming*: where the sudden reduction of steam pressure caused when a large load is suddenly applied may result in boiler water being pulled into the pipework. Not only is this bad for plant operation but often results in boiler 'lock-out', from which it will take some time to return to operational status. The discharged water can also give rise to waterhammer in the pipework.

The warm-up period depends on many factors and will be different for every plant. A small low-pressure boiler in a compact plant such as a laundry, for example, could be brought up to operating pressure in less than 15 minutes whereas a large complex may take many hours. The starting point, when safely bringing a small boiler on line, is the main stop valve, which should be opened slowly.

On larger plants the rate of warm-up is difficult to control using the main stop valve. This is because the prime function of the main stop valves is to provide good isolation. For this reason it is good practice to install a control valve after the main stop valve to ensure the flowrate, and hence warm-up rate, is better controlled.

9.2.5 Preventing unwanted pressurisation

Where two or more boilers are connected to a common header, a means of double isolation must be provided. This allows better protection for a decommissioned boiler when isolated from the distribution header.

Unless a separate non-return valve is fitted in the steam connection, one of the two stop valves must incorporate a non-return facility.

Double isolation (using two valves or a special single-bodied valve) may also be required downstream of the boilerhouse to ensure maintenance can be safely carried out.

9.2.6 Ensuring proper steam distribution

It is often convenient for the boiler steam lines to converge at a steam manifold usually referred to as the main distribution header, see Figure 9.4. The size of the header will depend upon the number and size of boilers and the design of the distribution system.

It provides an extra separating function if the boiler separator is overwhelmed, and a means of allowing the attached boilers to share the distribution system load.

Diameter

The header diameter should be calculated with a maximum steam velocity of 15 m/s under full-load conditions (15 m/s would be a low velocity in a steam system; typical velocities for saturated steam would be 25–40 m/s). Low velocity is important as it helps any entrained moisture to fall out.

Off-takes

These should always be from the top of the distribution header. This ensures that only dry steam is exported.

Steam trapping

It is important that condensate is removed from the header as soon as it forms. If the header is the first trapping point after the boiler off-takes, the condensate can contain carryover particles and it may be useful to

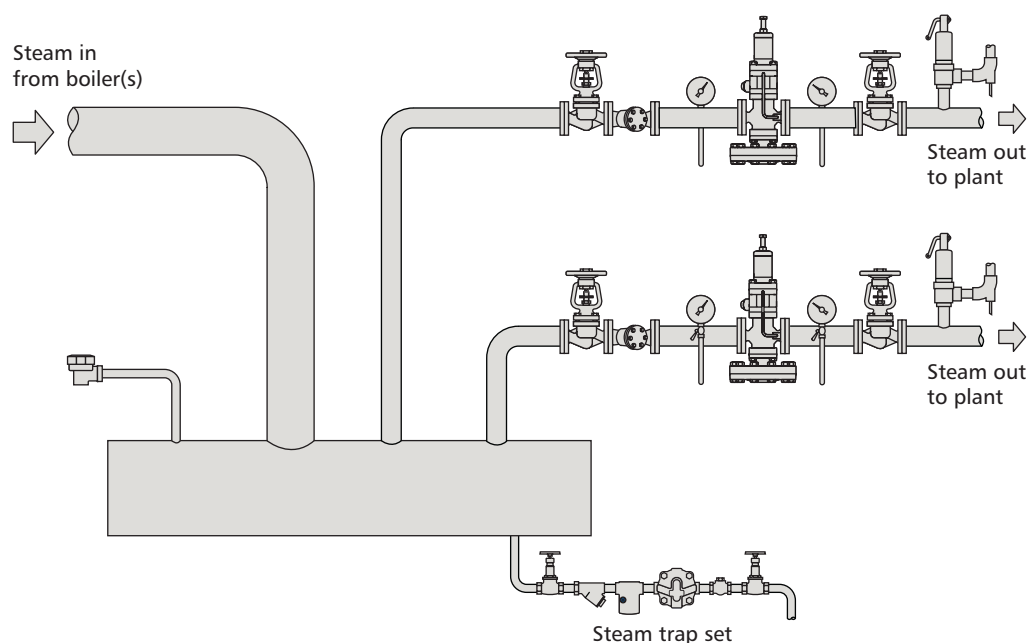


Figure 9.4 Typical steam distribution manifold (courtesy of Spirax-Sarco)

drain this steam trap into the boiler blowdown vessel, rather than the boiler feedtank.

9.2.7 Feedwater for steam boilers

The supply of water to the steam boiler comes from the feedtank. The water in the feedtank must be kept at a high temperature to minimise the content of dissolved oxygen and other gases. Feedtanks should be maintained at a minimum temperature of 85 °C. This reduces the amount of oxygen scavenging chemicals required as well as preventing thermal shock in the boiler.

9.2.8 Blowdown, TDS control, and heat recovery

9.2.8.1 Boiler blowdown

Suspended solids in boiler water drop to the bottom of the boiler and, if allowed to accumulate, will form a sludge that inhibits heat transfer from the boiler firetubes, leading to the tubes overheating.

The recommended method of removing this sludge is by short, sharp blasts using a relatively large blowdown valve at the bottom of the boiler. The blowdown water will pass into a steel blowdown vessel, generally situated above ground.

The very high energy flowrate associated with blowdown develops substantial reactionary forces. Therefore boiler blowdown must be handled in a safe manner and, if in doubt, industry experts should be consulted.

The very high flowrate, in short bursts for a total of perhaps only 15 seconds a day, makes heat recovery from bottom blowdown impractical. In multiple boiler installations, only one blowdown key should be held in the boilerhouse to ensure that only one boiler is blown down at a time. This is a health and safety requirement under section 34 of the Factories Act 1961⁽³⁾.

9.2.8.2 Control of total dissolved solids

Water entering the boiler will contain dissolved solids. The type and concentration will depend upon the water source, a typical value being 250 ppm. As the water is evaporated the concentration increases and, above a certain level, will give rise to foaming and foam being carried over into the steam space with the steam.

The maximum acceptable level of total dissolved solids (TDS) in a boiler will depend on the boiler type and the manufacturer will provide appropriate data. Conventional shell boilers are normally operated with the TDS in the range of 2000–3500 ppm.

Control of the TDS level is achieved by blowing down a certain amount of concentrated water so that incoming replacement water will dilute the concentration of that remaining.

The required blowdown rate can be calculated as follows:

$$BD = \frac{T_f \times S}{T_b - T_f} \quad (9.1)$$

where BD is the blowdown rate (kg/h), T_f is the feedwater TDS (ppm), S is the steam generation rate (kg/h) and T_b is the required boiler water TDS (ppm).

Example

A 10000 kg/h boiler operates at 10 bar(g) and has a maximum allowable boiler TDS of 2500 ppm. The boiler feedwater TDS is 250 ppm. What blowdown rate is required?

From equation 9.1:

$$BD = \frac{250 \times 10\,000}{2500 - 250} = 1111 \text{ kg/h}$$

9.2.8.3 Automatic TDS control

TDS levels can be controlled by automatic systems that measure the boiler water conductivity, compare it with a set point, and open a blowdown control valve if the TDS level is too high.

Whereas heat recovery from bottom blowdown may be impractical due to its intermittent nature, recovering heat from TDS blowdown is a viable option.

Advice on the equipment associated with TDS control and heat recovery is best sought from a specialist manufacturer.

9.2.9 Water level controls and alarms

9.2.9.1 Level controls

As steam is generated, the water in the boiler evaporates and the boiler must receive a supply of water to maintain the correct level.

Safety is of paramount importance. If the boiler operates with insufficient water, severe damage could occur and there is ultimately the risk of explosion. Too high a water level can also have serious consequences. For this reason, systems are required that will:

- provide an external indication of the water
- monitor and control the water level.
- detect if a low water level point is reached, and take appropriate action.

A gauge glass shows the level of water in a boiler. Control of this level can be achieved in either an 'on-off' or modulating manner.

On/off control (by starting and stopping the boiler feedpump) is the least expensive and most common method employed, but can result in erratic boiler operation. Modulating control is more sophisticated and therefore more expensive, but results in better boiler performance. The advantages and disadvantages of both

Table 9.1 Comparison of water level control types

Control type	Advantages	Disadvantages
On/off	● Simple ● Inexpensive ● Good for boilers on standby	● Each boiler requires its own feed pump ● Greater wear and tear on the feed pump and control gear ● Variable steam pressure and flowrate ● Greater boiler water carryover ● Higher chance of daily operating problems under large load swings
Modulating	● Steady steam pressure and flowrate within the boiler's thermal capacity ● More efficient burner operation ● Less thermal stress on the boiler shell ● Less boiler water carryover ● Less wear and tear on the feedpump and burner	● More expensive ● Feed pump must run continually ● Less suitable for standby operation

types of control are shown in Table 9.1. See HSE publication *Safe management of industrial steam and hot water boilers*⁽⁴⁾ for additional information.

9.2.9.2 Alarms

Low water alarm

Where boilers are operated without constant supervision (which includes the majority of industrial boilers) low water level alarms are required to shut down the boiler in the event of a lack of water in the boiler.

The action of the low water level alarms is generally as follows:

- 1st low level alarm: shuts down the burner at the alarm level, but allows it to re-fire if the level recovers.
- 2nd low level alarm (often called 'lockout'): also shuts down the burner at the alarm level, but the burner controls remain 'locked out' even if the water level recovers and any faults have been rectified. The lockout has to be manually reset to allow the burner to re-fire.

High water alarm

Excessively high water level can result in some of the boiler water entering the steam system causing damage to system components, reduced heat output due to fouling of surfaces and increased risk of waterhammer damage.

The dangers of an excessively high water level are too serious to ignore, and deserve equal consideration to that given to low water level conditions.

9.3 Flow metering

9.3.1 Why measure steam?

Measuring steam flow is an essential tool for good housekeeping. It provides knowledge of steam usage and costs, which is vital to an efficiently operated plant or building. The main benefits for using steam flowmetering include improvement in:

- plant efficiency
- energy efficiency
- costing control.

Plant efficiency

By analysing the relationship between steam flow and production, optimum working practices can be determined.

The flowmeter may also be used to:

- track steam demand and changing trends
- establish peak steam usage times
- identify sections or items of plant that are major steam users.

This may lead to changes in steam usage patterns. It can also reduce problems associated with peak loads on the boiler plant.

Energy efficiency

Steam flowmeters can be used to monitor the results of energy saving schemes and to compare the efficiency of energy usage from one period to another.

Costing control

Steam flowmeters can measure steam usage (and thus steam cost) either centrally or at individual user points. Charging departments or buildings for steam used will generally result in a reduction in consumption.

9.3.2 Types of steam flow meters

There are many types of flowmeter available, the main types used to measure steam flow being:

- orifice plate flowmeters
- turbine flowmeters (including shunt or bypass types)
- spring loaded variable area flowmeters
- vortex shedding flowmeters.

Each flowmeter type has advantages and limitations, see Table 9.2. To ensure accurate and consistent performance, it is essential to match the flowmeter to the application.

— *clean*: correct boiler feedwater treatment will minimise corrosion of pipes; strainers should be fitted.

9.3.3

Installing a steam meter

9.4.2

Pipes and pipe sizing

To ensure a steam meter gives the accuracy, repeatability and turndown specified by the manufacturer, correct installation is essential (more so for some meters than others), see Table 9.3.

The consequences of oversized pipework are:

— pipes, valves, fittings etc. will be more expensive than necessary

— higher installation costs will be incurred, including support work, insulation etc.

— for steam pipes, a greater volume of condensate will be formed due to the greater heat loss; this, in turn, means that either more steam trapping is required or wet steam is delivered to the point of use.

9.4

Steam distribution

9.4.1

Introduction

The aim of a distribution system should be to deliver steam:

— *at the right pressure*: steam pipes must be adequately sized

— *dry*: steam pipes need to be well laid out and drained

— *free of air and other incondensables*: steam pipes need to be vented of air

The consequences of undersized pipework are:

— a lower pressure may only be available at the point of use

— a risk of steam starvation

— a greater risk of erosion, waterhammer and noise due to the inherent increase in steam velocity.

Table 9.2 Comparison of types of steam meter

Meter type	Advantages	Disadvantages
Orifice plate	- Simple - No moving parts - Reasonably robust	- Limited flow range (really only effective over a load change (turndown) ratio of 4:1 or 5:1) - Installation requirements critical
Turbine	- Proven technology - Better turndown ratio than orifice plate (up to 10:1) - Can be used as insertion, or in a bypass on larger pipes to reduce cost	Not ideally suited to aggressive steam environment
Spring-loaded variable area (SLVA)	- Very good turndown performance (up to 100:1) - Ideal for applications with wide flowrate changes (e.g. summer and winter loads)	Requires steam to be clean and dry to prolong life
Vortex	- No moving parts - Reasonable turndown performance (25:1) - No pressure drop	- Sensitive to pipe vibration - Requires high velocity to obtain good turndown - Similar installation requirements to orifice plates

Table 9.3 Installation requirements for steam meters

Meter type	Installation requirements
Orifice plate	- Turbulence through meter must be prevented - Minimum of five straight pipe diameters downstream (upstream generally more, depending on pipework configuration)
Turbine	- Flow straighteners needed - Steam should be dry and clean
Spring loaded variable area (SLVA)	- Less critical straight pipe runs than with any other type (typically only six diameters upstream and three downstream) - Steam should be dry and clean
Vortex	- Ensure no pipe vibrations - Ensure protruding gaskets and other obstructions do not cause unwanted vortices. - Upstream and downstream straight length requirements similar to orifice plates

To keep pipe sizes and costs as small as possible, steam should be distributed at high pressure (usually boiler pressure), because of its smaller volume. Conversely, steam should be utilised at low pressure because of its higher enthalpy of evaporation per kilogram of steam.

Steam pipes should be sized to carry the required steam flowrate with an acceptable pressure drop. Two methods are commonly used:

- sizing based on reasonable velocities
- sizing based on a specified pressure drop along the length being sized.

9.4.2.1 Sizing on velocity

This method is quick and easy, and the most common method of pipe sizing but it provides no guarantee of

pressure at the 'using' end. It is normally used for pipe runs up to 50 m in length.

Reasonable velocities for dry saturated steam are 25–40 m/s. Higher velocities can lead to higher pressure drop and possible noise. The longer the pipe run the lower should be the velocity. Table 9.4 can be used for sizing pipes by velocity.

Example

For the arrangement shown schematically in Figure 9.5 (below), determine the pipe sizes for pipe runs A–B, B–C and B–D.

(a) Length A–B

Length A–B is a main distributor, 30 m long. This section is to carry 1600 kg/h of steam at 7 bar(g).

Table 9.4 Pipe sizing on velocity

Pressure / bar(g)	Velocity / m·s ⁻¹	Pipe size (nominal diameter (DN))										
		15	20	25	32	40	50	65	80	100	125	150
		Inside diameter (actual) / mm										
		15.80	20.93	26.64	35.04	40.90	52.50	62.70	77.92	102.26	128.20	154.05
Pipeline capacity (l / kg·h ⁻¹)												
0.4	15	9	15	25	43	58	95	136	210	362	569	822
	25	14	25	41	71	97	159	227	350	603	948	1369
	40	23	40	66	113	154	254	363	561	965	1517	2191
0.7	15	10	18	29	51	69	114	163	251	433	681	983
	25	17	30	49	85	115	190	271	419	722	1135	1638
	40	28	48	78	136	185	304	434	671	1155	1815	2621
1	15	12	21	34	59	81	133	189	292	503	791	1142
	25	20	35	57	99	134	221	315	487	839	1319	1904
	40	32	56	91	158	215	354	505	779	1342	2110	3046
2	15	18	31	50	86	118	194	277	427	735	1156	1669
	25	29	51	83	144	196	323	461	712	1226	1927	2782
	40	47	82	133	230	314	517	737	1139	1961	3083	4451
3	15	23	40	65	113	154	254	362	559	962	1512	2183
	25	38	67	109	188	256	423	603	931	1603	2520	3639
	40	61	107	174	301	410	676	964	1490	2565	4032	5822
4	15	28	50	80	139	190	313	446	689	1186	1864	2691
	25	47	83	134	232	316	521	743	1148	1976	3106	4485
	40	75	132	215	371	506	833	1189	1836	3162	4970	7176
5	15	34	59	96	165	225	371	529	817	1408	2213	3195
	25	56	98	159	276	375	619	882	1362	2347	3688	5325
	40	90	157	255	441	601	990	1411	2180	3755	5901	8521
6	15	39	68	111	191	261	430	613	947	1631	2563	3700
	25	65	114	184	319	435	716	1022	1578	2718	4271	6167
	40	104	182	295	511	696	1146	1635	2525	4348	6834	9867
7	15	44	77	125	217	296	487	695	1073	1848	2904	4194
	25	74	129	209	362	493	812	1158	1178	3080	4841	6989
	40	118	206	334	579	788	1299	1853	2861	4928	7745	11 183
8	15	49	86	140	242	330	544	775	1198	2063	3242	4681
	25	82	144	233	404	550	906	1292	1996	3438	5403	7802
	40	131	230	373	646	880	1450	2068	3194	5501	8645	12 484
10	15	60	105	170	294	401	660	942	1455	2506	3938	5686
	25	100	175	283	490	668	1101	1570	2425	4176	6563	9477
	40	160	280	453	785	1069	1761	2512	3880	6682	10 502	15 764
14	15	80	141	228	394	537	886	1263	1951	3360	5281	7625
	25	134	235	380	657	896	1476	2105	3251	5600	8801	12 708
	40	214	375	608	1052	1433	2362	3368	5202	8960	14 082	20 333

Table 9.5 shows that a nominal diameter (DN) 65 pipe will carry 1600 kg/h of steam with an acceptable velocity of between 25 and 40 m/s.

(b) Length B–C

Length B–C can be considered as a branch line. This section is to carry 500 kg/h of steam at approximately 7 bar(g).

Table 9.5 shows that, for a pressure of 7 bar(g), an DN32 pipe will carry 500 kg/h of steam with an acceptable velocity not exceeding 40 m/s.

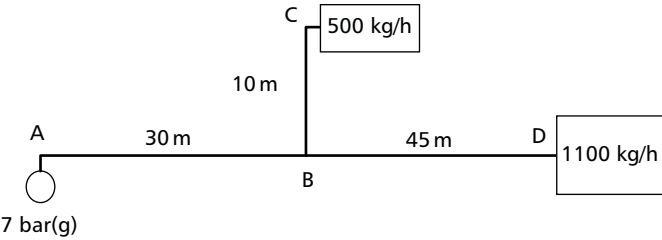


Figure 9.5 Pipe sizing on velocity — example

(c) Length B–D

Length B–D can be considered as a branch line. This section is to carry 1100 kg/h of steam at approximately 7 bar(g).

Sizing on velocity means that the pressure at point B is unknown, so it is necessary to consider the total length from A to D.

As the total length of 75 m from A to D is greater than 50 m, section B–D should be sized on an upper velocity limit of 25 m/s to prevent undue pressure drop.

Table 9.5 suggests that a DN65 pipe will carry 1100 kg/h of steam with a velocity of just below 25 m/s.

9.4.2.2 Sizing on pressure drop

Sizing on pressure drop is more complex and is covered in CIBSE Guide C⁽¹⁾, Appendix 4.A4. A graphical method is given below, see Figure 9.6. Sizing on pressure drop is generally recommended for lengths in excess of 50 m.

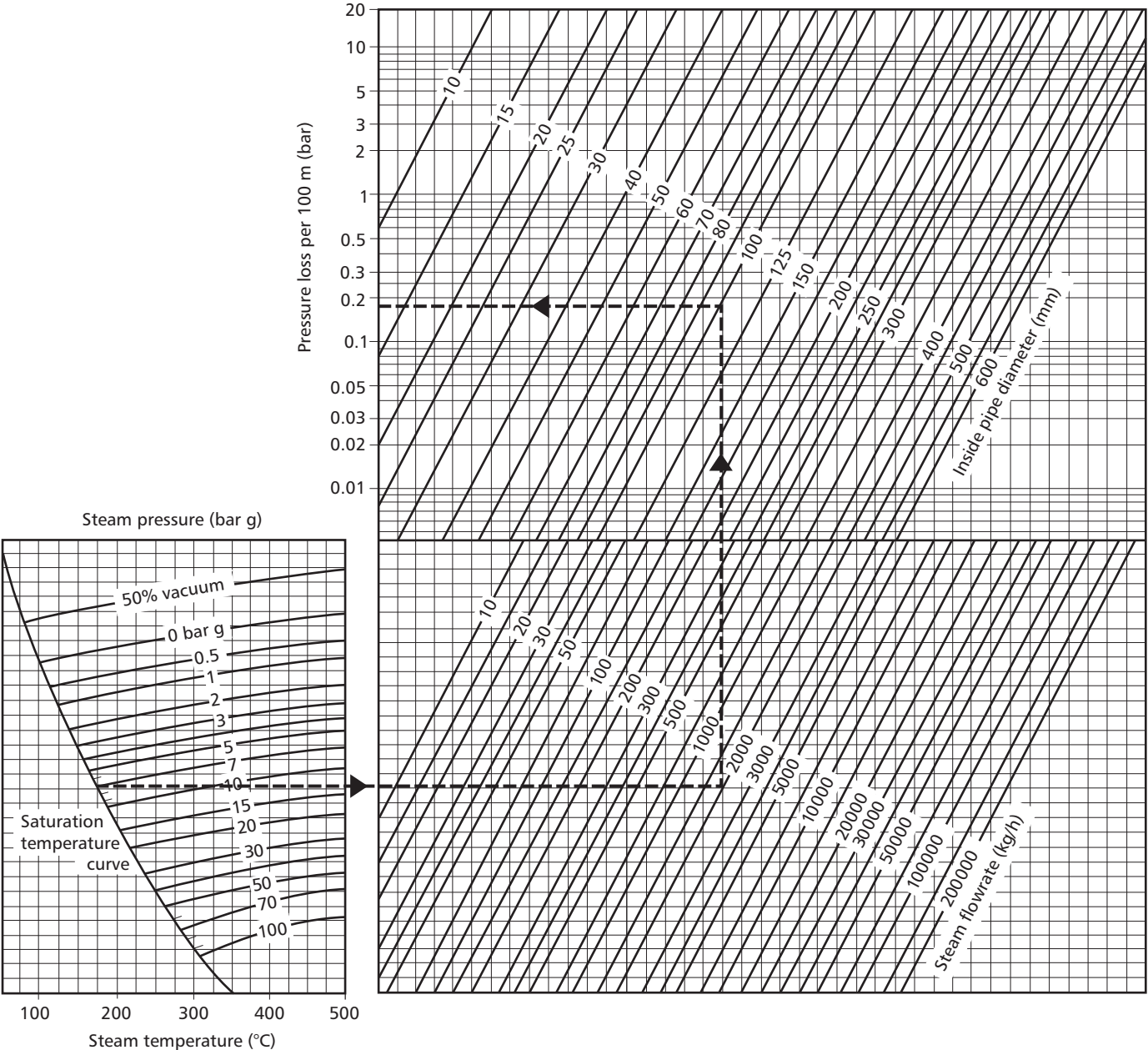


Figure 9.6 Chart for steam pipe sizing by pressure drop (courtesy of Spirax-Sarco)

Example

Figure 9.6 shows how to calculate the pressure drop along a 150 m long DN100 pipe supplied with saturated steam at 7 bar(g), where the flowrate is 2000 kg/h.

The chart shows that there is a pressure drop of slightly less than 0.2 bar for every 100 m. Therefore, for a pipe run of 150 m the pressure drop would be $0.2 \times 1.5 = 0.3$ bar.

9.4.3 Steam pipe layout and drainage

Steam pipes need to be drained of any water carried over from the boiler and of condensate formed in the pipe due to heat losses. The rate of condensation is highest at plant start-up when the system is cold. Beyond this period, the rate is small.

Condensate will gravitate to the bottom of the pipes and will be swept along by the steam flow. This condensate must be removed by installing steam trapping points at regular intervals. Particular attention should be paid to any low points where water may gather.

9.4.3.1 Pipe layout

Steam pipes should be installed with a fall of not less than 1:100 (i.e. 1 m fall for every 100 m of pipe run), in the direction of the steam flow, see Figure 9.7. This slope will ensure that gravity, as well as the flow of steam, will assist in moving the condensate towards the next drain point, which typically should be 30–50 m apart.

Where a steam main must run across rising ground, or applications where the contours of the site make it impractical to lay the pipe with a 1:100 fall in the direction of flow, the condensate must be encouraged to run downhill and against the steam flow. Good practice is to size the pipe on a low steam velocity of not more than 15 m/s, to run the line at a slope of not less than 1:40, and

install the drain points at intervals of not more than 15 m, see Figure 9.8.

9.4.3.2 Drainage

Drain points should be fitted:

- at all low points where condensate could collect
- at intervals of between 30 m and 50 m
- at terminal ends of pipe runs where condensate will tend to be pushed.
- immediately before manual or automatic valves that may be closed for periods.

A typical drainage point is shown in Figure 9.9.

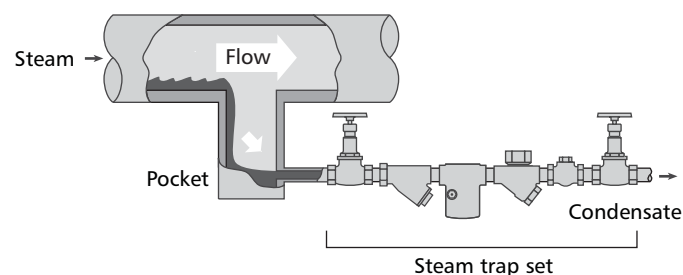


Figure 9.9 Typical drainage point (courtesy of Spirax-Sarco)

The steam trap line should be at least 25–30 mm from the bottom of the pocket for steam mains up to 100 mm diameter, and at least 50 mm for larger mains. This allows a space below for any dirt and scale to settle.

The bottom of the pocket may be fitted with a removable flange or blowdown valve for cleaning purposes.

Recommended drain pocket dimensions are shown in Table 9.5 below.

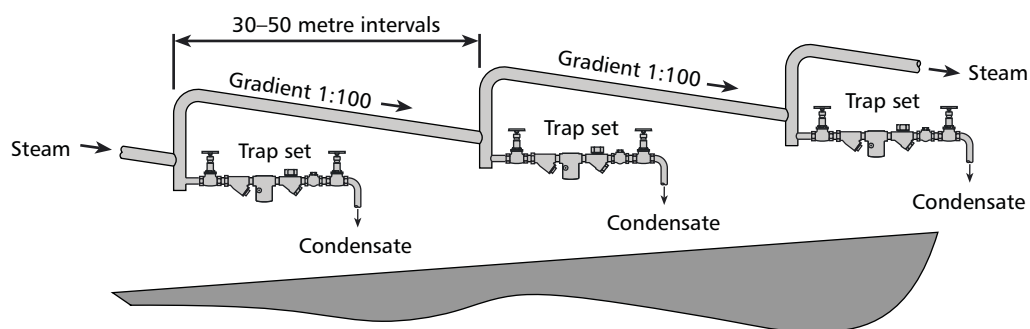


Figure 9.7 Typical steam pipe installation (courtesy of Spirax-Sarco)

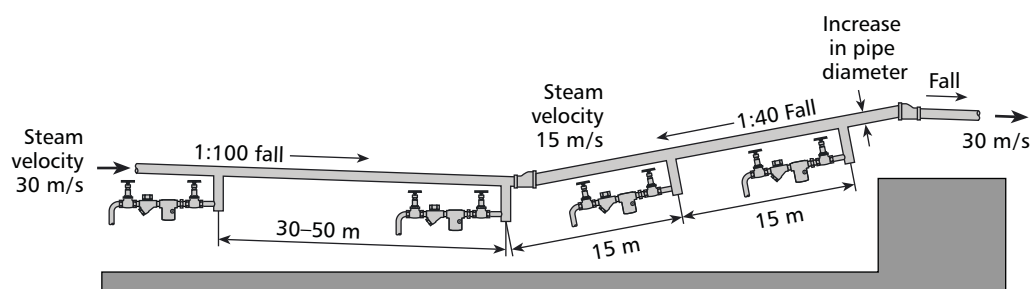
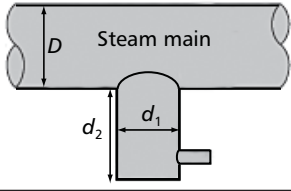


Figure 9.8 Reverse gradient on steam main (courtesy of Spirax-Sarco)

Table 9.5 Recommended dimensions for drain pockets

Nominal diameter of main, D	Pocket diameter, d_1	Pocket depth, d_2
Up to 100 mm	$d_1 = D$	$d_2 = 100$ mm minimum
125–200 mm	$d_1 = 100$ mm	$d_2 = 150$ mm minimum
≥ 250 mm	$d_1 \geq D/2$	$d_2 = D$ (minimum)



9.4.3.3 Pipe size reducers

Pipe size reducers should be of the eccentric type to allow condensate to freely flow along the pipe to the next drain point, see Figure 9.10.

9.4.3.4 Strainers

Strainers in horizontal pipe should be fitted on their sides to prevent the build up of condensate, see Figure 9.11.

9.4.3.5 Branch connections

Branches should come from the top of mains where the steam is driest, see Figure 9.12.

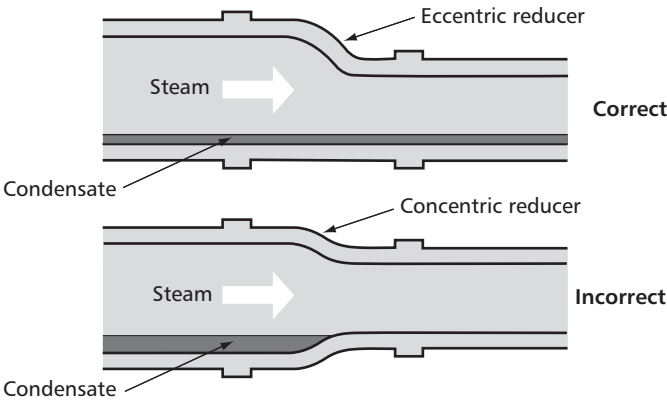


Figure 9.10 Pipe size reducers

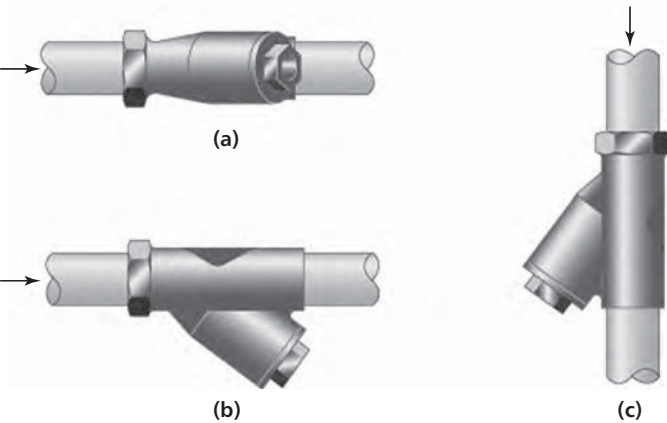


Figure 9.11 Typical strainers; (a) steam or gas applications, (b) liquid applications, (c) flow vertically downwards (courtesy of Spirax-Sarco)

Steam trap capacity

The calculation of the mains drainage steam trap capacity needs to be considered in two parts:

- *Warm-up load*: steam will be condensed (consumed) in bringing the pipe and fittings up to steam temperature. This can be determined by calculation, knowing the mass and specific heat of the pipework and fittings.
- *Running load*: once the steam main is up to operating temperature, the rate of condensation is mainly a function of the ambient conditions, pipe size and the quality and thickness of the insulation.

9.4.3.6 Pipework expansion, supports and insulation

Allowance for expansion

Allowance for expansion within the steam distribution system is required to give the necessary flexibility, as the system heats up to ensure no undue stresses are set up.

Expansion in long lengths of pipework can be taken up by a number of devices but selection should lie with a specialist engineer.

Pipe supports

The frequency of pipe supports will vary according to the bore of the pipe, the pipe material and whether the pipe is horizontal or vertical. It is recommended that specialist advice be sought when designing piping systems and their proper support.

Insulation of pipework

Steam condenses inside pipework and fittings as heat is lost by radiation to the surrounding air; this is wasteful of energy. To minimise losses, pipes and fittings such as flanges, valves and separators should be insulated. The most economic thickness will depend upon several factors:

- pipework temperature
- size of the pipework

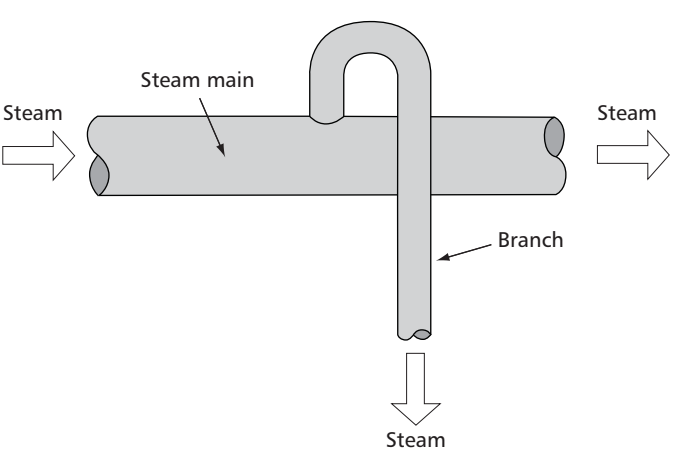


Figure 9.12 Arrangement of branch connections

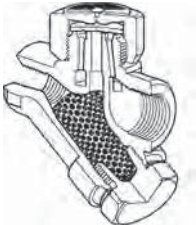
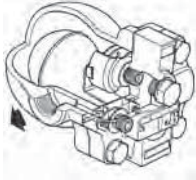
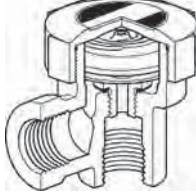
- ambient air conditions, e.g. temperature, humidity and wind speed
- in accordance with Building Regulations Part L^(5,6).

9.4.3.7 Summary

Proper pipe alignment and drainage requires the observance of a few simple rules, as follows:

- Steam lines should be arranged to fall in the direction of flow, at not less than 100 mm per 10 m of pipe run (i.e. 1:100). Steam lines rising in the direction of flow should slope at not less than 250 mm per 10 m of pipe run (i.e. 1:40).
- Steam lines should be drained at regular intervals of 30–50 m and at any low points in the system.
- Where drainage has to be provided in straight lengths of pipe, then a large bore pocket should be used to collect condensate.
- If strainers are to be fitted, then they should be fitted on their sides.
- Branch connections should always be taken from the top of the main from where the driest steam is taken.
- Separators should be considered before any piece of steam using equipment ensuring that dry steam is used.
- Traps selected should be robust enough to avoid waterhammer damage and frost damage.

Table 9.6 Steam traps for HVAC applications

Type	Features	Principle of operation
Thermodynamic 	Small, rugged and able to operate over a wide pressure range. Discharges condensate as soon as it forms.	Hot condensate passing under the disc flashes off to steam. The increased velocity of the steam creates a low pressure, drawing the disc on to its seat. A drop in pressure caused by the flash steam condensing above the disc causes the trap to open.
Mechanical 	Continuous discharge, automatically adjusting to pressure and flow rate changes. Large capacity, discharging condensate as soon as it forms. Can be damaged if frozen.	Operate on the difference in density between water and steam. A float will rise in water, so opening the valve to allow the water to drain out. An inverted bucket operates in the reverse way, with steam inside it causing it to float, and close the valve. An internal, integral air vent, or a separate bypass is used to remove air. Float types are much more common in building services applications. With the inclusion of an air vent, they are commonly referred to as 'float thermostatic'.
Thermostatic 	Hold back condensate until it has cooled, so making use of some sensible heat and reducing flash steam formation. Suitable for applications where waterlogging can be tolerated. Excellent air handling ability.	Can be balanced pressure or bimetallic. Balanced pressure is commonly used in building services applications. An internal capsule contains a liquid that vaporises as the surrounding condensate approaches steam temperature. This vaporisation causes the valve to close. Condensate is then held back until it subcools. The vapour in the capsule condenses and the valve opens. By varying the filling, the operating temperature can be changed.

9.5 Steam trapping and air venting

9.5.1 Introduction

The purpose of a steam trap is to retain steam within the process for maximum utilisation of heat, but release condensate and incondensable gases at the appropriate time.

9.5.1.1 Types of steam traps and their application

There are three types of steam traps that are most widely used in HVAC applications. These are described in Table 9.6.

9.5.1.2 Steam trap selection

The choice of type of steam trap should be made taking into account the characteristics of the steam plant to which it is connected, under all operating pressure and condensate flow rate conditions.

Table 9.7 below shows the recommended traps for some common applications.

Table 9.7 Steam trap selection

Application	First choice	Second choice
Steam mains:		
— horizontal runs	Thermodynamic	Mechanical (float thermostatic)
— terminal ends	Thermodynamic	Float thermostatic
— shut-down drain	Thermostatic (balanced pressure)	—
Boiler header	Float thermostatic	Inverted bucket
Separator	Float thermostatic	Inverted bucket
Space heating equipment (heat exchangers, unit heaters, air heater batteries)	Float thermostatic	Inverted bucket
Kitchen equipment:		
— boiling pans	Float thermostatic	Thermodynamic
— steaming ovens	Balanced pressure thermostatic	—
Laundry equipment:		
— garment presses	Thermodynamic	Float thermostatic
— ironers and calenders	Float thermostatic	Inverted bucket
— tumble dryers	Float thermostatic	Inverted bucket
Autoclaves and sterilizers	Balanced pressure thermostatic	Float thermostatic

9.5.2 Sizing steam traps

Steam traps are sized on the quantity of condensate to be removed and the differential pressure across the trap (i.e trap inlet pressure minus outlet pressure). Account should be taken of any back-pressure on the trap caused, for example, by a lift in the outlet pipework.

The differential pressure is commonly taken as the steam pressure at the plant inlet.

Traps must be sized both for normal running and to cope with start-up conditions. During start-up the steam condensation rate will be at its highest, whilst the pressure at the trap inlet will initially be very low. As the system comes up to temperature, the condensate flow rate decreases whilst the pressure increases.

To ensure traps are suitable for the start-up conditions, they are sized on the differential pressure and condensate flow rate under normal running conditions, multiplied by a factor, typically two or three.

Example

Select a steam trap type for a hot water storage calorifier requiring 300 kg/h of steam at 4.0 bar(g). The condensate return pipe is at high level, requiring a lift in the pipework after the trap of 5 m.

From Table 9.8, a float thermostatic type steam trap is the first choice for this application.

Using a factor of three on the normal running load, the trap should be sized to pass 900 kg/h of condensate. The back-pressure on the trap caused by the 5 m lift will be 0.5 bar. The differential pressure is therefore 4.0 – 0.5 = 3.5 bar.

A float thermostatic trap able to pass 900 kg/h with a differential pressure of 3.5 bar would be selected.

9.5.3 Steam trap installation

A typical steam trap station, see Figure 9.13, should comprise a means of isolating the trap upstream (and downstream if there is any possibility of back-pressure) for maintenance purposes. A pipeline strainer (if not part of the trap itself) should be included to protect the trap from dirt. A check valve is required where backflow is a possibility. Some means of checking the trap’s operation should be incorporated (see section 9.5.5).

All of these items will be the same size as the trap connections. To reduce installation time, prefabricated steam trap sets could be considered.

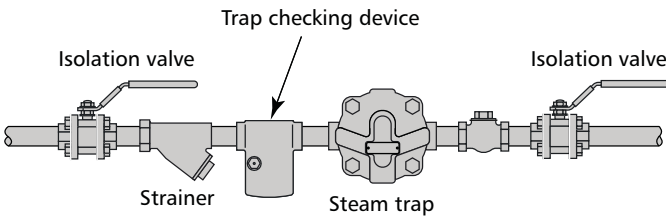


Figure 9.13 Typical steam trap station (courtesy of Spirax-Sarco)

9.5.4 Air venting

During start-up, steam will push the air in the pipework and plant to the furthest points. This air should be removed as it can delay the time taken for the steam-using equipment to reach operating temperature.

Automatic air vents, strategically located where air will be driven by the steam, or will naturally collect, will remove any air and gases reaching them.

A steam air vent operates in the same way as a balanced pressure thermostatic steam trap. The discharge from these air vents should be piped to a safe place.

9.5.5 Testing and maintenance of steam traps

Even if steam traps are protected by strainers, small particles of dirt may reach them and cause a malfunction. Failure in the closed position means waterlogging of the steam space, resulting in reduced output and the danger of waterhammer damage. On the other hand, if a trap fails in the open position, plant output may not be affected but live steam will leak through the trap, considerably increasing fuel costs and CO₂ emissions.

There are various methods employed to check the operation of steam traps, from regular manual audits to permanently installed monitoring devices.

9.6 Control of steam pressure

9.6.1 The need to reduce steam pressure

The main reasons for reducing steam pressure are:

- To allow boilers to operate at their design pressure where lower pressure steam is needed downstream.
- To allow distribution at high pressure, thereby reducing pipe sizes. High pressure steam has a smaller volume for the same mass, hence acceptable velocities can be achieved in smaller diameter pipes. However, it will be necessary to reduce the pressure at point of use.
- To save energy: reduced pressure means lower pipework temperatures, thereby reducing heat loss. The amount of flash steam from drain traps is also reduced.
- To control temperature: because steam pressure and temperature are related, control of pressure can be used to control temperature in some processes, e.g. hospital sterilizers
- To save cost: for the same heating duty, a heat exchanger designed to operate on low pressure steam will probably be larger than one designed to be used on high pressure steam, but the lower design specification may mean lower cost.
- For safety: the safe working pressure of components in the downstream system may be less than the steam generation or upstream pressure.

9.6.2 Types of reducing valve

The main types of reducing valve are described in Table 9.8 (page 9-16).

9.6.3 Pressure reducing valve stations

A pressure reducing valve station would normally comprise the valve itself, some means of providing isolation and conditioning the incoming steam, as well as a safety valve. Pressure gauges provide a means of setting and faultfinding. A typical station is shown in Figure 9.14.

Where there are large changes in steam load, and/or where standby valves and large pressure reductions are required, two pressure reducing valves may be needed. These can be fitted in series or in parallel.

Valves in parallel would be used where:

- 100% standby is required
- the turndown ratio between the maximum and minimum flow rates is very high (e.g. more than 10:1).

When demand is at a maximum, both valves operate; when flow is reduced, the valve set at the lower pressure shuts off first, leaving the second valve in control. This is achieved by setting the valves at slightly different pressures.

