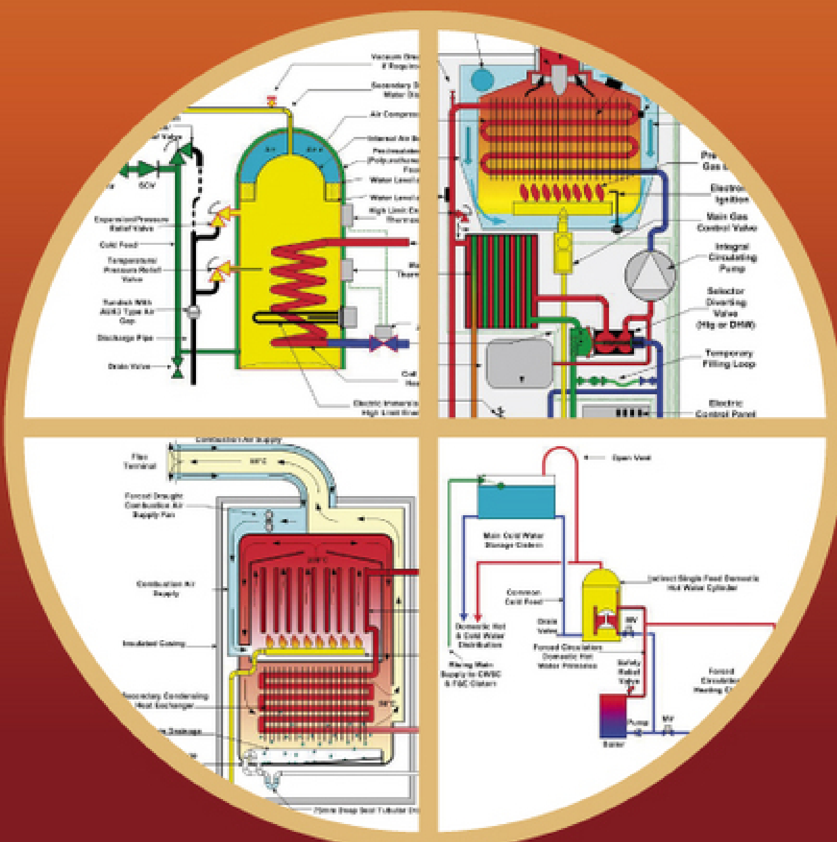
Heating Services in Buildings

David E. Watkins



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Design, Installation, Commissioning & Maintenance

David E. Watkins

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Preface

There have been a number of books written on the subject of heating over the years, which would fill a sizable section of any notable library if collected together.

On examining the more recent of these books, that is those published over the last twenty years, it was found that they could be categorised as belonging to one of three groups. These are books written for the DIY market which are of little use to any student who is serious about studying to become a qualified heating professional. Alternatively, there are a number of books aimed at the craft level student concentrating only on the practical aspects of the subject. The third category of technical books, of which there are fewer available, has been written for the qualified professional engineer that assumes the student has previously obtained the basic engineering knowledge that is required to advance to a higher level of their education.

This observation becomes apparent when looking for a suitable technical book to support the NVQ Level 4 Higher Professional Diploma in Building Services Engineering and other design based engineering courses.

The search found that no single book was available to support these courses and the student would have to purchase a large number of publications to cover the subject to the extent required. This would also result in the student incurring a high financial cost to obtain copies of these publications.

The answer to this situation was to produce a number of supporting handout papers that expanded upon the course lectures that eventually developed over the years into a sizable set of notes when bound together.

During the course of developing these supporting notes, the subject of heating buildings, both for domestic residential properties and commercial buildings, has changed enormously, particularly with regard to the need to conserve energy, develop alternative forms of energy and provide controls that are suitable for the system's needs.

This requirement has manifested itself in the form of increased mandatory regulations and improved technology that has been developed to meet these compulsory regulations and conservation targets.

It was that necessity to incorporate explanations and detailed information on these changes that led to the set of supporting notes being developed into the basis of this book.

The aim of this work is to provide in a text and illustrative form a complete guide from basic principles to an advanced level to all the elements that combine to impart the engineering knowledge required on the subject of hydronic heating systems.

