Heating

Introduction

Modern central heating systems have to be capable of meeting the user's expectations of providing an adequate level of heating in an efficient manner. An efficient system is one that provides the correct amount of heat at the correct place at the correct time, burning the fuel used in the most efficient way possible and switches off the boiler when the demand is satisfied. Achieving this objective will require correct system design, avoiding inefficient oversizing of plant, and the use of appropriate controls. However, the more sophisticated the system the greater the potential for problems and so good design often requires a compromise between what is the ideal solution and what is advisable in terms of operational and maintenance considerations. The recommendations in this Guide relate primarily to domestic and small commercial installations with boiler input ratings not exceeding 60kW, although much of the content will also be applicable to larger systems. For a greater understanding of efficiency requirements reference should be made to the Resource efficient design section.

Building design/ construction

New buildings

In designing a new building, there are many considerations which will have a direct impact on the design of the heating system and its operational efficiency, such as fabric selection, constructional details, orientation, internal layout, nature of occupancy/use, domestic hot water loading and provision for plant installation, access & maintenance.

To maximise the desirable influences and ameliorate those that have an undesirable effect on the building operational efficiency, the heating engineer should, ideally, have an early involvement in the design of the building.

Existing buildings

With existing buildings, insulation levels may be far from satisfactory and the design engineer should determine what cost effective insulation measures can be taken in order to reduce heat losses and therefore the size and capital cost of the installed heating system, such as :

a. Increase insulation levels within roof voids to 200mm thickness.

b. Ensure window and door openings are adequately draught proofed and un-used chimneys closed off. Ensure that there is still adequate ventilation to prevent odour /moisture build-up and if closing off a chimney, leave just sufficient ventilation to protect the internal fabric of the chimney from deterioration.

c. Insulate flat roofs by the application of insulation on top of the existing roof waterproofing membrane.

d. Insulate external walls. There are several types of material used for cavity wall insulation and solid walls can be insulated internally or externally, although the choice of method needs careful evaluation.

e. Consider replacing window frames in poor condition with sealed double- glazed units, possibly using low emissivity glass where there are potential solar radiation gains. It is not cost effective to install double-glazing simply to reduce energy consumption.

Surveying an existing building

With an existing building, the prerequisite of a successful heating system design is the carrying out of a detailed survey, which should provide the necessary information for the heat loss calculations and for the system preliminary design. The following details the various aspects that should be covered by the survey and could form the basis of a check list.

Occupancy

Details of pattern of occupancy - preferred temperatures.

Building layout

Orientation, positions of windows, doors and major items of furniture - party and external walls (load bearing ?). For each room, ceiling height, floor dimensions, skirting and sill height, window size and type of glazing - wall and roof construction. Floor construction - if suspended, direction and depth of floor joists and position of any steel beams - if solid, type of construction (e.g. reinforced concrete, beam and pot). Details of any natural ventilation shafts (e.g. open chimneys) and/or ventilation fans.
Possible locations for any envisaged equipment, taking access for installation/ maintenance into consideration.

Insulation

Existing levels of insulation and draught proofing (if any). Adequate, or do they need improving?

Boiler

Preferred type of boiler - combined primary storage unit (CPSU), fuel (location of nearest supply - storage), floor/wall mounted, conventional/balanced flue. Possible locations (including any ancillary equipment), taking into account possible pipe routes, flue requirements - conventional/ balanced and fan assisted balanced flues - condensate drainage provision (condensing boilers).

F & E cistern

Position for F & E cistern - routes for cold feed and safety vent pipes and location of rising main for float valve supply. Alternatively, space for sealed system expansion vessel and pressurisation set.

Electrics

Source of electrical supply and position for controller, thermostats, etc. Adequacy of existing earthing. Position of socket outlets, etc. Equipment/lighting loads?

Pipe routes

Possible/acceptable pipe routes (concealed/exposed?) including drops for between floor connections.

Heaters

Client preference for type of system/ components and reasons?