A parallel pressure reducing valve station is illustrated in Figure 9.15.

Pressure reducing valves would be fitted in series where there is a large turndown in pressure (e.g. more than 10:1). A typical series pressure reducing station is shown in Figure 9.15.

An intermediate pressure should be selected such that the pressure drop is shared between the two valves. Note the need for a trapping point between valves

9.6.4 Safety valves

9.6.4.1 Introduction

Safety valves must be installed wherever the maximum allowable working pressure (MAWP) of a system or pressure-containing vessel is likely to be exceeded. In steam systems, safety valves are typically used for boiler overpressure protection and other applications such as downstream of pressure reducing controls

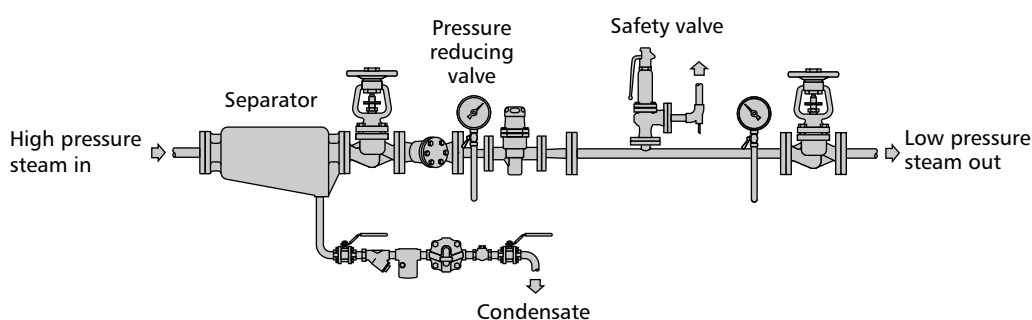
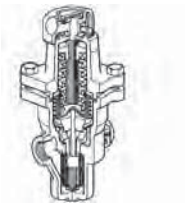
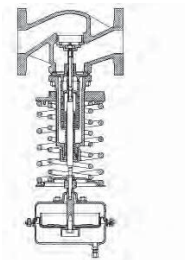
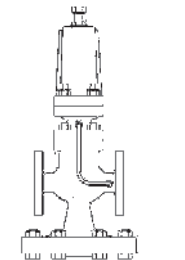
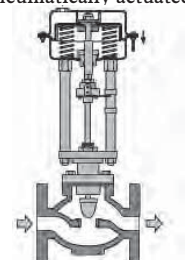


Figure 9.14 Typical pressure reducing valve station (courtesy of Spirax-Sarco)

Table 9.8 Types of reducing valve

Type	Operation	Advantages	Disadvantages
Direct acting (bellows operated) 	Downstream pressure balanced through the use of a bellows, against a spring force produced by the adjustment spring.	Inexpensive. Small and compact. Easy to install. Fairly robust, being tolerant to imperfect steam conditions.	Proportional control only. Wide proportional band. Variations in upstream pressure will affect downstream pressure
Direct acting (diaphragm operated) 	Downstream pressure balanced against the adjustment spring force, using a rubber diaphragm.	Robust, will tolerate dirty and wet steam. Available in large sizes. Easy to set, adjust and maintain.	More expensive than bellows operated valves, but robust construction reduces lifetime cost. Large proportional band meaning large changes in downstream pressure with changing load. Bulky.
Pilot operated 	Downstream pressure is sensed by a pilot valve, which then operates the main valve using a diaphragm or a piston.	Very accurate control due to narrow proportional band (typically less than 200 kPa). Relatively unaffected by upstream pressure changes. Low hysteresis, meaning repeatable pressure control. Low cost compared to comparably accurate valves	More expensive than simple bellows operated valves. Small internal clearances make them more susceptible to failure from wet steam and dirt.
Pneumatically actuated 	Pressure is sensed electronically or pneumatically, sending a signal to a controller. This controller compares the signal to the set point and repositions the main control valve by varying the air (or water) pressure to a pneumatic actuator.	Can be linked to PID controller to provide accurate and responsive control. Very accurate and flexible in terms of size and pressure range. Powerful enough to cope with high differential pressures. Set point can be remotely adjusted.	Requires external power source (generally compressed air). Expensive controls package compared to self acting systems described above.

Typical examples of safety valves used on steam systems are shown in Figure 9.17

9.6.4.2 Operation

Safety valves operate when the inlet static pressure rises above the set pressure of the safety valve. The way the valve reacts to this rising pressure depends on its construction. Some operate with a pop action, others open more in proportion to the pressure rise. With both types, there will be an additional rise in pressure before the safety valve will discharge its rated capacity. This additional pressure is called ‘overpressure’.

The allowable overpressure depends on the standards being followed and the particular application. For compressible fluids, such as steam, this is normally between 3% and 10% of the set pressure.

Once normal operating conditions have been restored, the valve is required to close again. The valve will not close until the pressure has dropped below the original set pressure. The difference between the set pressure and this reseating pressure is known as the ‘blowdown’, and it is usually specified as a percentage of the set pressure. For compressible fluids, the blowdown is usually less than 10%. Figure 9.18 shows the operation of a typical safety valve.

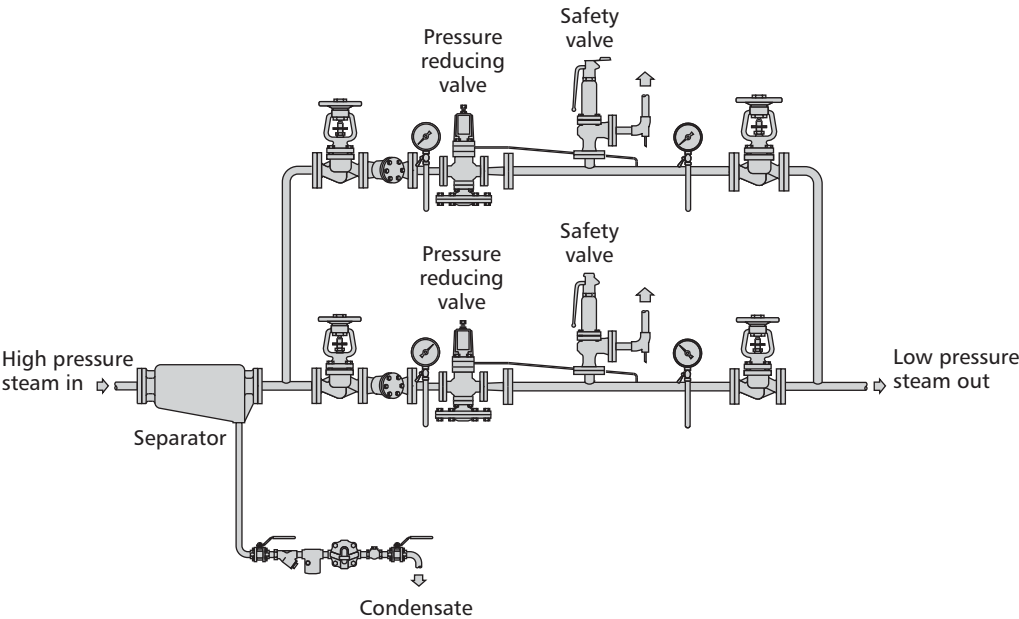


Figure 9.15 Typical parallel pressure reducing valve station (courtesy of Spirax-Sarco)

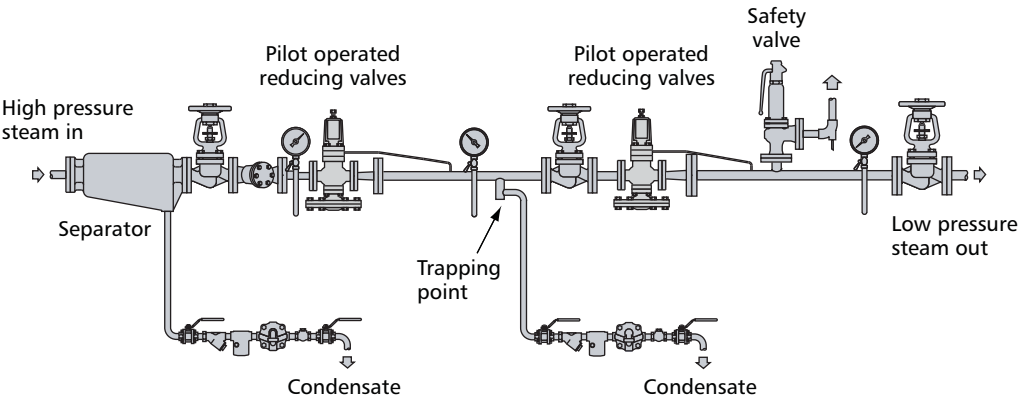


Figure 9.16 Typical series pressure reducing valve station (courtesy of Spirax-Sarco)

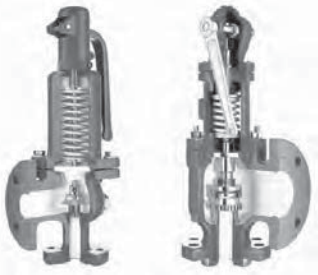


Figure 9.17 Typical steam safety valves

9.6.4.3 Installation

The correct installation of a safety valve is essential to ensure its safe operation. The manufacturer’s instructions should always be consulted and the examples quoted below are for general guidance only.

A safety valve with a damaged seat will leak steam. Seat damage is commonly caused by dirt and debris left in the pipework after installation.

The system should be flushed out before the safety valve is installed and the valve must be mounted where dirt, scale and debris cannot collect.

Leakage can also occur through a build-up of condensate on the upstream side of the valve seat. This can be prevented by installing the safety valve above the steam pipe as shown in Figure 9.19.

Other general recommendations for correct safety valve installation are as follows:

- Safety valves should always be installed with the bonnet vertically upwards.
- Safety valves should be installed at least 8–10 pipe diameters downstream from any converging or diverging ‘Y’ fitting, or any bend.

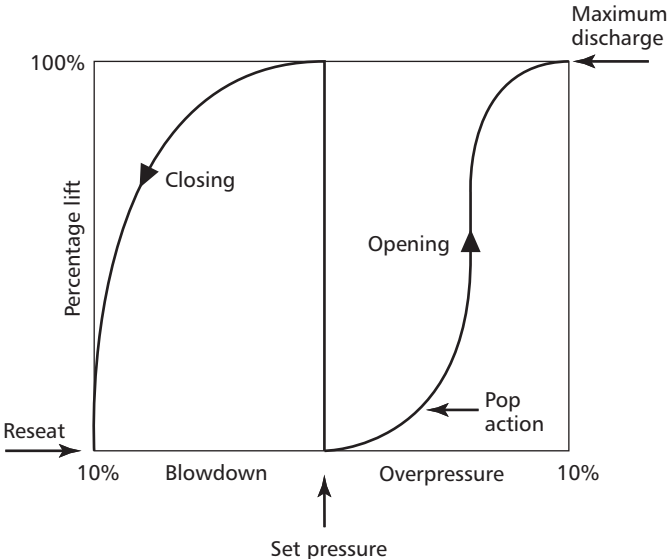


Figure 9.18 Typical safety valve operation

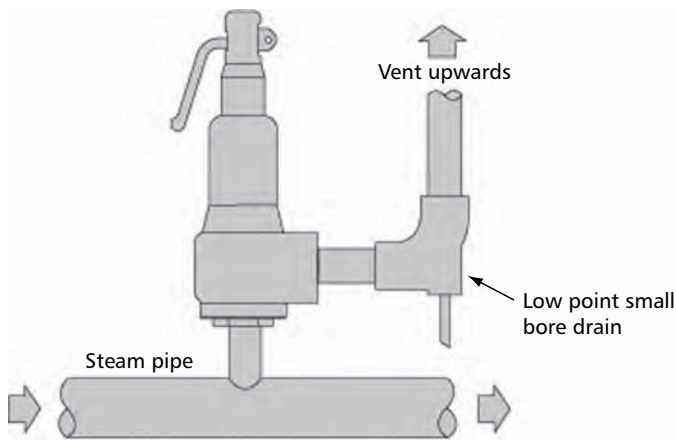


Figure 9.19 Correct installation of a safety valve on a steam system (courtesy of Spirax-Sarco)

Inlet pipework

The pressure drop in the inlet pipework must be minimised. Excessive pressure loss can lead to 'chatter', which may result in reduced capacity and damage to the seating faces and other parts of the valve. BS EN ISO 4126-1⁽⁷⁾ recommends that the pressure drop be kept below 3% of the set pressure when discharging.

Other recommendations on inlet pipe design are as follows:

- Inlet pipework must be at least the same size as the safety valve inlet connection.
- Inlet pipework must be kept as short as possible.
- Ensure that any corners or bends are suitably rounded BS EN ISO 4126-1 recommends that corners should have a radius of not less than one quarter of the bore.

Outlet pipe work

There are two possible types of discharge system: open and closed. An open system discharges directly into the atmosphere whereas a closed system discharges into a manifold along with other safety valves.

It is recommended that discharge pipework should rise for steam systems. Horizontal pipework should have a downward gradient of at least 1 in 100 away from the valve to ensure that any discharge will be self-draining. It is important to drain any rising discharge pipework so that downstream flooding (which can also encourage corrosion and leakage) cannot occur. Vertical rises will require separate drainage.

Many safety valves are provided with a body drain connection to ensure condensate removal. If this is not used or not provided, then a small bore drain should be fitted in close proximity to the valve outlet (see Figure 9.19).

Excessive back-pressure on a safety valve outlet will affect the valve's performance.

BS EN ISO 4126-1 states that the pressure drop should be maintained below 10% of the set pressure. In order to

achieve this, the discharge pipe can be sized using the following equation:

$$d = \left(\frac{L_e \dot{m}^2 \left(\frac{v_g + 2}{2} \right)^{1/5}}{0.08 P} \right) \quad (9.2)$$

where d is the pipe diameter (mm), L_e is the equivalent length of pipe (m), $\dot{m}$ is the rate of discharge (kg/h), P is the safety valve set pressure (bar(g)) multiplied by the required pressure drop (%) and v_g is the specific volume of saturated steam at pressure P (m³/kg).

The pressure P should be taken as the maximum allowable pressure drop according to the relevant standard. In the case of BS EN ISO 4126-1, this would be 10% of the set pressure and it is at this pressure that v_g is taken.

9.7 Pipeline ancillaries

Various pipeline ancillaries and their functions in steam systems are described in Table 9.9.

9.8 Heat exchangers

9.8.1 Introduction

The use of steam in a building services environment is generally to provide heat indirectly to water or air thorough a heat exchanger.

9.8.2 Heat exchangers (calorifiers) for water systems

9.8.2.1 Shell and tube

Heat exchangers in building services have traditionally been of the shell and tube design, with steam in the tube and water in the shell. The tube side of the units are generally of a much higher pressure rating than the shell side, to cope with the steam pressure being used.

All shell and tube heat exchangers, due to their pressure volume ratio, are considered as pressure vessels and are therefore subject to inspections on a periodic basis, generally every other year. A further complication in their use is that once made, their duty cannot be readily increased. Careful initial sizing is therefore important.

There are principally two types: storage and non-storage. The former are used to produce (domestic) hot water, generally for washing, and the latter, water for space heating.

Storage

Hot water storage calorifiers are designed to raise the temperature of the entire contents from cold to the storage

Table 9.9 Steam pipeline ancillaries

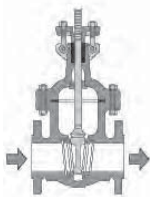
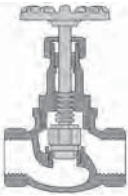
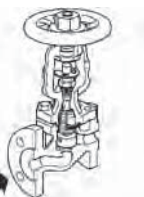
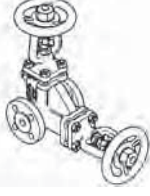
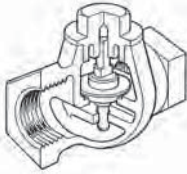
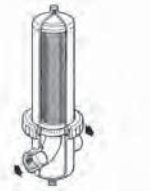
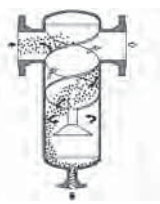
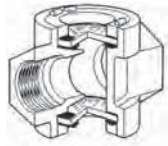
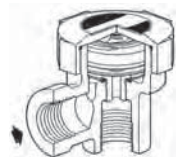
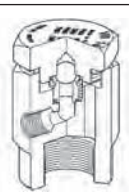
Function	Equipment		Main application	Main advantages	Disadvantages
Isolation	Parallel slide gate valve		Isolation of main steam pipes	No pressure drop; free passage for condensate	Tight shut-off more difficult than with globe valve; traditional gland sealing only
	Globe valve		Isolation of steam supply on distribution pipework and at point of use; used also on condensate systems	Tight shut-off; suitable for higher pressures than parallel slide valves	Can trap condensate in the body
	Bellows sealed valve			Prevents loss of steam/condensate through the gland seal	More expensive than standard globe valve
	Double block and bleed valves			Double isolation for safety purposes in one valve body	More expensive than standard globe valve, but less expensive than two separate valves
	Ball valves		Isolation of steam and condensate at point of use	Tight shut off; easy to operate and actuate; easy to see whether open or closed	Can be opened too quickly and cause waterhammer damage
Back-flow prevention	Piston valve			Combination of good shut-off and being less prone to seat damage from dirt or wire drawing	More expensive than simple globe or ball valve
	Lift check valve		Prevents reverse flow on system shut-down; prevents flow under gravity; relieves vacuum conditions	Small and compact design; inexpensive; robust, requiring little maintenance	Less easy to install than wafer/disc valve
	Wafer/disc check valve			More reliable shut off than lift type	More moving parts and more expensive than lift type

Table continues

Table 9.9 Steam pipeline ancillaries — *continued*

Function	Equipment		Main application	Main advantages	Disadvantages
Cleaning	Strainer		Traps dirt, rust, pipe jointing compound and other unwanted debris commonly found in steam and condensate systems	Simple and effective; prevents damage to more expensive downstream items such as valves and meters	Can act as condensate trap if installed incorrectly; care needs to be taken to match screen size to application
	Filter		Provides steam that is cleaner than a normal strainer may provide; generally for medical or culinary applications	Provides filtration typically down to 1 µm	Prone to blockage if not protected by coarser strainer upstream; more expensive than simple strainer
Drying	Separator		Remove moisture that is entrained with the steam	Simple and maintenance free with no moving parts; very effective	Adds cost to installation
Monitoring	Pressure gauge		External indication of what is taking place within the steam and condensate system	Vital in setting and establishing performance of pressure controls	Adds cost to installation
	Sight glass			Simple means of checking performance of a steam trap	Often obscured by deposits from system; glass can break
Removing non-condensable gases	Air vent		Removes air and other non-condensable gases that can cause internal corrosion or reduce heat transfer ability	Low cost way of prolonging life of steam system and equipment it serves	Discharge needs to be piped to safe place in case of leakage
Preventing vacuum	Vacuum breaker		Prevents the formation of a vacuum when steam condenses, particularly at shut-down; allows removal of condensate under gravity from steam equipment	Low cost; effective; prevents possible implosion damage in items such as tanks and calorifiers	Will allow air to be drawn back into steam system

temperature within a specified period. Hot water is stored to cope with the on/off nature of domestic hot water demand. A typical storage calorifier is shown in Figure 9.20.

Non-storage

In a non-storage heat exchanger, water is heated as it passes through the shell. The relatively steady demand created by space heating means that storage is not needed. A typical non-storage heat exchanger is shown in Figure 9.21.

9.8.2.2 Plate and frame

Plate and frame heat exchangers have traditionally been used for process applications. They have now become widely used in building services for the provision of heating and hot water.

A plate heat exchanger consists of a series of thin corrugated metal plates between which a number of channels are formed, with the primary and secondary fluids flowing through alternate channels. Heat transfer takes place from the primary fluid (steam) to the secondary fluid (water) in adjacent channels across the

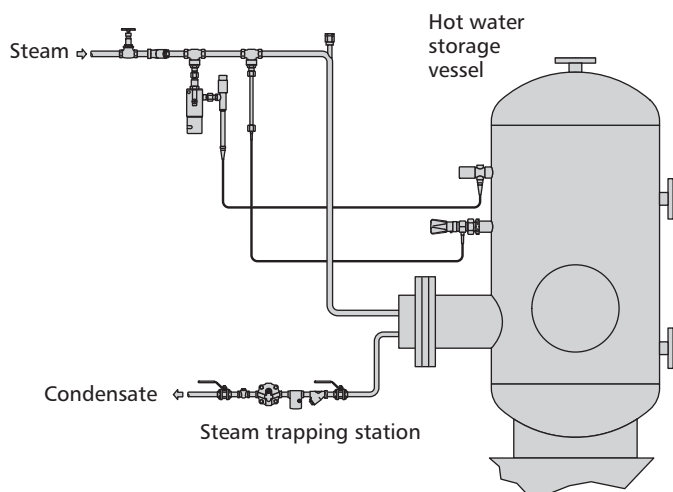


Figure 9.20 Typical storage heat exchanger (calorifier) for steam heating system (courtesy of Spirax-Sarco)

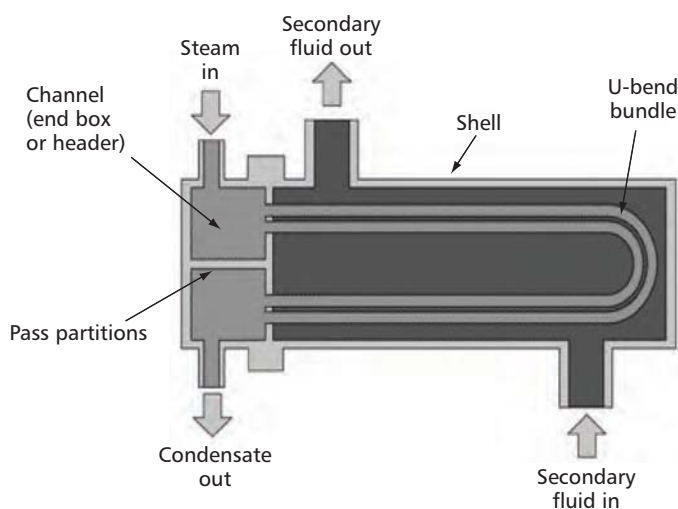


Figure 9.21 Non-storage steam heat exchanger (courtesy of Spirax-Sarco)

plate. Figure 9.22 shows a schematic representation of a plate heat exchanger.

The primary and secondary sides have the same pressure rating and, due to the low pressure to volume ratio, they are generally not considered as pressure vessel and so are not subject to inspection. Due to their better heat transfer capabilities, plate and frame heat exchangers are generally only 20% of the size of an equivalent shell and tube exchanger. This, coupled with no requirement for space to allow tube withdrawal, means that they require much less plantroom space.

Another major advantage is that plates can be added or removed to increase or reduce the duty, if required.

The disadvantage over shell and tube designs is that the secondary pressure drop is higher. This needs to be taken into consideration in pump selection.

9.8.2.3 Plate and shell

Plate and shell heat exchangers are a relatively recent innovation and are, in effect, a hybrid of shell and tube and plate and frame heat exchangers. They are of an all-welded construction and so cannot be modified after manufacture. The pressure ratings for the primary and secondary sides are generally different, as with shell and

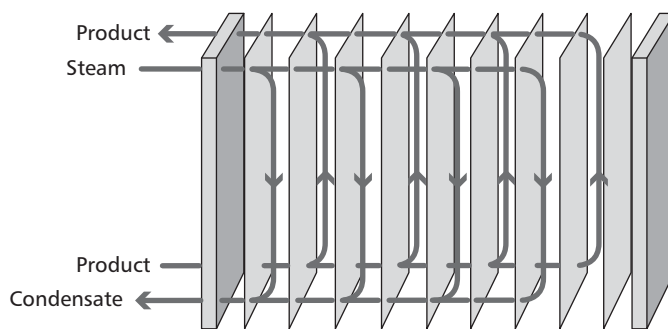


Figure 9.22 Schematic diagram of a plate heat exchanger (courtesy of Spirax-Sarco)

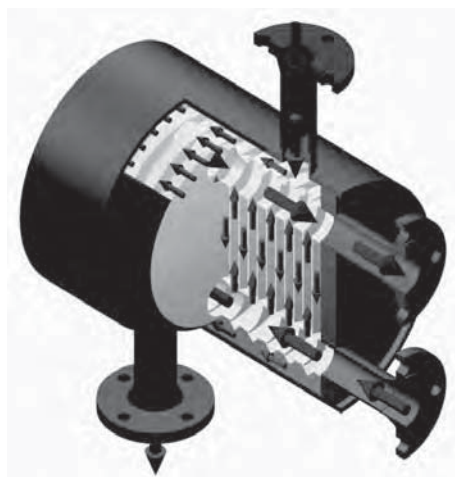


Figure 9.23 Schematic of a plate and shell heat exchanger (courtesy of Vahterus Oy.)

tube units. A typical configuration is shown schematically in Figure 9.23.

9.8.3 Heat exchangers for air systems

Steam is commonly used as the primary heating medium in heat exchangers for air, or air heater batteries. Steam flows through (generally) vertical tubes attached to which are fins to increase the heat transfer area. Air is either blown across these fins through ducts, see Figure 9.24, or drawn through from the surroundings, see Figure 9.25.

Like other forms of heat exchanger, effective removal of condensate is vital, see section 9.9, but the added danger with air heater batteries is the possibility of freezing if tubes are allowed to become waterlogged.

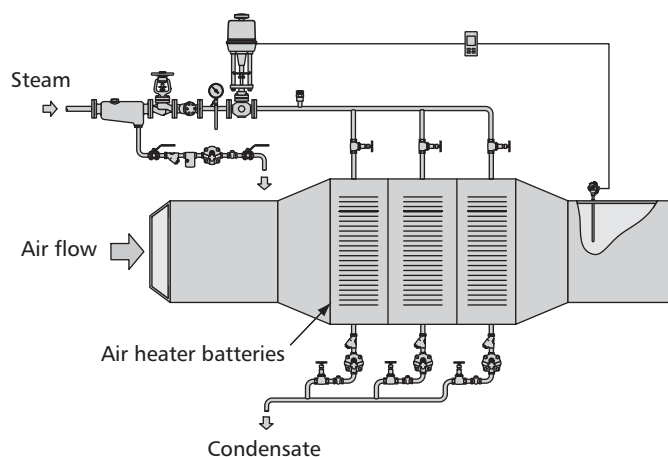


Figure 9.24 Ducted steam-to-air heat exchanger (courtesy of Spirax-Sarco)

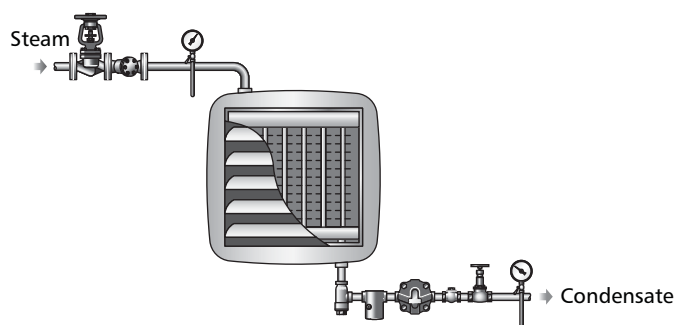


Figure 9.25 Stand-alone steam-to-air heat exchanger (courtesy of Spirax-Sarco)

9.8.4 Steam consumption calculations

9.8.4.1 Non-storage heat exchangers

Non-storage shell and tube heat exchangers and plate heat exchangers are typical examples of flow type applications. Therefore, when determining the steam consumption for these applications, the following procedure may be used.

First calculate the heat load:

$$\Phi = \dot{m} c_p \Delta\theta \quad (9.3)$$

where Φ is the heat energy (kW), $\dot{m}$ is the mass flowrate of the secondary fluid ($\text{kg}\cdot\text{s}^{-1}$), c_p is the specific heat capacity of the secondary fluid ($\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$), and $\Delta\theta$ is the temperature rise of the secondary medium (K).

Once the heat load has been established, the steam consumption required to meet this load is calculated using:

$$\dot{m}_s = \Phi / h_{fg} \quad (9.4)$$

where $\dot{m}_s$ is the mass flowrate of steam (kg/s) and h_{fg} is the specific enthalpy of evaporation of steam at operating pressure ($\text{kJ}\cdot\text{kg}^{-1}$).

These two equations are commonly combined to give:

$$\dot{m}_s = \frac{\dot{m} c_p \Delta\theta}{h_{fg}} \quad (9.5)$$

Example

Calculate the mean steam load of a heating (non-storage) calorifier designed to operate at full load with steam at 2.8 bar(g) (i.e. 380 kPa absolute) in the primary steam space. The secondary water flow and return temperatures are 82 °C and 71 °C respectively, at a pumped water rate of 7.2 kg/s. The specific heat capacity of water (c_p) is 4.19 $\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}$.

From equation 9.3:

$$\Phi = 7.2 \times 4.19 \times (82 - 71) = 332 \text{ kW}$$

The enthalpy of the steam is found from steam tables. CIBSE Guide C⁽¹⁾, Table 2.1, gives the specific enthalpy of evaporation of saturated steam at 380 kPa as 2139.5 $\text{kJ}\cdot\text{kg}^{-1}$.

Hence, from equation 9.4:

$$\dot{m}_s = 332 / 2139.5 = 0.155 \text{ kg/s} = 558 \text{ kg/h}$$

9.8.4.2 Storage heat exchangers

For storage heat exchangers, a similar calculation is used, with the secondary flow rate being the mass of water to be heated divided by the heat-up time (recovery period).

The mean rate at which steam is condensed during the heat up or recovery period can be calculated using:

$$\dot{m}_s = \frac{m c_p \Delta\theta}{h_{fg} t} \quad (9.6)$$

where $\dot{m}_s$ is the mass flowrate of steam (kg/s), m is the mass of water heated (kg), c_p is the specific heat capacity of the water ($\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$), $\Delta\theta$ is the temperature rise of the secondary medium (K), h_{fg} is the specific enthalpy of evaporation of steam at operating pressure ($\text{kJ}\cdot\text{kg}^{-1}$) and t is the recovery time (s).

Example

Calculate the mean steam load of a storage calorifier with a capacity of 2272 litres (i.e. 2272 kg), which is designed to raise the temperature of this water from 10 °C to 60 °C in 30 minutes with steam at 2 bar(g) (i.e. 300 kPa absolute). The specific heat capacity of water (c_p) is 4.19 $\text{kJ}\cdot\text{kg}^{-1}\cdot\text{K}$.

From CIBSE Guide C, Table 2.1, the specific enthalpy of evaporation of saturated steam at 300 kPa is 2163.9 $\text{kJ}\cdot\text{kg}^{-1}$.

Hence, from equation 9.6, the mean rate at which steam is condensed is:

$$\begin{aligned} \dot{m}_s &= \frac{2272 \times 4.19 \times (60 - 10)}{2163.9 \times (30 \times 60)} = 0.122 \text{ kg/s} \\ &= 440 \text{ kg/h} \end{aligned}$$

9.8.4.3 Air heater batteries

An approach similar to the above is taken for air heater batteries. Here, the secondary flow rate is normally quoted in volumetric terms, so the formulae used need to be modified to take this into account, i.e:

$$\dot{m}_s = \frac{\dot{v} c_p \Delta\theta}{h_{fg}} \quad (9.7)$$

where $\dot{m}_s$ is the mass flowrate of steam (kg/s), $\dot{v}$ is the volume flowrate of air heated ($\text{m}^3\cdot\text{s}^{-1}$), c_p is the specific heat capacity of air at constant pressure ($\text{kJ}\cdot\text{m}^{-3}\cdot\text{K}^{-1}$), $\Delta\theta$ is the temperature rise of the air (K) and h_{fg} is the specific enthalpy of evaporation of steam at operating pressure ($\text{kJ}\cdot\text{kg}^{-1}$).

For air at atmospheric pressure, the specific heat at constant pressure is 1.3 $\text{kJ}\cdot\text{m}^{-3}\cdot\text{K}^{-1}$.

Example

Calculate the steam load on an air heater battery required to raise the temperature of air flowing at $2.3 \text{ m}^3/\text{s}$ from 5°C to 30°C with steam at 3.0 bar(g) (400 kPa absolute) in the coils.

The rating of the battery is unknown, but the steam consumption can be calculated using

From CIBSE Guide C, Table 2.1, the specific enthalpy of evaporation at 400 kPa is $2133.9 \text{ kJ}\cdot\text{kg}^{-1}$.

From equation 9.7:

$$\dot{m}_s = \frac{2.3 \times 1.3 (30 - 5)}{2133.9} = 0.035 \text{ kg/s} = 126 \text{ kg/h}$$

9.9 Condensate removal and recovery

9.9.1 Introduction

When saturated steam gives up its heat in any type of heat exchanger, it produces water at the same temperature as the steam.

Whether it is a steam main or a heat exchanger, condensate needs to be removed and, once removed, returned to the boiler feedtank either under its own impetus or pumped.

9.9.2 Layout of condensate return mains

Condensate systems will generally function better if the pipework slopes from the process outlet to a common point at which condensate can be collected (a vented receiver) and then pumped from there, see Figure 9.26.

It can be seen from this figure that the receiver has a vent to atmosphere. This ensures that the pressure in the receiver does not rise above atmospheric pressure, so that the condensate is not subjected to an undue back-pressure. The pump will be driven either electrically or mechanically, depending on the circumstances.

A rising pipe, see Figure 9.27, makes it difficult to remove the condensate from the heat exchanger as the discharge line is continuously flooded.

Consequently, the only time that condensate can flow from the heat exchanger to the receiver is when the pressure in the heater is higher than atmospheric pressure plus the back-pressure created in the flooded line. When the heater pressure is less than the condensate pressure, the system is said to have 'stalled' as there is no discharge movement of condensate. This type of back-pressure will reduce the capacity of the steam trap, and interfere with the performance of the heater.

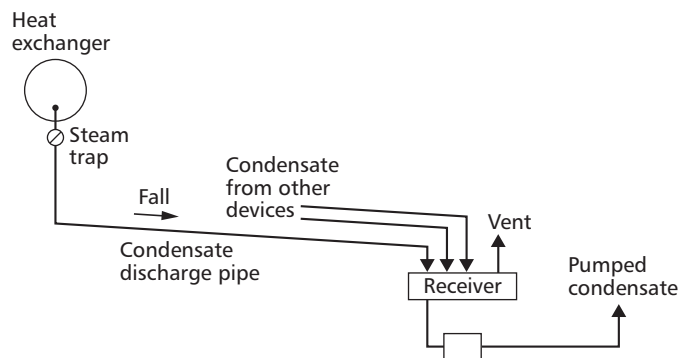


Figure 9.26 A gravity flow condensate pipe from processes to a receiver

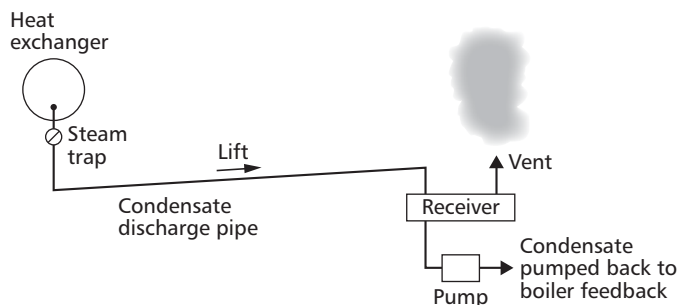


Figure 9.27 A rising condensate pipe from a process to a receiver

The disadvantage of systems with an atmospheric vent is that hot condensate reaching the receiver can release small quantities of flash steam and hence lose valuable heat via the vent to atmosphere.

This system can be improved by ensuring that condensate goes first to a pressurised receiver or flash vessel, see Figure 9.28. Pressurised steam from this vessel can be used in other processes, rather than be lost to atmosphere via the vent.

See section 9.9.4 for more information on flash steam recovery.

Steam and condensate pipes are usually run together to optimise installation costs; and usually at ceiling height to keep them out of the way of people and plant, see Figure 9.29.

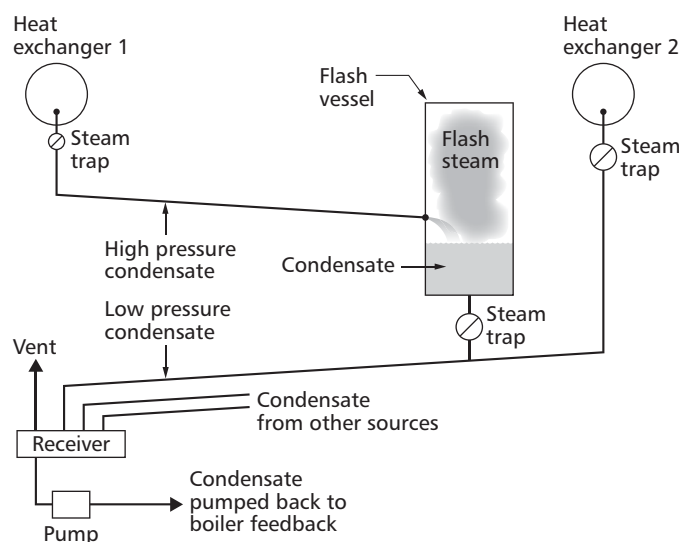


Figure 9.28 A flash vessel installation

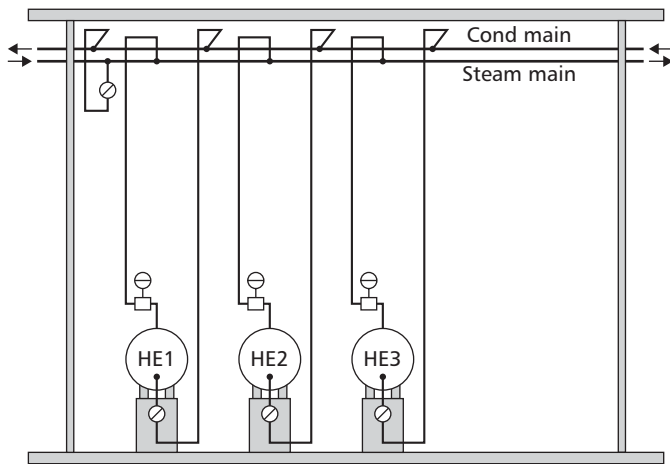


Figure 9.29 Typical plantroom installation

A back-pressure is imposed on the steam traps due to the lift to the condensate return main. With a mains drainage trap this does not matter as the steam pressure is constant, but in the heat exchangers the pressure will vary and sometimes be less than the back-pressure. Condensate then finds it difficult to get away, and performance will suffer. The flooded trap discharge lines can also cause waterhammer and noise.

A better configuration is shown in Figure 9.30, where the heat exchangers are raised higher off the plantroom floor, allowing a flash condenser to be installed underneath. From here condensate can gravitate down to a common vented pump set. The flash condensers ensure that no flash steam is emitted from the receiver vent.

Sometimes a plant room will only contain one steam-using piece of equipment and therefore it may not be economically viable to install a flash condenser and a separate pump set. Under these circumstances, it would be more economical to replace the steam trap with a combined pump and trap, which will allow condensate to be removed from the heat exchanger under all load conditions. This is illustrated in Figure 9.31.

A local vented receiver is not required, as the pump-trap operation is not affected by the backpressure caused by the lifting condensate.

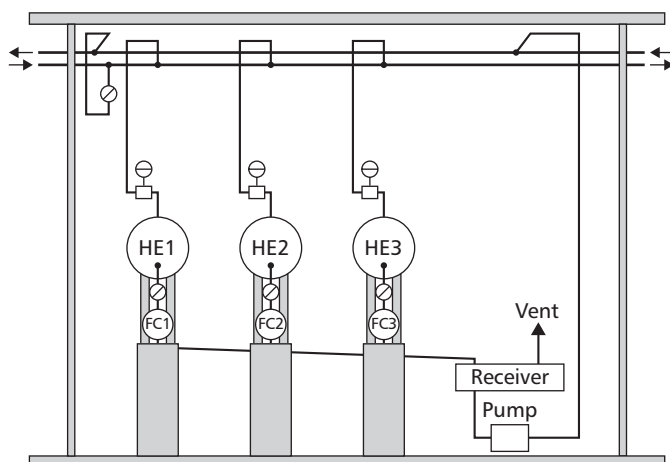


Figure 9.30 Plantroom installation using flash condenser and pump

9.9.3 Sizing condensate return lines

The pressure and temperature of the condensate can have a large influence on the size of pipe needed. Condensate discharging from steam traps cannot be thought of as just being water; it will be a mixture of hot water and flash steam (see section 9.9.4).

Because the volume of the flash steam formed is so much greater than the hot water, the size of the condensate pipe must take flash steam into account where it is known to exist.

There are three main types of condensate lines:

- *drain lines*: connecting the process to traps (no flash steam present)
- *discharge lines*: discharging condensate from traps (flash steam present)
- *pumped lines*: discharging liquid condensate from pumps (no flash steam present)

The common condensate pipe sizing chart shown in Figure 9.32 can be used to size all types of condensate lines. The use of the chart is illustrated by means of examples, see below.

The chart will normally indicate a pipe size between two values.

If the condensate line rises at any point between the trap, pump-trap, or pump, and the line's termination point, use the upper value; if the line is horizontal or falls to its termination point, use the lower value.

9.9.3.1 Drain lines

Example: typical drain line from process to trap

See Figure 9.33(a), page 9-26.

For a condensate flowrate of 600 kg/h, simply reading horizontally across the chart indicates a pipe diameter between 15 mm and 20 mm.