The book has been arranged to present the subject matter in a logical order that builds on each preceding chapter and culminates to provide the complete informative material. The book also demonstrates that there is little difference between domestic and commercial heating systems in the approach to the engineering and design of the systems, but makes mention where there is a difference.

This book has been developed over many years from the collection of handout notes to its present volume, where it originally supported a City & Guilds supplementary heating course, which further developed to support the heating design and installation course accredited by the European Registration Scheme (ERS) and other similar academic courses presently run today.

It is also intended that this volume will support Unit 11, 'Space heating technology and design', which is a module contained in the NVQ Level 4 Higher Professional Diploma in Building Services Engineering.

The book is aimed at both craft level plumbing students qualified to NVQ Level 3 standard aspiring to bridge the educational gap to an engineering career, plus school leavers with the necessary academic 'A' level qualifications and employed in a building services engineering consultancy.

Although this volume has been produced to support the NVQ Level 4 course and similar design/engineering courses, it is hoped that it will be of equal interest and use to anyone concerned with the design and installation of hydronic heating systems.

This book has resisted the inclusion of over explaining or illustrating elements in order to provide the information in an affordable manner to all those concerned. This gives the lecturer the opportunity to expand upon each subject and provide further examples in the classroom.

It is also correct to acknowledge that a work of this type has only been possible due to the encouragement and assistance of many other people, most notably Mr David Bantock, whose original set of notes I inherited when I started as a part-time lecturer delivering the course, and who has been instrumental in his encouragement during its development. Also my wife, Jenny Watkins, for proofreading and endless patience, and the many students who encouraged its eventual publication.

Special acknowledgement should also be mentioned for permission to reproduce Figure 5.23, Room Height Temperature Gradients, from Elsevier Publishing, which is based on a similar illustration in their book entitled Faber & Kell's Heating & Air-conditioning of Buildings. Also, for permission granted by Baxi Heating to reproduce Figure 15.8, Illustration of a Micro-Combined Heat and Power Generating Unit and M H Mear Co. Ltd for permission to reproduce Figure 7.3, of a Mear's Slide Rule Heating Calculator.

David E. Watkins

1

Introduction to Heating Services

The broad term 'central heating' is used to describe many types and forms of heating, and some usage is totally misleading and inaccurate, through ignorance of the subject. This chapter is a basic introduction to the mechanics of central heating, which is discussed in greater detail in the following chapters.

If we examine the term, it implies a system where heat is produced from a central source and distributed around the whole building. The method of heat generation and distribution may vary with the type of heating system employed.

Central heating is sometimes referred to as space heating. To be understood fully, this must be described by its type or system arrangement, and may be categorised as being either full, part or background heating.

Full central heating may be defined as being a system of heating from a central source where all the normally habitable or used rooms/spaces are heated to achieve guaranteed temperatures under certain conditions. By today's standards, all heating systems installed in residential dwellings and most commercial buildings should conform to this category, unless there are acceptable reasons for not doing so.

Partial central heating is the term applied where only part of the building is to be heated, but even then the rooms or spaces that are heated should still have guaranteed temperatures under stated conditions. This form of central heating would be a rare occurrence for a residential dwelling but not so uncommon for some commercial buildings, especially where part of the building complex is not normally occupied.

The term 'background heating' is used to describe a form of central heating whereby lower than normal or standard recommended temperatures are aimed at for the type of building involved. The term is sometimes used to refer to heating systems installed in buildings where the room temperatures are not guaranteed. This form of heating is unacceptable by today's standards on both environmental and efficiency grounds.

It should be noted that, unless otherwise specified, full central heating should normally be designed to current regulations and standards and installed in a professional manner. In some instances, usually due to a specific use or financial reasons, the client may only require or specify partial heating to be installed, sometimes with the request that safeguards are included to allow the system to be extended at a later date to achieve full central heating.

Heating Services in Buildings: Design, Installation, Commissioning & Maintenance, First Edition. David E. Watkins.