Calculation of heating loads

The heating load of a building is dependent upon fabric heat loss and ventilation heat loss due to air infiltration. In commercial installations there may be offsetting internal gains from people, equipment, lighting, etc., but this is only taken into account if it is continuous during the pre-heat and heating periods. Such gains are normally ignored in domestic situations, as are solar radiation gains.

Heat transfer theory

Heat is a form of energy and its transfer occurs through three basic processes - conduction and convection, which both require a medium through which the heat is transmitted, and radiation which occurs from one body to another and does not require a medium. All three processes require a temperature difference for heat transfer to occur.

Conduction is a process whereby heat is transferred without an appreciable movement of the molecules within the medium concerned. For a solid material, the rate of heat transfer is directly proportional to the area (A) across which the heat is being conducted and the temperature gradient (t_1 -t_2). It is inversely proportional to the thickness of the material (I).

$$Q = \frac{\lambda A(t_1 - t_2)}{l}$$

Q = heat transfer rate in Watts

A = area in m^2

l = thickness in metres

t = temperature in °C (or Kelvin)

λ = thermal conductivity in $\frac{W}{m° C}$

The thermal conductivity for a material can vary, depending upon its mean temperature, moisture content and density. For liquids and gases, it will also depend upon pressure. Good insulators have low thermal conductivity.

The reciprocal of the conductivity gives the resistivity of the material

Dividing the conductivity of a specific material by its thickness gives its thermal conductance and its reciprocal gives the thermal resistance 'R'.

$\frac{\lambda}{l}$ = thermal conductance - its reciprocal

$\frac{l}{\lambda}$ = thermal resistance 'R'

Convection

Convection is a process whereby heat is transferred as a result of the actual movement of the fluid molecules within the medium.

Radiation

Radiation is the transfer of heat between two bodies at different temperatures due to electromagnetic radiation waves passing through the intervening space and the rate of radiant heat transfer depends upon their shape, orientation and their relative emissivity and absorptivity.

Emissivity Factor (E)

Emissivity Factor (E) is the ratio of heat emitted by a unit surface area of a material to that emitted by a unit area of a perfect black surface at the same temperature - most building materials have an emissivity of 0.9 - 0.95 - shiny/reflective surfaces have a low emissivity of around 0.05.

Heat loss calculations and 'U' values

Calculation of the rate of heat loss (Q) from a building is straightforward. It involves calculating the area (A) of each constructional element of the building through which heat is going to flow, such as the wall, roof, floor and windows - different areas of the same element may be of different construction and so the heat loss across each area must be separately calculated. The area is then multiplied by the temperature differential across each element (t1 -12) and the 'U' value.

$$Q = UA(t_1 - t_2),$$

The constructional elements considered are usually those which form the boundary between the inside and outside of the building, with the temperature difference being that between the inside and outside design temperatures. In some cases it may also be necessary to calculate the heat loss from one internal space to another, if they are at significantly different temperatures (say 3°C or more) - an example would be a bathroom at 22°C with an adjacent bedroom or hallway at 18°C.

Alternatively, the adjacent area may be unheated, such as a garage beneath a bedroom, and so the likely temperature of the unheated space has to be determined. This can be calculated, but in most instances it is sufficient to make a reasoned 'guess'. The temperature in an unheated garage within the envelope of a house is likely to be some 5°C to 8°C above outside design temperature - if it has an exposed roof and walls, then 2°C may be more appropriate.

Consideration must also be given to the additional heating load resulting from air infiltration.

It is worth noting that whilst temperatures are usually quoted in degrees Centigrade (°C), temperature differences are often quoted in degrees Kelvin (°K). One degree difference in the Centigrade scale is the same as one degree difference in the Kelvin scale, but they are not the same for actual temperatures: 0°K is -272°C!

'U' value

The 'U' value is a measurement of the rate of heat flow across one square metre of the element of the structure in consideration, with a 1°C temperature differential across that element and assuming steady state heat transfer conditions. It can be written as:

$$U = \frac{1}{R_{si} + \frac{l_1}{\lambda_1} + \frac{l_2}{\lambda_2} + \ldots R_a + R_{so}}$$

where R_{si} and R_{so} are the internal and external surface resistances; Ra is the resistance of any airspace; l_1 -, l_2, etc. are the thicknesses of each of the structural elements (in metres, not millimetres) and λ_1, λ_2 etc. are the conductivities of the respective materials.