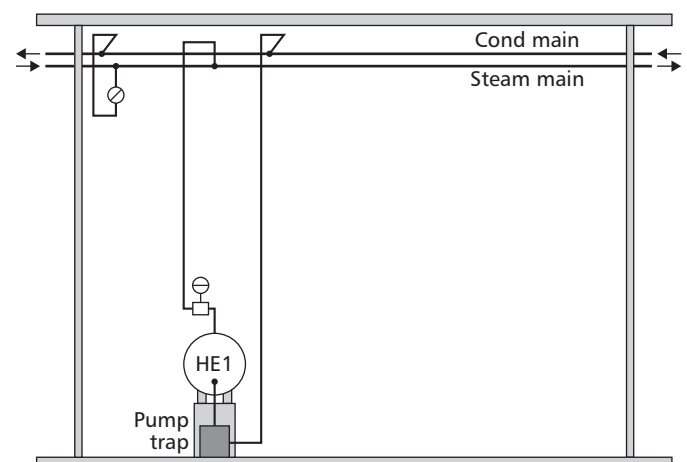


Figure 9.31 Plantroom installation using a combined pump and trap

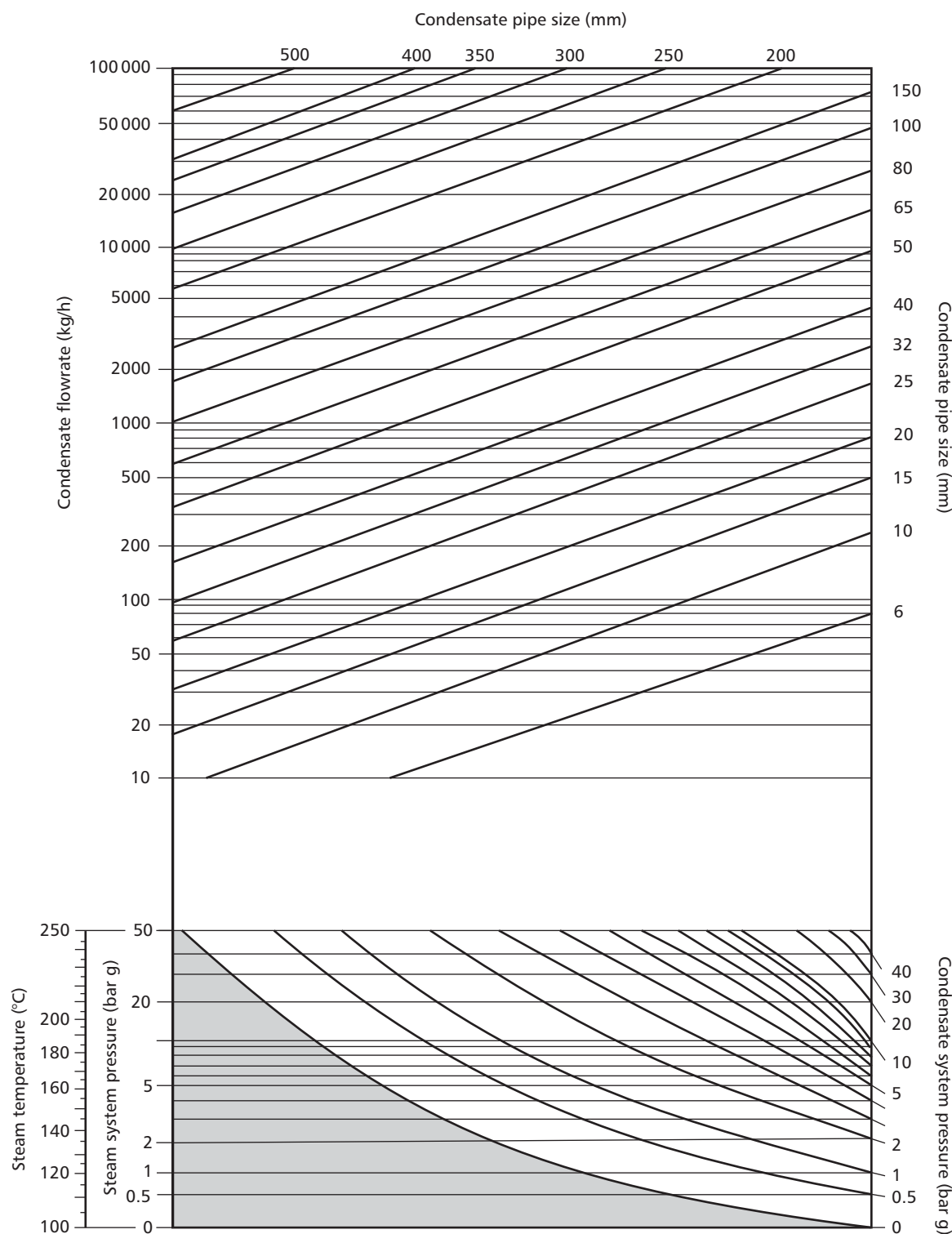


Figure 9.32 Condensate pipe sizing chart (courtesy of Spirax-Sarco)

9.9.3.2 Discharge lines

Example: typical discharge line from trap (or combined pump-trap)

See Figure 9.33(b), page 9-26.

Starting at the lower left for a steam pressure of 4 bar(g), read horizontally to meet the curve representing 0 bar(g), then read vertically up to a condensate flowrate of 150 kg/h. This point lies between the lines representing pipe diameters of 20 mm and 25 mm.

9.9.3.3 Pumped lines

Example: typical pumped line from a vented mechanically-driven pump

See Figure 9.33(c), page 9-26.

Because mechanical pumps operate in an on/off manner, the time to fill the body is often well in excess of the discharge time. Consequently the pipework downstream is commonly sized based on a flowrate of four times the capacity of the pump at given operating and back-pressures.

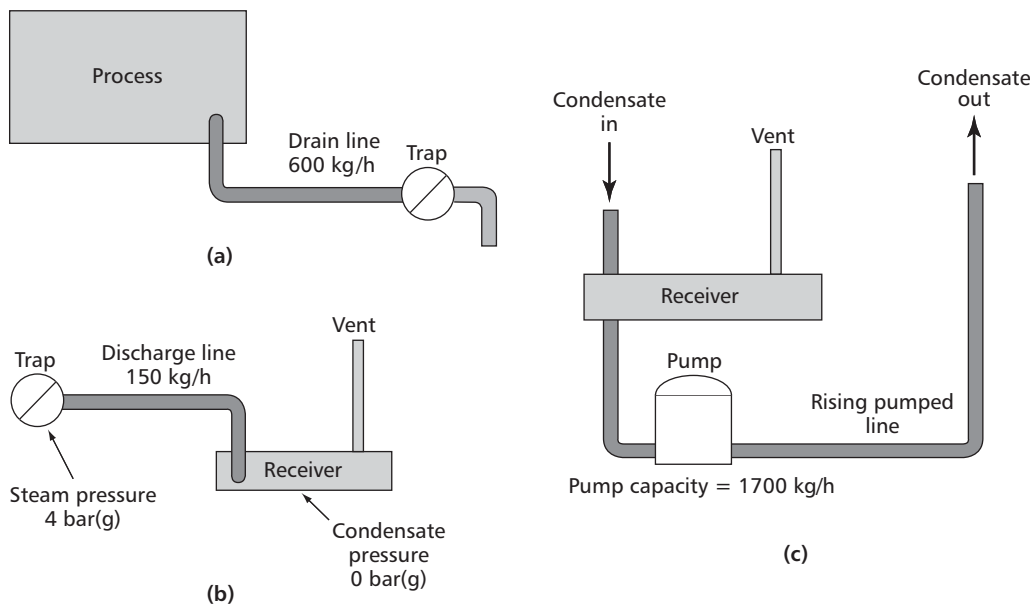


Figure 9.33 Example: sizing condensate lines; (a) drain line, (b) gravity discharge line, (c) pumped discharge line

Pump capacity (from manufacturers' charts) = 1700 kg/h.

Therefore size pump discharge line on $4 \times 1700 \text{ kg/h} = 6800 \text{ kg/h}$.

For a condensate flowrate of 6800 kg/h, read horizontally across the chart to give a pipe diameter between 40 mm and 50 mm.

Example: typical pumped line from a vented electrically-driven pump

Again, see Figure 9.33(c).

For electrical pump sets, a commonly used factor to determine discharge rate is $1\frac{1}{2}$ times the capacity of the pump, again to take account of on/off operation.

As in the previous example, pump capacity from manufacturers' charts is 1700 kg/h.

Therefore size pump discharge line on $1.5 \times 1700 \text{ kg/h} = 2550 \text{ kg/h}$

In this case, reading horizontally across the chart gives a pipe diameter between 25 mm and 32 mm.

9.9.4 Flash steam

9.9.4.1 Flash steam production

'Flash steam' is released from hot condensate when its pressure is reduced. The steam released by the flashing process is as useful as steam released from a steam boiler.

Flash steam is no less valuable as what is known as 'live steam'. Every kilogram of flash steam captured and reused is a kilogram of steam that does not need to be supplied by the boiler. It is also a kilogram of steam not vented to atmosphere, from where it would otherwise be lost.

A typical use for recovered flash steam would be to supplement low pressure heating, or to produce domestic hot water.

9.9.4.2 Using flash steam

The rules for using flash steam are as follows:

- ensure that the source of the flash steam and the use for it are synchronised
- because flash steam is generally low in pressure pipe sizes can be large, so uses close to the source should be found to minimise pipe runs
- live steam should be used to supplement the supply when flash steam is not available; this also provides a means of regulating the flash steam pressure.

Examples of efficient flash steam recovery processes are:

- production of hot water (generally a year-round need)
- frost coils or preheaters in steam air heated batteries
- boiler feedtank heating

9.9.4.3 Availability of flash steam

The quantity of flash steam available is readily determined by calculation, or can be read from simple tables or charts.

Example

In the system shown in Figure 9.34, condensate enters the steam trap as saturated water, at a gauge pressure of 7 bar(g) and a temperature of 170 °C. Steam tables indicate that the amount of heat in the condensate at this pressure is 721 kJ/kg.

After passing through the steam trap, the pressure in the condensate return line is 0 bar(g). At this pressure, the maximum amount of heat each kilogram of condensate can hold is 419 kJ and the maximum temperature is 100 °C. There is an excess of 302 kJ of heat, which evaporates some of the condensate into steam.

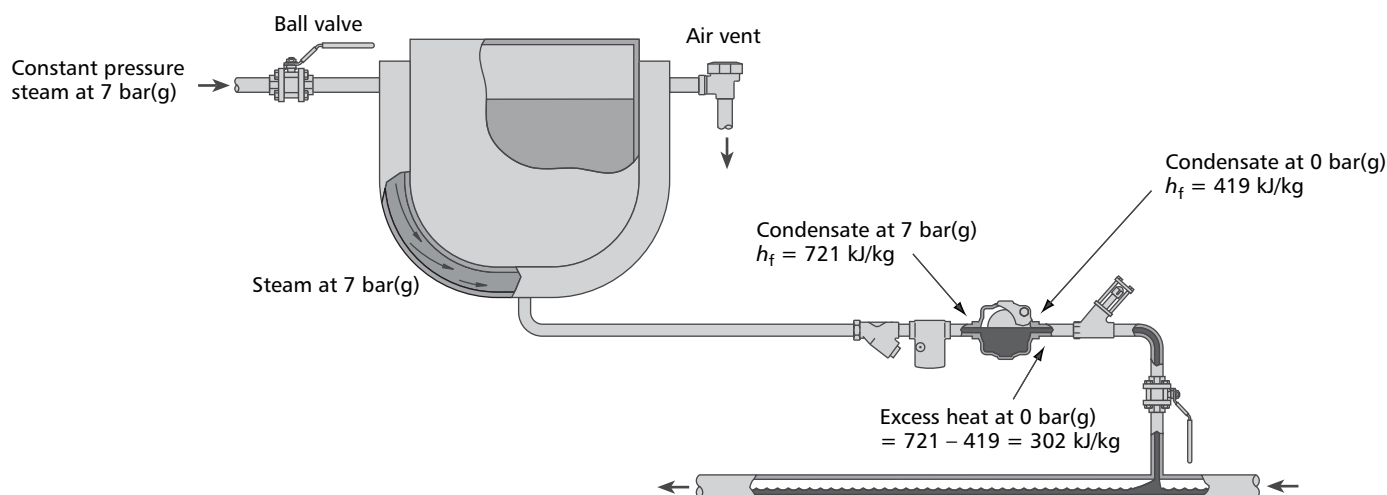


Figure 9.34 Example: availability of flash steam (courtesy of Spirax-Sarco)

The heat needed to produce 1 kg of saturated steam from water at the same temperature, at 0 bar(g), is 2257 kJ. An amount of 302 kJ can therefore evaporate, i.e.

$$302 / 2257 = 0.134 \text{ kg of steam per kg of condensate}$$

From each kilogram of condensate in this example, the proportion of flash steam generated therefore equals 13.4% of the initial mass of condensate.

If the equipment using steam at 7 bar(g) were condensing 250 kg/h, then the amount of flash steam released by the condensate at 0 bar g would be:

$$0.134 \times 250 \text{ kg/h} = 33.5 \text{ kg/h of flash steam}$$

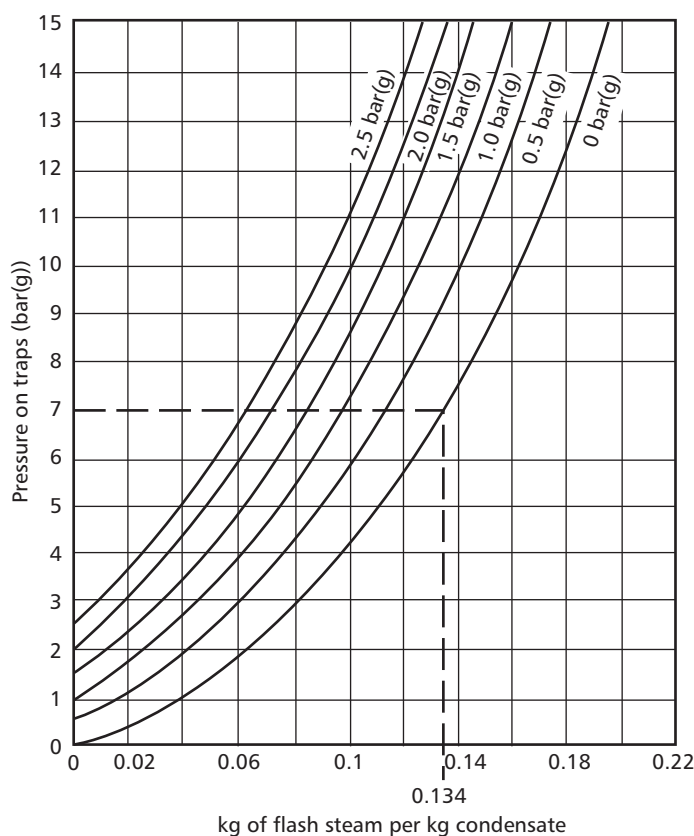


Figure 9.35 Flash steam calculation chart

Alternatively, for the moderate and low pressures encountered in many plants, a chart such as that shown in Figure 9.35 can be used. For the above example, the chart confirms that 0.134 kg of flash steam is produced per kg of condensate passing through the trap.

References

- 1 Reference data CIBSE Guide C (London: Chartered Institution of Building Services Engineers) (2007)
- 2 Heating, ventilating, air conditioning and refrigeration CIBSE Guide C (London: Chartered Institution of Building Services Engineers) (2001/2002)
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- 4 Safe management of industrial steam and hot water boilers HSE INDG436 (Sudbury: HSE Books) (2011) (available at <http://www.hse.gov.uk/pubns/indg436.htm>) (accessed February 2013)
- 5 Building Regulations 2010 Statutory Instrument No. 2214 2010 (London: The Stationery Office) (available at <http://www.legislation.gov.uk/uksi/2010/2214>) (accessed February 2013)
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10 Swimming pools

10.1 Introduction	Summary This chapter provides guidance to the engineer on the requirements associated with swimming pool design. Various design standards, water treatment techniques and sustainability requirements in particular to backwashing and pool water replenishment, which have recently been updated, are considered. Guidance in this chapter covers filtration, water distribution, chemical water treatment, chemical dosing, electrical requirements, plant space and location, hall conditions and operation and maintenance of pool and plant. Furthermore, example design calculations are provided to assist the engineer.
10.2 Design considerations	
10.3 Water treatment system	
10.4 Water distribution design	
10.5 Chemical water treatment	
10.6 Pool hall conditioning	
10.7 Operation and maintenance	
References	
Bibliography	

10.1 Introduction

There are a number of reference documents generally accepted as providing authoritative guidance relating to the design of swimming pools and their associated water treatment systems. The data and guidance provided in this chapter are based on current practice. Design and performance of the water treatment system is therefore fundamental to the financial viability of a facility.

The data provided in this section are intended to mirror the Pool Water Treatment Advisory Group (PWTAG) guidance, placing emphasis on the aspects relating to the engineering input to the design and operation. Additionally information relating to residential, paddling and spa pools is also included.

Relevant British Standards include:

- BS EN 15288-1: 2008: *Swimming pools. Safety requirements for design*⁽¹⁾
- BS EN 15288-2: 2008: *Swimming pools. Safety requirements for operation*⁽²⁾
- DIN 19643-4: 1999: *Treatment and disinfection of water used in bathing facilities. Combined coagulation, ozonization, multi-layer filtration and chlorination method*⁽³⁾ (German standard)
- BS EN 13451: *Swimming pool equipment*⁽⁴⁾
- BS EN 1069: *Waterslides over 2 m height*⁽⁵⁾
- BS EN 1992-3: *Eurocode 2. Design of concrete structures. Liquid retaining and containing structures*⁽⁶⁾
- BS 5385-4: *Wall and floor tiling. Design and installation of ceramic and mosaic tiling in special conditions. Code of practice*⁽⁷⁾

- HSG 179: 2003: *Managing health and safety in swimming pools*⁽⁸⁾.

The scope of BS EN 15288 is defined as follows:

- *Type 1:* Public pools and aquatic parks
- *Type 2:* Hotels, campsites, clubs and hydrotherapy pools
- *Type 3:* Pools in rented villas
- *Type 4:* Domestic pools serving more than 20 homes.

These Standards are applicable both to new pools and the refurbishment of existing pools

The main source of information on water treatment for swimming pools is the PWTAG publication *Swimming Pool Water: Treatment and Quality Standards*⁽⁹⁾. BS EN 15288^(1,2) and DIN 19643⁽³⁾ should be used along with relevant Health and Safety Executive publications as guidance for swimming pool, spa and water feature design.

There is public concern as to the personal health risks that can be associated with the use of pools, the sea and rivers for bathing. The public is now much more informed and has a greater perception as to what constitutes acceptable water quality. The design and performance of the water treatment system is therefore fundamental to the financial viability of a bathing facility.

Everyone involved with the design and construction of pools should give careful consideration to the standard works of reference.

10.2 Design considerations

Swimming and bathing pools vary considerably in size, shape and in the intensity and pattern of use. The design and operational management brief should be considered by all the relevant professionals and no aspect should be determined in isolation.

The choice of water treatment system is dependent on a variety of factors, including:

- the nature of the incoming water supply
- the size and shape of the pool and variety of features to be incorporated in the scheme
- the anticipated bathing loads and pattern of use
- the finances available.

10.2.1 General construction

The pool hall construction should avoid cold bridging, with robust insulation and continuous vapour barriers. The materials should be carefully selected for suitability for their use in high humidity, corrosive atmospheres.

All perimeter ducts and foundations that are integral with the pool tank and their associated relative settlement, must be considered. Water leakage testing is essential, preferably before finishes are applied to the tank

Pool water distribution, filtration and disinfection is critical on all pools, spas etc. Designers should be aware that floating floors can affect pool water distribution substantially. Ensure that there is good surface water draw-off with clean fresh water distributed to each part of pool, especially in deep and leisure type pools, with particular attention to corners. Generous water turnover rates should be selected.

The pros and cons of the various disinfection systems, their application, combination, effectiveness, size requirements, installation costs, running costs and maintenance should be considered when selecting the water treatment system.

The type of system selected also has implications for the design of the pool hall air handling and heat recovery equipment and operating costs. The designs need to be developed and properly co-ordinated to ensure the client’s requirements are fully met in all respects.

Energy consumption is critical, and heat recovery costs and heat generation costs need to be carefully considered in relation to the installation costs, running costs, maintenance and longevity of the plant.

An effective balanced pool hall air distribution system should be provided to supply air at high level (external walls and roof) with the extract at low level, as near as possible to the high moisture zone.

Controls must be capable of working in high humidity and corrosive atmospheres. They should have a narrow control band around the set-points and be positioned correctly to aid energy efficiency.

Natural and electrical lighting should be designed and located to prevent glare on the water surface, which could hinder rescue in an emergency.

10.2.2 Pool and pool hall

Some specific design considerations are given below.

10.2.2.1 Pool tank floor

In water depths of less than 1.5 m avoid abrupt changes of depth. Design for a maximum gradient of 1:10 (but 1:16 is preferred). In water depths less than 0.8 m the maximum recommended gradient is 1:20.

Floors in water areas less than 1.35 m deep should, as a minimum, have ‘group A’ slip resistance and in water areas less than 0.8 m deep the minimum slip resistance should be ‘group B’⁽⁸⁾.

In water depths less than 1.35 m, changes in inclination must be marked by a contrasting colour and tactile surface and there must be a conspicuous line marked on the floor where depths change from 1.35 m to deeper than 1.35 m.

10.2.2.2 Pool tank walls

These must be smooth and free from structural protrusions down to 1.5 m, except for rest ledges.

Rest ledges are recommended in water depths greater than 1.4 m. Rest ledges must be between 1.0 m and 1.5 m from the water surface, with a minimum width of 100 mm and a maximum protrusion of 150 mm

Anchor points must be installed at water level on the shallower side 0.5 m before the change to allow installation of a device to define an area for non swimmers

10.2.2.3 Pool surrounds

Minimum widths of pool surrounds are given in Table 10.1⁽¹⁾.

The minimum distance between a swimming pool and a diving pool should be 3.0 m, and the minimum distance between a swimming/diving pool and a learner pool should be 4.0 m.

Table 10.1 Minimum width of pool surrounds⁽¹⁾

Location	Minimum width for stated pool type* / m			
	Type 1	Type 2	Type 3	Type 4
Main access from changing	3.0	2.5	1.25	2.5
Other surrounds generally	2.5	2.0	1.25	2.0
Where starting blocks are installed	3.0	2.5	1.25	2.5

* Type 1: public pools and aquatic parks; Type 2: hotels, campsites, clubs and hydrotherapy pools; Type 3: pools in rented villas; Type 4: domestic pools serving more than 20 homes

Where the water depth is greater than 1.35 m, the distance between a casualty treatment area and the pool surround should be no greater than 20 m.

Water on pool surrounds must not be allowed to contaminate the pool water.

10.2.2.4 Circulation areas

All floors in wet areas must have effective drainage, i.e. a fall of 1:50 to 1:20.

The maximum ramp inclination is 1:12.5 (1:20 preferred). All floors should have a minimum of 'A' slip resistance in terms of German standard DIN 51097⁽¹⁰⁾, which defines three levels of slip resistance ('A', 'B' and 'C'), 'A' being the least resistant and 'C' the most resistant. Gradients steeper than 1:33 need greater slip resistance.

Single steps should have a maximum height of 250 mm (180 mm preferred), with contrasting nosing.

10.2.2.5 Pool covers

Pool covers are not yet covered by BS EN 13451⁽⁴⁾.

They must be able to withstand a vertical load of 1000 N over an area of 0.5 m × 0.5 m.

They should extend over the whole water surface. If not, access to the pool should be prevented.

10.2.2.6 Wave pools

The requirements of BS EN 13451⁽⁴⁾ apply to wave pools.

Rest ledges, stairs and ladders must be recessed. A surveillance point with a full view over the water, and fitted with an emergency stop, must be provided.

10.2.2.7 Water features

Water features require control panels from which they can be controlled. They are located so as to provide a good overview of the water area and pool surrounds. They may be combined with the first aid room.

10.2.2.8 Electrical

Where indoor and outdoor pools are integrated indoor pools and changing accommodation for outdoor pools must have lightning protection.

Where indoor and outdoor pools are connected, a bonded separation gate must be installed. On the inside there should be provision for a floating barrier 2.0 m from the gate to prevent public access

10.2.2.9 Heating and ventilation

A controlled environment must be provided. The ventilation system should be designed to minimise concentration of pollutants.

The air temperature in the pool hall should be approx. 2 °C above water temperature⁽¹¹⁾ and the relative humidity should be between 40% and 80% (60%RH preferred). The recommended air velocity in proximity of the bathers is 0.1 m/s

10.2.2.10 Acoustics

The pool hall should be designed to ensure that reverberation allows effective communication. A maximum reverberation time of 1.5–2 s is recommended.

10.2.2.11 Lighting

Maximum use should be made of natural light.

For recreational swimming, the *SLL Code for Lighting*⁽¹²⁾ recommends a uniform illuminance of 200 lux. Lower levels are permitted with increased supervision. Underwater lighting is recommended in pools with deep water.

For circulation areas, plant rooms and changing areas, a uniform illuminance of 100 lux is suggested.

Emergency lighting providing 5 lux should be installed.

10.2.3 Plant and plant space

The following will be required:

- filter room/space
- chemical feeder
- disinfection equipment/ozone generator
- monitoring equipment
- switchgear
- water balancing and supply
- water break-tank
- pumps
- ventilation plant
- workshop.

The economic operation of a facility can be affected by the design and function of the plant and plant space.

Equipment rooms must be adequately ventilated, and floor drains arranged so as to serve the treatment processes. The room lighting must take into account the health and safety of the personnel operating in these areas.

Some specific design considerations relating to plant-rooms and ancillary areas are summarised below.

10.2.3.1 Plant rooms

Consideration to be given to adequately sized access openings, haul routes for equipment replacement, and for repair and maintenance of equipment. Special measures (frost protection) are required for outdoor pools.

10.2.3.2 Chemical stores

The use of automatic dosing and control systems is preferred. Where possible disinfection and pH control plant should be in a separate plant room.

These must be located away from public areas and separate or segregated from plant rooms. Access by ramp, rather than stairs, is recommended. Natural ventilation is preferred; if mechanical ventilation is used a 'system malfunction' alarm is required. Chlorine gas must be stored in a gas-tight room. On some sites the chemicals are stored in a separate room.

10.2.3.3 First aid rooms

The necessity of a first aid room should be based on pre-design risk assessment. If provided, a first aid room must have a minimum floor area of 8 m² and height of 2.5 m.

A wash basin with hot and cold water must be provided.

A direct exit route to emergency vehicles must be provided with a minimum width of 1.2 m and no stairs. Where possible, the first aid exit route should not be visible from the pool.

10.2.4 Plant space allocation

The space required for water treatment plant depends on many factors. Table 10.2 suggests space allocations for various types of water treatment plant that may be used when employing vertical sand pressure filters. This excludes either mechanical or electrical plant associated with the facility.

10.2.4.1 Filter room

The floor area and room height must provide adequate working space for maintenance and inspection. Space is required along the side of the filter, for staff and their equipment, so that the filter media can be installed and removed. If steel-cased filters are used then access to all sides will be needed to enable protective coatings to be applied.

In the case of DIN 19624-type filters, the following equation can be used to provide an indicative space requirement:

$$h = (s \times d_c) + 3.1 \quad (10.1)$$

where h is the clear room height (m), d_c is the casing diameter (m) and s is the space factor.

The space factor is given as 0.7 for casing diameters (d_c) from 0.75 m to 1.6 m, and 0.4 for d_c from 1.6 m to 2.3 m.

In the case of DIN 19605-type filters, then:

$$h = 0.6 d_c + 2.9 \quad (10.1)$$

A minimum clearance of 600 mm from other equipment must be maintained above and at the sides of the casing.

Table 10.2 Guide to water treatment plant space requirements

Pool type	Disinfection system	Space allocation as percentage of conventional pool area
Conventional	Hypochlorite	20%
	Hypochlorite (electrolytic generation)	25%
	Ozone and hypochlorite	30%
Leisure	Hypochlorite	30%†
	Hypochlorite (electrolytic generation)	35%†
	Ozone and hypochlorite	40%†
Spa	Depends on the complexity of the selected disinfection and filtration plant	up to 200%

† Add up to a further 10% to the allocation shown above for a leisure pool in each case depending on number and type of features provided.

10.2.4.2 Chemical feeder room

A room located next to the filters will be required for the chemical feeders.

10.2.4.3 Monitoring and equipment room/workshop

Depending on the size of the facility, a room with a minimum floor area of 6 m², complete with laboratory sink and water supply, should be provided to allow for in-house monitoring of the operation of the system.

It is also recommended that a room be allocated for maintenance and repair activities, and for storing spare parts.

10.3 Water treatment system

The objective of a pool water treatment system is to provide a hygienic, safe, comfortable and aesthetically pleasing environment for bathing. This needs to be achieved irrespective of the loading within the predetermined parameters.

The primary functions of the system are to filter, disinfect, and heat the re-circulating pool water so as to achieve these objectives.

The water treatment should be capable of:

- providing clear, colourless and bright water by removing suspended and colloidal matter
- removing organic matter, which may provide a source of food for bacteria and cause a cloudy, dull appearance to the water
- destroying and removing bacteria and ensuring that the water is bactericidal
- maintaining the pH of the water at an optimum for disinfection and bather comfort
- maintaining the water at a comfortable temperature for bathers.

To assist in reducing the bacteria loadings and improve the performance of the water treatment regime, bathers should take a good shower (without soaps or shampoo) before entering the pool. No cleaning agents or surfactants should be allowed to enter the pool water. The make-up water may need additional filtering to remove phosphates and organics.

10.3.1 Filtration design

10.3.1.1 System volume flow (turnover times)

The accepted method of establishing system volume flow has been to estimate the turnover time required for the particular pool arrangement under consideration. The pool water volume (m^3) divided by the turnover time (hours) equates to the system flow ($\text{m}^3 \cdot \text{h}^{-1}$).

The advent of leisure pool complexes has led to layouts incorporating areas for beaches, lagoons, rapids, flumes, spas and separate teaching/learner pools. In these circumstances consideration must be given to the varying turnover requirements in the different zones so that the volume flow for each can be established.

Typical turnover times are shown in Table 10.3 and these are based on the assumption that the greater the intensity of use and/or proportion of shallow water, the faster the turnover time required.

10.3.1.2 Bathing loads

Application of the recommended turnover times should provide a volume flow to each pool or pool zone to ensure

Table 10.3 Recommended pool water turnover times

Pool type	Turnover time / h
Leisure water bubble	<0.33
Flume splash	0.5
Leisure waters:	
— <0.5 m deep	0.5
— 0.5–1.0 m deep	0.5–1.0
— 1.0–1.5 m deep	1.0–2.0
— >1.5 m deep	2.0–2.5
Teaching/learner	0.5–1.5
Leisure (overall)	1.0–1.5
Conventional pool (up to 25 m long with >1.0 m at shallow end):	
— municipal	2.5–3.0
— school	2.5–3.0
— hotel	2.5–3.0
— club/private (heavy use)	2.5–3.0
— club/private (light use)	4.0
Training/competition	3.0–4.5
Diving (>2.0 m deep)	4.0–8.0
Paddling	0.33–0.5
Residential (domestic use)	6.0–7.0
Spa:	
— heavy use	0.1
— light use	0.125
— residential	0.25

acceptable clarity of water, provided that there is control over the number of bathers.

The filtration system should be capable of supporting an approximate bather load of one person for each 2 m^3 of treated water returned to the pool in a 24-hour period. i.e:

$$\text{System volume flow } (\text{m}^3 \cdot \text{h}^{-1}) = \frac{2 \times \text{total bathers per day}}{24}$$

The average hourly capability of the filtration plant can be expressed as the total bathers per day divided by the number of hours that the facility is open.

The maximum number of bathers that the pool can physically accommodate at any time without compromising safety or comfort depends on the depth of water and the activity taking place.

Table 10.4 shows the minimum acceptable pool water surface area per person applicable for a variety of water depths ranges. In circumstances where a pool covers more than one depth range the total should be established on a zonal basis.

Table 10.4 Recommended minimum pool water surface area per person for comfort and safety

Pool type	Surface area per person / m^2
Depth:	
— <1.0 m	2.2
— 1.0–1.5 m	2.7
— 1.5–2.0 m	4.0
Diving pools	4.5
Spa pools†	0.37

† Spa pool shells should also provide a minimum of 0.25 m^3 of water per bather.

Intensively used pools are likely to operate for periods with the maximum number of bathers compatible with physical safety or comfort. The physical safety or comfort maximum should be compared with the hourly average number of bathers for the filtration capability to establish if there is a potential for overloading the plant.

Where the physical safety maximum is in excess of the hourly average, the intended use and projected bather load profiles should be studied and consideration given to increasing the system volume flow and consequent filtration capability to minimise the potential for overloading.

10.3.1.3 Filter types and applications

Filters deal with removal of suspended colloidal material and/or particulate matter which would otherwise cause excessive turbidity. The most consequential source of these pollutants is the bathers themselves, although outdoor pools also experience the additions of atmospheric debris such as dust, leaves, insects etc.

Large suspended matter should be removed by passage through a basket-type strainer fitted on the suction line

from the pool at the pump inlet. The strainer should have a free area of at least six times that of the suction pipe line.

The main types of filter in general use are:

- pressure sand filters
- active filter media
- pre-coat filters
- cartridge filters.

It should be noted that manufacturers' claims of filtration rates through their media can be misleading but an allowance must be made over and above the calculated flow rates for unusual loading, e.g. overcrowding. This additional allowance needs to be small as there are costs attached to an oversized filter.

The performance of all filter media is inversely proportional to the flow of water passed through the bed: the slower the flow, the better the performance. Ideal flow rates for swimming pools should be less than 15 m³/h per square metre of filter bed.

Regardless of the type of filter selected, it must be constructed of materials which are compatible with the chemical water treatment employed. Mild steel filter shells should be suitable treated internally to withstand the corrosive nature of the water.

Pressure sand filters

Pressure sand filters are the most universally available and are suitable for all types and sizes of pool. They are capable of filtering matter down to 5–10 microns. Typical data for pressure sand filters are:

- maximum filtration rate: 24.5 m³·h⁻¹/m²
- media depth:
 - 1.25 m (multi-grade)
 - 1 m (single grade)
- backwash rate: 28 m³·h⁻¹/m²
- compressed air scouring rate: 32 m³·h⁻¹/m²

Table 10.5 shows approximate capacities for a range of vertical pressure sand filter diameters and ratings.

Table 10.5 Approximate capacities of vertical pressure sand filters

Shell diam. / mm	Bed area / m ²	Filtration rate / (m ³ ·h ⁻¹ /m ²)							
		15.0	17.5	20.0	25.0	30.0	35.0	40.0	50.0
750	0.44	6.6	7.7	8.8	11.0	13.2	15.4	17.6	22.0
900	0.63	9.3	11.0	12.6	15.8	18.9	22.0	25.2	31.6
1200	1.13	17.0	19.8	22.6	28.3	33.9	39.6	45.2	56.6
1500	1.76	26.4	30.8	35.2	44.0	52.8	61.6	70.4	88.0
1800	2.54	38.1	44.5	50.8	63.5	76.2	88.9	101.6	127.0
2100	3.46	51.9	60.6	69.2	86.5	103.8	121.1	138.4	173.0
2400	4.52	67.8	79.1	90.4	113.0	135.6	158.2	180.8	226.0
2700	5.72	85.8	100.1	114.4	143.0	171.6	200.2	228.8	286.0
3000	7.07	106.5	123.7	141.4	176.8	212.1	247.5	282.8	353.6

The flocculant is lost during the backwash cleansing and a suitable feed facility is required in order to introduce the flocculant during the filtration cycle with a throughput of 3.4–4.1 × 10⁻³ m³·h⁻¹/m².

Figure 10.1 shows typical medium-rate and high-rate pressure sand filters.

Active filter media

Active filter media (AFM) are offered as an alternative to standard filter sand. The media actively resist bacterial growth and bacteria levels can be a million times lower than in an equivalent sand filter. Therefore, use of these media will resist bio-fouling, making a difference to the water quality and the production of trichloramine.

Trichloramines are toxic and can cause lung damage in children.

Good coagulation and flocculation prior to AFM filtration will help reduce the bio-film and trichloramine production.

The levels of chlorine used in most pools and spas will not affect the growth of bacteria on the sand, or on any surface in contact with the water.

It is important to ensure removal of solids during backwash, as they act as nutrients for bacteria and will help to increase the levels of the trichloramines.

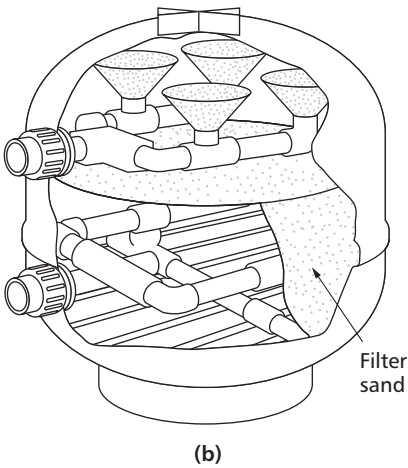
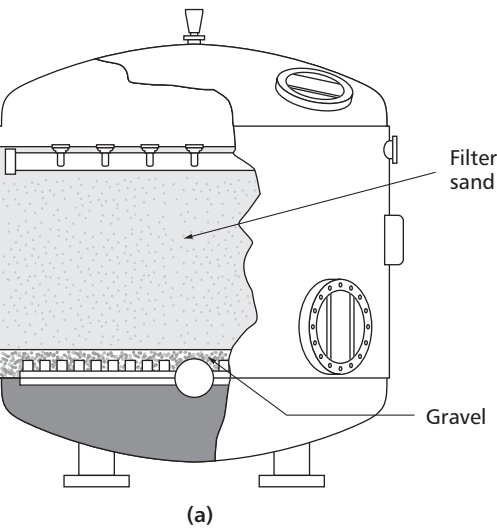


Figure 10.1 Typical pressure sand filters (a) medium-rate (b) high-rate

Thorough cleaning requires an air scour rate of $70\text{--}90\text{ m}^3\cdot\text{h}^{-1}/\text{m}^2$ of bed for a period of 5 minutes. This should be followed by a backwash rate that expands the bed by at least 15% using a water flow rate of $40\text{--}45\text{ m}^3\cdot\text{h}^{-1}/\text{m}^2$.

Pre-coat filters

Pre-coat filters differ from the sand filters in that they use an expendable medium that is renewed each time the filter is cleaned. The normal medium used for this purpose is powdered diatomaceous earth. This is made-up into a slurry and, for pressure pre-coat filters, is pumped into the filter shell where it is deposited onto plates or cones. Dirt collects on the medium until the rising pressure indicates that cleaning is necessary. The water flow is then reversed, flushing the medium and dirt from the plates into the base of the shell to drain.

A vacuum diatomaceous filter is also available which uses the same principle but the screens are located in an open tank installed on the pool water suction line.

The main advantage of pre-coat filters is that they can provide a much greater surface area of filter than a comparably sized sand filter and consequently need less plant space. In addition, they filter out bacteria and organic substances of sizes down to 1–5 microns, which can result in fine water clarity and polish. The ability to remove bacteria and the oocysts/cysts of organisms such as *Cryptosporidium parvum* and *Giardia lamblia*, means that pre-coat filters are ideal in areas where the quality of the source water is poor or where these aspects are particularly problematic.

For use in the UK, these advantages need to be balanced against the operational and maintenance costs and the generally excellent quality of mains supplied source water. Particular expertise is also required in operational staff although problems associated with septum failures are less common with the current generation of synthetic cloths. Another factor to consider is the fact that water companies do not generally approve of the disposal of the effluent, which includes the medium, directly into the drainage system. This means that settling tanks are normally required with subsequent sludge removal and disposal. This allows recovery of the waste water for treatment and re-use and this may be a further factor if sustainability of resources is a consideration.

Pressure pre-coat filters should have a filtration rate of approximately $6\text{ m}^3\cdot\text{h}^{-1}/\text{m}^2$ and vacuum pre-coat filters approximately $4\text{ m}^3\cdot\text{h}^{-1}/\text{m}^2$. Backwash rates for pressure pre-coat filters should be the same as the filtration rate.

Cartridge filters

Cartridge or pad filters offer low capital cost filtration. They are normally of the induced or vacuum flow type, and are designed primarily for small, lightly loaded pools. Some cartridges or pads are disposable and expensive whilst others can be removed, hosed down and reused.

Filtration rates vary between $1\text{ and }25\text{ m}^3\cdot\text{h}^{-1}/\text{m}^2$ depending on the membrane material. They also vary widely in efficiency, filtering particles between 1 and 25 microns.

Spa pools should operate with employing polyester material and not paper.

Table 10.6 identifies maximum recommended filtration rates for various pool and filter combinations.

Table 10.6 Maximum recommended filtration rates for various pool and typical filter combinations for guidance

Pool type	Filtration rate / ($\text{m}^3\cdot\text{h}^{-1}/\text{m}^2$)			
	Pressure sand	Pressure precoat	Vacuum precoat	Cartridge
Flume	19–25	<6	<4	NR
Paddling	19–25	NR	NR	NR
Teaching/learner	19–25	<6	<4	NR
Leisure	19–25	<6	<4	NR
Conventional:				
— municipal	19–25	<6	<4	NR
— school	19–25	NR	NR	NR
— hotel, club or private (heavy use)	19–25	<6	<4	NR
— hotel, club or private (light use)	<50	NR	NR	1–25
Training	<35	<6	<4	NR
Diving	<35	<6	<4	NR
Residential	<50	NR	NR	1–25
Spa:				
— heavy use	<25	<6	<4	NR
— light use	<35	<6	<4	<2.5
— residential	<50	NR	NR	<2.5

NR = not recommended

10.3.3.4 Flocculation

Apart from improved water clarity as a result of the increased filter efficiency, the use of a coagulant can also reduce the quantity of disinfectant required.

The trend is now towards continuous addition of liquid flocculants such as polyaluminium chloride (PAC). Coagulants should ideally be dosed in solution, using a suitable dosing unit.

The use of coagulants to increase flocculation and aid filtration depends on the nature of the incoming water supply, the bather loads and type of filtration system. Coagulants form a gelatinous precipitate on the filter bed that attracts suspended and colloidal material that would not otherwise be retained by the filtration process.

Such material can include *Cryptosporidium parvum* and *Giardia lamblia*, microscopic protozoa found throughout the environment, often in animals. They cause diarrhoeal illness and are of particular relevance in pools as the infective oocysts/cysts are small and resistant to chlorine disinfectants. The organisms can be transported via the water supply but usually enter the pool as a result of a faecal release by an infected person.

Effective filtration with flocculation and backwashing is essential for the removal of these oocysts/cysts.

10.3.3.5 Algicides

Algae grow quickly in the presence of warmth and sunlight and need to be eradicated quickly.

The capacity of the disinfection system should be such that where a chlorine donor system is used, a free chlorine concentration of up to 10 mg/litre can be attained.

Increasing the free chlorine to 10 mg/litre for several hours is usually sufficient to kill off the algae.

10.3.3.6 Total dissolved solids

In order to minimise chloride attack on metals and sulphate attack on tiles and grouting, then the concentration of total dissolved solids should not rise above a maximum of 1500 mg/litre.

In order to maintain the total dissolved solids below this level, a proportion of the pool water needs to be replaced on a regular basis.