As an aid to lecturers and students, full colour versions of the figures in this chapter may be found at www.wiley.com/go/watkins

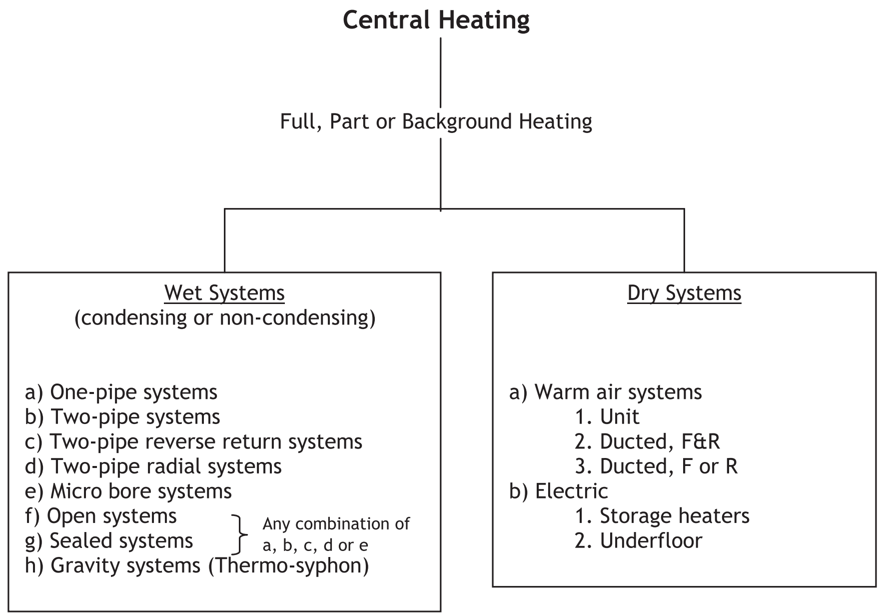

Figure 1.1 Heating system categories

Background heating, where lower than normal or recommended temperatures are aimed at, should only be used when specifically requested by the client for some reason. Even then, agreed temperatures should be incorporated into the design and guaranteed before any installation work commences. Under no circumstances should any heating system be installed without first agreeing specific room temperatures to be achieved when certain conditions exist. These conditions are discussed in Chapter 2.

Having understood the extent of the heating system and its classification, be it full, part or background heating, heating systems may be further divided under the headings of 'wet' or 'dry' systems. The terms wet or dry refer to the medium used to convey the heat from its source of generation to its point of use. Wet systems may be further classified by the piping circulation arrangement, with dry systems being divided into warm air and electric heating.

Figure 1.1 indicates the broad classifications of heating systems.

Heating systems can be sub-divided even further, but this will be explained in Chapter 21.

Wet heating systems

All wet types of heating systems employ a liquid as a medium to convey the heat from its source of generation. It is then distributed around the system to each heat emitter, where it transfers part of that heat through the heating surface of the heat emitters. Finally, the liquid is returned to the source of generation for the process to cycle continuously. The source of heat is commonly referred to as a boiler.

In all domestic heating systems, and most heating systems for other types of buildings, water is chosen as the medium for conveying the heat due to its low cost and being readily available. However, water does have the disadvantages of a low boiling point and high freezing point; it can also be corrosive to metallic materials and has a limited heat carrying capacity. The corrosive nature of the water can be reduced by water treatment, which is discussed later in this volume.

The temperature limitations and heat carrying capacity of water will have to be accepted unless we change the atmospheric conditions of the system, or we can change the liquid. Liquids known as 'thermal fluids' are available and have been used successfully on larger commercial type heating installations. They possess different properties to water, such as being less aggressive to common materials, having higher boiling points and lower freezing points, a greater heat carrying capacity than water and, in some cases, a lower viscosity. The merits of thermal fluids are much superior to those of water but are generally discounted for all domestic heating systems owing to their higher capital cost and not being readily available. They are also rarely used on larger commercial systems for the same reasons, but when conditions are right they can be considered attractive. The difficulty of availability can cause problems when replacement fluid is required immediately, following any emergency maintenance work. Thermal fluids have been used for domestic applications on limited occasions in countries that experience much lower temperatures than in the UK, as the lower freezing point of the fluid can be an important advantage when sub-zero ambient temperatures are experienced for prolonged periods with the heating system in a non-operating mode. They have also been employed as the heat carrying medium for some solar heating systems.

The purpose of the water used in heating systems differs from that used in domestic hot and cold water installations. In those systems, water is the end product or consumable item and after it has been used, it is discharged to waste. The water employed in a heating system is a non-consumable substance. It is the medium used to carry the heat required and, after it has transferred some of the heat, it is returned to the boiler to be re-used over and over again.

Dry heating systems (warm air)

Warm-air dry-type heating systems differ from wet-type heating systems insofar as the fluid employed is not only the medium used to convey the heat, but is also the end product. As the name implies, air is the fluid used to carry the heat from its source of generation, a warm air heater. It is then distributed, usually through a network of ducting, where it is arranged to enter directly into the room under controlled conditions to displace the cooler air. Finally, a mixture of the two is partly returned to the warm air heater for the process to be repeated.

Warm-air heating systems are generally disliked by many occupants of dwellings that have such systems installed, but this is usually because the systems are either not designed correctly, not installed correctly or are, in many cases, incomplete. This is mainly down to ignorance of the fundamental principles of warm air heating, which, if given the respect deserved, can be a very good form of heating. This work exclusively concentrates on wet-type heating systems since it is aimed at students and engineers in the plumbing industry.

Dry heating systems (electricity)

Electrical heating systems may technically be classified as dry systems, but they do not employ a medium as they generate their heat at the point of use. For this reason, electrical heating systems are not included in this book, with the exception of heating systems that use electricity as the source of power to heat the water. Here they are classified as being wet or hydronic heating systems.

Supplementary heating

This is a term applied to describe heating appliances, either fixed or portable, that are used to supplement the central heating system – either during extreme cold spells when the outside air temperature falls well below the base design temperature, or during the heating-off season in spring or autumn, when the outside temperature drops to below that considered comfortable.

Examples of such heating appliances include:

- Radiant electric fires, portable and fixed
- Oil filled radiators
- Oil room heaters
- LPG room heaters
- Gas fires
- Open solid fuel fires.

The list is not intended to be exhaustive, but meant to serve as a general representative selection of supplementary heating appliances.

2

Wet Heating Systems

Wet heating systems, commonly referred to as hydronic heating systems because they use a liquid as a medium, nearly always employ water as the medium to convey the heat from its source of generation, a boiler. This is rather a misnomer, as a boiler must be designed to avoid boiling the water, but is probably a leftover term from the days of raising steam. The heated water is circulated around the system, transferring part of its heat, and returns back to the boiler for the process to be repeated.

The water is fed into the heating system via a fixed piped connection to either a feed and expansion cistern, or a direct connection, as in the case of a sealed heating system. The water is allowed to enter the heating system slowly, thus avoiding creating turbulence, to fill it with all air expelled through the open vent, or by releasing it using manually operated air vents or automatic air release vents.

Water has many advantages as a heat carrying medium when used in hydronic heating systems; not least its plentiful availability. For this reason water is almost exclusively used for domestic heating systems.

Hydronic heating systems are classified by the following basic principles:

- Temperature of medium
- Pressure of system
- Circulation method of medium
- Piping arrangement for distribution.

The classifications are to a certain extent inter-related, as the selection of one of the basic operating principles has an influence on the selection of the others, which is explained in the following discussion.

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TEMPERATURE AND PRESSURE

The classification of hydronic heating systems by the temperature of the circulating water exiting the boiler is closely related to the operating pressure of the system, and the two must be considered together. This is because pressure is required to maintain the water in a liquid form at high temperatures: as water will boil and convert to steam at 100°C at atmospheric pressure when measured at sea level, any increase in that pressure will have a corresponding increase in the boiling temperature of water. Likewise, any decrease in pressure below atmospheric pressure will have the effect of allowing water to boil at temperatures lower than 100°C.

Table 2.1 gives the temperature/pressure classification commonly used in the UK. The minimum pressures listed are those required to prevent the water from evaporating but should not be confused with their vapour saturation pressures, which are lower.

It can be seen from Table 2.1 that water may be retained in liquid form when the operating temperature is above 100°C by pressurising it, giving all the advantages of a liquid and none of the disadvantages of a vapour such as steam. The method of pressurising the heating system is explained later in this chapter.