The quantity of replacement water will depend on the nature of the supply water, the chemicals employed and the bathing loads. If insufficient water is replaced by backwashing, bather and evaporation losses alone, then additional dumping and make-up of water will be required.

10.3.4 Pool water discharge

Water is discharged to drain during backwashing of filters, during dilution procedures and when emptying the pool. The waste water is classified as a trade effluent and should not be discharged into a sewer or water course without the consent of the local water company, the Environment Agency or other relevant authority. In Scotland the relevant authorities are the local water authority and the Environmental Protection Agency and in Ireland the Department of the Environment. There may be specific requirements in respect of the rate and/or chemical composition of the water discharged. The drain facility should address these requirements and in certain circumstances the provision of holding tanks may be necessary so that the rate and quality of the water released can be appropriately controlled. Refer to chapter 4 for further information.

Especially where holding tanks are required, consideration should be given to the possibility of recovering the waste water for re-use. Re-use in a 'grey water' system or for irrigation could be achieved with nil or relatively little re-treatment. For re-use in the pool it is likely that the water would need to undergo significant re-treatment.

10.4 Water distribution design

10.4.1 Pumps

Pumps should be sized to deliver the required volume flow at the total resistance of the system, including lift, when the filter resistance is at a maximum (i.e. prior to backwashing). Where the pump operates with a suction

lift the selection must ensure that the available net positive suction head (NPSH) of the system is greater than the required NPSH of the pump in order to prevent cavitation at the inlet leading to loss of performance, vibration and erosion of metal surfaces, see section 6.3.

Where multi-filter installations are provided, consideration should be given to the selection of multiple pumps in parallel in order to give greater flexibility of use for load variations, filter backwashing and standby. A standby facility is essential as pool circulation systems should operate continuously.

All installations should have sufficient instrumentation to permit the main circulation rate of flow, backwashing rate and head loss across the filter units. Each pump set should be provided with an ammeter, hours run meter and pressure gauges on both sides of the pump. A separate electric meter giving power consumption would be an asset. Inlets to the pool should be capable of enough adjustment to ensure that they each take their design proportion of the flow at a minimum velocity of 0.4 m/s.

For further information on pumps and pumping, see chapter 6.

10.4.2 Pipework, fittings and valves

Pipework should be sized in accordance with normal hydraulic requirements (see CIBSE Guide C, chapter 4⁽¹³⁾).

Pipe velocities should be limited to a maximum of 1.5 m·s⁻¹ for suction pipework and 2.5 m·s⁻¹ for delivery.

Pipework materials should be selected to suit the operating conditions in terms of pressure, temperature and the chemical composition of the circulating water.

Valves should be provided for isolation, system balancing and any other operational purposes.

Multi-port valves may be specified for smaller installations (available up to 75 mm diameter). These have up to six ports which allow the filter cycle flow changes to be achieved by moving a single lever. The valve has positions marked:

- 'Normal' (filter): normal circulation through filter and the pool
- 'Backwash': cleansing of filter by reversing flow to drain
- 'Rinse': resettles bed after backwashing with normal flow through filter to drain
- 'Waste': dumps water directly to drain bypassing the filter
- 'Shut' (closed): no flow
- 'Re-circulate': normal flow bypassing the filter (usually blanked off).

Larger systems need to offer the same functions, but this is achieved by operation of a number of valves in sequence.

Flow measuring equipment is essential and there should be sufficient provision to control and balance main and sub-circuit flow volumes as well as the backwash quantity for each filter. Various types of flowmeter are available but orifice plates have proved reliable and cost-effective. Orifice plates with mercury as the manometer fluid should be avoided for reasons of safety.

Care should be taken in the design of suction fittings to ensure a velocity of below $0.3 \text{ m}\cdot\text{s}^{-1}$ across open grids, grilles or drains. Designs should not incorporate single suction fittings especially on lines from shallow water. Multiple suction fittings should be spaced or of sufficient size such that it is not possible for all of the outlets to be covered by a single bather. There are many recorded cases or serious injury due to bathers becoming trapped on suction fittings. Grids or grilles should be of robust construction and designed so that they cannot be damaged in use and can only be removed by authorised persons. Under no circumstances should bathers be able to access the suction pipe connection at these fittings. Apertures in grilles and openings should not exceed 8 mm where there is a risk of entrapment of fingers and toes. The risk of hair entrapment should also be considered, especially in the design for spa pools.

Velocity at inlets should generally be $0.5 \text{ m}\cdot\text{s}^{-1}$ although in sensitive areas such as shallow water may need to be as low as $0.3 \text{ m}\cdot\text{s}^{-1}$.

See HSG 179: *Managing Health and Safety in Swimming Pools*⁽⁸⁾ for additional information on safety.

Suction lines should be kept to a minimum, especially if the pump operates with suction lift. Pipework should rise up to the pump suction as close to the pump as possible.

Materials recommended for use in water treatment systems are shown in Table 10.7.

Stainless steel can be sensitive to some oxidants, high levels of chlorides and carbon-based filtration media, and it is essential that the correct grade is specified for any particular application.

PVC-U can be prone to environmental stress cracking when used for ozone or ozonised water lines.

Swimming pool water is aggressive but there is additional risk of corrosion close to chemical injection points. The chemical composition at various points in the system may be therefore different and pipework, valves etc. should be selected for the most stringent requirements.

The circumstances under which materials and/or protective measures are to be employed should be confirmed with the manufacturer to ensure compatibility and correct specification.

10.4.3 Water make-up supply

Make-up water may be derived directly from sources other than the water company main supply as is the case with borehole, spring or sea water fed pools. Regional variations in the quality and composition of the make-up supply from the water company mains will influence the choice of water treatment chemicals and the appropriate selection should minimise the potential for chemical pollutants to be formed. The water treatment produces pollutants which can only be controlled by dilution of the pool water with fresh make-up water.

Table 10.7 Materials recommended for use in water treatment systems

Application	Materials	Comments
Filter vessels	● Steel with internal corrosion protection ● Plastics ● Concrete ● Stainless steel	Corrosion protection depends on chemical composition of water and, where applicable, ozone concentration.
		Not suitable for ozone vessels using carbon-based media
Poolwater pipework:		
— general	● PVC-U ● ABS ● Polyethylene ● Polypropylene ● Stainless steel ● Ductile cast iron ● Copper/tin alloys	With molybdenum content as Type 316
— valves	● Unalloyed steel and cast iron ● PVC-U ● ABS ● Polypropylene ● Stainless steel	With resistant coating
		With molybdenum content as Type 316
Chemical dosing pipework:		
— general	● Polyethylene ● PVC-U	
— chlorine gas	● Unalloyed steel ● Copper	With chlorinated rubber coating or cadmium plated Cadmium plated
— valves	● PVC-U ● ABS ● Polypropylene	With corrosion-resistant sealants

Guidance on the water quality of the raw water and requirements for the circulating pool water is available in *Swimming Pool Water: Treatment and Quality Standards*⁽⁹⁾ but it is advisable to seek specialist advice. The Water Supply (Water Fittings) Regulations 1999⁽¹⁴⁾ should also be consulted regarding protection against backflow.

To some extent the dilution is achieved by water replacement to offset water lost to evaporation, to bathers and during backwashing but further dilution may also be necessary to control pollutants especially where bather loading is high. Quantities equal to 30 litres per bather per day of make-up water are recommended.

It should be noted that rigid application of the 30 litres per bather per day rule can in some circumstances result in a higher percentage of water replacement which may not be practical on a regular basis. For example, intensively used leisure pools which incorporate significant areas of shallow water may require a weekly water replacement in excess of 50% of the total pool volume to control levels of dissolved solids and combined chlorine within the normal ranges.

The make-up supply line should be fitted with a water meter to enable the quantities to be monitored. The water should be introduced via a break tank and the tank supply, tank and feed should be of sufficient size to refill the pool after backwashing or dilution in a practicable period of time. Associated heating and chemical dosing equipment also needs to be able to maintain satisfactory operating conditions during and after refilling. Backwashing normally takes place outside the hours of pool opening or use, but the make-up facility should ideally be independent of the general building cold water storage provision.

10.4.4 Balance tanks

A balance tank is required to take up displacement caused by bathers and wave surge and provides a source of backwash water so that water in the pool remains at a constant level. The tanks should be closed or covered with vents and overflows. They should be capable of being completely drained, and have access for cleaning.

An area would be allocated below the level of the water in the pool to provide adequate gradients for the inlet pipes.

Figure 10.2 shows a nomogram for the sizing of the wave surge element of a balance tank. It shows the example of a 25 m × 12.5 m level deck pool, with a volume flow of 182 m³·h⁻¹ and 50% removal via the level deck.

A is the pool surface area (312.5 m²), the length of the level deck edge is $2 \times (12.5 + 25) = 75$ m, and q is the flow into the level deck channel in litre·s⁻¹/m:

$$q = \frac{182 \times 0.5 \times 10^3}{3600 \times 75} = 0.34 \text{ litre} \cdot \text{s}^{-1} / \text{m}$$

Hence, from Figure 10.2, $V_w = 10.7$ m³.

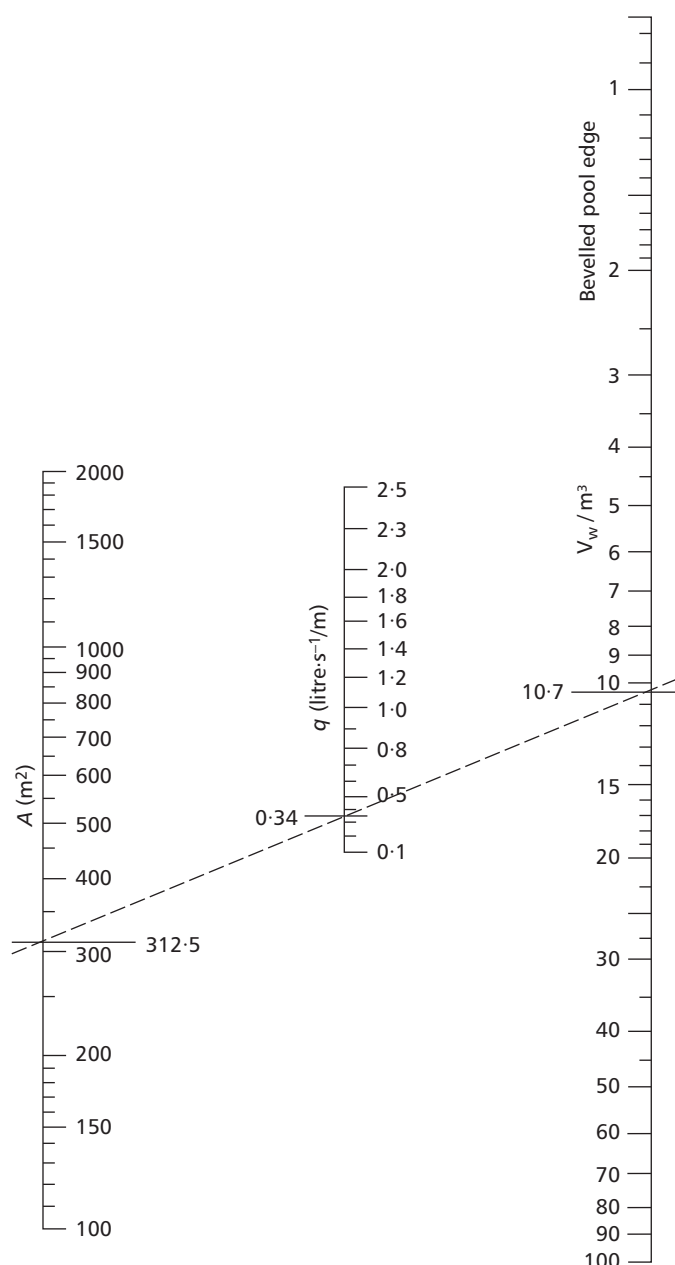


Figure 10.2 Nomogram for determining wave surge element (V_w) in sizing of balance tanks

10.4.5 Circulation within pool

There are a number of proven arrangements of inlets and outlets for conventional pools. Figure 10.3 shows typical arrangements for orthodox, cross-flow, 'surflow' and deck level circulation in a conventional pool.

In the orthodox system (Figure 10.3(a)) the inlet is at the shallow end of the pool, through a number of openings in the shell wall. The outlet is at the deep end through gratings in the shell floor.

In the cross-flow system (Figure 10.3(b)) the inlet is through a number of openings along the length of one long side. Outlets are similarly placed along the opposite wall.

In the 'surflo' system (Figure 10.3(c)) the inlet is through a multiplicity of openings disposed along the central length of the shell floor. The outlet is by overflow to a continuous scum trough in the walls of the pool.

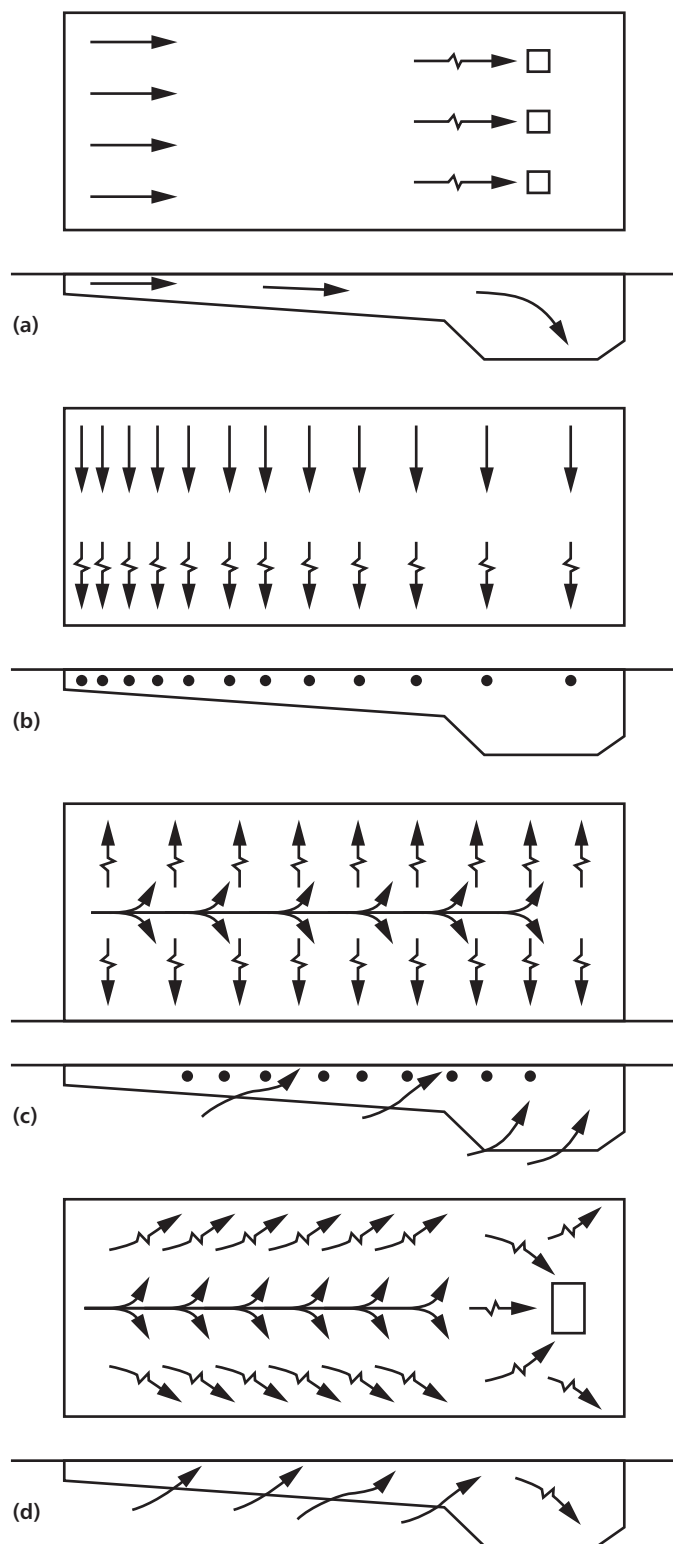


Figure 10.3 Circulation in conventional pool; (a) orthodox, (b) cross-flow, (c) 'surflo', (d) deck level

In the deck level system (Figure 10.3(d)) the inlet is through a multiplicity of openings disposed along the central length of the shell floor or along the walls. The outlet is by overflow to a continuous deck level channel in the surround around the edge of the pool although some outlet could also be to a deep end floor grating.

The most effective circulation is achieved by a system which incorporates inlet through a multiplicity of openings in the shell floor with 100% surface level removal through a continuous scum trough or deck level outlet. The degree of sophistication of the circulation

system will however need to take into account the intended use for the pool and any economic restraints.

The irregular shapes of leisure pools and the need to create zones with differing turnover times has made the placing of inlets and outlets more critical. A typical leisure pool would be provided with a level deck gulley and skimmers or a scum trough designed to remove 50% of the total flow with the remainder passing through sump outlets. A mixture of spreader and jet inlets in the side wall are placed and sized to give the required turnover in each zone. There are variations which incorporate floor inlets with all the outlet water removal at the surface level. Continuous surface level removal by a combination of deck level channel and scum trough is more effective than a system which incorporates skimmers.

10.5 Chemical water treatment

10.5.1 General

The layout of a typical swimming pool water treatment plant is shown in Figure 10.4.

The most significant factor in the selection of the type of disinfection is the nature of the incoming mains supply. The objective of the design of the water treatment system should be to minimise the addition of different types of chemicals and to simplify the operator involvement.

Chemical water treatment combines the actions of disinfection, pH control and water balance.

There are a number of different options of water treatment systems available and various factors to be considered prior to making a selection. The following factors should be considered:

- (a) the nature of the incoming mains water supply to the locality in which the pool is to be built
- (b) the size of the pool and relative position of plant room
- (c) the design bather load
- (d) the cost
- (e) the ease of application of the chemicals.

Other factors affecting disinfection include:

- elevated temperature
- high turbulence from wave machines, flumes or other features.

Selection should represent minimum risk in handling and use compatible with a satisfactory performance. These aspects are covered by the Construction (Design and Management) Regulations 2007^(15,16) and the Control of Substances Hazardous to Health Regulations 2002⁽¹⁷⁾, including risk assessments applied to the control of biological agents such as *Legionella*, *Pseudomonas* and other microorganisms that colonise water systems.

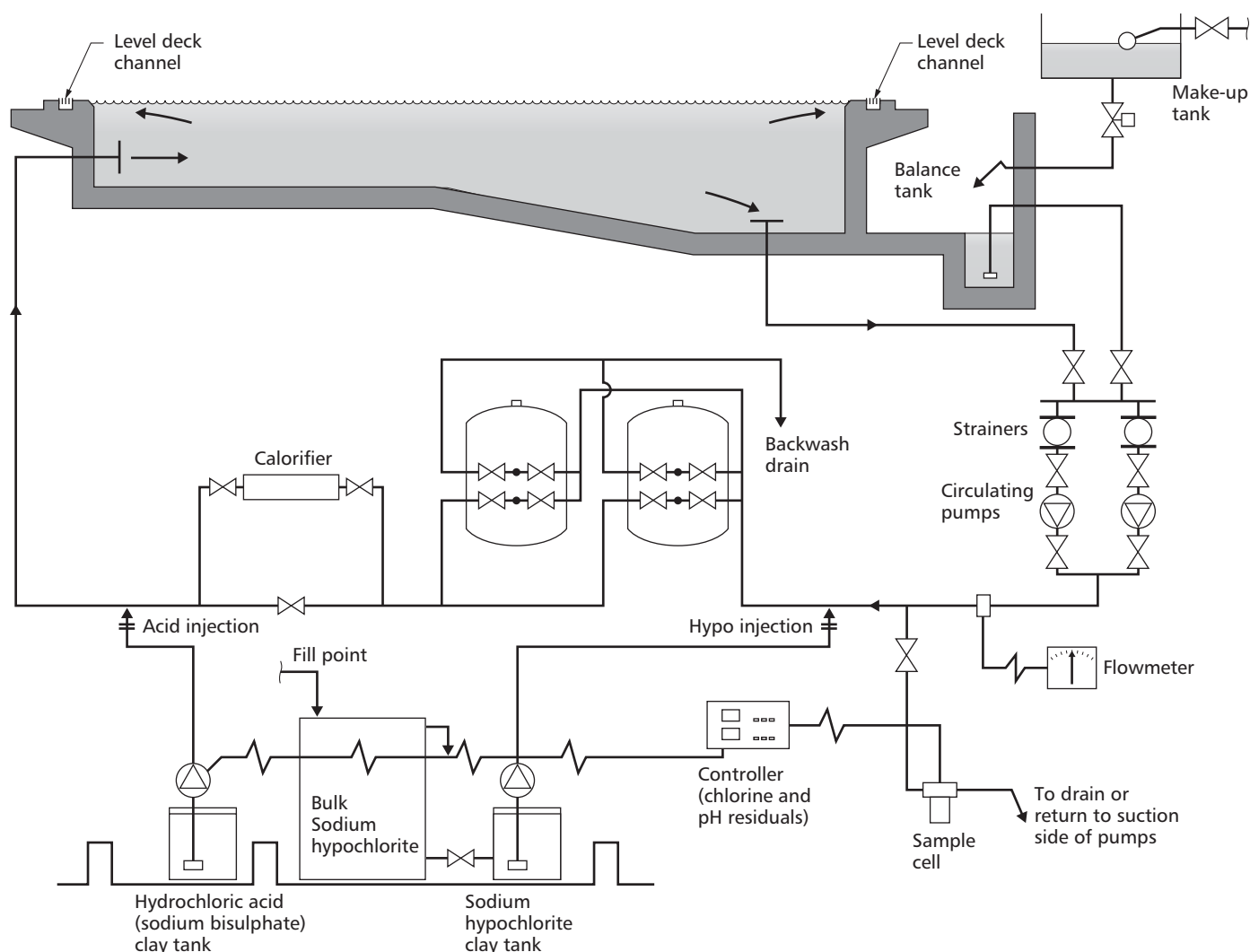


Figure 10.4 Typical swimming pool water treatment plant layout

10.5.2 Disinfectants

Disinfectants used in swimming pool treatment fall into three main categories:

- (a) Chlorine based disinfectants:
 - sodium hypochlorite: which to be effective must have effective pH control within a range of 7.2–7.8 with a target of 7.2–7.4
 - calcium hypochlorite: suitable for soft water areas
 - chlorine gas
 - trichloroisocyanuric acid: easy to handle.
- (b) Bromine based disinfectants: tend to give a green hue to pool water, rather than the blue colour associated with chlorine based disinfectants:
 - liquid bromine
 - bromochlorodimethylhydantoin (BCDMH)
 - sodium bromide plus hypochlorite.
- (c) Two-part disinfection:
 - ozone and hypochlorite
 - ultra-violet light and hypochlorite.

10.5.3 pH control

pH control is important since it can optimise the disinfection ability of the disinfectant. If maintained at between 7.2 and 7.8, the pH of the water will be similar to the pH of body fluids and is therefore less likely to cause stinging and irritation to bathers.

Disinfectants are either acid, alkaline or neutral (see Table 10.8) and the pH needs to be controlled by an appropriate pH adjuster. Alkaline disinfectants will normally require an acidic pH controller and vice versa for acidic disinfectants (see Table 10.9). The pH adjustment required for neutral disinfectants will largely depend on the nature of the incoming mains supply.

10.5.4 Water balance

The main factors used to determine water balance are temperature, pH, total dissolved solids, calcium hardness and alkalinity.

Certain water constituents can be interrelated in a complex way to determine whether pool water following treatment is scale forming or corrosive. Provided the pH is maintained between 7.2–7.8 and the total dissolved solids below 1500 mg/litre there should be minimum scale deposition or corrosion.

Table 10.8 Disinfectants

Alkaline	Acidic	Neutral
Sodium hypochlorite	Chlorine gas	Trichloroisocyanuric acid
Calcium hypochlorite	Bromine gas	Bromochlorodimethylhydantoin

Table 10.9 pH controllers

Alkaline	Acidic
Sodium carbonate	Carbon dioxide
Dolomitic filter media†	Sodium bisulphate Hydrochloric acid

† Note: pH can be controlled by the use of solid dolomitic media in the filter bed but this may not always operate satisfactorily as it is dependent on the nature of the supply water, the disinfectant employed and use of any ancillary chemicals. Consequently it does not offer the flexibility and the same degree of control as sodium carbonate.

10.5.5 Combined chlorine or bromine concentrations

Pollution from bathers consists primarily of bacteria and nitrogenous products from urine and perspiration. The disinfection process not only kills the bacteria but breaks down the urine and perspiratory products to nitrogen. During the course of disinfection this may result in the formation of intermediary products called chloramines (combined chlorine) or bromamines (combined bromine) depending on whether chlorine or bromine compounds are being used as the disinfectant.

Under certain conditions chloramines can volatilise into the atmosphere causing irritant effects to bathers. High concentrations of chloramines suggests that the water treatment plant is not coping effectively with the bather

loading and may also indicate insufficient water replacement is occurring.

In order to minimise this effect the combined chlorine concentration should be maintained at less than 1 mg/litre and ideally below 0.5 mg/litre.

To combat communicable diseases, Chlorine should be added while the water treatment system is operating, even when the facility is closed.

The free chlorine concentration in bath or pool water should be 0.2–0.5 mg/litre. For hot whirlpool baths the concentration should be 0.7–1 mg/litre.

Bromamines are recognised as having a less irritant effect on bathers than chloramines. No standard has been set for the maximum values allowed.

10.5.6 Ozone plant

Ozonation is the addition of ozone to water for the purposes of oxidation and disinfection. Ozone must be used with a secondary disinfectant, usually sodium hypochlorite, which is added to prevent cross-infection within the pool. A typical ozone plant is shown in Figure 10.5.

Dose rates of between 0.8–1.0 g of ozone per m³ of circulating water and contact times of 2–2.5 minutes are necessary for effective disinfection. For pools operating above 28 °C, as with chlorine systems, the dose rate may need to be increased to 1.0–1.2 g·m⁻³ as the effectiveness of disinfection is reduced with the increase in temperature.

There are various options available for application of ozone and all have been shown to operate successfully. The most appropriate schemes are described in detail in British Water’s *Code of Practice for Ozone Plant for*

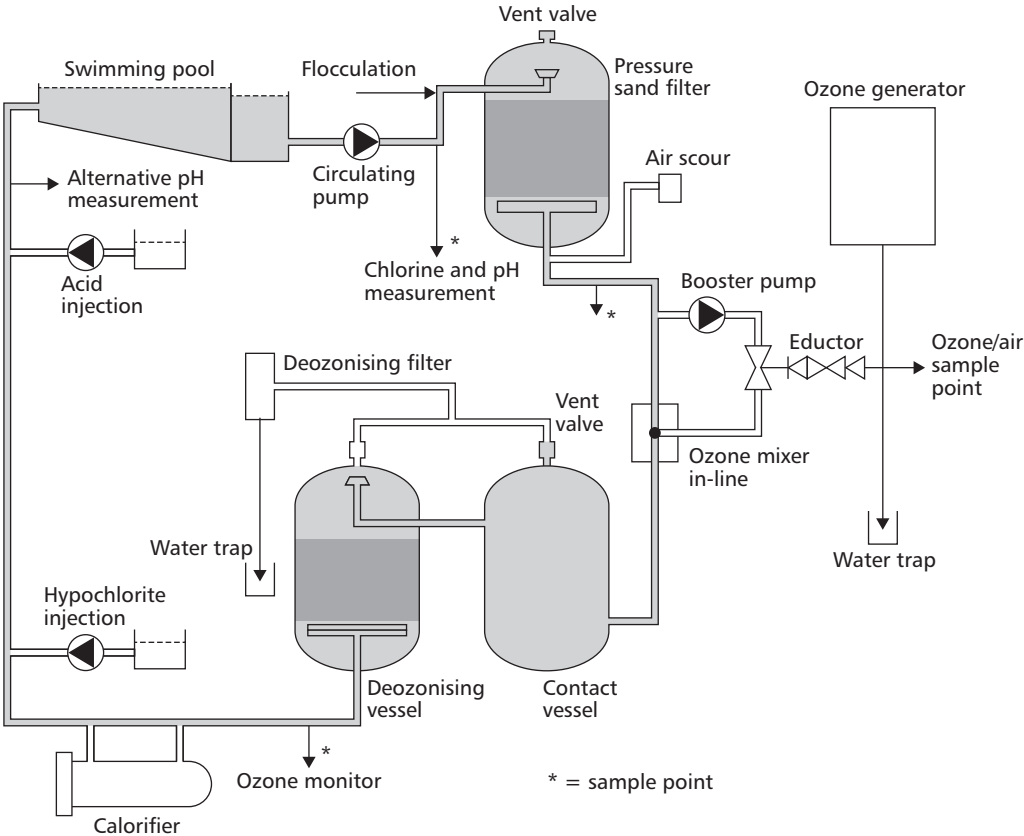


Figure 10.5 Schematic of a typical ozone system

Swimming Pool Water Treatment⁽¹⁸⁾. These schemes differ in the number of vessels employed and the point at which ozone is introduced. They vary between the use of a combined vessel (in which ozone contact, de-ozonisation and filtration are achieved in one vessel) and the use of three separate vessels for filtration, ozone contact, and de-ozonisation.

Ozone contact vessels need to be provided with a system to allow excess ozone gas and air to be safely vented. The exhaust gas should be de-ozonised before discharge at a suitable point to avoid any re-entry into the building.

10.6 Pool hall conditioning

10.6.1 General

The pool hall conditioning should ensure that the space temperature is maintained at an acceptable level for bathers and that the air and the pool water are in balance in order to minimise evaporation.

An air temperature of at least 2 °C above the water temperature (to a maximum of 30 °C) and a maximum relative humidity of 60–70% is the typical requirement to ensure bather comfort and protection of the building fabric and air plant from condensation.

Evaluation of the precise evaporation losses is difficult, especially in leisure pools where features enhance the rate considerably. The main factors affecting the evaporation rate are:

- (a) the vapour pressure gradient between pool water and the pool side air
- (b) the bather activity
- (c) the number and type of features and the sequence of operation
- (d) the air velocity across the pool water surface.

A ventilation rate of 10–15 litre·s⁻¹/m² of wetted surface area can be used as a guide for conventional pools. Also note additional allowances of 30 litre·s⁻¹/m run of ride for flumes and up to 5 litre·s⁻¹/m² of wetted surface area for leisure pools, depending on the number and nature of the features installed. There is some flexibility during commissioning in determining a sequence of operation of features which fall within the overall installed ventilation capability.

There should be an outdoor air supply rate of 12 litre·s⁻¹ per occupant (including bathers, spectators and staff).

The supply and extract air must be evenly distributed to achieve satisfactory conditions. The system should remove the contaminants arising from the disinfection process within the pool in a way which produces low air velocity across the surface, thus minimising evaporation.

The volume and nature of the contaminants (chloramines) in the pool hall air depend on the disinfectants and other chemicals employed in the particular pool and on the extent of the pollutants added by the bathers.

Where outdoor air input is used as the only means of controlling humidity the chloramines are exhausted along with the humid air. The increased evaporation rates inherent in leisure pools mean that the ventilation plant become larger and more costly to run. However, systems operating with a primary disinfectant such as ozone offer potentially lower quantities of chloramine release into the pool-side atmosphere and this, coupled with the need for energy conservation, has resulted in the design of central plant which incorporate heat recovery and/or heat pump dehumidification to allow recirculation of air.

The economies of such systems require detailed consideration, and experience has shown that recirculatory systems, even those operating on ozone with residual chlorination, can operate under conditions which cause severe corrosion and loss of performance in a short timescale. The materials and treatments for ductwork and central plant components must be compatible with the most corrosive conditions likely to be encountered and recirculatory systems must ensure that the chloramines present are sufficiently removed by the dehumidifying process. Similar care must also be taken when selecting materials for heat exchangers which provide heat recovery into the pool water circuit as typical pool water composition may exclude some options.

10.6.2 Heating

The recommended water temperature mainly depends on the activity taking place and in some circumstances on the age and/or disposition of the bathers. The operating temperature for hydrotherapy pools will usually be decided by the physiotherapist in charge of the treatment.

In many cases pools need to cater for a variety of activities over a relatively short timespan and the selected operating temperature will be a compromise but the design should be capable of achieving the maximum in accordance with Table 10.10. The operating temperature range for the pool should also be compatible with the design of the shell structure and tiling if damage is to be avoided.

For a leisure complex with a variety of pool types served by a common water treatment plant, supplementary heating can be provided on return lines to areas having a higher temperature requirement. However, care must be taken to ensure that the relative volumes at higher temperatures are not sufficient when mixing at the plant to cause loss of temperature control in areas requiring the standard temperature.

The heat exchangers should be sized so that, when filled with fresh water, the pool can be raised to the operating temperature at a rate which will not involve thermal change likely to cause damage to the shell or the tiling. BS

Table 10.10 Maximum recommended pool water temperatures

Pool type	Water temperature / °C
Conventional	28
Leisure	29
Teaching	29
Training/competition	25–27
Diving	28
Hydrotherapy	32–40
Spa	40

5385-4: 2009⁽⁷⁾ gives specific details for heating pools on refilling and this suggests a maximum rate of 0.25 °C per hour. However, it is accepted that heat exchangers are sized to be capable of raising the entire contents of the pool by 0.5 °C per hour at normal operating conditions.

10.7 Operation and maintenance

Under the COSHH Regulations⁽¹⁷⁾, pool operators need to ensure that the risk of exposure to biological agents is adequately controlled by monitoring of the performance of the water treatment system and by bacteriological/chemical sampling and analysis to confirm that a satisfactory water quality is maintained. The requirements for monitoring are reiterated in the 'water treatment system' section of HSG 179: *Managing Health and Safety in Swimming Pools*⁽⁸⁾.

HSG 179 requires that a written 'pool safety operating procedure' (PSOP) is prepared. The PSOP should include a 'normal operating plan' (NOP) and an 'emergency action plan' (EAP). Guidance on formulation of a PSOP is given in Appendix 4 of HSG 179. The NOP requirements include details of the pool water treatment plant and the associated operational and maintenance requirements for safe and effective performance.

10.7.1 Pool water monitoring

The monitoring of pool water is an essential indication of the effectiveness of the water treatment plant both in terms of the design of the system and operator efficiency.

Independent monitoring on a monthly basis should be undertaken to establish the bacteriological and chemical condition of the pool water.

10.7.1.1 Chemical analysis

Chemical analysis can enable an assessment to determine:

- the level of corrosion of pool plant and equipment
- the potential for tile and grout attack
- the level of water replacement
- that there is effective oxidation of pollutants
- that hand dosing of chemicals has occurred
- the general efficacy of the filtration system.

The analysis should include the following data to enable the above information to be ascertained:

- permanganate value (4 h at 27 °C)
- ammoniacal nitrogen as N
- nitrite nitrogen as N
- nitrate nitrogen as N
- albuminoid nitrogen as N
- pH
- alkalinity as CaCO₃

- total hardness as CaCO₃
- calcium hardness as CaCO₃
- chloride
- sulphate (optional and dependent on the nature of the incoming water supply and whether sodium bisulphate is used)
- total dissolved solids
- iron
- copper
- zinc.

10.7.1.2 Bacteriological analysis

Bacteriological analysis can determine the cleanliness of the pool filters, surrounds and furniture, and the bactericidal efficiency of the pool water.

The analysis should include the following data to enable the above information to be ascertained:

- total viable count at 37 °C (24 hours' incubation)
- total coliforms
- whether *E. coli* (*Escherichia coli*) bacteria are present
- whether *Pseudomonas* bacteria are present (these should be identified where possible).

Chemical and bacteriological analysis enables an overall assessment of the effectiveness of the water treatment system and highlights any potential health risk to bathers.

10.7.2 Testing

On-site pool water tests should be undertaken on a regular basis, ideally every two hours for public and heavily loaded pools, and at least four times a day for school pools. A suitable comparator, and colourimetric discs and a total dissolved solids meter should be provided for operators to undertake these tests.

The type of test will vary with the disinfectant used and should determine the following levels:

- total chlorine or bromine (mg·litre⁻¹)
- free chlorine (mg·litre⁻¹)
- combined chlorine (mg·litre⁻¹)
- pH
- total dissolved solids (mg·litre⁻¹) (daily)
- cyanuric acid (mg·litre⁻¹) (daily for pools using isocyanurates or where cyanuric acid stabiliser has been added)
- balanced water test (weekly).

Tests will need to be carried out at various locations including the autocontroller sampling point. The actual locations will vary depending on the design of the pool or pools and the inlet and outlet arrangements in each case. The values of residual disinfectant concentrations can also vary from location to location for the same reasons. Guidance will need to be provided in respect of the

sampling locations and the acceptable variation in concentration.

Automatic controllers should be recalibrated at regular intervals.

Additional testing may be required at times when correction of the water treatment parameters is required.

10.7.3 Records

Record data sheets should be designed to allow for the inclusion of routine testing for the following:

- residual disinfectant concentrations ($\text{mg}\cdot\text{litre}^{-1}$)
- pH
- temperature of air and water
- numbers of bathers
- total dissolved solids ($\text{mg}\cdot\text{litre}^{-1}$)
- frequency and volume of backwashing and/or water replacement
- appropriate plant operating information i.e. filter pressure differentials, water meter readings, plant down-time etc.

10.7.4 Operation of water treatment plant

Correct operation of the plant is essential in order to maintain the water quality and to prevent damage to the water treatment equipment, the pool hall fabric and the associated air systems. The designer/installer is required under the CDM Regulations^(15,16) to provide the operator with a comprehensive operation and maintenance (O&M)

manual. This should include all relevant design and installed equipment information and step-by-step guidance for all the operational and maintenance procedures necessary to achieve safe and optimum performance from the water treatment installation.

Recommended disinfectant and pH ranges for swimming pools and for spa pools are shown in Tables 10.11 and 10.12 respectively. The tables also show a recommended operating residual concentration for guidance purposes. However, systems should be operated as close as possible to the lowest residual concentration quoted for the disinfectant employed. Disinfection is only achieved if a residual concentration of disinfectant is maintained throughout the pool at all times. Therefore, the actual operating residual concentration applicable to a particular pool will depend on the effectiveness of the water circulation within the shell, the control system and the pattern of bather loading.

For example the 'ideal' installation could be defined as a 'surflo' or deck level type pool water inlet and outlet distribution which is correctly designed and commissioned to achieve the desired turnover in all zones, which has a regular bathing load profile and a control system giving minimal deviation (see also sections 10.6.2 and 10.5.1). Under these circumstances it may be possible to operate with a significantly lower residual free chlorine concentration than those recommended in Tables 10.10 and 10.11.

10.7.5 Maintenance of water treatment plant

Plant maintenance information is provided in more detail in *Swimming Pool Water: Treatment and Quality Standards*⁽⁹⁾. Typical maintenance and operational tasks are as follows.

Table 10.11 Recommended disinfectant and pH ranges for swimming pools

Disinfectant type	Disinfectant residual	pH	Cyanuric acid	Dimethylhydantoin
Sodium hypochlorite	1–5 $\text{mg}\cdot\text{litre}^{-1}$ free chlorine	7.2–7.8	—	—
Set to control at:	2 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.4		
Calcium hypochlorite	1–5 $\text{mg}\cdot\text{litre}^{-1}$ free chlorine	7.2–7.8	—	—
Set to control at:	2 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.4		
Electrolytically generated sodium hypochlorite	1–5 $\text{mg}\cdot\text{litre}^{-1}$ free chlorine	7.2–7.8	—	—
Set to control at:	2 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.4		
Trichloroisocyanuric acid	1–5 $\text{mg}\cdot\text{litre}^{-1}$ free chlorine	7.2–7.8	<200	—
Set to control at:	2 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.4		
Dichloroisocyanurates	1–5 $\text{mg}\cdot\text{litre}^{-1}$ free chlorine	7.2–7.8	<200	—
Set to control at:	2 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.4		
Liquid bromine	2–4 $\text{mg}\cdot\text{litre}^{-1}$ total bromine	7.4–8.2	—	—
Set to control at:	3 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.8		
Bromochlorodimethylhydantoin	4–6 $\text{mg}\cdot\text{litre}^{-1}$ total bromine	7.4–8.2	—	<200
Set to control at:	5 $\text{mg}\cdot\text{litre}^{-1}\dagger$	7.8	—	—
Ozone with residual disinfection	Will vary but likely to be in the order of 1–2 $\text{mg}\cdot\text{litre}^{-1}\dagger$ free chlorine, 2–4 $\text{mg}\cdot\text{litre}^{-1}\dagger$ total bromine.	pH dependent on residual disinfectant	—	—

$\dagger$ It will be necessary to establish the concentration of residual disinfectant necessary to ensure a satisfactory bacteriological standard under all conditions of bather loading. In certain circumstances it may be possible to operate at significantly lower residual free chlorine concentrations than those listed.

Table 10.12 Recommended disinfectant and pH ranges for spa pools

Disinfectant type	Disinfectant residual	pH	Cyanuric acid	Dimethylhydantoin
Sodium hypochlorite	3–5 mg·litre ⁻¹ free chlorine	7.2–7.8	—	—
Set to control at:	4 mg·litre ⁻¹ †	7.4		
Calcium hypochlorite	3–5 mg·litre ⁻¹ free chlorine	7.2–7.8	—	—
Set to control at:	4 mg·litre ⁻¹ †	7.4		
Electrolytically generated sodium hypochlorite	3–5 mg·litre ⁻¹ free chlorine	7.2–7.8	—	—
Set to control at:	4 mg·litre ⁻¹ †	7.4		
Trichloroisocyanuric acid	3–5 mg·litre ⁻¹ free chlorine	7.2–7.8	<200	—
Set to control at:	4 mg·litre ⁻¹ †	7.4		
Dichloroisocyanurates	3–5 mg·litre ⁻¹ free chlorine	7.2–7.8	<200	—
Set to control at:	4 mg·litre ⁻¹ †	7.4		
Liquid bromine	4–6 mg·litre ⁻¹ total bromine	7.4–8.2	—	—
Set to control at:	5 mg·litre ⁻¹ †	7.8		
Bromochlorodimethylhydantoin	4–6 mg·litre ⁻¹ total bromine	7.4–8.2	—	<200
Set to control at:	5 mg·litre ⁻¹ †	7.8		
Ozone with residual disinfection	Will vary but likely to be in the order of 2–3 mg·litre ⁻¹ † free chlorine, 4–6 mg·litre ⁻¹ † total bromine.	pH dependent on residual disinfectant		

† It will be necessary to establish the concentration of residual disinfectant necessary to ensure a satisfactory bacteriological standard under conditions of heavy loading. This will vary from spa to spa and will depend on design and operation.