In contrast to the UK practice of temperature/pressure classification, in the United States of America the classification of heating systems differs slightly, outlined in Table 2.2.

It can be seen from Table 2.2 that the US has higher temperature and pressure classifications than the UK. However, in practice there is very little difference in the operating principles of hydronic heating system either side of the Atlantic.

Almost without exception, all domestic residential heating systems are classified as being low pressure and temperature (LPHW). It is considered safer to install heating systems using materials suitable for working pressures and temperatures below 100°C, therefore avoiding the potential hazard of flash steam occurring in the event of a pipe fracture or valve gland leak.

It has traditionally been the custom to design LPHW systems with a water flow temperature of 82°C and a Δt (temperature difference) of 11–12°C, giving a return water temperature of 71°C. More recently, the Δt has been increased in certain circumstances to take into account the requirements of condensing boilers that are influenced more by lower return temperatures than flow temperatures to function efficiently. This

Table 2.1 Hydronic design operating water temperatures and pressures (UK practice)

Classification	System temperature (°C)	Operating static pressure (bar absolute)
Low pressure hot water (LPHW)	<100	1 to 3
Medium pressure hot water (MPHW)	100 to 120	3 to 5
High pressure hot water (HPHW)	>120	>5*

*Account must be allowed for varying static pressures that would exist in a tall building.

Table 2.2 Hydronic design operating water temperatures and pressures (US practice)

Classification	System temperature (°C)	Operating static pressure (bar gauge)
Low temperature hot water (LTHW)	<120	2
Medium temperature hot water (MTHW)	120 to 175 Normally below 160	<11
High temperature hot water (HTHW)	>175 Normally about 200	<20

has a secondary effect on the increased sizing of the heat emitters, which is discussed in more detail in Chapter 8. Another situation where one should question the return water temperature and the flow water temperature is in heating systems employing underfloor heating sections that require the floor temperature to be limited to an acceptable level.

Low temperature heating systems may be further categorised as being either 'open' systems – where the heating system incorporates an open feed and expansion cistern and operates at atmospheric pressure, plus the static pressure created by the feed and expansion cistern at the traditional flow temperature of not exceeding 82°C – or sealed systems.

With a sealed heating system, the feed and expansion cistern is replaced by a sealed expansion vessel that allows the heating system to operate at a slightly higher pressure above atmospheric pressure and also permits the flow water leaving the boiler to have fractionally higher operating temperatures, in the region of 85–95°C.

If operating water temperatures higher than 82°C are selected for the heating system, then greater consideration must be given to the choice of heat emitters to be used, and all contactable heating surfaces such as traditional panel or column type radiators should be avoided so as to reduce the risk, scalding anyone who comes into physical contact with them.

Low water temperature heating systems are the most commonly used category of operating temperatures and pressures, suitable for all buildings ranging from small domestic residential through to very large and complex developments.

Medium temperature (MPHW) heating systems are favoured where a high heat output is desired so that smaller heat emitters and corresponding smaller pipe sizes can be used. The heat emitters must be of the non-contactable type, such as convectors, low surface temperature radiators and fan coil units. These systems are more suitable to commercial type buildings where the materials used are more robust than domestic low pressure type materials, and the system is more likely to be regularly serviced and maintained. This type of system in a domestic situation would be considered unsafe.

The use of high temperature and pressure systems (HPHW) is normally considered for use in industrial applications as some industrial processes require higher temperatures for manufacturing, or for developments that have a main central plant room that distributes the primary heat at high pressure and temperature to local plant rooms, which then circulate the secondary heat at a lower temperature. This arrangement is ideal for developments that are spread out over a large geographical area, and makes full use of more economical pipe sizes and equipment. As with the medium temperature systems, material selection and maintenance are critical factors.

CIRCULATION

Heating systems can also be classified by the method of circulation employed, i.e. either by gravity (thermosiphon), or forced circulation by a pump, or a combination of both.

Full gravity heating systems have not been installed since the development of the glandless circulating pump. The practice of having a gravity circulation to the domestic hot water cylinder whilst the heating system has a forced circulation, which can have some merit when suitable conditions exist, is no longer permitted by the Building Regulations for residential dwellings, which unfortunately limits the design engineer in the options available. Even where the situation exists that the domestic hot water cylinder is located directly above the boiler at the optimum height, and the occupant's needs are such that heating part of the system is not required for a great deal of the time but domestic hot water is, we are no longer permitted to use this method.

A fully forced method of water circulation for both heating and domestic hot water primaries is by far the most efficient arrangement in the majority of applications and gives freedom in the choice of plant equipment location, but this is not always the best option.

PIPING DISTRIBUTION ARRANGEMENT

Having discussed the temperature, pressure and method of circulating the water, the piping arrangement can be established. The different arrangements listed in Figure 1.1 form the basic systems for which there are numerous variations or modifications, but each may be categorised as belonging to one of the basic forms.

These arrangements each have their own advantages and disadvantages and the final selection should be made on the most efficient and economical method suited to each individual application. Also, a combination of any of the piping arrangements described may be used if it is considered by the design engineer to best meet the needs of the system.

The various piping arrangements depicted on the following pages have been produced to explain the operating principles of each system and are not supposed to be complete. For this reason most control elements and components have been omitted for the sake of clarity as these are dealt with in detail in Chapter 11. Also, the provision to include the means of producing domestic hot water has been included in each case, minus the controls element, to complete the piping arrangement: this may be by gravity primary circulation or by forced circulation. In most cases, either method may be used, unless noted otherwise. It is not the intention here to give the impression that either a gravity primary circulation or a forced primary circulation is the preferred option for satisfying the domestic hot water requirements, but just to show the different options.

ONE OR SINGLE PIPE SYSTEM

Of all the piping arrangements used for heating distribution, the single pipe system is the simplest. It consists of a single pipe main that extends from the boiler around the building as a circuit, or number of circuits, and returns to it with all heat emitters connected to the pipe by their own branch pipe flow and return connections.

Figure 2.1 illustrates the operating principles of the single pipe system and its limitations: a progressive temperature drop around the heating pipe circuit caused by each heat emitter returning its water back into the common circuit pipe. This has the effect of cooling the flow water available to other heat emitters being served by this circuit, which in turn results in subsequent heat emitters having to be oversized to compensate for a lower mean water temperature across the heat emitter.

To avoid heat emitters at the end of each pipe circuit having to be excessively large due to the decreasing mean water temperature available, heating pipe circuits should be limited to supplying water to a few heat emitters each, to restrict the mean water temperature across the heat emitter to no less than 70°C for non-condensing systems, or lower for condensing.

Another effect of pipe circuits suffering from excessive temperature drop is that the piping system on each circuit would also have to be oversized to compensate for the lower circulating water temperature.

The piping arrangement depicted in Figure 2.2 demonstrates that this need not be the case: if the branch circuits supply a minimum number of heat emitters, then the single pipe arrangement is just as suitable for larger domestic residential properties or commercial building applications, as the small domestic heating system.

The object in the design of this system is to limit the temperature drop across each pipe circuit so as to avoid having to significantly increase pipe sizes or heat emitter sizes to compensate, and so lose the lower cost advantage claimed by this system.

From the schematic layout depicted in Figure 2.2, it can be seen that if each piping circuit is limited to a reasonable temperature drop across it, and if each piping circuit is similar in its heat carrying load to each other, then the single pipe heating arrangement is suitable for heating system compositions in larger buildings. It can also be seen that the piping system is fairly evenly balanced in its heat distribution