Daily:

- Undertake check of plant status and operation.
- Undertake tests for free chlorine and pH at required intervals.
- Clean the swimming pool walkways.
- Check the contents of the disinfectant and pH adjustment units and refill as necessary with appropriate chemicals.
- Complete relevant record logs.

Weekly (or sooner if required by conditions):

- Clean out coarse strainer basket.
- Backwash the pool filter(s) as required.
- Replace a minimum 10% of the pool water with fresh water (by backwashing plus additional dumping if necessary; to maintain total dissolved solids (TDS) >1500 mg·litre⁻¹).
- Vacuum the pool.
- Clean the pool water scum line.
- Visual inspect plant for leaks and check the injection points and dosing lines for blockages.
- Recalibrate automatic controller.
- Complete relevant record logs.

Annually:

- Service pumps, filter and associated treatment plant. Include checking/cleaning of dosing tanks, foot valve dosing lines, injectors etc.

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11 Irrigation

11.1 Introduction	Summary
11.2 Horticultural considerations	Considerable investment is often made not just in crops but in commercial soft landscape schemes. To maximise the benefit of this and to protect against the stress to, or loss of, planting during periods of drought, irrigation is often required.
11.3 Types of irrigation systems	
11.4 System design considerations	Irrigation allows non-native plants to be used and makes agriculture possible in areas normally unsuitable for intensive crop production.
11.5 Irrigation water	Correct water application rates/methods and water quality matched to the plant types are essential in effective irrigation systems; however, soil media should also be considered carefully.
11.6 Irrigation plant	
11.7 System components	An assessment should be made of the environmental impact of any irrigation scheme prior to detailed design.
11.8 Irrigation management and maintenance	
References	
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11.1 Introduction

This chapter is intended to provide guidance on the main features and techniques employed in irrigation systems. It will often be appropriate to seek specialist advice to ensure specific plant requirements are achieved, however, this section is intended to provide the background and base design information for the system infrastructure and outline design.

11.2 Horticultural considerations

11.2.1 Water requirements of plants

In the UK during the summer months, turf requires an average of 15 mm (amenity turf) to 30 mm (intensively managed turf) of water every 7 days.

The grass plant transpires these large quantities of water into the atmosphere during daylight, there being little or no transpiration at night.

The plant normally obtains mineral nutrients from those dissolved in the soil water. A small proportion of the water is combined chemically to form new plant material, but most passes to the atmosphere through pores in the leaves.

Another function of water taken into the plant is to provide mechanical strength to non-woody tissues. If water loss from the leaves exceeds the intake at the roots the plant tissues are no longer self-supporting and the plant wilts. Where this happens the plant leaves are no longer able to absorb sunlight and the process of photosynthesis and growth ceases.

Table 11.1 Typical irrigation demands

Location	Daily demand		
	Trees	Grass	Shrubs
UK	20 to 60 litres	3 to 5 mm	4 to 6 mm
Middle East	60 to 150 litres	10 to 13 mm	10 to 15 mm

Note: the above figures are subject to planting types and densities

Typical irrigation demands for plants in the UK and the Middle East are shown in Table 11.1.

11.2.2 Soil moisture properties

Soil consists of particles of clay, salt, sand, and organic matter. Because particles of these substances are irregular in shape, water fills the spaces between them, potentially excluding air. When the air is completely excluded the soil is said to be at saturation point, or waterlogged. This condition is maintained as long as the rate of drainage from the underside of the waterlogged layer is lower than the rate at which water continues to fall on the ground surface. When the drainage rate exceeds the rate of precipitation, air is drawn into the spaces between the soil particles, thus replacing the water with air. Depending on the type of soil, after a period when the surface tension of the water film around each soil particle is balanced by gravitational pull, free drainage ceases, and the soil is said to be at 'field capacity', see Figure 11.1. A rule of thumb is that field capacity is generally reached 1–3 days after saturation.

A high specification irrigation system should maintain a field capacity; excess watering is wasteful, produces 'waterlogging' and the leaching out of plant nutrients from the soil. However, in arid climates where excess quantities of salts tend to build up in the soil and damage planting, the irrigation management system should be

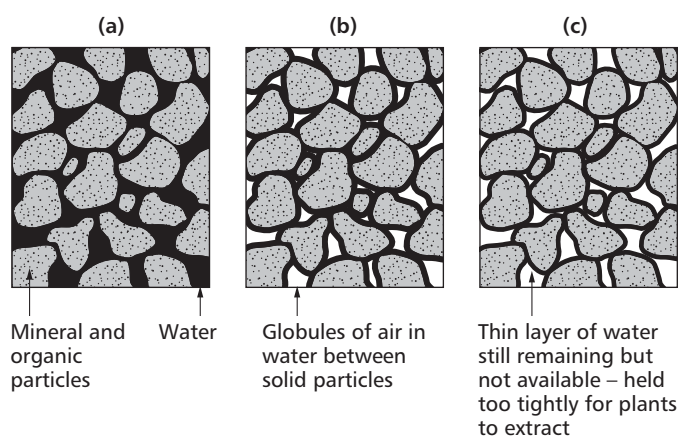


Figure 11.1 Levels of soil moisture content; (a) saturation, (b) field capacity, (c) wilting point

designed to occasionally apply excess quantities of irrigation water to bring the soil to saturation point and 'leach out' the excess levels of salt present in the soil. This may also be the case with irrigation systems in temperate zones where fertiliser is applied through the irrigation system.

When designing a system of irrigation for specialist planting, advice should be sought to ensure that the design adequately addresses the type of planting and conditions. Some aspects to consider may include the following:

- the plant's moisture sensitive growth stages, which may require additional system flexibility or control, e.g. young plants or at times of pollination
- the provision of mulching to control moisture loss through evaporation
- that the chemical and physical (suspended solids) quality of the water is appropriate for the planting being irrigated.

Care should be taken when designing an irrigation scheme for a nursery where chlorine can be a problem with some tender plants, as indeed can rainwater if it is acidic.

It should be remembered that an increase in temperature, decreasing relative humidity, light and increased wind speed will all increase the irrigation demand.

11.2.3 Infiltration rate

Some soils absorb water more rapidly than others. When irrigating, it is important to maintain a slow enough rate of water application to allow the soil to take up the water as quickly as it falls. If the application rate exceeds the infiltration rate, water will form on the soil surface; this may cause erosion and 'run-off' which results in water wastage.

Figure 11.2 illustrates the wetted zones for three types of soil when water is applied at a single point.

11.2.4 Drainage

Ground drainage is an important part of an irrigation system. Poorly drained soil should never be regularly

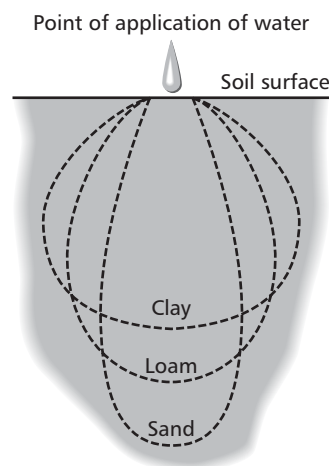


Figure 11.2 Composition of wetted zones in clay, loam and sand

irrigated. Such soils will become saturated as water is applied, but when watering ceases there will be no downward movement of water and no movement of air into the soil through its surface.

11.2.5 Loss of soil water

Once at field capacity, well drained soil can only lose water either through transpiration from the plants growing in it, or through evaporation from the surface of the wet soil exposed to the sun. As long as the soil surface is wet, the rate of evaporation, for all practical purposes, will be the same as that from an open water surface. It can be assumed that moisture at depths of up to 18 mm will be lost by direct evaporation from the top of the soil, although this can be increased or decreased by employing differing methods of mulching etc.

11.2.6 Available soil water

Plants can take up water from the soil at any level of moisture content between field capacity and permanent wilting point. The quantity of water that a soil can supply between these points is known as its available water capacity.

The available water capacity is a characteristic property of a soil and to some extent this can be changed by good husbandry and the use of organic matter. Table 11.2 provides a guide to the moisture properties of typical soils of the UK.

11.3 Types of irrigation systems

11.3.1 Sprinkler systems

Spray systems are generally used where water is available in sufficient quantity and quality and where turf or grass is the plant material to be irrigated. Large quantities of water can be distributed above-ground over fairly large areas in a short period of time. The operating pressure of the system will vary from one installation to another, but will generally be in the range of 300–800 kPa.

Table 11.2 Soil moisture properties of typical UK soils

Soil type	Moisture content
Low water capacity soils: — coarse sand — loamy coarse sand — coarse sandy loam	Not more than 38 mm per 300 mm depth of sample (12.7%)
Medium water capacity soils: — loamy sand — sand — loamy fine sand — fine sand — sandy loam — fine sandy loams — loam — silty loam — clay loam — sandy clay loam — silty clay loam — sandy clay — silty clay — clay	More than 38 mm but less than 65 mm per 300 mm depth of sample (between 12.7% and 21.7%)
High water capacity soils: — loamy very fine sand — very fine sand — very fine sandy loam — peat — loamy peat — peaty loam	65 mm or more per 300 mm depth of sample (exceeding 21.7%)

It is usual for the sprinkler installations, particularly on amenity landscape projects, to be restricted to early morning, late evening or night operating. These are the best times to irrigate as it avoids water loss by evaporation and is less hazardous to the public. A good sprinkler system will be generally 65% efficient, i.e. 65% of the water passing the pump will be taken up by the plant; 35% will be lost to leaks, deep percolation, evaporation etc.

11.3.2 Drip systems

Drip systems are installed where the supply of water is less plentiful or a better targeting of water is required. They operate at a lower pressure. There is very little water loss through wind drift as the system distributes water at or just below ground level, directly into the soil adjacent to the plant. However, it is very difficult to satisfactorily irrigate very large areas of turf or grass using this method. It is a very efficient system and only distributes water slowly through an emitter at a rate that allows the water to be readily absorbed into the soil. It is a very popular method of irrigation and is used extensively in arid climates.

Due to the method of application there is normally no restriction to the operating times of drip systems and there is little hazard to the public. However irrigating during daylight hours increases evaporation prior to percolation.

11.3.3 Bubbler systems

There are two basic types of bubbler system: stream jet and flood. As the name implies, the stream jet bubbler produces two to six controlled jets of water, depending on the pattern of bubbler selected. The projection of the

stream or jet ranges from 0.5 to 1.5 m in radius according to the inlet pressure. However most manufacturers provide a means of local site adjustment of the water stream. The flood bubbler produces a continuous stream of water through 360° with a short water projection from the bubbler.

Both types of pattern are mounted on fixed riser pipes above ground level; the stream bubbler normally sits at a height of up to 1 m, while the flood bubbler is normally close to the ground.

Bubbler systems are useful for irrigating flower beds, shrub areas, ground cover and narrow areas that are difficult to efficiently irrigate with sprinklers. They normally form a separate part of a sprinkler or drip system and operate most efficiently at pressures of between 400–600 kPa at flows ranging from 1 to 10 litres per minute, depending upon the pattern selected and the operating pressure.

11.3.4 Capillary systems

There are several different forms of capillary systems available, all employing the same principle but differing in detail. They range from the basic capillary bench, incorporating a perforated hose located in a sand bed or absorbent matting (used in the horticultural industry), see Figure 11.3, to various proprietary systems available for incorporation in planting boxes for the internal landscaping of buildings. The advantage of capillary systems is that water is introduced directly to the root zone of the plant. The main disadvantage is that the watering process is unseen and cannot be measured. This means that over- or under-watering is not immediately obvious until the planting shows signs of distress.

11.3.5 Sub-soil systems

Irrigation by sub-soil methods is similar in principle to capillary systems, except sub-soil systems are normally used in the open ground outside buildings. Perforated pipes or containers are buried in the ground in a free draining material. They can be automatically controlled, although the systems that employ buried containers are usually manually filled periodically, and therefore require experienced supervision.

The main advantage of sub-soil systems is that water is introduced directly to the root zone, and they are less expensive in terms of initial capital cost. However, it must be remembered that plants will rapidly ‘seek out’ water, and their fine roots will quickly enter pipes and containers through the perforations, causing blockages and affecting the efficiency of the system. In addition, as with capillary systems, efficient watering cannot be seen to be taking place, and over- or under-watering may occur; this will not be immediately obvious until the planting shows signs of distress.

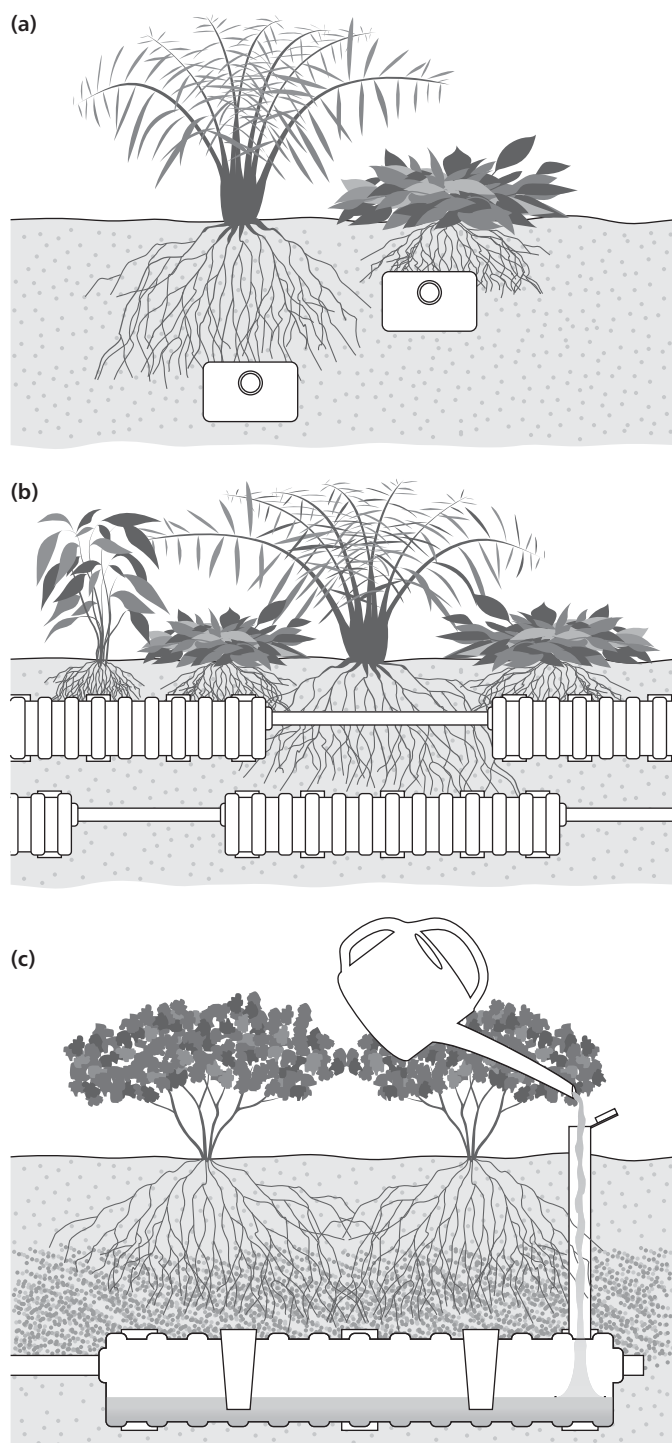


Figure 11.3 Typical capillary irrigation system (a) end elevation (b) side elevation (c) operation

11.3.6 Applications

11.3.6.1 Sports fields

A range of sprinklers is available for use on sports fields. Rain guns have been developed from their original agricultural application. They can be used where it is necessary to keep irrigation equipment out of the field yet still provide an automatic system. They are located in the margins, usually at corners of the field, and project the irrigation water in a cannon onto the field.

Alternatively, a range of pop-up rotary sprinklers are available. These can be located in the field with thick

protective rubber or artificial turf covers to render them almost invisible and protect players from potential injury due to falling on a sprinkler head.

The output of rain guns is much greater than that of sprinklers and requires a large volume of water at a high pressure in order to project the water over a greater distance (sometimes in the order of 50 m). In addition, the water droplet size is larger than that for sprinklers, and therefore care must be taken to ensure there is no damage to the soil structure during prolonged periods of irrigation.

11.3.6.2 Green roofs and walls

Selectively watered for periods such as establishment, these areas are usually irrigated using low volume micro spray/drip emitters operated and controlled by an automated solenoid valve. Product selection is subject to visual/aesthetic requirements and size of the planting area.

Final water requirement is subject to planting type and visual requirements.

For detailed information on green roofs, see CIBSE KS11: *Green roofs*⁽¹⁾ and *Guidelines for the design and application of green roof systems*⁽²⁾.

11.4 System design considerations

11.4.1 Preliminary design

At an early stage in the design process, the following preliminary design factors need to be considered:

- duration of the irrigation cycle (or irrigation day) in hours
- interval between irrigation cycles
- amount of water to be applied during the irrigation cycle
- determination of irrigation zones, according to areas or types of planting, and method of application (sprinklers, emitters or bubblers) so as to produce unit areas of similar hydraulic requirements
- any significant variation in the elevation of land to be irrigated
- location and volume of irrigation water storage
- location of irrigation pumps and equipment.

All of these factors are derived from basic data about the climate, soil, plants to be irrigated and an inspection of the site, particular note being made of the topography. At this stage outline approvals from the water companies should be obtained or consideration of other water sources should be evaluated.

11.4.2 Detailed design

Following the preliminary design study, the irrigation system should be developed in more detail which will require consideration of the following factors, but not necessarily in the sequence shown:

- (a) The type and duty of sprinklers, emitters or bubblers: every effort should be made to standardise these items of equipment. The landscape designer and/or horticulturalist should be contacted for information on the application methods to be used for the various planting arrangements.
- (b) Determine the frequency of sprinklers, emitters or bubblers within the irrigation zones.
- (c) Determine the arrangements of manifold headers and distribution laterals within the irrigation zones on which are located sprinklers, emitters or bubblers at regular intervals. The layout of the lateral lines and location of the supply header should be considered in relation to the slope of the ground.
- (d) The sizes of the manifold headers and laterals should be ascertained, using hydraulic charts and simple calculation of the number of applicators and their duties. Every effort should be made to standardise on a pipe size, although this will cause some under- or over-capacity.
- (e) Each irrigation zone should be provided with a solenoid valve assembly housed in a suitably sized ground box with a removable cover. This assembly should comprise a solenoid valve to allow the automatic control of the zone, and a pressure regulating valve upstream to assist in achieving a uniform rate of water application regardless of pressure fluctuations in the mains distribution. These valves should be protected with a filter and isolating valve to shut down the whole zone if necessary. The size of the valve assembly will be determined by the hydraulic capacity of the zone.
- (f) Depending on their area, the irrigation zones may be further divided into smaller sections for ease of design, installation, and maintenance of the system. These sections are normally manually controlled by isolating valves.
- (g) During installation, maintenance and alterations, sand and dirt may enter the pipelines. Careful consideration must be given to the proper location of simple isolating valves to operate as 'flushing valves' for the removal of debris that will otherwise block the irrigation applicators or impair their efficiency. These valves should be located at the end of a 'tail header'. Screwed pipe flues can also be used as a cheaper option.
- (h) The location of the irrigation controller should be considered. The electrical control unit may potentially be best located remotely from the plant, for example in a maintenance office, where the system can best be monitored and controlled.
- (i) Determine the volume of irrigation water storage, which should be based on at least one day's peak demand. The volume should be agreed with the responsible water company or authority, together with the client, to determine an acceptable risk to

supply against the cost of storage. In arid climates, suitably treated sewage effluent is often used. With such an arrangement, separate tanks must be provided and the irrigation water separately drawn and mixed in a daily irrigation tank. All necessary backflow prevention should be in place to prevent contamination of the potable water supplies. In arid climates, sun shields should be provided if tanks are exposed and a risk assessment undertaken to ensure health risks from irrigation water are minimised.

- (j) The irrigation consultant will be familiar with, and have a preferred method of, arriving at a duty for pumps. However, the following points should be noted:
 - Endeavour to obtain flooded pump suction, otherwise maintain low suction lifts.
 - Determine the difference in ground levels across the site relative to the location of the pumps and make appropriate allowances.
 - Determine the working pressure of the irrigation applicator at the highest point on the site, and make an allowance for residual head at this point.
 - Determine the frictional pressure loss in the pipeline to the furthest point of the system. If the mains distribution has been designed on ring main principles (ground contour allowing) this will have the effect of reducing frictional pressure loss.
 - Determine the pressure loss through the main filters.
 - Arranging irrigation zones of similar hydraulic capacity will assist in arriving at an optimum capacity for the main pumps.
 - When calculating the pumping capacity over the length of an irrigation window, always allow spare capacity, e.g. if the length of the irrigation window is eight hours, the pumps should be capable of applying the peak load in, approximately, 6.5 hours.

11.5 Irrigation water

11.5.1 Water supply sources

An adequate, dependable water supply of suitable quality is essential for any irrigation project. Irrigation water may be obtained from surface sources such as rivers, rainwater harvesting, streams and lakes, and from ground sources by means of wells or boreholes, or from a public supply. The suitability of each possible source needs to be carefully assessed and the most dependable supply chosen. Other sources such as air conditioning condensate water, recovered greywater and rainwater can be considered, although the storage and use of such water will require careful consideration, as will its potential impact upon planting.

In most overseas cases, and in all instances in the UK, a license must be obtained from the appropriate river or water authority before any water is abstracted/taken, or before increasing an existing abstraction.

The volume of water required for irrigation purposes is usually quite high and substantial on-site storage is normally required. The amount stored will depend upon the peak watering requirement and the reliability of a good source of supply. Even if a reliable supply is available it is still prudent to provide storage as this will afford some protection in the event of interruption of the supply resulting from the failure of a supply main, or any harmful, accidental pollution of surface sources from which an irrigated supply is taken.

The volume of storage is usually equal to a day's requirement at peak demand. However, in arid climates this volume may need to be adjusted to suit local conditions. In all circumstances, but particularly where storage volumes or temperatures are high, a design risk assessment should be undertaken so that the risk of *Legionella* or other waterborne pathogens causing harm, is minimised.

The method of storing water for irrigation will vary from site to site depending on the volume of storage to be provided. The type of storage will also depend on the topography of the site and/or the plant room size, with cost and inflow volume usually being the prime considerations.

11.5.2 Irrigation water quality

The chemical and biological quality of water for irrigation may affect its suitability for use, and water with too high a level of suspended matter will quickly 'clog up' irrigation equipment, reducing the water flow and the efficiency of the installation, resulting in high maintenance costs. Water obtained from roof areas, hard standing runoff etc, is often polluted and will need subsequent treatment and/or cleansing. Issues such as filtration, pollution, and disease, present a risk both to the end user, maintenance staff and to irrigation equipment.

In the UK, water from a public supply (subject to compliance with the Water Supply (Water Fittings) Regulations 1999⁽³⁾ or the Scottish *Water Byelaws 2004*⁽⁴⁾) or from air conditioning condensate will be suitable for most irrigation needs. However, in areas where the water is very hard, calcium deposits quickly clog the small waterways of some irrigation equipment, though this may be managed with acid injection equipment. Care must be taken to prevent backflow, see section 11.7.10 below and chapter 2 section 2.5.4.8.

Water sources contaminated with sewage and industrial effluent may contain metal salts such as chromium, zinc, copper, or other chemicals like borates and detergents, all having a harmful effect on crops and planting. Crops destined for possible human consumption are particularly vulnerable since many varieties can absorb and concentrate contaminants (metal salts in particular) to an unacceptable level. The regular use of irrigation water containing these contaminants should be discouraged unless careful and regular monitoring of the irrigation water and the quality of the crops is feasible and practical.

The effect of water quality on irrigation equipment and pipework also has to be considered. For instance, water containing copper salts will affect aluminium equipment, and soft acid waters will attack galvanised steel.

In arid climates, water containing high levels of sodium chloride, commonly described as 'brackish' or 'saline', should only be used with care. If containing a sodium chloride concentration of less than 0.05%, the water is usually considered safe for use. However, it is possible to use water with a higher concentration providing only salt-tolerant plants are irrigated.

One problem in using brackish or saline water for irrigation in arid climates is the high level of salt that is rapidly deposited on, and accumulates in the soil or growing medium. Unless flushed away by leaching, the salt eventually kills even salt-tolerant plants.

11.6 Irrigation plant

This section lists the major components of both sprinkler and drip irrigation systems, and important factors to be considered in their selection. It is essential to verify that any materials used are suitable for the water and ground conditions, and to confirm the types of fertiliser likely to be used. Metals should be nonferrous.

11.6.1 Storage tanks or ponds

Where storage ponds are used, good rough screening to pump suctions should be provided, and these should be carefully located to avoid drawing silt from the bottom of the pond, or air from its surface.

In the UK, if irrigation water is taken from a supply under the control of a water services company, it is obviously necessary to comply with the requirements of the Water Supply (Water Fittings) Regulations 1999⁽³⁾ or Scottish *Water Byelaws 2004*⁽⁴⁾. In the case of external tanks used in hot arid climates, consideration should be given to the provision of effective shading for the tanks.

11.6.2 Automatic pumps

Automatic pumps should be of the standard centrifugal, direct electrically driven and controlled type. Centrifugal vertical multistage pump units are generally managed by a variable frequency drive which speeds up and slows down the pump to automatically match required output/pressure. This reduces water hammer and reduces power consumption.

See chapter 6 for detailed information on pumps and pumping.

11.6.3 Media pressure filters

These typically use special fine sand as the filter medium. They are particularly suitable for filtering irrigation water heavily polluted with organic matter. The filters should be capable of being backwashed and should be provided with suitable drainage and servicing time allowance.

11.6.4 Particle filtration

Stainless steel through-flush canister screen filters are commonly used as an alternative to media filters where there is mainly inorganic particulate but little organic pollution. Various grades of screen mesh ranging from 30 to 200 micron mesh are employed to filter the irrigation water. These are automatically backwashed. Screens can easily be replaced or the grade of mesh changed. In addition to media or canister filters, in-line 'Y-type' filters are installed on the upstream side of solenoid valve assemblies to protect the solenoid valve sprinklers and emitters from particulates that may accidentally have been drawn into the system.

11.6.5 Water meters

Water meters indicate the rate and volume of flow, and are usually located downstream from the media pressure filter so as to monitor the water usage of various parts of the system. If a supply is taken from a water company main it is most likely to require a water meter upstream of any filters at the point of connection to the supply, to enable the volume of water used to be recorded and charged. Further downstream metering of underground pipework may be considered in order to aid leak detection.

11.6.6 Solenoid control valves

Low-voltage, electrically operated manual override solenoid valves are used to control irrigation zones and range from 25 mm to 150 mm in diameter. It is also possible on large installations for the irrigation zone to be controlled by hydraulically or pneumatically operated valves. All valves should be pressure regulating; alternatively, separate pressure regulating valves may need to be installed.

11.7 System components

11.7.1 Quick coupler valves

Quick coupler valves are placed upstream of the solenoid valve and are under constant pressure. They are operated by a quick coupler key, allowing water to flow via an attached swivel elbow and garden hose attachment. This provides a means of supplying emergency water and for use when 'planting out'.

11.7.2 Pressure regulators

Pressure regulators are used to provide water at a constant pressure to ranges of sprinklers or emitters, for instance where the ground is undulating or sloping. This avoids over-watering, due to excess pressure.

11.7.3 Isolating valves

Isolating valves are used to isolate ranges of sprinklers or emitters. Waterworks pattern sluice valves are used on distribution mains.

11.7.4 Flushing valves

Flushing valves are used to flush through pipelines to remove any sand or silt. They are most useful during commissioning of the system. On some installations these valves are replaced by screwed pipe plugs.

11.7.5 Valve boxes

These are often of high density polyethylene construction with a removable/lockable cover providing access and protection to valves that would otherwise be buried.

11.7.6 Sprinklers and sprays

These are manufactured either from brass or plastic, and can be of the fixed or pop-up rotary type. They are available to irrigate segments or complete circles, with the projection of spray governed by the inlet pressure. They are located at ground level. The pop-up type normally require a minimum of 300 kPa to operate and use a strong spring to ensure positive retraction when the irrigation cycle is complete. Most spring-retracted pop-ups require a minimum operating pressure of 300 kPa. They should also be complete with a good wiper seal to prevent silt and sand entering into the sprinkler body.

Because of 'wind drift' and high evaporation rates, a 50% overlap is normally used with a triangular spacing configuration to provide an even watering pattern; square spacing patterns may be used but are generally less uniform in their application. Where high winds are a problem, low-trajectory sprays should be used. The sprinkler or spray head pattern selected should incorporate an integral removable filter.

Where turf is being irrigated, it is important that the sprinkler head should be resistant to impact damage and provided with a flexible, and not direct, connection to the distribution pipework. This avoids the problem of fractured pipes should heavy loads (e.g. when grass cutting and rolling) be accidentally applied.

11.7.7 Mist sprays

These are usually installed in horticultural nurseries, and are manufactured from brass or plastic. They should be of the low-volume and low-trajectory type and operate at pressures of 69–207 kPa (10–30 psi).

11.7.8 Bubblers

These are manufactured from brass or plastic, with a fixed or adjustable flow pattern, and should be of the pressure-compensating type to provide an even flow, see Figure 11.4 below. There are various flow patterns available to give two, four, or six streams, or a 360° flood pattern if required. The selected bubbler should be suitable for operating pressures within the range 138–414 kPa (20–60 psi) and flow rates of 0.02–0.06 litre·s⁻¹. They should incorporate an integral removable filter.

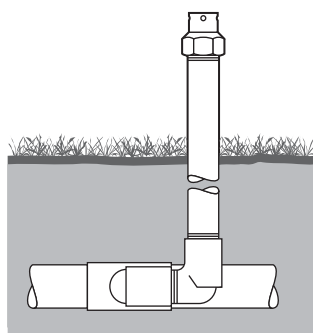


Figure 11.4 Typical stream bubbler

11.7.9 Drip emitters

Emitters are manufactured from plastic and are available for a range of duties and operating pressures, see Figure 11.5. Types of emitter include pressure-compensating and non-compensating, and automatic self-flush-cleansing models.

It is important to select emitters suitable for the required operating pressure and degree of filtration of the irrigation water. Emitters are available to suit levels of filtration from 30 to 140 micron mesh, pressures in the range 69–241 kPa (10–35 psi) and flow rates of 2.3 to 9.0 litre·h⁻¹.

There are four main features to be considered in selecting an emitter:

- relatively low but uniform and constant flow regardless of minor differences in pressure head
- relatively large flow cross-section to reduce clogging problems
- inexpensive
- compact.

11.7.10 Backflow preventers

These are available in corrosion resistant materials and are designed to prevent the backflow of irrigation water at high pressures caused by differences in ground elevation, booster pumps, or by vacuums resulting from lowered mainline pressure due to a high level of water withdrawal.

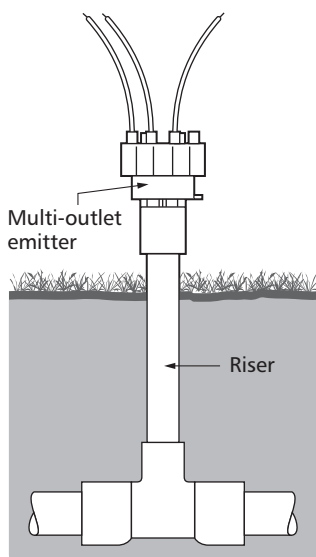


Figure 11.5 Typical permanent multiple-outlet emitter

Irrigation systems are categorised by the Water Supply (Water Fittings) Regulations 1999⁽³⁾ as follows:

- System without insecticides or fertiliser additives and with fixed sprinkler heads not less than 150 mm above ground level: fluid category three (FC3). A double check valve may be used as an acceptable backflow prevention device.
- Mini-irrigation system in a domestic garden, without insecticide or fertiliser additives, such as pop-up sprinkler or permeable hose: fluid category four (FC4); requires a reduced pressure zone valve or break tank with an air gap giving FC4 protection.
- Irrigation outlets at or below ground level, with or without chemical additives: fluid category five (FC5); requires a break tank with an air gap giving FC5 protection. See WRAS *Water Regulations Guide*⁽⁵⁾ section 6.

Fluid categories are described in chapter 2, Table 2.2.

11.7.11 Controllers

Irrigation controllers automatically control the operation of the irrigation system to suit the watering demand. There are generally two types of control: 'sequential controllers', which operate valve stations in turn for pre-programmed times or 'non-sequential controllers' which irrigate based on the need of the station. More complicated non-sequential control is often incorporated that can hydraulically optimise an irrigation cycle, communicate with weather stations and moisture sensors etc.

Controllers should be suitable for the on-site electrical supply and be provided with lightning protection.

11.7.12 Distribution mains

Irrigation mains are usually buried and convey water from the source through the pumping, filtration and treatment plants to the zone of application (normally the solenoid valve assembly). The mains piping should be of a material suitable for the system operating pressure and ground conditions. Suitable materials include medium density and high density polyethylene pressure pipe. Joining should be flanged, electro fusion, or butt welded.

11.7.13 Manifold headers and distribution laterals

Manifold headers usually convey water from the downstream side of the solenoid valve assemblies through distribution laterals along which are located either sprinkler heads or emitters at regular intervals. Headers and laterals should be of a material suitable for the operating water pressures and ground conditions.

Normally with sprinkler installations these types of mains are buried, but with drip emitter systems they can be buried or laid on the surface of the ground according to the design of the irrigation system. The materials normally used are medium density or low-density poly-

ethylene pipe, coloured black. Jointing is best achieved by compression-type fittings.

Where laterals are laid on the surface of the ground in conjunction with drip emitters, the pipework is snaked around and between planting. Emitters are connected directly to the laterals by means of holes punched into the tube, which are then secured with barbed connections.

In some instances, the laterals are buried and in these cases emitters are fixed to a riser tube terminating at ground level. Where bubblers are employed, the riser is extended above-ground and stabilised with a stainless steel stake.

11.8 Irrigation management and maintenance

However well an irrigation scheme has been designed and installed it must be operated properly to provide satisfactory results.

Equipment cannot be expected to perform consistently outside design limits. Systems have a maximum capacity and it is important that, at an early design stage, the peak demands and any foreseeable increases in demand are properly allowed for and agreed with the client.

From discussions with the client, the design engineer should be able to appreciate the requirements for managing the system and any cost limits that may be imposed, so as to provide an irrigation system that can be flexibly managed. Two important functions of the management system are to ensure that proper maintenance is carried out on all mechanical items, and that crops and planting are receiving correct watering. During the various seasons of the year adjustment will

have to be made to the volumes of irrigation water applied in order to avoid under- or over-watering.

A regular, structured, service/maintenance agreement should be in place, as well as a full operational risk assessment. Regular sampling of the water for disease risks and quality must also be undertaken by the end user.

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12 Corrosion and corrosion protection

12.1 Introduction	Summary
12.2 Factors affecting corrosion	Corrosion is a complex issue and one that can cause significant damage and performance loss to plumbing systems where not 'designed-out' or controlled.
12.3 Assessment of corrosive environments	This chapter aims to provide the basic information to inform the designer in the material selection and system design in order to minimise the potential for corrosion.
12.4 Prevention of corrosion	
12.5 Chemical cleaning and passivation	
References	

12.1 Introduction

Open systems such as domestic water services, which are intended to convey aerated water, will therefore need a different approach to corrosion control

12.1.1 General

A wide variety of materials, both metallic and non-metallic are used for building services. All these materials, under certain environmental conditions, can break down prematurely impairing the function of a component or system.

To select the most appropriate material, it is necessary to understand the likely conditions, both environmental and functional, which have to be accommodated. Selection of materials is also undertaken with the knowledge that certain additional protective measures can be adopted to permit otherwise unsuitable materials to be used. The most obvious of these is the provision of surface coatings, e.g. paint or metallic, or the modification of the environment, e.g. water treatment.

System performance must also be protected. Deterioration of a system can result from the internal build-up of corrosion products blocking flow paths or deposition causing further attack elsewhere in the system. In an inadequately protected system, scale can also change heat transfer characteristics eventually resulting in, for example, the fracture of boiler sections due to overheating. Microbiological growths need to be controlled as they also lead to blockages and can result in corrosive attack on some metals.

Oxygen is one of the most important factors when considering corrosion. Corrosion in closed systems, such as heating circuits, is controlled primarily by limiting the amount of oxygen that can enter the system, either through make-up water or by aeration of the system due to negative pressures.

12.1.2 Definition

Corrosion may be defined as the reaction of a metal with its environment resulting in damage which impairs the function of a component or system.

Non-metallic materials can also break down and this is generally termed degradation. Corrosion or degradation may be also exacerbated by the presence of mechanical forces, e.g. stress or fatigue, which are created by the service conditions, and are often very difficult to predict.

The following sections cover the factors which affect corrosion, how to assess the local environment and methods of prevention. Water treatment, which may be used to control corrosion and scaling is covered elsewhere.

12.1.3 Metallic and non-metallic materials

12.1.3.1 Metals

Corrosion is the principal cause of premature failure in metallic building services components and systems. Not only is it responsible for increased maintenance but also losses in efficiency, particularly in heating and air conditioning systems.

12.1.3.2 Polymeric materials

This group encompasses a wide variety of materials and formulations, which are being expanded all the time and includes polymeric coatings, paints, thermo-plastics, thermosetting resins and rubbers. Whilst the properties, performance and the environmental capabilities of these materials is being improved all the time, it is often difficult to predict the precise behaviour due to variations in processing and formulation. When determining the suitability of plastics and rubber, the mechanical, thermal, chemical, biological and weathering abilities must all be considered in relation to demands of the application. The wide range and available formulations of these materials makes it impossible to provide detailed guidance on their selection for specific duties.

The designer must consult manufacturers to obtain details of the characteristics of the materials.

12.1.3.3 Other materials

The building services engineer will inevitably encounter both timber and inorganic materials. Timber can suffer from both wet and dry rot, however some treatments used to prevent decay can leach out and attack metals with which they are in contact. Some woods are quite acidic and under damp conditions cause corrosion. Cementitious materials are very alkaline when fresh, and in the presence of moisture can attack certain metals such as zinc, aluminium and lead. Other materials such as plaster and stone etc. can also cause corrosion, but this is very dependent on their composition and the prevailing environmental conditions.

12.1.4 Causes and environments

Corrosion is the term used to describe the process of conversion of metals into oxides or other compounds. There are two basic types of corrosion involved.

12.1.4.1 Aqueous corrosion

This is the reaction between a metal and the atmosphere whereby a surface scale, usually oxide or sulphide, is formed, e.g. tarnishing or high temperature scaling. This process is only likely to affect the building services engineer in relation to heating and boiler plant where metal surfaces reach higher temperatures, i.e. greater than 200 °C.

12.1.4.2 Wet corrosion

This is the most significant form of corrosion and occurs by an electrochemical mechanism which in most cases requires the presence of oxygen. Dissolution occurs where metals with dissimilar electrochemical potentials result in an electrochemical cell being set up (see section 12.2.2), where a complimentary reaction occurs in the anodic region and a complimentary reaction occurs at the cathode.

Natural and supply waters contain dissolved salts which make them capable of carrying an electric current and sustaining the corrosion process.

12.1.4.3 Environments

External corrosion occurs when moisture, in the form of rain, natural waters or in condensation comes into contact with the metal surface. Levels of pollutants can greatly affect the overall rate of corrosion as can the duration of wetness.

Atmospheric pollutants in industrial regions include carbon, carbon compounds and sulphur dioxide along with smaller amounts of hydrogen sulphide, nitrogen oxides and other by-products from industrial processes. Sulphur dioxide, which in the presence of moisture and oxygen is converted into sulphuric acid, is the main accelerator of atmospheric corrosion. Near the coast, sea salts will be present and when carried on the wind can cause corrosion several miles inland.

Underground, external corrosion of embedments or unprotected pipework may be caused by the presence of oxygen or bacteria in anaerobic conditions. Ground waters may contain a large variety of contaminants, such as natural salts, fertiliser residues, industrial pollutants, dissolved gases and organic impurities (e.g. oils, industrial waste or synthetic detergents).

12.2 Factors affecting corrosion

12.2.1 Microbiological growths

There many different micro-organisms (including fungi, algae and bacteria) that can exist in water systems. Some of these are aerobic, which grow only in oxygenated water and some are anaerobic, which grow only in water containing low levels of oxygen. Most micro-organisms will die at temperatures above 60 °C, but thermophiles can grow at temperatures even higher than 80 °C.

The most important micro-organisms that can result in microbially influenced corrosion (MIC) in heating, chilled water and domestic water systems are sulphate reducing bacteria (SRB). These are anaerobic bacteria, which produce acid and hydrogen sulphide (H₂S) as a by-product of their metabolism in reducing sulphates in the water. They tend to grow in the anaerobic conditions existing under deposits, especially iron oxide sludge, and under bio-films.

High levels of slime forming bacteria, especially *Pseudomonas*, produce bio-films on pipework and other metal surfaces in systems. While *Pseudomonas* is not a direct cause of MIC, by forming these biofilms they produce the anaerobic conditions required for SRB to grow.

Other bacteria, such as iron oxidising bacteria can increase corrosion, but the effect of these is not as important as SRB. Nitrate/nitrite reducing bacteria (NRB) reduce nitrates or nitrites in corrosion inhibitors and can produce ammonia, which is aggressive to copper and copper alloys.

Waters, which favour MIC, tend to be soft, surface waters containing more organic material. High levels of sulphate in the water also favours growth of SRB. MIC can occur on steel and cast irons, copper and copper alloys and stainless steels.

12.2.2 Bimetallic effects

When different metals are immersed in an electrolyte, each will attain a characteristic potential after a period of time. Using these potentials, it is possible to arrange metals in what is termed a galvanic series. Figure 12.1 shows the galvanic series for most common metals and alloys when in contact with sea water, a very strong electrolyte. Note that the precise order may alter slightly, but not necessarily significantly, with other electrolytes. Bimetallic corrosion can occur when two differing metals are in contact in the presence of an electrolyte. The rate of corrosion generally depends on the difference in potential. However, there are four other factors which can influence the rate of corrosion at a bimetallic contact and these are as follows:

- relative areas of cathode and anode
- conductivity of electrolyte
- electrical contact
- contact with other materials.

Usually a potential difference of at least 0.5 V is needed for significant galvanic corrosion to occur. In closed systems, galvanic corrosion is limited by the low levels of dissolved oxygen in the plumbing system.