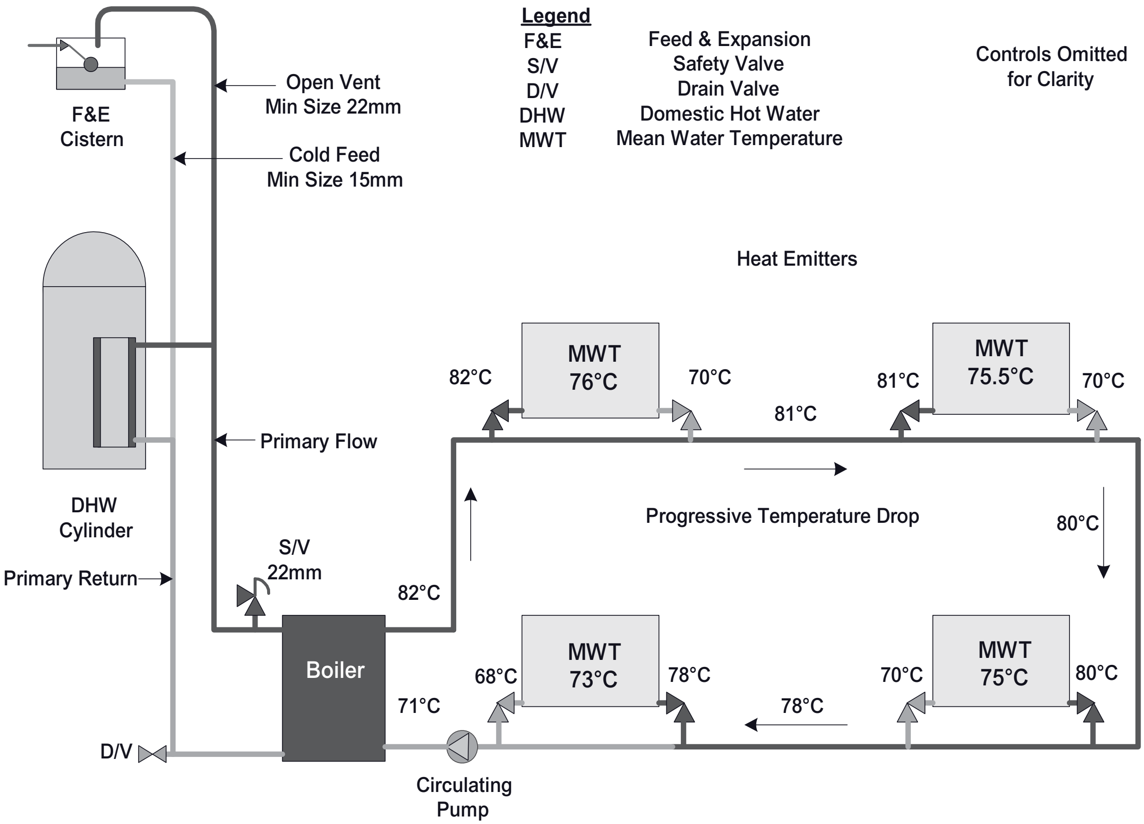

Figure 2.1 Operating principles of single pipe heating system (non-condensing)

in order to achieve the temperature drop required from each heating circuit. This is accomplished by balancing the circulating piping system with the use of regulating valves when the heating system is being commissioned.

The primary flow and return to the domestic hot water cylinder in this illustration is in fact a two pipe arrangement. Lower temperatures may be selected for condensing heating systems.

The single pipe heating system benefits from the employment of special tees, known as 'diverting' or 'inducing' tees. These special fittings are designed to encourage a degree of flow into the heat emitter by creating a resistance to the flow between the flow and return branch connections, in the form of a pressure drop on the single pipe circulating main. This creates the conditions for circulation to occur through the heat emitter, as the resistance of this passage is less than that of the heating main.

The isometric layout illustrated in Figure 2.3 demonstrates the use of these diverting tees, whereby the up feed risers only require one diverting tee to be fitted on the return connection as the thermal head will assist the circulation, but the down feed pipes should be fitted with diverting tees on both the flow and return branch connections because no thermal head exists in this situation.

Diverting tees may be obtained in a copper alloy or malleable iron and are constructed with a venturi shaped restriction inside as shown in Figure 2.4. These tees are similar in design to 'tongued' tees that were commonly used on gravity heating systems.

Figure 2.4 shows how the flow of water through the venturi of the diverting tee induces the flow from the return connection of the heat emitter.

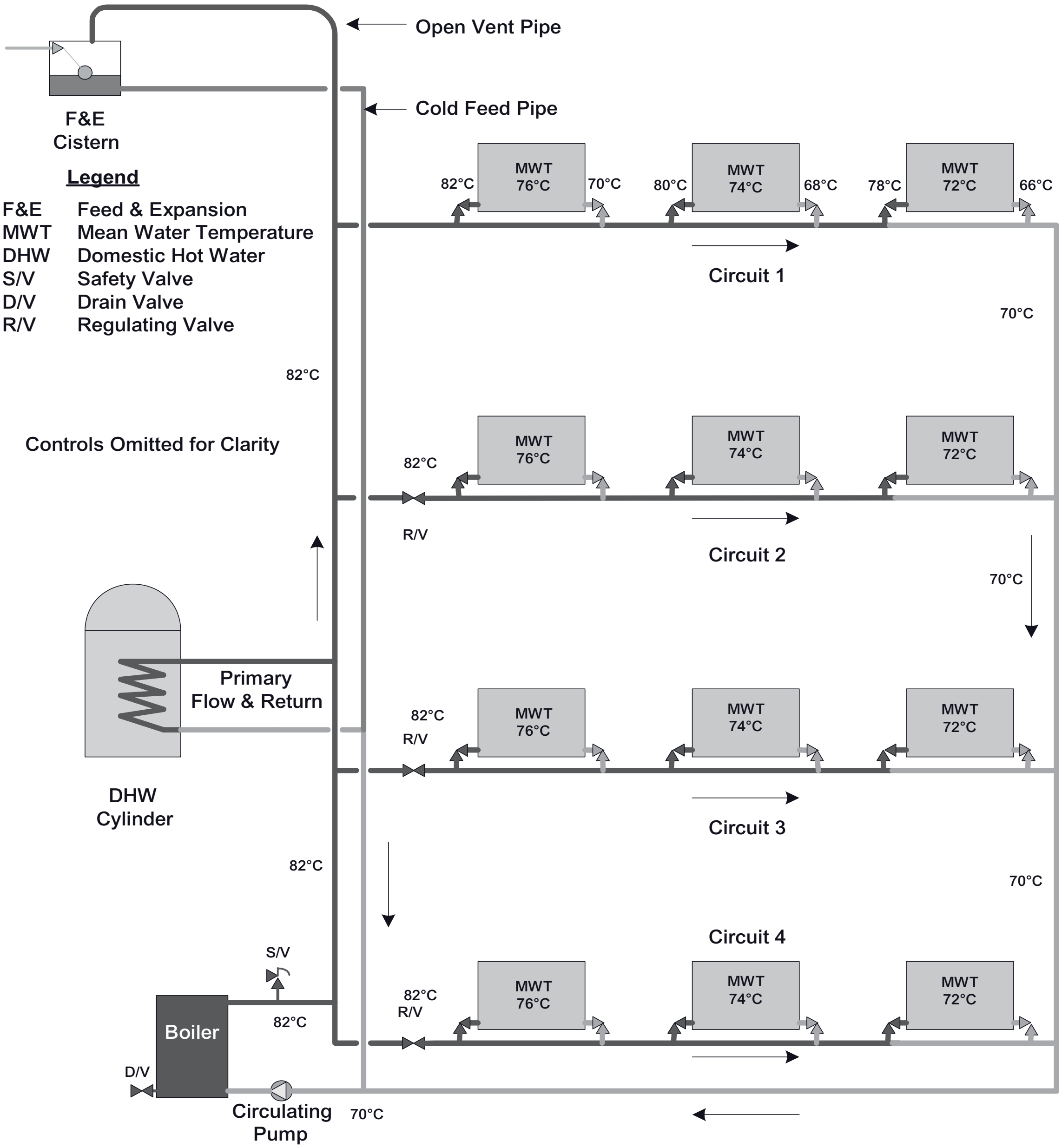

Figure 2.2 Single pipe system for larger building with limited circuit Δt (non-condensing)

Figures 2.5 and 2.6 show how the diverting tees are arranged and how they function for both upward connections to the heat emitters using one diverting tee on the return, and downward connections where diverting tees are employed on both the flow and return connections to the heat emitters.

Diverting tees have been successfully fabricated on site from standard capillary copper pipe fittings, either the end feed type, or integral solder ring type, using a standard tee, a spigot and socket straight reducing fitting, with the larger spigot end cut short but square, which is placed inside one socket end of the tee so that the reduced socket end protrudes past the branch of the tee. The cut spigot end of the reducer must