12.2.2.1 Relative areas of cathode and anode

If the relative area of the cathodic metal is large compared with that of the anodic (corroding) metal, corrosion will be concentrated onto a smaller area resulting in a more rapid attack.

12.2.2.2 Conductivity of electrolyte

Where the conductivity of the electrolyte is low, attack will be confined to the contact area but may be relatively intense. In electrolytes of high conductivity, the level of general corrosion will be greater and the attack spread out over the whole anodic surface.

12.2.2.3 Electrical contact

Some metals, in particular stainless steel and aluminium, form coherent, non-conductive oxide films in air. If they limit or prevent electrical contact, and consequently current flow between the two metals, then any resulting corrosion is reduced or prevented. In the absence of dissolved oxygen in the electrolyte, bimetallic corrosion of iron and steel is limited.

12.2.3 Contact with other materials

A great variety of non-metallic materials are found in and around buildings and may under certain conditions be responsible for corrosive attack on metals. Some types of wood are acidic in nature and in the presence of moisture, can attack steel, cadmium, zinc and lead. Many timbers used in buildings are now treated against fungus, rot and other forms of attack with either organic or inorganic chemicals.

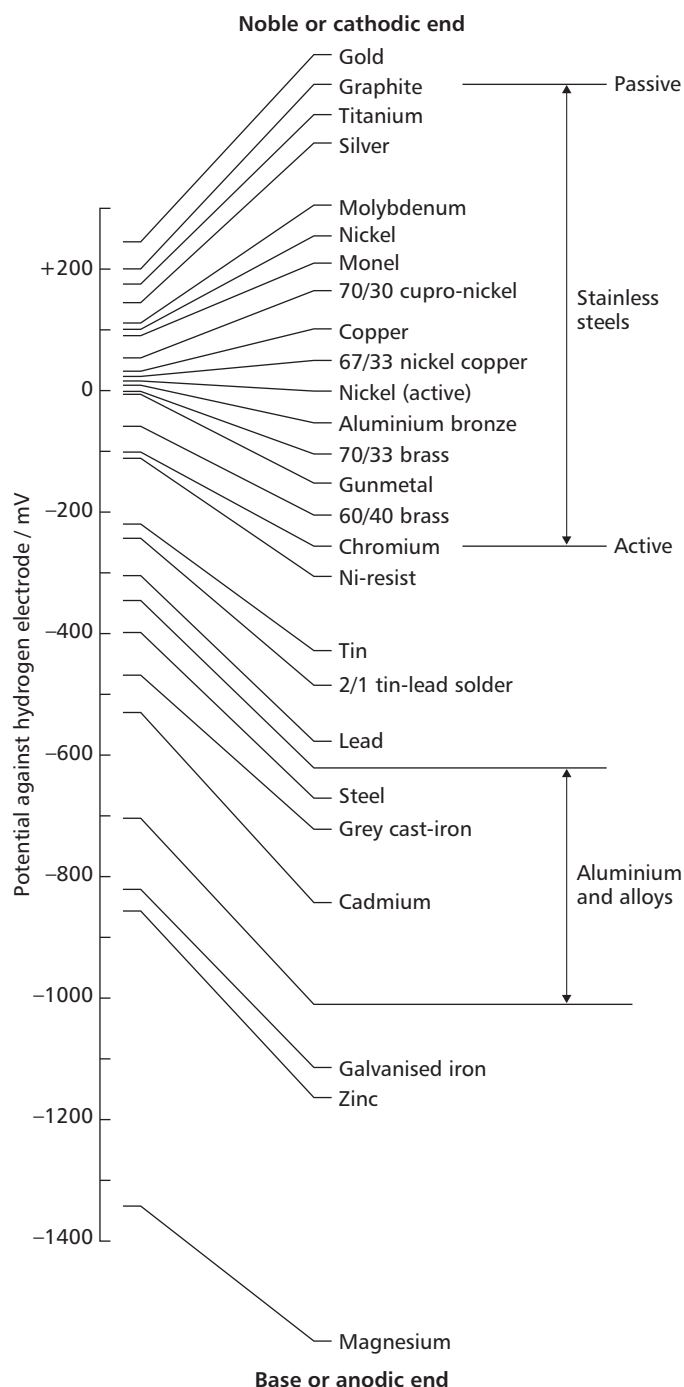


Figure 12.1 Galvanic series for common metals and alloys when in contact with natural waters

Concrete and cement are very alkaline (with pH values of between 12.6 and 13.5) when fresh, but the pH gradually reduces in the exposed surface and to a increasing depth with time as carbonation occurs. This alkalinity is responsible for protecting steel reinforcement against corrosion, but other metals, e.g. zinc, aluminium and lead, can be attacked.

Some soldering fluxes and bleaches contain high levels of chloride which will cause rapid corrosion of many metals, in particular copper and stainless steel. Other materials, e.g. some plastics, on heating and subsequent degradation will give off acidic and/or chloride by-products which will also cause attack on some metals in the presence of moisture.

Therefore it is important to flush the system fully before use^(1,2).

Corrosion in soils is similar in many ways to corrosion in water. Soils are complex in nature and very variable in properties. The main corrosion factors are:

- water content
- presence of oxygen
- electrical conductivity, depending on the presence of dissolved salts and pH.

Unprotected steel structures will normally only corrode in the presence of water and oxygen. Important exceptions are iron and steel, mainly in neutral water-logged clay, where oxygen is absent. Corrosion results from rapid localised attack caused by sulphate-reducing bacteria. Another important cause of attack is the presence of industrial waste such as acidic residues, ashes or clinker.

Other industrial wastes, e.g. oils, can attack plastic pipework or synthetic protection on metal pipework, in which case the underlying surfaces are exposed to corrosion.

12.2.4 Differential aeration

Where the contact of part of a metal surface with air is prevented by the presence of deposits, mill scale or other components or materials, the natural oxide film can break down. Due to the absence of oxygen these areas become anodic to areas where oxygen is available and which can result in localised attack. This is called differential aeration or crevice corrosion.

Corrosion under deposits due to differential aeration may be exacerbated by MIC. Of particular danger is when systems are left in a drained-down state. Pools of water are invariably left at the bottom of pipes or in vessels, leaving a 3-phase (air/water/metal) boundary. Differential aeration results in intense attack just below the water line.

12.2.5 Dissolved salts and ion concentration

Salts dissolved in natural or supply waters can greatly influence corrosion and the effect depends, not only on the concentration, but more importantly on the type of ion produced in the solution.

Sulphate and chloride ions are generally aggressive as they inhibit the formation of a protective scale or film. Ions such as carbonate and bicarbonate, which derive from calcium and magnesium salts in supply waters, can inhibit corrosion by laying down protective scales on the metal surfaces.

12.2.6 Flow, erosion, impingement and cavitation

In most instances, corrosion rates increase with the velocity of flow. This is due to the fact that the overall rate is controlled by the speed with which reactants and corrosion products can approach and leave the metal surface. At higher speeds, the flow will become turbulent and the impingement of gases, liquids, solids in suspension, or a combination of all three, can cause

mechanical damage (erosion) that removes or prevents the formation of a protective film. If the metal is subject to corrosion in that environment, then localised attack will ensue. Corrosion by erosion is particularly common in copper drinking water systems, especially in hot water return lines.

A particular type of attack that occurs when a metal surface is exposed to a high-velocity, low-pressure liquid is called cavitation. At very low pressures, which may be caused locally by the flow conditions, pockets of vapour (steam) form and suddenly collapse when the pressure increases.

12.2.7 Gases

Oxygen and carbon dioxide are the two most important gases to consider from a corrosion point of view.

12.2.7.1 Carbon dioxide

Carbon dioxide is present in some supply waters, particularly those derived from deep wells. Carbon dioxide is acidic in nature, and lowers the pH of the water which can dissolve protective films and stimulate attack. Carbon dioxide is also produced by the breakdown of bicarbonates in the feed water of steam boilers and, especially if oxygen is present, can cause rapid corrosion of condensate pipes.

12.2.7.2 Oxygen

In closed heating and cooling systems, dissolved oxygen levels in the initial filling water rapidly fall to very low levels, thus limiting the amount of corrosion that occurs. There are several ways that oxygen can enter the system through bad design, commissioning and maintenance. This is discussed further in BS EN 14868: 2005⁽³⁾.

Oxygen is responsible for the majority of corrosion problems. Within a certain range in aqueous environments, the rate of attack depends on the oxygen concentration, higher levels causing increased attack. However, with some metals, oxygen can cause passivity when present in high concentrations and the presence of certain ions, for example chlorides, may also influence the behaviour. It should be noted that plastic materials, unlike metals, are permeable to gases. Oxygen can be taken into heating systems, for example, through plastic pipework and cause internal corrosion of iron and steel components. There are however some plastic pipes available which incorporate a barrier layer to overcome this problem.

12.2.8 Organic matter

Organic matter can originate from either natural or industrial sources. When dissolved in supply waters it can affect the pH or deposition of any protective scale, and provide a source of bacterial activity by reducing levels of sulphate or by the build-up of deposits leading to localised corrosion under both aerobic and anaerobic conditions.

12.2.9 Acidity and alkalinity

Alkalinity or carbonate hardness is not the pH, but a measure of the total bicarbonate, carbonate and OH⁻ ions in the water. In natural waters of pH up to 9.6, the alkalinity is nearly all as bicarbonate. Soft waters have generally lower alkalinity than hard waters and have therefore lower buffering capacity.

Many corrosion processes depend on the pH as well as anode–cathode potential differences.

12.2.10 Stray current corrosion

Corrosion of buried metals may be caused by stray electric currents, e.g. from electric railways. The buried metal provides a preferential path of low resistance for the stray currents, acting as a cathode where the positive current enters the metal and as an anode where it leaves. The effect of direct currents may cause severe corrosion.

This is more of a problem in pipelines external to buildings. To prevent stray current corrosion of pipes and components in water systems, earth bonding should be carried out.

12.2.11 Stress

The presence of stress in specific metals and alloys when in contact with a corrosive environment can cause failure as a result of a phenomenon called stress corrosion cracking. Typical examples of this are seen in the cases of brass in the presence of ammonia or ammonium salts and stainless steels in the presence of chlorides.

12.2.12 Surface effects and deposits

The presence of surface contaminants, such as grease, mill scale and scale deposits on a metal can increase its susceptibility to localised corrosion. Increased susceptibility may be due to the cathodic nature of the film, bimetallic effects or the generation of differential aeration cells. For example, the presence of carbon films in the bore of copper tubes results from the breakdown of drawing lubricant. Carbon is cathodic to copper and where breaks in the film are present, rapid localised attack will occur causing eventual leakage.

Copper tubes with carbon film residues can result in type 1 pitting in domestic cold water systems fed by hard borehole waters.

12.2.13 Temperature

The effect of temperature is difficult to predict or quantify. Although corrosion rates would normally be expected to increase with temperature, there are several factors which can change this generalisation. Some corrosion rates are controlled by the solubility and diffusion rates of dissolved gases. For instance, the corrosion rate of steel is partly determined by the availability of oxygen at the surface. In open systems this reaches a maximum at between 70 °C and 85 °C, a rate of approximately four times that at ambient temperatures.

At temperatures above this, the dissolved oxygen level falls rapidly and hence corrosion rates fall. In closed systems, oxygen is usually removed from the system by deaerators placed in the hottest part of the system, which therefore limits the corrosion.

If there are significant temperature differences on the same metal component, this can result in differences in potential resulting in increased corrosion at the anodic area.

12.3 Assessment of corrosive environments

12.3.1 Below-ground environment

Soils can vary enormously in terms of corrosion risks due to the presence of moisture and natural, industrial or domestic contamination.

Ferrous metals are those most likely to be attacked, but plastics materials may be affected by organic contaminants and certain cements attacked by the presence of sulphates. Chemical analysis can be used to characterise a soil, but this method can be relatively costly due to the number of samples that may need to be taken.

An alternative method for assessing the aggressiveness of soils is by using resistivity data. This method measures the likelihood of oxidative corrosion, and is most applicable to buried metals, particularly ferrous (i.e. steel and cast iron). Soils may be considered aggressive to iron if the resistivity is less than 2000 $\Omega \cdot \text{cm}^{-1}$ at the specified depth.

Where ground has been subject to industrial contamination, extensive work may need to be carried out to identify the contaminants present and possible hazards.

12.3.2 Above-ground environment

12.3.2.1 Internal

Corrosion is only likely to occur internally if conditions allow the formation of condensation on metal surfaces.

12.3.2.2 External

Where external surfaces are exposed above ground, they are likely to be subject to rainfall and condensation containing a varied level of pollutants. In general, the higher the level of pollution, in particular from sulphurous compounds, the higher the risk of corrosion.

12.3.3 Aqueous environments

The nature of aqueous environments can vary enormously.

12.3.3.1 Open systems

Potable water

Advice on the corrosivity of local water supplies can usually be obtained from the local water utility.

Cooling water

The corrosivity of this environment can vary rapidly with time as well as location within the system, particularly as bacteriological growths can quickly proliferate without treatment.

12.3.3.2 Closed systems

These comprise primary and secondary heating systems and chilled water systems. Monitoring is again carried out using chemical and bacteriological analysis techniques.

12.4 Prevention of corrosion

12.4.1 Introduction

The appropriate solution should be based on economic considerations for the project concerned. For example, there is little point in selecting an expensive, corrosion-resistant material if this then outlives the other components. The material, and protection applied, must relate both to the life of the equipment and to the overall costs involved.

12.4.2 Uses and corrosion properties of materials

The properties and behaviour of the most common materials used in building services are given below.

12.4.2.1 Aluminium and aluminium alloys

Although aluminium is a very reactive metal, most alloys resist corrosion due to the presence of tenacious oxide films. These films have good resistance to atmospheric corrosion providing the surfaces are regularly washed by rain. However, where deposits are allowed to build up on sheltered surfaces, condensation can increase the rate of attack and the surfaces become unsightly.

Pure aluminium is generally stable in neutral solution, but it can be attacked by both acid and alkaline conditions.

Contact with copper alloys and steels should be avoided.

12.4.2.2 Cast irons

Cast irons are available in a great variety of alloys which are used for many applications in mainly heating and drainage systems.

Generally, corrosion rates are similar to those of steel. However, due to the thicker sections used, service lives are

longer. Cast irons may suffer a form of attack called graphitisation where corrosion of the iron leaves a weak, porous structure composed of graphite and iron oxides. This occurs in some natural waters, particularly those that are slightly acidic or contain chlorides, and can result in catastrophic failures without warning.

12.4.2.3 Copper

Copper is used extensively for pipework and heat exchangers due to its excellent ductility and thermal conductivity.

Corrosion can occur for a number of reasons. Copper can suffer pitting corrosion by two distinct mechanisms:

- 'Type 1' pitting can occur in moderately hard well waters, free from organic matter, and is characterised by fairly large well-defined pits containing loose corrosion products
- 'Type 2' pitting occurs in certain soft waters and is characterised by small, deep pits containing hard corrosion products.

Both these types of pitting are exacerbated by stagnant conditions, crevices or the presence of surface deposits.

Normally, in domestic water systems corrosion of copper is prevented by the build-up of copper oxides overlaid by basic copper carbonate (green patina). It is only when these layers do not form properly or become disrupted that problems of pitting or blue water occur.

The critical velocities for erosion corrosion are affected by water temperature and water composition, with erosion corrosion more likely the higher the temperature and softer the water. (see NPL Good Practice Guide 120⁽⁴⁾). Also, sharp bends and burrs on copper pipes increases the likelihood of erosion corrosion. To prevent erosion corrosion occurring flow rates should not be greater than 1.2 m/s in hot water and 2 m/s in soft water. This only applies to domestic water systems.

The corrosion rate of copper is much greater in waters containing carbon dioxide and the resulting corrosion products can result in green staining in baths and basins, etc.

Copper and its alloys comprise a vast range of versatile materials which are used mainly in plumbing applications. Providing the protective oxide film formed by contact with oxygen and water is not broken down, these materials can offer a long service life.

12.4.2.4 Brasses

Brasses consist of a range of copper alloys consisting of zinc (10–50%) and other minor alloying elements.

Brasses are subject to a selective form of corrosion called dezincification whereby zinc is preferentially removed leaving porous copper, which has little strength. The risk of dezincification is increased by higher proportions of zinc, high temperatures, high dissolved chloride contents, low pH, low temporary hardness, low water velocity and the presence of surface deposits or crevices.

Because of the susceptibility of brasses to this type of corrosion, an alloy has been developed which is made using a controlled composition and heat treatment. It can still be processed as a duplex brass but resists dezincification. This material is called dezincification-resistant (DZR) brass and fittings are marked with the symbol 'DR'.

Brasses containing up to about 37% zinc are single alpha phase, while those containing more than about 37% contain both alpha and beta phases. Dezincification does not occur with alloys containing <15% zinc. More than one dezincification-resistant brass (DZR) alloy exists. These also contain small amounts of arsenic to prevent dezincification of the alpha phase. Alloying elements do not prevent dezincification of the beta phase.

Brasses may also fail as a result of stress corrosion cracking, especially in waters containing ammonia.

As with copper, brasses suffer from impingement or cavitation attack. This can be a particular problem downstream from valves due to variations in pressure.

12.4.2.5 Other copper alloys

Bronzes and gunmetals comprise a range of alloys of copper and tin that generally offer improved corrosion resistance over brasses and are resistant to dezincification type attack but are significantly more expensive. Aluminium bronzes have a high resistance to corrosion impingement attack and cavitation erosion.

Cupro-nickel alloys are used in heat exchangers due to their excellent resistance to corrosion in many environments including those containing chlorides.

12.4.2.6 Lead

Lead and lead alloys have good resistance to atmospheric corrosion but can be attacked by organic acids derived from growths, some types of wood, and free alkali from fresh cement.

Insoluble, adherent protective films are formed in contact with most natural and treated waters.

12.4.2.7 Magnesium

Magnesium is mainly employed as cathodic protection to the interior of steel and galvanised tanks and the external surfaces of buried steel structures and pipelines.

12.4.2.8 Nickel

Nickel is used mainly as a protective, plated finish and in chemical plant. It is resistant to hot or cold alkalis, dilute non-oxidising inorganic and organic acids and all atmospheric conditions. Alloying nickel with copper improves its resistance and to pitting in sea water. Chromium increases its resistance to oxidising conditions, and molybdenum, its resistance to reducing conditions.

12.4.2.9 Stainless steels

Stainless steels encompass a wide variety of alloys which can be conveniently divided into ferritic, martensitic and austenitic grades.

Ferritic and martensitic grades contain 12–18% chromium. Ferritic alloys are used for flue and sink components whereas the addition of up to 2% carbon in the martensitic grades confers 'hardenability' for applications requiring high strength, as well as wear resistance combined with corrosion resistance.

The common austenitic alloys contain 15–20% chromium together with 6–11% nickel which gives them higher corrosion resistance. These grades are used for pipework, boiler flues, sinks and urinals. Even greater corrosion resistance can be obtained by the addition of 2–4% molybdenum. Stainless steels perform best under fully aerated or oxidising conditions so as to maintain their protective film. Any conditions that cause these protective films to break down can result in corrosion rates comparable to those of mild steel. The most dangerous environments for stainless steels are those containing chlorides which can cause rapid pitting and initiate intergranular attack and stress corrosion cracking.

Additions of molybdenum increase the pitting resistance of austenitic stainless steels. In hot water containing more than 60 mg/litre of chloride, AISI* 316 stainless steel should be used in preference to AISI 304 stainless steels. For much higher chloride levels, it may be necessary to specify duplex stainless steels.

Attack at welds can occur in austenitic stainless steels due to a phenomenon of sensitisation. This can largely be avoided by the use of low carbon grades.

12.4.2.10 Low-alloy steels

In closed heating and cooling systems, passive magnetite layers should form on the surface of these metals, limiting corrosion. When dissolved oxygen levels increase, loose magnetite sludge can be formed, which gives rise to flow problems, blockages and wear on valves. In grossly aerated systems, pits form under corrosion tubercles, which ultimately may lead to wall perforation.

Their corrosion resistance in most environments, notably those containing water and oxygen, is generally poor when compared with most other metals, and although small additions of other elements are often claimed to improve corrosion properties, the overall results are often insignificant.

12.4.2.11 Tin alloys (solders)

Soft solders are used mainly as joint materials in domestic copper plumbing services. Although some corrosion would be expected, because soft solders are anodic to copper, corrosion is rarely a problem because of the small area that is exposed and the nature of the protective film formed. Most problems occur as a result of aggressive flux residues which often cause perforation adjacent to the joint.

* American Iron and Steel Institute (<http://www.steel.org>)

12.4.2.12 Titanium alloys

These have a high resistance to corrosion in sea water, industrial atmospheres and industrial processes. Alloys are used in chemical plant where the high costs can be justified.

12.4.2.13 Zinc

Zinc is used almost exclusively as a protective coating on steel.

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 forms a basic carbonate film which is protective to the base metal. At ambient temperatures zinc is anodic to steel and will provide protection even if change is present in the coating.

However, in some natural waters a reversal of potential occurs above 65 °C, which results in the localised attack (pitting) of any bare areas. Temperature has a great effect on the rate of corrosion of zinc. The rate at 70 °C is about 100 times the rate at ambient temperatures due to a change in the nature of the protective film.

Under atmospheric conditions, the rate of corrosion is largely governed by the level of pollution. In industrial areas, where sulphur dioxide levels are high, the corrosion rate may be increased by a factor of 10.

Underground, galvanised coatings suffer a high level of attack in poorly aerated soils, because of a high acid or soluble salt content.

Zinc can suffer bimetallic attack when in contact with or exposed to copper and copper alloys. Where the water is cupro-solvent, traces of dissolved copper can subsequently be deposited on zinc surfaces and stimulate internal attack in water distribution systems. Galvanised steel, however, can normally be used safely upstream from copper pipework.

12.4.2.14 Plastics and rubbers

Although plastic and rubber materials do not corrode, they can degrade when exposed to ultraviolet (UV) light, heat and certain organic and inorganic compounds. These materials are used in a wide variety of applications as materials in their own right, as substitutes for metals and as protection against corrosion, and so on.

Various plastics and rubber materials can be damaged by contact with soldering flux, grease, smoke generated by testing equipment, or with general purpose lubricants that are not approved for the application. Only WRAS-approved lubricant should be used when jointing piping intended to convey wholesome water. Plastics can also be damaged by stress cracking if pipes are bent beyond the minimum radius recommended by the manufacturer, or if threads are over-tightened beyond their recommended limit.

12.4.3 Systems: corrosion risks and design

This section provides a guide to the design of various building services systems, with a view to limiting potential corrosion damage. Influential features are highlighted and typical physical conditions listed.

12.4.3.1 Cold water services

Materials to be used in contact with cold water supplies must be selected to combat certain corrosive conditions. In general terms, the water will pass through the system only once. Therefore, it is unlikely that water treatment can be used to eliminate corrosive characteristics at this stage due to the chemical effects on the potability of the water and the economics of treating substantial quantities of water, much of which is going to waste.

The use of copper in some soft water areas with free carbon dioxide may result in contamination by dissolved copper. Copper tube may also suffer from pitting corrosion. This usually occurs when the tube contains a surface film cathodic to the underlying metal. Any break in the surface film will result in accelerated attack of the copper beneath. This is known to occur in hard, or moderately hard, waters.

The use of dissimilar metals in a system may create an electrolytic cell. If a combination of metals is to be used, the electrolyte relationship between them should be examined and suitable precautions taken to limit corrosive action. Furthermore, galvanised steel should not be used downstream from copper pipework or storage tanks.

12.4.3.2 Domestic hot water services

Like cold water services, domestic hot water is consumable and not continuously recirculated. Therefore, water treatment is not usually a practical or economic solution to corrosion and scaling. Potential problems are best dealt with by careful selection of materials and controlled operating conditions. Components may need occasional servicing and should be accessible for inspection and maintenance.

The composition of the water will influence the corrosion potential within the system. Hard waters may be associated with a reversal of the electrical potential between zinc and steel. The protective zinc becomes cathodic in some types of hard water at temperatures above 60 °C and corrosion of the steel may result. Formation of a protective scale early in the life of a system may overcome this problem but high temperatures and wide temperature variations can displace the scale and expose fresh metal surfaces to corrosion.

Mixtures of metals in domestic hot water systems with aggressive waters has led to failures. Small amounts of copper picked up by the flow of water, if deposited on new galvanised steel, will set up an electrolytic cell. The zinc will rapidly corrode and expose the steel base to attack. If copper and galvanised steel are to be used in the same system the copper should only be used downstream of the steel.

12.4.3.3 Heating

Heating systems are often designed on the assumption that some major elements will last as long as the process or the building they serve. Where components are likely to be subjected to more concentrated wear and/or corrosion hazards, the design should ensure that maintenance or replacement can be carried out.

The key to corrosion protection is maintaining very low dissolved oxygen levels in the system. The use of corrosion inhibitors is routinely used to limit corrosion further, especially if some oxygenation of the system water occurs. Some inhibitors contain anti-scaling components but in hard water areas, the use of base-exchange softened water may be considered.

12.4.3.4 Steam services and condensate return

Steam boilers are generally made of mild steel. Before being put into use they should be thoroughly cleaned internally in order to remove all debris and grease.

Boiler feed water can be made up of raw water, suitably softened or treated, or returned condensate plus softened or treated make-up raw water, depending upon the particular process served. Water treatment and conditioning are essential to provide the following water conditions:

- (a) The water should be fully softened to prevent scale formation on heat exchange metal surfaces.
- (b) The water should be de-aerated, or treated with oxygen-scavenging chemicals in order to limit oxygen corrosion of the heating surfaces.
- (c) The water should be maintained in an alkaline condition, in order to sustain a protective oxide film on the metal surfaces and limit the effect of oxygen, chlorides and carbon dioxide introduced with the feed water. The alkalinity should be maintained at not less than 10–20% of the total dissolved solid content of the boiler water.
- (d) The dissolved solids concentration in the boiler must be kept within the limits recommended by the manufacturer. This entails a blowdown procedure, the amount of which can be assessed from:

$$B = \left(\frac{S_1}{S_2 - S_1} \right) E \quad (12.1)$$

where B is the blowdown volume ($\text{litre}\cdot\text{s}^{-1}$), E is the boiler evaporation ($\text{kg}\cdot\text{s}^{-1}$), S_1 is the solids concentration in the boiler feed (ppm) and S_2 is the permissible solids concentration in boiler (ppm).

The dissolved solids concentration in the feed water must take into account the dilution effect of recovered clean condensate and any increase in solids due to the addition of conditioning chemicals.

If the calculated blowdown is high, say 8%, then continuous blowdown systems with heat recovery may be required to avoid reducing boiler output and efficiency, or alternatively a more elaborate feed treatment system may reduce blowdown requirements and consequent heat loss.

When the plant is burning sulphur-bearing fuels, the temperature of metal surfaces must be maintained above the acid dew-point in order to avoid excessive corrosion.

Condensate pipework may be fabricated in mild steel or copper. In the former, corrosion can be very severe where the raw make-up water has a high alkaline hardness and is treated with a base exchange softener. This combination causes bicarbonates in the boiler water to break down and allow carry over of CO_2 in the condensate system, resulting in acidic conditions. Amines and other chemical dosing can be used where toxicity is not a problem, or an alternative method of water treatment for the feedwater could be used, e.g. de-alkalisation.

12.4.3.5 Fire services

The fire services considered in this section are those where materials are in contact with water supplies, i.e. sprinklers, drenchers and hose reel systems. Sprinkler and drencher systems can be considered as having the same requirements.

Sprinklers and drenchers

After initial filling at mains water temperature the water will stabilise to ambient temperature and is unlikely to significantly affect the rate of corrosion. The local water supply will have its own composition including impurities which will both aggravate and inhibit corrosion. The local water supply analysis should be considered to identify the corrosion potential.

In wet systems the material normally used for pipework downstream of the valve station is black mild steel as systems are often welded. Being a one-fill system, corrosion is not normally a problem, but if the local water is particularly aggressive some treatment may be required. Pipework from the mains or pump set, up to the valve station, is subject to replenishment as regular discharging of water occurs when tests are carried out at the valve station. This section of the system requires protection and this is normally achieved using galvanised mild steel. Such protection is suitable for most types of water, but not with acidic or soft water with a free carbon dioxide content greater than $30 \text{ mg}\cdot\text{cm}^{-3}$. Ductile iron pipework with a hot applied bitumen-based coating may be a more suitable alternative with some waters. Thermoplastic pipework is available for this part of the system and offers a solution to corrosion issues.

Fire hydrants and hose reels

After initial filling at mains water temperature the system will stabilise to ambient temperature, which is unlikely to significantly affect the rate of corrosion. Whilst the system is basically a static one, there will be some turnover of water when fire hydrants and hose reels are tested.

12.4.3.6 Sanitation and waste disposal

Corrosion from natural waters is not normally a problem but great consideration should be given to chemical and acidic wastes.

Urinal wastes

Corrosion of copper pipework and brass traps and fittings by uric acid can be a problem and such waste pipes are best installed using PVC-U or polypropylene. Limescale will also adhere more readily to copper than plastic and the bore of a copper urinal waste can be reduced considerably in a few years. Regular disinfection with hypochlorite can cause rapid attack if left to stagnate in copper traps so treatment should always be followed by adequate flushing.

Photographic equipment wastes

Wastes from processing equipment such as X-ray processors should not be carried in metal pipes as the waste solution contains high levels of silver, and electrolytic action will result with all metals commonly used for waste pipes. Silver is the noble metal in all cases and the pipework will suffer corrosion. Processor wastes should be discharged via plastic piping directly to a silver recovery unit before being discharged to the drainage system and subject to approval by the local water and drainage utility.

Laboratory wastes

Corrosion protection in laboratories is very much a case of material selection. A list of the chemicals, temperatures and solution strengths likely to be used in the laboratory must be obtained. This should be checked against the chemical resistance charts for various waste pipe materials. In many small laboratories, polythene or polypropylene may be adequate but in extreme cases, borosilicate glass with polytetrafluoroethylene (PTFE) encapsulated O-rings will be required.

12.4.3.7 Solar energy systems

The collector will be exposed to all atmospheric conditions. Ambient temperature and moisture, airborne pollutants, heat transfer media and aesthetic considerations all influence the choice of materials. Water, possibly including anti-freeze additives, heat transfer oils, oil-water emulsions and air are all used as heat transfer media. Materials must not suffer deterioration from contact with the fluid under any of the anticipated operational or idle conditions. Plastic pipework should be avoided due to the potentially high temperatures of primary solar hot water circuits.

In most systems the working fluid is retained and recirculated. Therefore it may be adjusted chemically to be non-aggressive to the materials with which it is in contact. Special attention is required if anti-freeze or other chemicals are introduced. The system will include both metallic and non-metallic materials. These systems often contain glycols. Glycols may oxidise to organic acids and therefore inhibited glycols must be used.

12.4.3.8 Fumes and flue gases

The term 'fumes' is used here to describe unwanted, mainly gaseous, emanations from industrial processes, decaying vegetable matter, combustion products and similar processes. Fumes can be corrosive, foul smelling,

hot or cold and may contain particulate matter. They may all be considered as having corrosion potential.

12.4.3.9 Fuel supply

This section covers various forms of fuel supply systems for boiler plants and similar applications.

Gas systems

These are systems designed for natural gas taken from the gas mains, either above ground or buried. Above-ground mains can be adequately protected by painting them externally. Underground steel mains pipework may require wrapping and, in some cases, cathodic protection. Natural gas is normally dry and there is no danger of internal corrosion.

Oil systems

Installation of oil storage tanks and pipework must comply with the relevant British Standards. The following materials should not be used where they may be in contact with oil fuels: yellow brass, including low grade alloys of copper and zinc, lead and zinc, galvanised metals, natural rubber.

In general, thermoplastic materials are not suitable for use with industrial oil fuels although nylon and PTFE are satisfactory for valve seatings, seals and similar purposes. Specialised multi-layer and composite thermoplastic pipe systems are however available.

If oils or petrol are contaminated with water, then severe corrosion can ensue in the bottom of tanks because of the large cathodic area formed by the oil.

Buried pipework must be protected by suitable wrappings, together with electrical methods of corrosion prevention where dictated by soil conditions.

12.4.3.10 Swimming pools and ice rinks

Swimming pool water undergoes a variety of water treatments mainly for the purpose of bacteriological control. This, together with the presence of high levels of dissolved oxygen, renders the water fairly aggressive to most metals except cupro-nickels and austenitic stainless steels. Any corrosion which results is not only detrimental to the life of the plant, but can cause unacceptable discolouration to the pool water.

The large surface area of water, particularly where the pools contain features, can result in very high humidity levels. All exposed services can therefore be subject to condensation and corrosive attack.

Corrosion of stainless steel fittings in swimming pools can occur due to concentration of chlorides, especially on upward facing and unpolished surfaces. This occurs due to repeated condensation and evaporation if there are large temperature changes between day and night. The problem can largely be overcome by better temperature regulation and frequent washing of the stainless steel fittings with fresh water.

Ice rinks can suffer condensation similar to that of swimming pools, but to a lesser extent due to the lower temperatures involved.

12.4.4 Corrosion prevention and protection

Whilst it is not possible to predict possible deterioration in every case, the majority of corrosion problems may be prevented by careful attention to materials selection, quality control or the correct choice of preventative measures. However, it may not always be economic to prevent corrosion as in certain cases allowing deterioration and carrying out regular replacement is the cheaper solution. The following sections outline the measures that may be taken to control corrosive attack.

12.4.4.1 Material selection

The simplest way of avoiding corrosion is to use resistant materials providing they possess the correct properties (mechanical, thermal etc.) and are economical to use. Some other materials, in particular polymers and plastics, are often more difficult to select due to the wide variety of formulations available for any particular grade.

However, the usual choice of a material is based on the cost, availability, 'formability' and good track record. Therefore, mild steel is used for radiators and pipework rather than stainless steels.

12.4.4.2 Modifying the corrosion environment

Water

Factors affecting the corrosion rate in water and methods of water treatment are described elsewhere

Atmosphere

The corrosion potential of an atmosphere depends upon the contaminants present and the moisture content. To minimise corrosion, dust and fumes must be removed and the relative humidity must be reduced to below the dew-point

Soils

Factors affecting the corrosion rates of metals in soils are discussed elsewhere. Acid soil can be made less corrosive if limestone chips are packed around buried metal, but it is difficult to modify the environment and resiting the buried structure or pipeline should be considered.

12.4.4.3 Surface protection

Coatings used to protect metals from corrosion can be divided into metallic, organic and inorganic types, which protect the metals by means of exclusion, inhibition or sacrifice. All coatings exclude the environment to some extent but those that protect by exclusion means alone must completely cover the surface, be impermeable to the corrosive medium and must resist mechanical damage or environmental degradation.

Sacrificial coatings act as excluders where the coating is sound and also provide cathodic protection at any gap, acting as a sacrificial anode. In these cases the metal coating is less noble than the metal being protected in prevailing corrosion conditions. It is essential that surface cleaning and preparation be carried out thoroughly prior to applying any coating.

Galvanising

This involves coating the steel surface with zinc, most commonly by dipping the steel into a molten zinc bath. The function of the coating is to delay corrosion of the underlying steel because zinc protects steel cathodically. When zinc and steel are in contact with each other and with a conducting liquid, a short-circuited electrolytic cell is set up. Current flows from the zinc to the solution, into the iron and back to the zinc, resulting in the dissolution of the zinc and leaving the steel unaffected. It is not necessary for the zinc to cover the entire steel surface, therefore the zinc coating is effective even when scratched.

Care must be taken when selecting galvanised steel for hot water applications. The corrosion rate increases above 50 °C to a maximum at approximately 65–70 °C, and then declines. In soft water, with appreciable bicarbonate content, a potential reversal of the zinc coating may lead to accelerated attack on the basic metal.

Chromium plating

This is used to protect steel- and zinc-based components. Chromium electro-deposits have a highly protective oxide film that can contain micro-cracks. Therefore, the components are first plated with nickel, which protects the underlying metal from cracks in the chromium coating. Various combination nickel-chromium coatings offering considerable protection against atmospheric corrosion have been developed. The coating is however not anodic to steel so any damage can allow the substrate to corrode.

Sprayed coatings

Many materials can be flame or plasma sprayed to give corrosion resistance coatings. The coatings produced by these processes are thin but the process is very quick. Aluminium and zinc are commonly sprayed to provide protection on steel structures exposed to industrial and marine environments.

Diffusion coatings

These are produced by causing elements, usually metals, to diffuse into the surface of steel where it forms a compound with a good corrosion resistance. An example of this is aluminising, in which aluminium diffuses into the steel to form an iron aluminoid layer which has good corrosion resistance because it is covered by a thin layer aluminium oxide. 'Sherardising' is a similar process. These coatings are normally restricted to low-precision components such as pipework grids and condenser plates.

Paints, pitch, tar and bitumen

These are common organic coatings which are applied to metals. With paints, the importance of adequate surface preparation cannot be overemphasised.

Plastic coatings

These are generally available in two types: relatively thin coatings, e.g. epoxy and polyurethane resins, and thicker coatings, e.g. PVC, polyesters (often referred to as polyester powder coating (PPC)), resins, and some fluorocarbons, which are often applied with a type of reinforcement. The thicker coatings act as chemically resistant linings.

Vitreous enamels

These are applied as a thin layer of glass, bonded to the surface of a metal, usually steel. Grit-blasting the surface is essential before enamelling is applied. Enamel coatings are used in chemical plant for their corrosion resistance. They are also used extensively for domestic items because the coatings are highly resistant to heat, acids and alkalis and are nontoxic.

Conversion coatings

These coatings are produced by treating the metal surface chemically with an appropriate solution. Phosphate coatings are produced by immersing the metal in a weak phosphoric acid solution of iron, copper or manganese phosphate. They provide only limited protection but make an excellent base for paint or other protective coatings.

Chromate coatings can be produced on aluminium and its alloys, magnesium, cadmium and zinc. These coatings form a useful degree of resistance to corrosion and a good preparation for painting. Anodising is an electrolytic process where the metal to be treated is made anodic in a suitable electrolyte to produce a layer of oxide on its surface. This process is applied to various non-ferrous metals but mainly to aluminium and its alloys. It provides corrosion protection and is also a good pre-treatment for painting.

12.4.4.4 Electrical methods

Cathodic protection

There are two methods of providing cathodic protection for minimising corrosion of metals in use: the sacrificial anode method and the impressed current method. Both depend upon making the metal to be protected the cathode in the electrolyte employed.

Sacrificial anode method

This includes the use of zinc, magnesium or aluminium as anodes in electrical contact with the metal to be protected. Positive direct current flows from the corroding (sacrificial) anode through the soil or electrolyte to any exposed pipe or tank metal, thus preventing ions leaving the metal surface. In buried pipelines, the sacrificial anode is usually connected to the pipe via an insulated wire taken through a link box at ground level. This enables the

pipe to soil potentials to be measured together with the current supplied by the anode. Each anode supplies only a small current (usually 10 to 500 mA for a 10 kg magnesium anode), depending on soil resistivity and the area of base metal cathode.

The use of sacrificial anodes is restricted in practice to soils of less than $3000 \Omega \cdot \text{cm}^{-1}$ capacity. Magnesium anodes have the advantage of the greatest potential difference from iron and a high electro-chemical equivalent ($\text{A} \cdot \text{h}/\text{kg}$). Protection of calorifiers, water tanks, etc. can be achieved internally or externally by the use of anodes welded to the sides or suspended centrally. The same principles apply as in the case of pipes in soils. Anodes must be checked regularly and replaced as they are consumed.

Impressed current method

This is similar in principle to the sacrificial method, except that the DC power is derived not from the natural difference in potential between anode and metal structure but from a rectified or transformed AC power supply or generator.

Careful measurements and calculations must be performed to determine the quality and number of anodes used, the operating current and any protection required for other structures in the area. Frequent monitoring of performance is essential since failure of the power supply leaves the metal surfaces unprotected.

12.5 Chemical cleaning and passivation

Chemical cleaning procedures are employed for two main purposes:

- (a) to thoroughly clean the pipework system of oils, greases, mill-scale and other corrosion-forming deposits (in the pre-commissioning phases); this follows the flushing out of the pipework system to remove loose scale, magnetite and other debris
- (b) in order to descale or clean individual items of plant which have built up deposits during operation, e.g. boiler scale, heat exchanger fouling, etc.

The chemicals employed and the method of application must be agreed between the client and the specialist chemical cleaning contractor. The latter normally provides all the necessary operating labour, chemicals, temporary pipework connections, temporary circulating pumps and test facilities.

Passivation is necessary in order to prevent corrosion of the metal surfaces after the chemical cleaning has been completed.

References

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- 2 BS EN 806-4: 2010: *Specifications for installations inside buildings conveying water for human consumption. Installation* (London: British Standards Institution) (2010)
- 3 BS EN 14868: 2005: *Protection of metallic materials against corrosion. Guidance on the assessment of corrosion likelihood in closed water circulation systems* (London: British Standards Institution) (2005)
- 4 Munn P *Avoidance of corrosion in plumbing systems* Measurement Good Practice Guide No. 120 (Teddington: National Physical Laboratory) (2011) (available at <http://www.npl.co.uk/publications/Avoidance-of-corrosion-in-plumbing-systems>) (accessed February 2013)

13 Miscellaneous data

13.1 Introduction
13.2 Standardised systems of units
13.3 Conversion of units
13.4 Pipework data
13.5 Drawing symbols
References
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Summary

Various miscellaneous data, relevant to public health and plumbing engineering has been collected for the convenience of the engineer. This section includes a useful reference guide to the conversion of various units from imperial to metric (SI units).

Various pipework data has also been collated to provide the engineer with a useful source of reference, including identification of pipework services, comparison of various pipework diameters and useful conversion data relating to pipework flow and velocities in drainage systems.

In addition, a drawing symbol section has been created identifying suggested symbols that are key to water services, drainage, gas services and fire engineering.

Finally, a bibliography containing the key legislation and British Standards has been included. It should be noted that additional mathematical data is contained within CIBSE Guide C: *Reference data*.

13.1 Introduction

This chapter aims to provide the engineer with the basic formulae and reference material that is commonly referred to in most aspects of public health and hydraulic engineering.

replaced elsewhere by the SI (metric) system. The UK completed its legal transition to SI units in 1995; however, various units are still in official use, e.g. volume of water may still be referred to in pints.

13.2 Standardised systems of units

Imperial (IP) units are widely used only in the USA, under the name 'U.S. customary units'. They have been

13.3 Conversion of units

See Tables 13.1, 13.2, 13.3 and 13.4.

Table 13.1 Conversion of units

Quantity	Imperial	Metric	Metric	Imperial
Length	1 inch	25.4 mm	1 mm	0.03937 inches
	1 foot	0.3048 m	1 m	3.281 ft
	1 yard	0.9144 m	1 m	1.094 yards
	1 mile	1.609 km	1 km	0.6214 miles
	1 thou	25.4 μm	1 mm	0.03937 thou
Area	1 in ²	645.2 mm ²	1 mm ²	0.00155 in ²
	1 ft ²	0.0929 m ²	1 m ²	10.76 ft ²
	1 yd ²	0.8361 m ²	1 m ²	1.196 yd ²
	1 acre	0.4047 hectare	1 ha	2.471 acres
Volume	1 in ³	16390 mm ³	—	—
	1 in ³	16.39 cm ³	1 cm ³	0.006102 in ³
	1 ft ³	0.02832 m ³	1 m ³	35.31 ft ³
	1 yd ³	0.7646 m ³	1 m ³	1.308 yd ³
	1 gallon	4.546 litre	1 litre	0.22 gallons
	1 pint	0.5683 litres	1 litre	1.76 pints
	1 ft ³	28.32 litres	1 litre	0.03531 ft ³
Velocity	1 ft/min	0.00508 m/s	1 m/s	196.9 ft/min
	1 ft/sec	0.3048 m/s	1 m/s	3.281 ft/s
	1 ft/sec	1.097 km/h	1 km/h	0.9113 ft/s
	1 mile/h	0.4470 m/s	1 m/s	2.237 mile/h
Mass	1 oz	0.02835 kg	1 kg	2.205 lb
	1 oz	28.35 g	1 kg	35.27 oz
	1 lb	0.4536 kg	1 g	0.03527 oz
	1 cwt	50.80 kg	1 tonne	0.9842 ton
	1 ton	1016.0 k	1 kg	0.01968 cwtg
Mass/length	1 lb/ft	1.488 kg/m	1 kg/m	0.672 lb/ft
Mass/area	1 lb/ft ²	4.883 kg/m ²	1 kg/m ²	0.2048 lb/ft ²
	1 lb/in ² (psi)	703.1 kg/m ²	1 kg/m ²	0.001422 lb/in ²
Density	1 lb/ft ³	16.02 kg/m ³	1 kg/m ³	0.06243 lb/ft ³
	1 lb/m ³	27680 kg/m ³	—	—
Flow rate	1 gal/min	0.07577 litre/s	1 litre/s	13.20 gal/min
	1 gal/h	0.001263 litre/s	1 litre/s	791.9 gal/h
	1 ft ³ /min	0.4719 litre/s	1 litre/s	2.119 ft ³ /min
	1 ft ³ /min	1.699 m ³ /h	1 m ³ /h	0.5886 ft ³ /h
	1 ft ³ /h	0.007866 litre/s	1 litre/s	127.1 ft ³ /h
	—	—	1 m ³ /s	2119.0 ft ³ /min
Force (1 kgf = 9.807 N)	1 lb f	4.448 N	1 N	0.2248 lb f
	1 ton f	9.964 kN	1 kN	0.1004 ton f
Pressure, stress	1 in water gauge (WG)	249.1 Pa	1 Pa	0.004014 in water gauge (WG)
	1 in water gauge (WG)	2.491 mbar	1 mbar	0.4014 in water gauge (WG)
	1 lb/in ² (psi)	6.895 kPa	1 kPa	0.145 lb/m ²
	1 lb/in ² (psi)	68.95 mbar	1 mbar	0.01450 lb/in ² (psi)
	1 ft head of water	0.06985 kPa	1 kPa	0.3345 ft head of water
	1 ft head of water	0.02989 bar	1 bar	33.45 ft head of water
	1 lb/in ² (psi)	0.06895 bar	1 bar	14.50 lb/in ² (psi)
	1 atmosphere	1.013 bar	1 bar	0.9872 atmosphere
Power	1 horsepower	745.7 W	1 kW	1.341 horsepower
Heat	1 Btu	1055 J	1 J	94.78 therm
	1 Btu	0.252 kcal	1 kcal	3.968 Btu
	1 therm	29.31 kW·h	1 kW·h	0.03412 therm
	1 therm	105.5 MJ	1 MJ	0.009479 therm
Heat flow	1 Btu/h	0.2931 W	1 W	3.414 Btu/h
	1 Btu/h·ft ²	3.155 W/m ²	1 W/m ²	0.3169 Btu/h·ft ²
	1 Btu/ft ³	0.03726 mJ/m ³	1 mJ/m ³	26.84 Btu/ft ³
	1 Btu·in/h·ft ² °F	0.1442 W/m ² ·K	1 W/m ² K	6.934 Btu·in/h·ft ² ·°F
	1 Btu/h·ft ² ·°F	5.678 W/m ² ·K	1 W/m ² K	0.176 Btu/h·ft ² ·°F
Temperature	1 °F (Fahrenheit)	0.555 K	1 K	1.8 °F
Velocity	1 ft/s	0.3048 m/s	1 m/s	3.281 ft/s
	1 ft/min	0.3048 m/min	1 m/s	196.85 ft/min
	1 ft/min	0.005 m/s	1 km/h	0.6214 mile/h (mph)
	1 mile/h (mph)	0.447 m/s	—	—
	1 mile/h (mph)	1.609 km/h	—	—
	—	—	—	—

Table 13.2 Conversion factors to obtain energy contents of fuels in kW·h (source: CIBSE Guide F⁽⁶⁾)

Fuel	Measured unit	Conversion factor*
Electricity	kW·h	1
Natural gas	m ³	10.7
	100 cu. ft.	30.3
	kW·h	1
	therm	29.31
Propane	tonne	13.78
	kg	13.78

* Multiply by factor to obtain energy content in kW·h

Table 13.3 Conversion factors for pressure

Units	bar	mbar	Pa	kPa	inches WG	mm WG	lb/in ²
bar	1	10 ³	10 ⁵	10 ²	4.01 × 10 ²	1.02 × 10 ⁴	14.5
mbar	10 ⁻³	1	10 ²	0.1	0.401	10.2	1.45 × 10 ⁻³
Pa	10 ⁻⁵	0.01	1	10 ⁻³	4.01 × 10 ⁻³	0.102	1.45 × 10 ⁻⁴
kPa	0.01	10	10 ³	1	4.01	102	0.145
inches WG	2.4 × 10 ⁻³	2.49	249	0.249	1	25.4	3.61 × 10 ⁻²
mm WG	0.981 × 10 ⁻⁵	0.981 × 10 ⁻²	9.81	9.81 × 10 ⁻²	3.94 × 10 ⁻²	1	1.42 × 10 ⁻³
lb/in ²	6.89 × 10 ⁻²	68.9	6.89 × 10 ⁻³	6.89	27.7	7.03 × 10 ²	1

Table 13.4 Conversion factors for head of water

Head (metres)	Pressure		Head (metres)	Pressure	
	kPa	bar		kPa	bar
1	9.81	0.098	25	245.17	2.45
2	19.61	0.196	30	294.20	2.94
3	29.42	0.294	35	343.23	3.43
4	39.23	0.392	40	392.27	3.92
5	49.03	0.490	45	441.30	4.41
6	58.84	0.588	50	490.33	4.90
7	68.65	0.686	60	588.40	5.88
8	78.45	0.785	70	686.47	6.86
9	88.26	0.883	80	784.53	7.85
10	98.07	0.981	90	882.60	8.83
11	107.87	1.08	100	980.66	9.81
12	117.68	1.18	200	1961	19.61
13	127.49	1.27	300	2942	29.42
14	137.29	1.37	400	3924	39.24
15	147.10	1.47	500	4903	49.03
16	156.91	1.57			
17	166.71	1.67			
18	176.52	1.77			
19	186.33	1.86			
20	196.13	1.96			

13.4 Pipework data

13.4.1 Pipework identification

See Tables 13.5 and 13.6.

Table 13.5 Buried pipes/ducts (source: *NJUG Guidelines*⁽⁷⁾)

Utility	Duct	Pipe	Colour of marker/warning tape (where used)	Recommended min. depth / mm	
				Footway/verge	Carriageway
Gas	Yellow	Yellow*	Black legend on PE pipes every linear metre	600 (footway) 750 (verge)	750
Water	Blue or grey	Blue polymer or blue or uncoated iron/GRP Blue polymer with brown stripe (removable skin revealing white or black pipe)	Blue or blue/black	750	750 (min)
Water (non-potable) and greywater	N/A	Black with green stripes	N/A	600–750	600–750
Water for special purposes (e.g. contaminated ground)	N/A	Blue polymer with brown stripes (non-removeable skin)	Blue or blue/black	750	750 (min)
Sewerage	Black	No distinguishing colour/material (e.g. ductile iron may be red; PVC may be brown)	N/A	Variable	Variable

* PE: up to 2 bar: yellow or yellow with brown stripes; 2–7 bar: orange. Steel: may have yellow wrap or black tar coating or no coating. Ductile iron: may have plastic wrapping. Asbestos and pit/spun cast iron: no distinguishable colour.

Table 13.6 Optional colour code for general building services pipework (source: BS 1710⁽⁸⁾)

Pipe contents	Basic colour (approx. 150 mm)	Coloured band (approx. 100 mm)	Basic colour (approx. 150 mm)
Water:			
— drinking	Green	Blue	Green
— cooling (primary)	Green	White	Green
— boiler feed	Green	Crimson — White — Crimson	Green
— condensate	Green	Crimson — Emerald green — Crimson	Green
— chilled	Green	White — Emerald green — White	Green
— heating (<100 °C)	Green	Blue — Crimson — Blue	Green
— heating (>100 °C)	Green	Crimson — Blue — Crimson	Green
— cold down service	Green	White — Blue — White	Green
— hot water service	Green	White — Crimson — White	Green
— hydraulic power	Green	Salmon pink	Green
— sea/river/untreated	Green	Green	Green
— fire extinguishing	Green	Safety red	Green
Compressed air	Light blue	Light blue	Light blue
Vacuum	Light blue	White	Light blue
Steam	Silver grey	Silver grey	Silver grey
Drainage	Black	Black	Black
Electrical ducts/conduits	Orange	Orange	Orange
Natural gas:	Yellow ochre	Primrose yellow	Yellow ochre
Refrigerants:			
— R12	Yellow ochre	Blue	Yellow ochre
— R22	Yellow ochre	Sea green	Yellow ochre
— R502	Yellow ochre	Golden brown	Yellow ochre
— R12	Yellow ochre	Dark mauve	Yellow ochre
— Other	Yellow ochre	Emerald green	Yellow ochre
Oil:			
— diesel fuel	Brown	White	Brown
— furnace fuel	Brown	Brown	Brown
— lubricating	Brown	Emerald green	Brown
— hydraulic power	Brown	Salmon pink	Brown
— transformer	Brown	Crimson	Brown
Acids/alkalies	Violet	Violet	Violet

13.4.2 Positioning of underground services

See Figures 13.1 and 13.2.

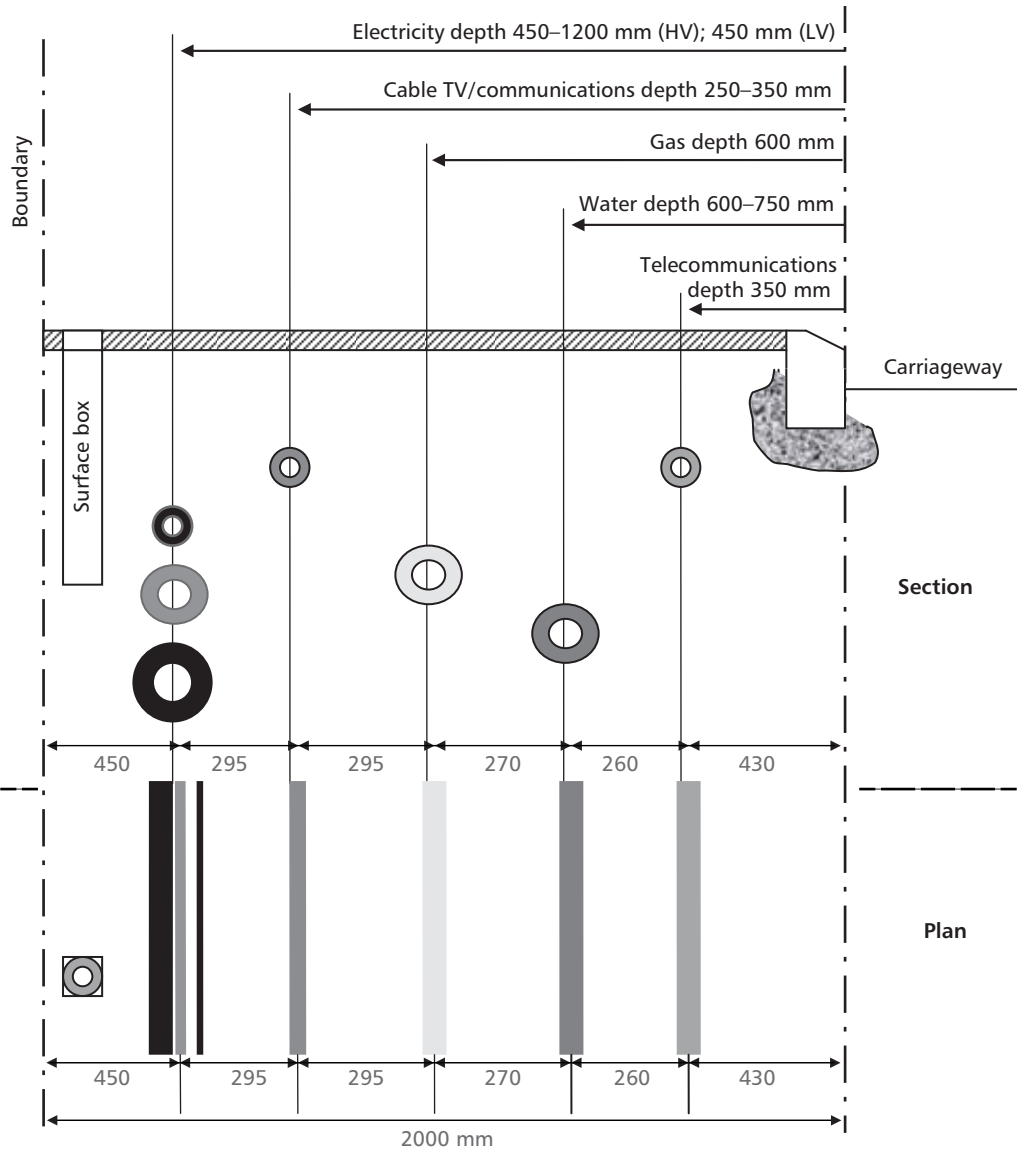


Figure 13.1 Positioning of mains under a 2 m footway (reproduced from *NJUG guidelines on the positioning and colour coding of utilities' apparatus*⁽⁷⁾ by courtesy of National Joint Utilities Group)

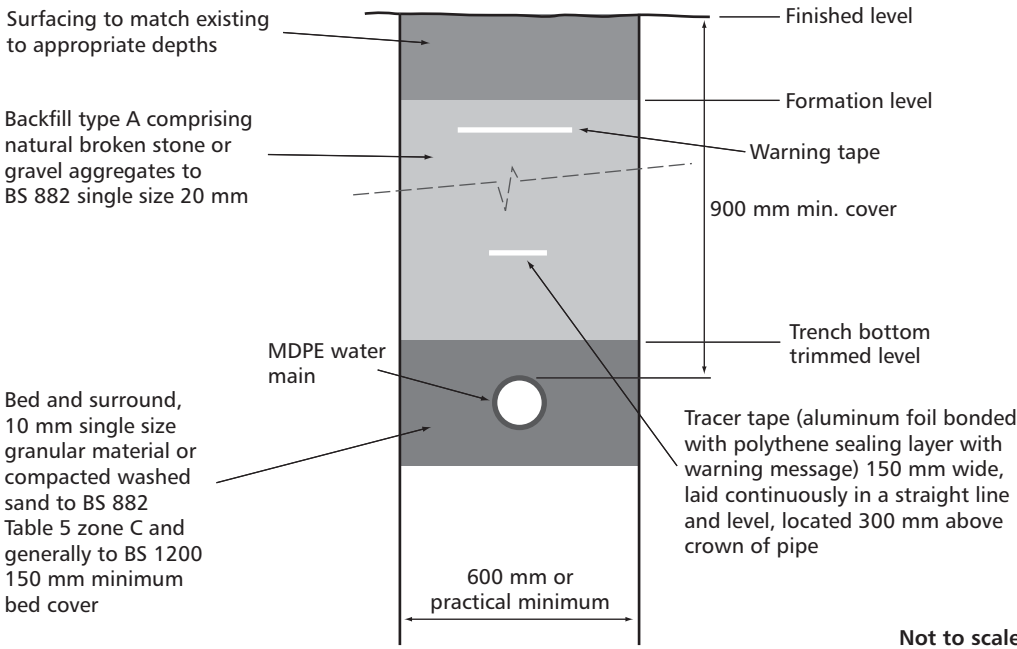


Figure 13.2 Section through a trench for a non-metallic water pipe

13.4.3 Standard pipe sizes

See Tables 13.7 to 13.12.

Table 13.7 Comparison of internal diameters of pipes of various materials

Application and material	Internal diameter (/ mm) for stated nominal (Imperial) diameter											
	½"	¾"	1"	1¼"	1½"	2"	2½"	3"	4"	5"	6"	9"
Water services:												
— polypropylene	20	25	32	40	50	63	—	90	110	—	160	—
— MDPE	20	25	32	50	50	63	—	90	125	—	180	—
— copper	15	22	28	35	42	54	67	76	108	133	159	219
— stainless steel	15	22	28	35	42	54	67	76	108	—	—	—
— ductile iron	—	—	—	—	40	50	65	80	100	125	150	225
Firefighting:												
— heavy steel	15	20	25	32	40	50	65	80	100	125	150	—
Drainage:												
— PVC-C	—	21.5	—	36	43	55	—	—	—	—	—	—
— PVC-U	—	—	—	—	—	—	—	82	110	—	160	—
— cast iron	—	—	—	—	—	50	—	75	100	—	150	225
— stainless steel	—	—	—	—	—	50	—	75	110	—	160	—

Table 13.8 Pipework dimensions (including pressure pipework) (sources: BS 3505⁽⁹⁾ and BS EN ISO 1452-2⁽¹⁰⁾)

Imperial sizes (BS 3505 ⁽⁹⁾)							Metric sizes (BS EN ISO 1452-2 ⁽¹⁰⁾)			
Nom. bore	Min. mean outside diam. (mm)	Min. wall thickness (mm)					Nom. outside diam. (mm)	Min. mean outside diam. (mm)	Min. wall thickness (mm)	
		Class B	Class C	Class D	Class E	Class 7			PN10	PN16
⅜"	17.0	—	—	—	1.5	3.2	16	16.0	—	—
½"	21.2	—	—	—	1.7	3.7	20	20.0	—	1.5
¾"	26.6	—	—	—	1.9	3.9	25	25.0	—	1.9
1"	33.4	—	—	—	2.2	4.5	32	32.0	1.6	2.4
1¼"	42.1	—	—	—	2.7	4.8	40	40.0	1.9	3.0
1½"	48.1	—	—	—	2.5	5.1	50	50.0	2.4	3.7
2"	60.2	—	2.5	3.1	3.9	5.5	63	63.0	3.0	4.7
2½"	75.2	—	3.0	3.9	4.8	—	75	75.0	3.6	5.6
3"	88.7	2.9	3.5	4.6	5.7	—	90	90.0	4.3	6.7
4"	114.1	3.4	4.5	6.0	7.3	—	110	110.0	5.3	8.1
—	—	—	—	—	—	—	125	125.0	6.0	9.2
5"	140.0	3.8	5.5	7.3	9.0	—	140	140.0	6.7	10.3
6"	168.0	4.5	6.6	8.8	10.8	—	160	160.0	7.7	11.8
—	—	—	—	—	—	—	180	180.0	8.6	13.3
—	—	—	—	—	—	—	200	200.0	9.6	14.7
8"	218.8	5.3	7.8	10.3	12.6	—	225	225.0	10.8	16.6
10"	272.6	6.6	9.7	12.8	15.7	—	250	250.0	11.9	18.4
12"	323.4	7.8	11.5	15.2	18.7	—	315	315.0	15.0	23.2

Table 13.9 Copper pipework dimensions: BS EN 1057 Type Y (R220 annealed) (previously BS 2871 Table Y)

Size	Nominal outside diam (mm)	Nominal wall thickness (mm)	Maximum working pressure* (bar)		
			Half-hard	Hard	Annealed
6	6	0.6	133	161	102
8	8	0.8	136	161	105
10	10	0.8	106	126	82
12	12	0.8	87	104	67
15	15	1.0	87	104	67
18	18	1.0	72	85	55
22	22	1.2	69	84	53
28	28	1.2	55	65	42
35	35	1.5	54	65	41
42	42	1.5	45	54	34
54	54	2.0	47	56	36
66.7	66.7	2.0	37	45	28
76.1	76.1	2.0	33	39	25
108	108	2.5	29	34	22

* Based on designated temper at 65 °C

Note: working pressure is affected by the jointing process; i.e. soldering or brazing would require de-rating because the pipe would then be in an annealed state.

Table 13.11 Copper pipework dimensions: BS EN 1057 Type Z (R290 hard) (previously BS 2871 Table Z)

Size	Nominal outside diameter (mm)	Nominal wall thickness (mm)	Maximum working pressure* (bar)
6	6	0.5	113
8	8	0.5	98
10	10	0.5	78
12	12	0.5	64
15	15	0.5	50
18	18	0.6	50
22	22	0.6	41
28	28	0.6	32
35	35	0.7	30
42	42	0.8	28
54	54	0.9	25
66.7	66.7	1.0	20
76.1	76.1	1.2	19
108	108	1.2	17
133	133	1.5	16
159	159	1.5	15

* Based on material in hard drawn condition at 65 °C

Table 13.10 Copper pipework dimensions: BS EN 1057 Type X (R250 half-hard) (previously BS 2871 Table X)

Size	Nominal outside diam (mm)	Nominal wall thickness (mm)	Maximum working pressure* (bar)		
			Half-hard	Hard	Annealed
6	6	0.6	133	161	102
8	8	0.6	97	118	75
10	10	0.6	77	93	59
12	12	0.6	63	76	48
15	15	0.7	58	71	45
18	18	0.8	56	67	43
22	22	0.9	51	62	39
28	28	0.9	40	48	31
35	35	1.2	42	51	33
42	42	1.2	35	43	27
54	54	1.2	27	33	21
66.7	66.7	1.2	20	27	17
76.1	76.1	1.5	24	29	18
108	108	1.5	17	20	13
133	133	1.5	14	17	10
159	159	2.0	15	18	12

* Based on designated temper at 65 °C

Note: working pressure is affected by the jointing process; i.e. soldering or brazing would require de-rating because the pipe would then be in an annealed state.

Table 13.12 Medium density polyethylene (MDPE) pipework dimensions

Diameter (mm)	Nominal bore (mm) for stated SDR*			
	11	17	21	26
20	15.25	—	—	—
25	20.3	—	—	—
32	25.8	—	—	—
50	40.4	—	—	—
63	50.9	—	—	—
90	72.9	78.7	81.0	—
110	89.1	96.3	99.0	—
125	101.2	109.5	112.5	—
160	129.6	140.3	144.0	147.4
180	145.9	158.0	161.9	165.8
225	182.4	197.3	202.4	207.4
250	202.8	219.6	224.9	230.4
280	227.1	245.9	251.9	258.0
315	255.6	276.6	283.4	290.3
355	288.1	311.5	319.4	327.6
400	324.6	351.2	360.0	368.7
450	360.1	395.2	404.9	414.8
500	406.3	438.9	449.9	460.9
560	454.7	493.9	503.7	516.3
630	511.5	553.1	566.9	580.8

* Standard dimension ratio (diameter: wall thickness)

13.4.4 Drainage pipe data

13.4.4.1 Velocity and flow rate

Hydraulic flow and velocity can be determined using the Colebrook-White equation for transitional flow, the general form being:

$$V = -2(2gDS)^{0.5} \log \left(\frac{k}{3.7D} + \frac{2.5\nu}{D(2gDS)^{0.5}} \right) \quad (13.1)$$

where k is the roughness coefficient (m), V is the velocity ($\text{m}\cdot\text{s}^{-1}$), D is the inside diameter of the pipe (m), S is the slope ($\text{m}\cdot\text{m}^{-1}$), ν is the kinematic viscosity of water (1.01×10^{-6}) ($\text{m}^2\cdot\text{s}^{-1}$), g is the acceleration due to gravity (9.81) ($\text{m}\cdot\text{s}^{-2}$).

A k -value of 0.6 mm is suggested for stormwater pipework and 1.5 mm for foul water pipework.

A minimum velocity of $0.75 \text{ m}\cdot\text{s}^{-1}$ is recommended to ensure a self-cleansing velocity is achieved, in line with the pipework being $3/4$ full. The effect of depth of flow on velocity is illustrated in Figure 13.3.

The flow rate, relative pipe diameter and gradient at which the pipe requires to be installed are fundamental in the design process.

Hydraulic flow charts for the most common pipe diameters, i.e. 100 mm and 150 mm, are shown below as Figures 13.4 to 13.7.

13.4.4.2 Calculation of gradient

The gradient or pipe fall between two points is calculated by measuring the length directly between the two points and dividing by the difference between the invert levels at these points, i.e:

$$\text{Fall} = \frac{\text{Distance}}{\text{Difference between invert levels}} \quad (13.2)$$

The invert level of a pipe is the level taken from the bottom of the inside of the pipe.

Example:

The distance measured between points A and B is 9.11 m. Invert level at A = 1.315 m; invert level at B = 1.164 m.

Thus:

$$\text{Fall} = \frac{9.11}{1.315 - 1.164} = 60.3$$

So the pipe fall (gradient) is 1:60.

If the pipe fall has been provided, the invert level may be calculated by rearranging equation 13.2, i.e:

$$\frac{\text{Difference between invert levels}}{\text{Fall}} = \frac{\text{Distance}}{\text{Fall}} \quad (13.3)$$

Example

The distance measured between points A and B = 9.11 m. The fall is given as 1:60. Therefore:

$$\frac{\text{Difference between invert levels}}{\text{Fall}} = \frac{9.11}{60} = 0.151 \text{ m}$$

The invert level at point A is lower than that at point B, which can be calculated as:

$$1.315 - 0.151 = 1.164 \text{ m}$$

A gradient conversion chart is given in Table 13.13.

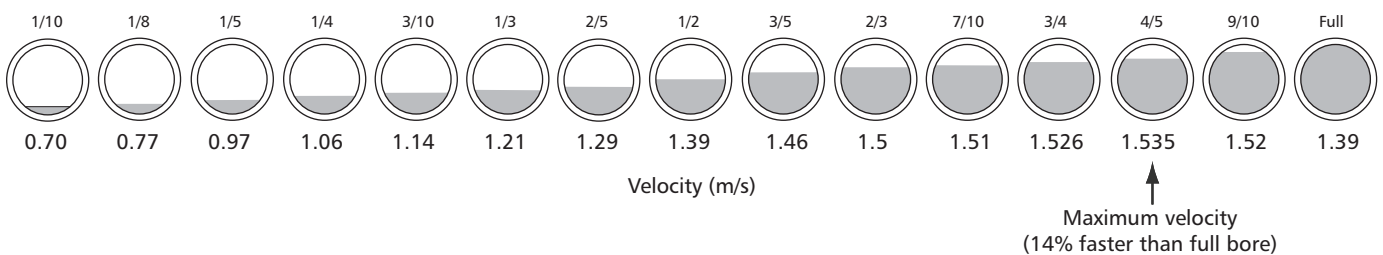


Figure 13.3 Effect of depth of flow on velocity (reproduced from *Drainage details*⁽¹²⁾ by courtesy of Taylor and Francis)

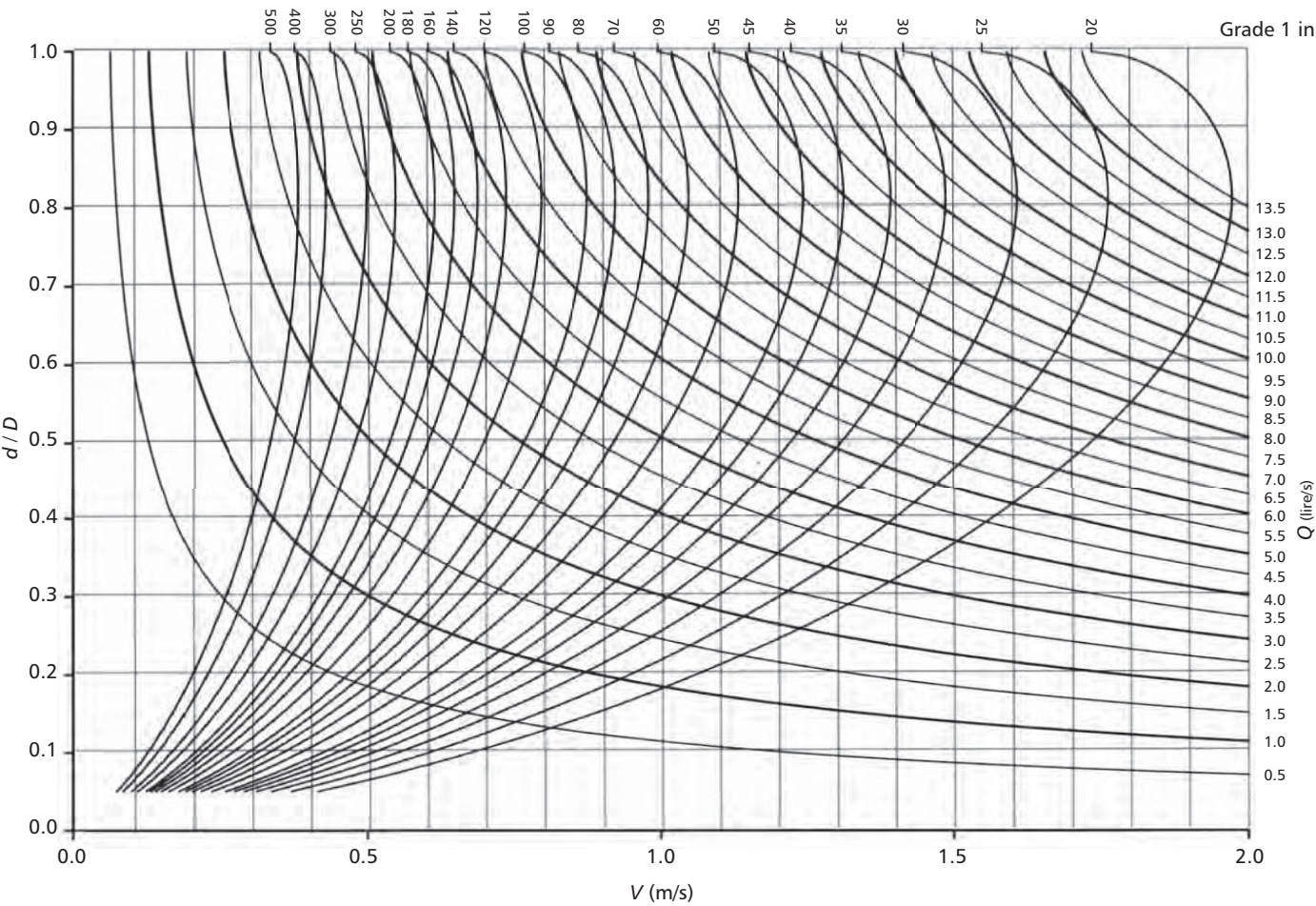


Figure 13.4 Hydraulic flow chart; $D = 100$ mm, $k = 0.6$ mm (reproduced from *Gravity flow pipe design charts*⁽¹¹⁾ by permission of Thomas Telford Ltd.)

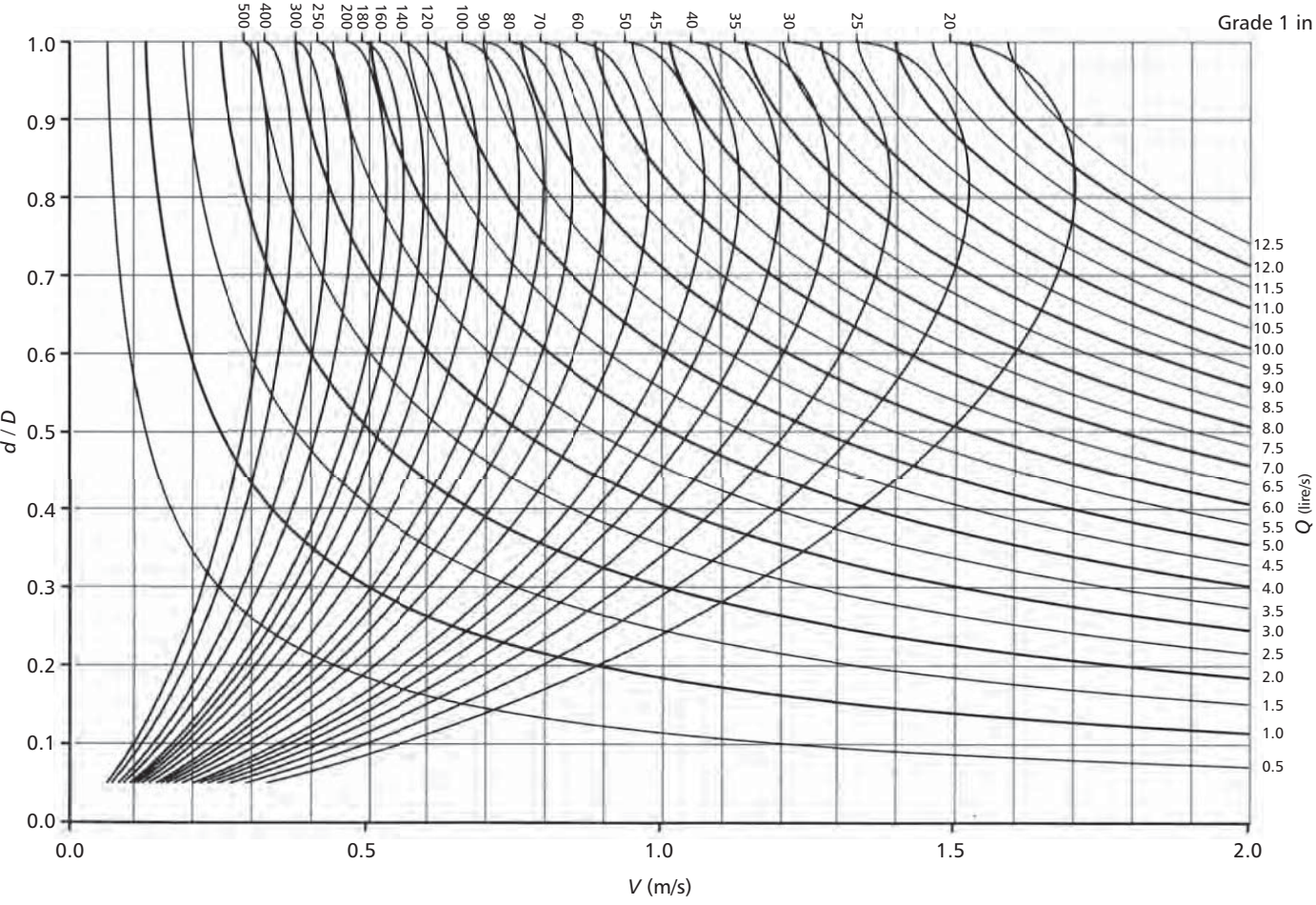


Figure 13.5 Hydraulic flow chart; $D = 100$ mm, $k = 1.5$ mm (reproduced from *Gravity flow pipe design charts*⁽¹¹⁾ by permission of Thomas Telford Ltd.)

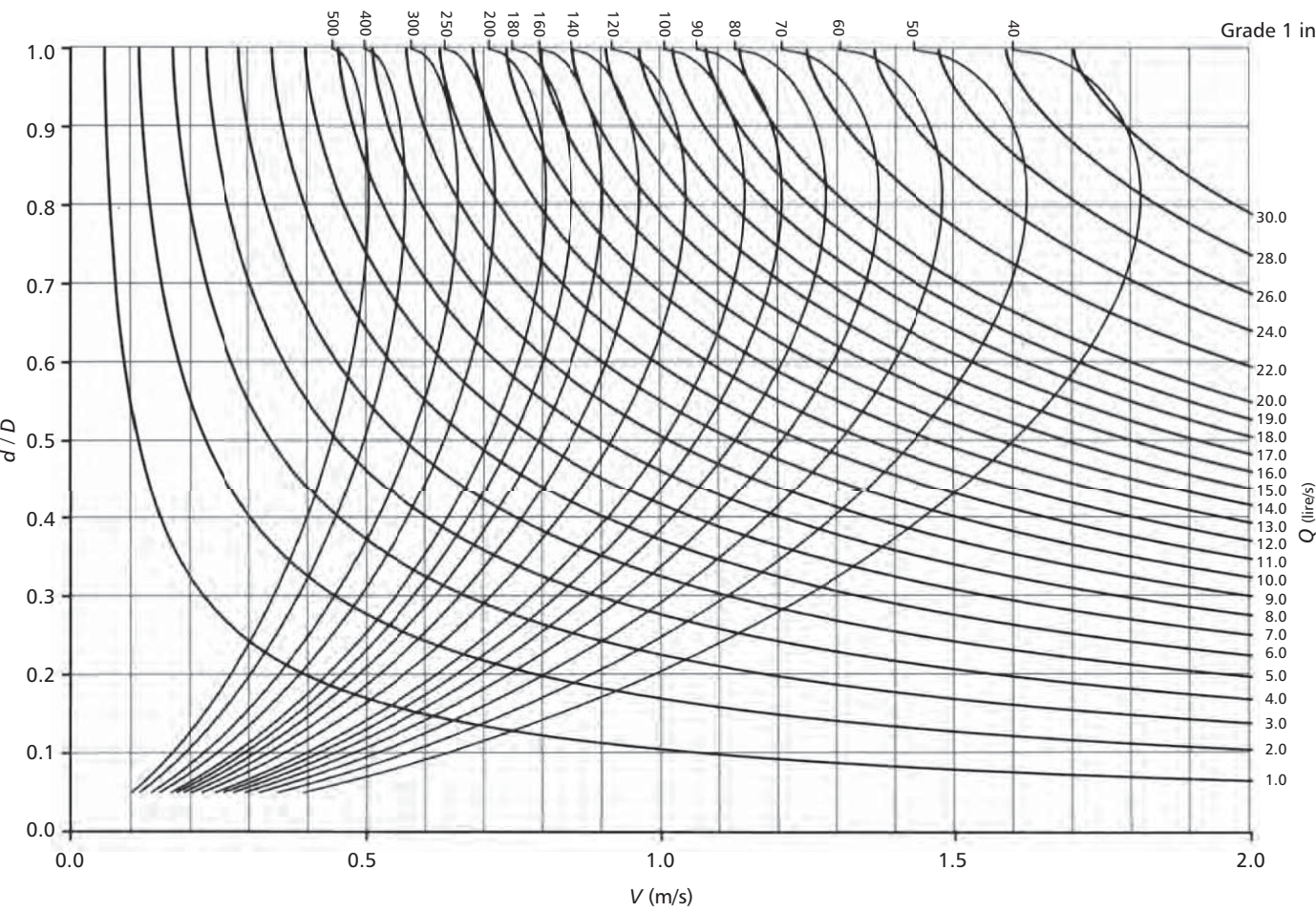


Figure 13.6 Hydraulic flow chart; $D = 150$ mm, $k = 0.6$ mm (reproduced from *Gravity flow pipe design charts*⁽¹¹⁾ by permission of Thomas Telford Ltd.)

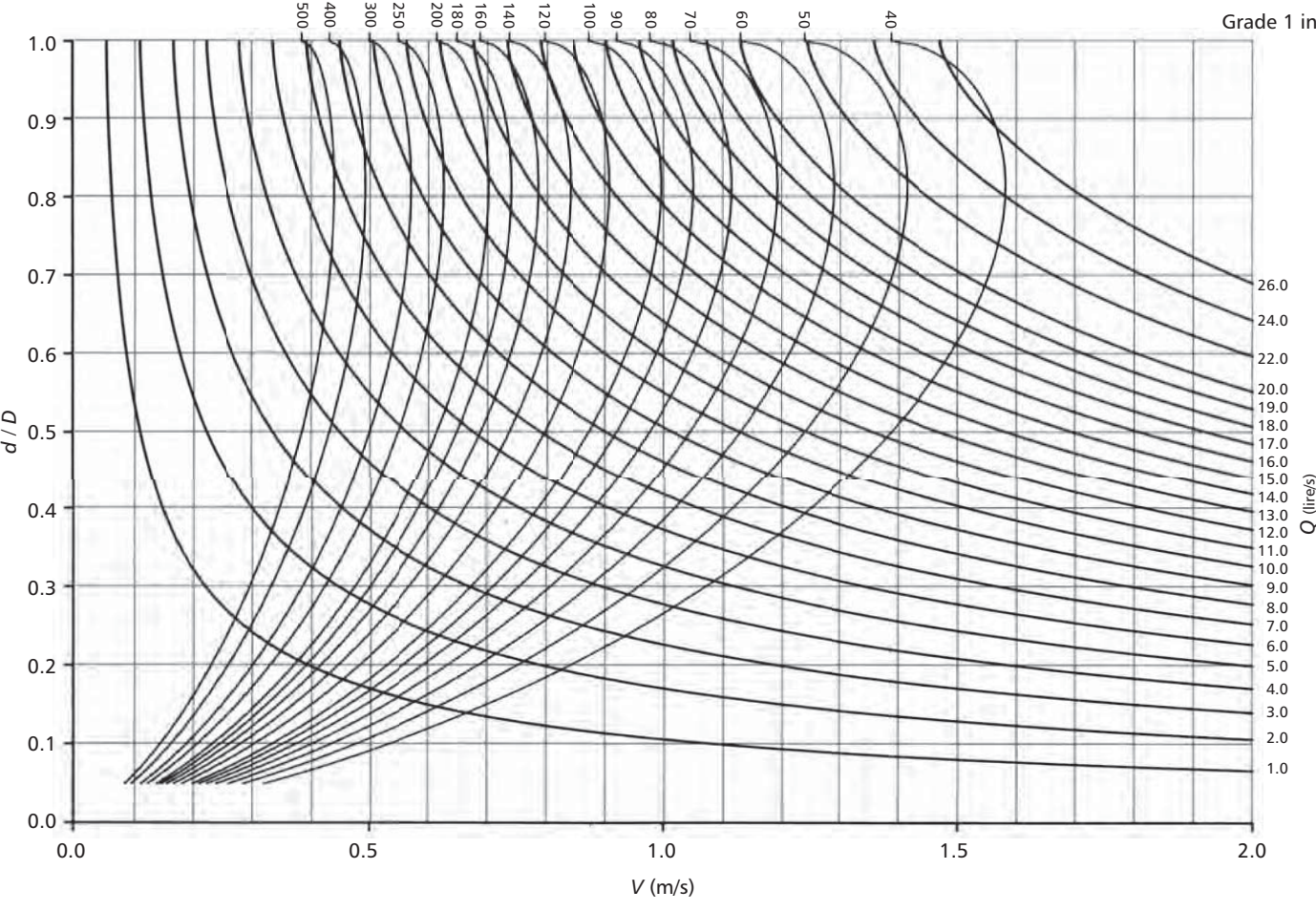


Figure 13.7 Hydraulic flow chart; $D = 150$ mm, $k = 1.5$ mm (reproduced from *Gravity flow pipe design charts*⁽¹¹⁾ by permission of Thomas Telford Ltd.)

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Table 13.13 Gradient conversion chart

Gradient	Grade (%)	Gradient	Grade (%)
1:10	10.000	1:50	2.000
1:11	9.091	1:55	1.818
1:12	8.333	1:60	1.667
1:13	7.692	1:65	1.538
1:14	7.143	1:70	1.429
1:15	6.667	1:75	1.333
1:16	6.250	1:80	1.250
1:17	5.882	1:85	1.176
1:18	5.556	1:90	1.111
1:19	5.263	1:95	1.053
1:20	5.000	1:100	1.000
1:21	4.762	1:110	0.909
1:22	4.545	1:120	0.833
1:23	4.348	1:130	0.769
1:24	4.167	1:140	0.714
1:25	4.000	1:150	0.667
1:26	3.846	1:160	0.625
1:27	3.704	1:170	0.588
1:28	3.571	1:180	0.556
1:29	3.448	1:190	0.526
1:30	3.333	1:200	0.500
1:31	3.226	1:225	0.444
1:32	3.125	1:250	0.400
1:33	3.030	1:275	0.364
1:34	2.941	1:300	0.333
1:35	2.857	1:350	0.286
1:36	2.778	1:400	0.250
1:37	2.703	1:450	0.222
1:38	2.632	1:500	0.200
1:39	2.564	1:550	0.182
1:40	2.500	1:600	0.167
1:41	2.439	1:650	0.154
1:42	2.381	1:700	0.143
1:43	2.326	1:750	0.133
1:44	2.273	1:800	0.125
1:45	2.222	1:850	0.118
1:46	2.174	1:900	0.111
1:47	2.128	1:950	0.105
1:48	2.083	1:1000	0.100
1:49	2.041	1:1500	0.067

13.5 Drawing symbols

13.5.1 Introduction

The use of drawings is one of the principal methods by which design information is conveyed between members of a project team (client, consultants, contractors, manufacturers, and facilities managers).

BS 1192⁽¹⁾ provides detailed information on building, architectural, engineering and construction drawing practise. This allows information to be presented in a clear

and professional manner, as well as produce and interpret drawings about the built environment using industry standards. Further reference can be made to the following:

- BS ISO 128: *Technical drawings. General principles of presentation*⁽²⁾
- BS ISO 128: *Technical drawings. General principles of presentation. Basic conventions for lines*⁽³⁾
- BS ISO 129: *Technical drawings. Dimensioning. General principles, definitions, methods of execution and special indications*⁽⁴⁾
- BS ISO 5455: *Technical drawings. Scales*⁽⁵⁾

13.5.2 Suggested symbols

Tables 13.15 to 13.18 suggest drawing symbols for water services, drainage, gas services and fire engineering. These are not intended as definitive but, in the absence of an industry-wide standard, are offered as a consistent set of drawing symbols. Abbreviations used are summarised in Table 13.14.

Table 13.14 Abbreviations for drawing symbols

Abbreviation	Description	Abbreviation	Description
AAV	Air admittance valve	MCWS	Main cold water service
AAV	Automatic air vent	PG	Plantroom gully
AC	Access panel/door	PRV	Pressure reducing valve
ASP	Anti-siphon vent pipe	RE	Rodding eye
BIG	Back inlet gully	RT	Rise to
CE	Cleaning eye	RWWP	Rainwater warning pipe
CWDS	Cold water distribution service	RWOF	Rainwater overflow
		RWP	Rainwater down pipe
DST	Deep seal trap	SP	Soil pipe
DT	Drop to	SS	Stub stack
FA	From above	SVP	Soil vent pipe
FB	From below	SWP	Soil waste pipe
FG	Floor gully	TA	To above
HDV	Header vent pipe	TB	To below
HL	High level	TD	To drain
HWF	Hot water flow	US	Underside
HWR	Hot water return	VP	Ventilation pipe
IL	Invert level	WHA	Water hammer arrestor
LL	Low level	WP	Waste pipe
l/s	Litres per second	WVP	Waste vent pipe

Table 13.15 Suggested drawing symbols: water services

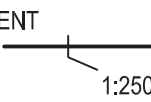
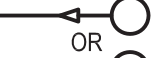
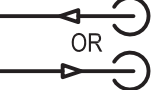
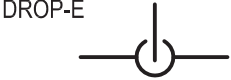
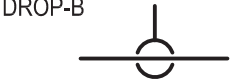
Symbol	Description	Symbol	Description
 CW	Cold water piping	 GRADIENT	Gradient/fall
 HW	Hot water piping	 PFA	Pipe flow arrow
 GW	Grey water piping	 FLAN	Flange
 IW	Irrigation water piping	 UNI	Union joint
 RWH	Rainwater harvesting	 CAP	Capped/plugged end
	Low/mid level (LL) pipework	 GUIDE	Pipe guide
	High level (HL) pipework	 ANCR	Anchor point
	Underground/below floor pipework	 EL	Expansion loop
	Above ceiling or in roof space pipework	 EC	Expansion compensators
	Existing pipework to be removed	 FC	Flexible connection
 P-BREAK	Pipe break	 FCO	Flexible coupling
	FA — from above or TA — to above	 IV	Valve, straight (hand wheel)
	FB — from below or TB — to below	 VAHW	Valve, angled (hand wheel)
 DROP-E	Branch off top (not flanged)	 LSV	Lockshield valve, straight
 DROP-B	Branch off bottom (not flanged)	 LSV2	Lockshield valve, angled
	Branch off side (not flanged)	 3WC	3-way cock
	Bend/elbow (not flanged)	 TMV	Thermostatic mixing valve
		 DC	Drain cock/valve (with hose union if shown on drawing)

Table continues

Table 13.15 Suggested drawing symbols: water services — *continued*

Symbol	Description	Symbol	Description
TC 	Test cock	SV1 	Pressure relief/safety valve (straight)
SC 	Stop cock	NRV 	Non-return valve or check valve
DRV 	Double regulating valve (without tappings)	PUMP 	Pump (any type)
RV 	Regulating valve (with tappings)	METR 	Meter (G = gas; W = water; H = heat; S = steam)
MV 	2-port motorised valve		Water meter
	Valve	FILT 	Filter
	Valve in vertical	STR 	Strainer
	Hose bib	BV 	Ball valve (gravity)
FMD 	Flow measuring device (orifice plate) (with press tappings)	DAFV1 	Delayed action float valve
FMS 	Commissioning set (DRV and orifice plate with tappings)	DAFV2 	Delayed action float valve
FMS 	Flow measuring set (close coupled isolating and orifice plate with tappings)	SCV 	Single check valve
VTRI 	Venturi (with press tappings)	FLOAT 	Float
AAV 	Automatic air vent (if shown on drawing)	BV2 	Ball valve float
AB 	Air bottles (if shown on drawing)	DCV 	Double check valve
MAV 	Manual air vents (if shown on drawing)	SP 	Sensor pocket (V = vacuum; T = temperature; P = pressure; A = altitude)
PRV 	Pressure reducing valve (non-return)	PG 	Gauge within sensor pocket (V = vacuum; T = temperature; P = pressure; A = altitude)
SV2 	Pressure relief/safety valve (angled)		

Table continues

Table 13.15 Suggested drawing symbols: water services — *continued*

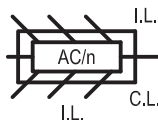
Symbol	Description	Symbol	Description
TP	 Pipeline test point	LOPT	 Lever operated pillar tap (H = hot; C = cold; D = drinking)
PT	 Pressure tapping	LMMD	 Lever monoblock mixed, deck mounted
ST	 Steam trap/separator	DHMM	 Dual handle monoblock mixer, deck mounted
CRT	 Condensate release trap	DLMW	 Double lever mixed, wall mounted
DP	 Dirt pocket	DLTM	 Double level pillar tap mixer, deck mounted
	 Water hammer arrestor	DHMM	 Dual handle mixer, wall mounted
	 Moisture sensor	DHDM	 Dual handle mixer, deck mounted
	 Riser designation	DPTM	 Double pillar tap mixer
	 Leader designation	TMTG	 Thermostatic mixer with bib tap and thermostatic gauge
	 Equipment designation	MHOP	 Wall mounted mixer with hose outlet and pistol grip valve control
SG	 Sight glass	WDHR	 Wash down hose reel unit
TAP	 Taps (H = hot; C = cold; D = drinking)	STM	 Thermostatic shower with fixed spray

Table 13.16 Suggested drawing symbols: drainage

Symbol	Description	Symbol	Description
150 mm 1/83 	Foul water (FW) sewer; pipe diameter and gradient	RWH 	Rainwater head
225 mm 1/156 	Surface water (SW) sewer; pipe diameter and gradient	RWO 	Rainwater outlet
300 mm 1/150 	Combined sewer; pipe diameter and gradient	RWP 	Rainwater pipe
F1(22,23) 	Adoptable foul water manhole; reference and invert level	RWS 	Rainwater shoe
S1(23,67) 	Adoptable surface water manhole; reference and invert level	RE 	Rodding (RE) or cleaning (CE) eye (in the horizontal)
C1(21,56) 	Adoptable combined manhole; reference and invert level	RE-V 	Rodding (RE) or cleaning (CE) eye (in a vertical upstand above spill-over level)
(22.0) F3(20,26) 	Backdrop manhole; reference and invert level	BD 	Back drop
(19.65) 	Pumping station; invert level of inlet	RE 	Access point (rodding eye)
100 mm 	Rising main (foul water); diameter of pipe and direction of flow	VP 	Valve pit
150 mm 	Rising main (surface water); diameter of pipe and direction of flow	R-TRAP 	Running trap
150 mm 	Rising main (combined); diameter of pipe and direction of flow	TRAP 	Trap
	Air release valve	RAI 	Reverse arm interceptor trap
HB 	Hatch box		Discharge pipe
EM 	Emptying valve		Channel and grating
		PFLN 	Puddle flange
		GIDE-FJ 	Flexible joint
		CAP 	Blank end

Table continues

Table 13.16 Suggested drawing symbols: drainage — *continued*

Symbol	Description	Symbol	Description		
FAI		Fresh air inlet	MH3		Bolted access chamber
GT		Grease trap	MH1		Rectangular inspection chamber
OR-PI		Oil (OI) or petrol (PI) interceptor	MH2		Circular inspection chamber
OTG		Open topped gully	I-TRAP		Interceptor trap
STG		Sealed top gully	MH2		Rectangular manhole
BIG-V		Back inlet gully, vertical	MH2		Circular manhole
BIG-H		Back inlet gully, horizontal	SVP		Soil vent pipe (SVP), waste vent pipe (WVP), vent pipe (VP), anti-syphon vent pipe (ASP)

Note: if colour is used to enhance the presentation of drawings, the following colours are recommended: foul water (brown); surface water (dark blue); combined (red); watercourses (light blue); building over/basements (orange); property not connected (yellow)

Table 13.17 Suggested drawing symbols: gas services

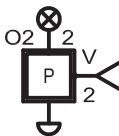
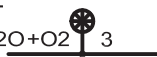
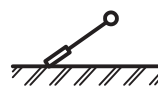
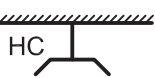
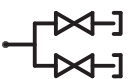
Symbol		Description	Symbol		Description
MV		Medical vacuum (figure denotes quantity)	ALP2		Alarm panel (number 2)
O2		Medical oxygen (O ₂) (figure denotes quantity)	PEND		Pendant (identify service as applicable)
N2O		Nitrous oxide (N ₂ O) (figure denotes quantity)	PEND, O2, MV & PA.		Pendant (e.g. oxygen, twin medical vacuum, ELV terminal)
N2O2		Nitrous oxide (N ₂ O) + oxygen (O ₂) mixture (figure denotes quantity)	BOOM		Boom
MCA		Medical compressed air (figure denotes pressure, e.g. 4 bar)	GOV		Gas governor
AGS		Waste anaesthetic gas scavenging (AGS)	LABTAP		Natural gas outlet (suffix denotes number of outlets)
VB		Valve box (identify service as applicable)	LABTAP		Laboratory/ward outlet (letter denotes gas, e.g. oxygen (O), nitrogen (N), propane (P), compressed air (CA), vacuum (V), carbon dioxide (C), natural gas (G))
MGL		Medical gas indicator light			

Table 13.18 Suggested drawing symbols: fire engineering

Symbol	Description	Symbol	Description
FHR	 Fire hosereel (water, 45 metres)	SHU	 Sprinkler head (up)
HR	 Hosereel (general purpose) (10 metres)	SHDI	 Sprinkler head (directional)
HR	 Hose cradle	SD	 Automatic smoke detector
LV	 Wet/dry riser landing valve (female connection)	HD	 Heat detector
RIV	 Wet/dry riser inlet valve (male connection)	FV1	 Fire shut-off valve (gravity operated)
FH	 Pillar fire hydrant (female connection)	FV2	 Fire shut-off valve (solenoid operated)
SHD	 Sprinkler head (down)	FLNK	 Fusible link (figures indicate temperature, e.g. 70 °C)

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14 Glossary of terms

Activated carbon (AC)

See *Carbon, activated*.

Adoption of sewers

See *Sewers, adoption of*.

Aeration, differential

Non-uniform oxygen distribution, often around crevices, which can increase local corrosion.

Aerobic

Pertaining to the chemical or biological corrosive action that occurs in the presence of oxygen.

Air entrainment

The process by which bubbles or pockets of air are caught within the fluid and transported with the flow.

Air scour

The use of compressed air as a preliminary stage prior to backwashing to lift and agitate the filter bed.

Algal bloom

See *Bloom, algal*.

Algal toxins

See *Toxins, algal*.

Alkalinity

The total concentration of alkaline salts (bicarbonate, carbonate and hydroxide) determined by titration with acid to pH 4.5.

Anaerobic

Pertaining to the corrosive chemical or biological action that occurs in the absence of oxygen.

Animalcule

General term for microscopic fresh water animals such as assellus (shrimps), cyclops and nematodes (worms).

Anion

Negatively charged particle, atom or molecule (ion), attracted to the *Anode*.

Anode

The positively charged electrode of an electrolytic cell.

Antecedent conditions

The wetness of a catchment before a particular rainfall event; see also *Catchment wetness index*.

Antecedent precipitation index

See *Precipitation index, antecedent*.

Area reduction factor

A factor applied to point rainfall depths or intensities to give values applicable to an area.

Attenuation

Limiting the peak flow rate in a drainage system during a storm by including a throttling method and providing a temporary storage facility to accommodate the excess rainwater.

Autographic raingauge

See *Raingauge, autographic*.

Available chlorine

See *Chlorine, available*.

Backdrop manhole

A manhole where there is a change in invert level created by a vertical drain or a drain ramped down at 45 degrees.

Backwashing

The cleansing of the media bed by reversal of water flow through the filter to drain.

Backwash rate

The rate of application of water for backwashing, expressed as volume flow per m² of filtration area (m³·h⁻¹/m²).

Backwater effects

The effect of water flows or depths on hydraulic conditions upstream; backwater effects can only occur in subcritical flow.

Balance tank

See *Tank, balance*.

Battered trench

See *Trench, battered*.

Bedding

Natural or synthetic material introduced around and under a drainage pipe to improve its load resistance.

Bedding factor

The ratio of the superimposed load to the crushing strength of a pipe.

Benching

A surface added at the base of a manhole to improve working safety; constructed so as to contain the channel and minimise the accumulation of deposits.

Biochemical oxygen demand (BOD)

See *Oxygen demand, biochemical*.

Biodegradation

Decomposition of organic matter by micro-organisms and other living things.

Birmingham curve

A rainfall depth–duration curve developed from rainfall data.

Blackwater

Water contaminated with animal, human, or food waste for example from WCs, bidets, urinals, kitchen sinks, dishwashers.

Bloom, algal

Prolific growth of single or multi-celled plants in eutrophic stored or stagnant water.

Brackish

A term used to describe a water supply which has a high salt content. Brackish water is not suitable for use as a potable water supply, and has been defined as containing between 100 and 10 000 ppm total dissolved solids.

Branch

A point where drainage pipework connects together in a downstream direction.

Breakpoint

Refers to the reaction between chlorine, chloramines and ammonia. It is the point (expressed as $\text{mg-litre}^{-1} \text{Cl}_2$) where all ammonia and chloramines are destroyed, and the presence of free chlorine is just detected.

Carbon, activated (AC)

Carbon, manufactured from wood, coal etc., ‘activated’ by heat treatment to improve its adsorption properties. (GAC is granular activated carbon and PAC is powdered activated carbon.)

Catchment

An area served by a single drainage system.

Catchment wetness index

An index of the wetness of a catchment before a rainfall event; see also *Urban catchment wetness index* and *Antecedent conditions*.

Cathode

The negatively charged electrode of an electrolytic cell.

Cation

Positively charged particle, atom or molecule (*Ion*), attracted to the *Cathode*.

Cavitation

A potentially damaging condition, occurring at high flow velocities, in which dissolved oxygen is released from solution at low pressure.

Chamber, overflow

A stilling chamber incorporated in some designs of storm overflow.

Channel, deck

A channel with grating cover at the edge of a pool surround, usually continuous, forming an integral part of the circulation system and designed to remove water from the surface level and return it to the filtration plant.

Chemical oxygen demand (COD)

See *Oxygen demand, chemical*.

Chloramines

A combination of chlorine as hypochlorous acid and ammonia achieved when the relative concentration of hypochlorous acid is too low to complete the reaction and fully oxidise the ammonia. Monochloramines, dichloramines and/or nitrogen trichloride are formed depending on conditions. Chloramines are bactericidal but the rate of disinfection is 60–100 times slower than that of free chlorine. Chloramines are usually the cause of eye irritation and ‘chlorine’ odours.

Chlorine, available

Chlorine in a form that is utilisable or ‘available’ for disinfection.

Chlorine, combined

Available chlorine in a combined form, e.g. *Chloramines*.

Chlorine, free available (FAC)

Also known as ‘free chlorine’. Available chlorine present in an uncombined state.

Chlorine, residual

Concentration of available chlorine remaining in the water at any instant.

Chlorine, total available (TAC)

Also total chlorine. The sum of the free and combined available chlorine.

Cistern, storage

The correct term under the Water Regulations for a domestic water storage container, often informally referred to as a ‘water tank’.

Cistern, WC

A cistern used to flush a WC pan.

Coagulant

See *Flocculant*.

Coatings, sacrificial

Metallic coatings which form the anode in an electrolytic cell in which the protected metal becomes the cathode.

Coliforms

A group of bacterial organisms generally, but not necessarily, indicative of faecal pollution. See also *Escherichia coli*.

Combined chlorine

See *Chlorine, combined*.

Combined system

See *System, combined*.

Conductivity

The electrical conductivity measured in microsiemen per cm ($\mu\text{S}\cdot\text{cm}^{-1}$) is the traditional indicator for mineral impurities.

Contact tank

See *Tank, contact*.

Contact time

See *Retention time*.

Cost–benefit ratio

The ratio of costs to benefits in an economic analysis.

Crevice corrosion

Corrosion in a narrow aperture due to localised variations in the electrolytic conditions.

Crown

The highest point on the internal surface of a pipe or channel at any cross-section.

Deck channel

See *Channel, deck*.

Detention basin

A vegetated depression, normally is dry except after storm events constructed to store water temporarily to attenuate flows. May allow infiltration of water to the ground.

Dew point

The temperature at which the saturated vapour pressure of water is equal to the partial pressure of the water vapour present in the atmosphere.

Dezincification

The removal by corrosion of zinc from the beta phase of a duplex brass, leaving porous copper.

Differential aeration

See *Aeration, differential*.

Distribution lateral

See *Lateral, distribution*.

Distributor

The device in a filter designed to provide uniform flow through the media bed and prevent erosion.

Drain, foul

A pipe conveying soil and waste discharges from sanitary appliances within a single curtilage.

Drain, sub-soil

A system of porous or unjointed pipes laid below ground to collect ground water and convey it to a convenient discharge point. Also termed field or agricultural drains.

Drain, surface water

A pipe containing rainwater from roofs and paved areas within a single curtilage.

Dry weather flow (DWF)

Refers to the flow in drains or sewers during times when no surface water is present.

Electrochlorination on-site (ECOS)

A disinfection process that generates sodium hypochlorite solution *in situ* from common salt.

Electrodialysis (ED)

A process for water purification/demineralisation using ion selective membranes.

Electrolyte

A solution of a chemical salt in water.

Environmental footprint

A measure of environmental impact based on the distance that resources for a development are transported.

Escherichia coli (E.coli)

A member of the coliform group of organisms. The presence of coliform bacteria, such as *E. coli*, in surface water is a common indicator of fecal contamination.

Eutrophic

Rich in essential plant nutrients.

Field capacity

The field capacity of a soil is a level of moisture content. It results from the soil being completely saturated with water and allowed to drain naturally for about 48 h.

Filter

A device designed to extract insoluble materials from water which is passed through it.

Filter, cartridge

A filter which employs a disposable cartridge to extract the insoluble materials (some cartridges can be cleansed and reused a number of times).

Filter cycle

The operating time between backwashing, usually expressed in days.

Filter, gravity sand

A filter with a media bed comprising silica/quartz sand and a gravel support bed through which water passes under gravity.

Filter, media bed

Various materials including silica/quartz sand placed in layers in a filter and through which the water is passed.

Filter, precoat

A device designed to filter water through a thin layer of material such as diatomaceous earth or volcanic ash which is precoated onto screens at the start of the filter cycle. The precoat material is washed to drain during the backwash procedure. Precoat filters can be designed to operate under pressure or vacuum conditions.

Filter, pressure sand

A filter with a media bed comprising silica/quartz sand and a gravel support bed through which water passes under pressure.

Filter sand

Grades of silica/quartz sand used as media in filters. The normal grades used are: 16–30 as filtering sand; and 8–15 as support sand.

Filter septum

See *Septum, filter*.

Filter strip

A vegetated area of gently sloping ground designed to drain water evenly off impermeable areas and filter out silt and other particulates.

Flocculant

Chemicals such as poly-aluminium chloride or alum, dosed into the circulating pool water which cause smaller suspended particles to congregate together so that they are entrained by the filtration process.

Flood routing

Design and consideration of above-ground areas that act as pathways permitting water to run safely over land to minimise the adverse effect of flooding. This is required when the design capacity of the drainage system has been exceeded.

Flow, free surface

Flow conditions which include a water surface subject to atmospheric pressure (compare with *Flow, surcharged*).

Flow, gradually varying

Flow conditions in which the discharge varies gradually with distance along the pipe or channel.

Flow, over-land

Flow over the ground surface, including both paved and unpaved surfaces and roofs.

Flow rate

The volume of water passing through the water treatment plant, normally expressed in $\text{m}^3\cdot\text{h}^{-1}$.

Flow, subcritical

Flow conditions in which the Froude number is less than unity.

Flow, supercritical

Flow conditions in which the Froude number exceeds unity; surface waves cannot propagate upstream in supercritical flow.

Flow, surcharged

Flow conditions in which the hydraulic gradient is higher than the pipe soffits (compare with *Flow, free surface*).

Flow, turbulent (also smooth turbulent, transitional and rough turbulent)

Flow conditions which occur in pipes when the Reynolds number exceeds about 2300.

Formation level

The level to which a trench is excavated before bedding is placed.

Foul drain

See *Drain, foul*.

Foul sewer

See *Sewer, foul*.

Free available chlorine (FAC)

See *Chlorine, free available*. Also known as 'free chlorine'. Available chlorine present in an uncombined state.

Froude number

The ratio of flow velocity to the speed of a wave in shallow water, expressed as $(V^2 B / g A f)$. The flow is described as *subcritical* if this ratio is less than unity and *supercritical* if it exceeds unity.

Greywater

Water that was originally supplied as wholesome water, but has already been used for some other application such as bathing, showering, hand washing or laundry (but not water from WCs or from dish washing).

Ground condition

An index used in the resource cost model to describe the sub-surface conditions encountered during excavation (see also *Site condition*).

Gulley

A trap usually incorporating a grating and a grit trap, to permit the entry of surface run-off into the pipe system.

Hardness

The total dissolved calcium and magnesium salts in water. Compounds of these two elements are responsible for most scale deposits.

Haloform

Group of volatile organic compounds formed during the chlorination of water (e.g. Trihalomethane).

Haunching

The material surrounding a buried pipeline, up to the depth at which the pipe width is a maximum.

Header and laterals

An underdrain system comprising of a network of pipes laid on a concrete or gravel bed in the base of a filter, designed to collect the filtered water under normal flow and to distribute backwash water under reverse flow. The laterals connect onto the central header and are provided with slots, holes or nozzles which permit water to pass in or out.

Header, manifold

A pipe of uniform diameter directly connected to a solenoid valve assembly and feeding several *distribution laterals*. As a guide, the cross-sectional area of the header should be approximately equal to the sum of the cross-sectional area of the distribution laterals.

Header, tail

A pipe of uniform size connecting the ends of distribution laterals, usually provided with a flushing valve or flushing plug enabling any debris to be removed from the system.

Humic substances

Complex organic material dissolved in water from decayed vegetation. Usually responsible for the yellowish hue of surface derived waters.

Hydraulic gradient

In an open channel, the gradient of the water surface; in a pressurised pipe, the gradient joining points to which water would rise in pressure tapings.

Hydraulic radius

The ratio of cross-sectional area of flow to the wetted perimeter of a channel or pipe.

Hydrograph

A series of values, in either numerical or graphical form, of flow rate varying with time.

Hydrograph, inlet

The hydrograph generated by surface run-off at the entry points to a sewerage system.

Hyetograph

A series of values of rainfall intensity varying with time; also known as *Rainfall profile*.

Hypochlorous acid (HOCl)

The most powerful disinfectant component of the chlorination process.

Impermeable

Referring to a surface type which resists the infiltration of water; in practice some infiltration occurs through pores and cracks.

Infiltration, ground

The flow of surface water into the ground.

Infiltration, pipelines

The entry of groundwater into pipelines.

Infiltration potential

The rate at which water flows through a soil (mm/h).

Infiltration trench

A trench, usually filled with stone, designed to promote infiltration of surface water to the ground.

In-flow

Surface run-off entering a sewerage system from areas not originally intended to be connected to the system.

Inlet

An entry point to a sewerage system, usually a *Gulley*.

Intangible

Description of costs or benefits to be considered in an economic evaluation, which cannot be expressed in monetary terms (opposite: *Tangible*).

Intensity–duration–frequency relationship

A table or graph showing the way rainfall intensity at a particular location is related to duration and frequency (or return period).

Interception

The process by which rainfall may be prevented from reaching the ground, for example by vegetation.

Invert

The lowest point on the internal surface of a pipe or channel at any cross-section, measured from a datum point.

Inverted syphon

See *Syphon, inverted*.

Ion

A positive or negatively charged atom or molecule.

Irrigation cycle

A period, expressed in hours, during which the required volume of irrigation water is applied.

Irrigation zone

An area of planting, consisting of species with the same or similar watering requirements, to be irrigated.

Jardi rainfall recorder

An instrument capable of measuring short duration, high intensity bursts of rainfall.

Kinematic viscosity

Absolute viscosity divided by fluid density (equal to $1.141 \times 10^{-6} \text{ m}^2\text{s}^{-1}$ for water at 15°C).

Lagoon

A pond designed for the settlement of suspended solids.

Lateral, distribution

A pipeline that supplies irrigation water to individual emitters, sprinklers or bubblers from a header pipe.

Lateral inflow

Flow entering a channel uniformly along its length.

Leaching

The removal of accumulated salts from the soil by deliberately passing (flushing) more water through it than would normally be applied for irrigation purposes.

Linear

A description of the relationship between two or more variables which vary in proportion to one another (compare *Non-linear*).

Lloyd-Davies method for storm drainage design

An adaptation by Lloyd-Davies of the rational method for storm drainage design (see also *Rational method*).

Manhole

A chamber designed to enable access to a drain or sewer.

Manhole, back-drop

A manhole at which a vertical drop in the longitudinal profile of the pipeline occurs.

Manifold header

See *Header, manifold*.

Mesh

A woven wire or plastic screen used to prevent the transportation of sand, gravel, and debris within the irrigation system, thus protecting irrigation equipment that have small openings and waterways from blockage.

Metal, base

The metal which has the lower electrode potential (i.e. anode) when two or more different metals are in contact in an aqueous solution. The base metal corrodes preferentially.

Metal, heavy

Chromium, lead, copper and other toxic metals.

Metal, noble

The metal which has the higher electrode potential (i.e. cathode) when two or more different metals are in contact in an aqueous solution.

Milligrams per litre (mg/litre)

Numerically equivalent to micrograms per millilitre ($\mu\text{g}\cdot\text{ml}^{-1}$) and parts per million (ppm).

Ministry of Health formulae

Equations recommended by the Ministry of Health in 1930 to provide rainfall intensities for storm drainage design.

Mulching

A layer of material applied to the surface of the soil to reduce water loss by evaporation, thus maintaining the moisture level in the soil. The selected material should permit the ingress of rainwater to the soil.

Muskingum–Cunge routing method

A method of routing flows in channels and pipes, first applied on the Muskingum River in the USA and subsequently modified by Cunge.

Non-linear

A description of the relationship between two or more variables, which takes the form of a power law rather than a straight line (compare *Linear*).

Normal depth

The water depth in normal flow conditions, i.e. with the hydraulic gradient equal to the gradient of the pipe or channel.

Nozzle plate

An alternative underdrain system to header and laterals comprising a plate located below the media bed to form an underdrain chamber in the base of the vessel. The plate is fitted with nozzles which permit water to pass to or from the underdrain chamber.

Off-line tank

See *Tank, off-line*.

On-line tank

See *Tank, on-line*.

Optimisation

The process by which a preferred solution is sought amongst several alternatives.

Orifice

A constriction in a pipeline to control the rate of flow.

Osmosis

The diffusion of pure water through a membrane separating two solutions of dissimilar concentration. See also *Reverse osmosis*.

Overflow chamber

See *Chamber, overflow*.

Overflow, storm water

A structure built within a combined sewerage system in order to spill to a waterhouse or relief system stormwater which cannot be carried along the pipe.

Overflow, vortex

A type of storm overflow which makes use of the spiralling flow in a vortex to retain polluting material within the pipe system.

Over–under factor

A factor used in the Water Research Centre study of sewerage costs to describe the difficulty of a particular construction scheme.

Oxygen absorbed (OA)

A measure of organic contaminants determined in a 4-hour test at 27°C.

Oxygen demand, biochemical (BOD)

The oxygen absorbed by a water sample in five days at 20°C.

Oxygen demand, chemical (COD)

The oxygen required to oxidise all organic material in a water sample. An indicator of the organic quality of water by measurement of the oxygen absorbed from acid potassium dichromate solution. Low COD indicates a high quality water.

Passivity

A condition, in which the anodic dissolution of a metal is strongly reduced, for example, by a thin oxide film.

Peakedness

A measure of the sharpness of a rainfall profile, in terms of the ratio of the maximum to the mean rainfall intensity; percentile peakedness gives the percentage of storms of a specified duration and return period with a peakedness less than or equal to that of a given profile.

Percentile

The percentage of occurrences within a stated range; for application to rainfall profiles, see *Peakedness*.

Performance-cost

A method of economic analysis in which costs and in-service performance are compared.

Permanganate value (PV)

A measure of the organic quality of water. The oxygen absorbed (in mg·litre⁻¹) from alkaline potassium permanganate solution, within a specified time and temperature. Low PVs indicate high quality water. Rarely used in modern laboratories.

Permeable surface

Description of a type of ground surface through which water may infiltrate; some surface run-off may occur if the ground becomes saturated.

pH

The acidity or alkalinity expressed on a scale of 0 (acid) to 14 (alkaline); pH 7 is considered neutral.

Photosynthesis

This is the process by which carbon dioxide is converted into carbohydrate by chlorophyll, under the influence of light.

Planting out

The process of transplanting mature or semi-mature plants into the open from a nursery environment.

Planting, shelter belt

A fairly dense screen of trees or shrubs located so as to provide a natural shelter and enclose areas for more delicate planting.

Polarisation

Displacement of the potential of the cathode towards that of the anode and vice versa.

Polishing

When used in relation to treated effluent, polishing is a general term describing the various processes by which the normal standard 30:20 effluent can be improved to further remove suspended solids and associated *Biochemical oxygen demand* (BOD), normally to a standard of at least 10:10.

Pond, stilling

A type of storm water overflow, intended to ensure that polluting material is retained within the pipe system.

Precipitation index, antecedent

An indicator of rainfall depth over a period preceding a particular event.

Pressure-compensating

The process by which irrigation equipment automatically adjusts itself to make allowance for any variations in inlet water pressure while maintaining a stated performance.

Pumped (pressure) drain

A system in which the effluent is elevated by pump or ejector.

Pumping station

A structure included within a sewerage system to pump water when drainage cannot be achieved by gravity.

Rainfall intensity

The rate of rainfall, expressed in mm per hour or inches per hour.

Rainfall profile

A series of values of rainfall intensity varying with time; see *hyetograph*.

Raingauge, autographic

A raingauge recording the variation of rainfall intensity with time.

Rainwater

Water arising from atmospheric precipitation.

Rainwater

Water arising from atmospheric precipitation.

Rational method

A simple method, in well-established use throughout the world, for calculating the peak discharge in a drainage system.

Recession

That part of a flood event or hydrograph when the flow is reducing after the peak.

Reclaimed water

Water which has been used for another purpose and then treated so that the quality is suitable for a particular specified re-use.

Regression analysis

A statistical technique by which a dependent variable is expressed in terms of one or more independent variables.

Reservoir storage

The phenomenon by which a volume of flow has to be stored temporarily on a surface, or in a length of pipe or channel, as the depth and rate of flow increase; the storage is depleted during the *Recession*.

Residual chlorine

See *Chlorine, residual*.

Resource cost

The cost of resources used in sewerage construction (materials, plant and labour); the resource cost is appreciably less than the final cost of construction.

Retention pond

A pond where runoff is detained (e.g. for several days) to allow settlement and biological treatment of some pollutants.

Retention time

The length of time a body of water is retained in, or takes to pass through, a filter, tank or reservoir (also known as contact time). See also *Tank, contact*.

Return period

The average period between occurrences of an event greater than or equal to a given value.

Reverse osmosis (RO)

A process of water purification/demineralisation using osmosis.

Reynolds number

The ratio of inertia force to viscous force in a flowing fluid (expressed as Vd/ν). The magnitude of the Reynolds number determines whether the flow is laminar or smooth-turbulent, transitional or rough-turbulent (see *Flow, turbulent*).

Run-off

Excess water which flows off the surface of a roof or hardstanding area.

Run-off, percentage

The percentage of the rainfall volume falling on a specified area which enters the stormwater drainage system.

Run-off, surface

Flow over the ground surface to the drainage system.

Sacrificial coatings

See *Coatings, sacrificial*.

Scum channel

A continuous channel in the side and end walls of a pool at the normal operating water level, designed to remove water from the surface level and return it to the filtration plant.

Separate system

See *System, separate*.

Septum, filter

That part of a filter consisting of screens on which the precoat material forms a layer.

Sewage, storm

Storm run-off mixed with foul sewage in a combined system (compare *Surface water*).

Sewerage system

A network of pipes or channels to convey foul sewage and/or stormwater from a developed area.

Sewer, foul

As foul drain, but conveying soil and waste from a number of curtilages; normally constructed and/or maintained by the local authority or water company.

Sewers, adoption of

Acceptance by the appropriate authority of statutory rights and duties relating to sewers.

Sewer, surface water

As for *Drain, surface water*, but serving a number of curtilages; usually the responsibility of the local authority or water company.

Shelter belt planting

See *Planting, shelter belt*.

Side weir

A weir constructed in the side of a pipe or overflow chamber to permit the spill of high flows into a relief system.

Silica

Soluble or 'reactive' silica concentration.

Simulation

The representation of specified conditions in a sewerage system using a rainfall run-off calculation method.

Site condition

An index used in the resource cost model to describe the surface condition encountered during sewer construction (see also *Ground condition*).

Skimmer

A device forming an integral part of the circulation system and designed to continuously remove water from the surface of a pool and return it to the filtration plant. Skimmers normally incorporate a self adjusting weir.

Soakaway

A pit, usually filled with large stone, into which surface water is drained to infiltrate into the ground.

Soffit (crown)

The highest point on the on the internal surface of a pipe or channel at any cross-section, measured from a datum point.

Soil moisture deficit (SMD)

A measure of soil wetness, prepared regularly by the Meteorological Office, indicating the capacity of the soil to absorb further rainfall.

Source control

The control of runoff or pollution at or near its source.

Standing wave

A wave formed on a water surface, which does not progress with the flow; usually associated with the occurrence of critical flow conditions (*Froude number* = 1).

Stilling pond

See *Pond, stilling*.

Storage tank

See *Tank, storage*.

Storm profile

A series of values of rainfall intensity varying with time, which may be expressed in terms of percentile peakedness.

Sub-area

A group of sub-catchments treated as a single unit for calculation purposes.

Sub-catchment

The area draining to a single pipe length.

Sub-soil

Ground below top-soil formation.

Sub-soil drain

See *Drain, sub-soil*.

Surface run-off

See *Run-off, surface*.

Surface water

Storm run-off not contaminated with foul sewage (compare *Storm sewage*).

Surface water drain

See *Drain, surface water*.

Surface water sewer

See *Sewer, surface water*.

Suspended solids

Particulate matter carried in suspension by fluid flow.

Swale

A shallow vegetated channel designed to conduct and retain water, but may also permit infiltration; the vegetation filters particulate matter.

Syphon, inverted

A pipeline carrying sewage or stormwater beneath an obstacle such as a river channel or a road in cutting.

System, combined

A system of drainage in which foul and surface water are conveyed in the same pipes to a common or combined sewer.

System, partially separate

A sewerage system in which part of the storm run-off is carried with the foul sewage in a combined system, and part is carried in a separate system.

System, separate

A sewerage system in which foul and surface water are segregated and discharged into separate sewers or other places of disposal (compare *Combined system* and *Partially separate system*).

Tail header

See *Header, tail*.

Tangent methods

Graphical methods of determining peak discharge from the time-area diagram.

Tangible

Description of costs or benefits to be considered in an economic evaluation, which can be expressed in monetary terms (opposite: *Intangible*).

Tank, balance

A tank designed to take up displacement caused by bathers and wave surge and provided a source of backwash water so that water in the pool remains at a constant level.

Tank, contact

Vessel to provide retention time for a chemical reaction to proceed (e.g. disinfection).

Tank, off-line

Detention tank which is physically separated from the flow of water along the pipeline.

Tank, on-line

Detention tank which forms part of the pipeline system, so that water flows through the tank between incoming and outgoing pipes.

Tank, storage

Tank constructed within a sewerage system to store a volume of water temporarily during peak flows (see also *Tank, off-line*, and *Tank, on-line*).

Tender cost

The cost of sewerage construction as estimated in tender proposals.

Time–area diagram

A diagram showing the increase of contributing area with time in a given catchment.

Time of concentration

The time taken for flow to reach the point under consideration from all contributing parts of the catchment; equal to time of entry plus time of flow.

Time of entry

The time taken for surface run-off to reach the entry to the pipe system from all contributing parts of the sub-catchment.

Time of flow

The time taken for flow to reach the point under consideration from the head of the pipe system.

Time offset method

A method of routing flood waves through channels or pipes by displacing the hydrograph by the flow time in the pipe or channel under consideration.

Total available chlorine (TAC)

See *Chlorine, total available*.

Total dissolved solids (TDS)

The solid residue, expressed in $\text{mg}\cdot\text{litre}^{-1}$, produced by boiling away a sample of water. The concentration of the dissolved solids present in the pool water and an indicator of the level of by-products of the pollution and water treatment processes.

Total organic carbon (TOC)

A measure of the total carbon present in a sample of water, excluding inorganic carbon from carbonate, bicarbonates and free CO_2 . Low TOCs indicate high quality waters.

Toxins, algal

Highly toxic substances released into the water by several algal species.

Trade waste/chemical drain

A pipe conveying the contaminated discharges from industrial processes; subject to rigorous local authority control.

Trench, battered

A trench with sloping sides.

Trihalomethane (THM)

See *Haloform*.

TRRL (Transport and Road Research Laboratory) method

A computer-based method for the determination of flow hydrographs in storm drainage systems and for the sizing of pipes.

Turbidity

A measure of the suspended solids present measured in nephelometric turbidity units (NTU).

Turnover rate

The time taken for the water treatment plant to circulate a volume of water equivalent to the capacity of the pool or pool zone (usually expressed in hours).

Typical storm methods

A category of methods for determining flows in storm drainage systems which used a single design storm as rainfall input.

Underdrain system

The system provided in the base of a filter, designed to collect the filtered water under normal flow and to distribute backwash water under reverse flow.

Urban catchment wetness index (UCWI)

A development of the catchment wetness index for application to urban catchments.

Volumetric run-off coefficient

The proportion of the rainfall on the catchment which enters the storm drainage system.

Vortex overflow

See *Overflow, vortex*.

Water table

The surface within soil or rock strata at which ground water saturation occurs.

Wet well

The entry chamber in a pumping station from which water is pumped to a higher level.

Wetland

A pond that has a high proportion of emergent vegetation in relation to open water.

Wilting point, permanent

When plants remain wilted, even in a humid environment, the soil is said to be at the permanent wilting point.

Wind drift

A term used to describe the effect of wind on the direction of water sprays from sprinkler heads.

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