The lower the 'U' value of a material, the better its thermal insulating properties - do not confuse with electrical insulation.

Tabulated 'U' values for specific constructions, or Thermal Conductivities for various materials can be found in a variety of sources including the CIBSE. Guide, Building Regulations Section L1, Insulation Industry Handbook, HVCA/CIBSE/IoP Domestic Heating Design guide, manufacturers' literature and many other sources.

Building Regulations

The Building Regulations (reference Approved Documents L1 and L2), that apply to replacement and new systems stipulate that 'reasonable provision shall be made for the conservation of fuel and power in buildings. For domestic dwelling designs, as covered by L1, this requires:

a. Limiting heat loss through the building fabric; from hot water pipes and hot air ducts and from hot water vessels

b. Providing space heating and hot water systems which are energy efficient

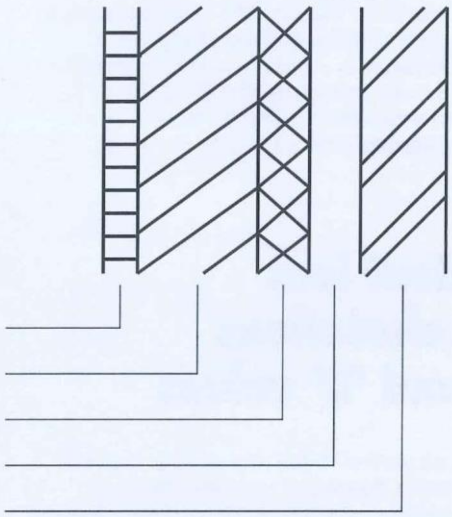
c. Providing lighting systems with lamps and controls that use energy efficiently.

For buildings other than dwellings, as covered by L2, in addition to the above, there are requirements relating to the provision of mechanical ventilation, air conditioning, lighting systems and more.

‘U’ value calculation

Thermal Conductivity (λ)

Plaster	0.16	W/mK
Celcon Solar	0.11	"
Rockwool	0.035	"
Brick (outer)	0.84	"
Thermalite	0.19	"
Wood	0.14	"
Fiberglass	0.04	"
Polystyrene	0.035	"
Concrete Block	0.57	"



13mm Plaster

150mm Celcon

50mm Rockwool

50mm Airspace

105mm Brick

Resistance		Walls	Roofs
Inner surface	R_{si}	0.12m² K/W	0.10m² K/W
Outer surface	R_{so}	0.06 "	0.04 "
Air space	R_a	0.18 "	0.18 "

$$R = 0.12 + \frac{0.013}{0.16} + \frac{0.15}{0.11} + \frac{0.050}{0.035} + 0.18 + \frac{0.105}{0.84} + 0.06 = 3.36$$

Therefore $U = \frac{1}{3.36} = 0.298\ W/m^{2\circ}C$

Figure 1 ‘U’ value calculation

All new housing and conversions must have an energy rating, calculated in accordance with the Government’s Standard Assessment Procedure (SAP) and which has to be declared for Building Regulations approval.

For domestic dwellings, the Building Regulations (Section L1) details three methods of demonstrating that the Regulations have been complied with in respect to the building heat loss - the Elemental method; Target U-value method and Carbon index method. Full details of the methods of calculation are given in Section L1, together with example calculations.

For other buildings, the Building Regulations (Section L2) details three methods of demonstrating that the Regulations have been complied with in respect to the building heat loss - the Elemental method; a Whole building method and Carbon emissions calculation method.

The calculated heat flow rate based on the ‘U’ value is for steady-state conditions and for the majority of situations, will give a perfectly adequate indication of the mean rate of heat loss from the structure. However, in reality the heat flow rate will vary in response to fluctuations in internal temperature, external temperature and variations in structural thickness and/or density.

If considering the dynamic performance of a structure (normally in relation to heat gain calculations) then it is necessary to take into account three factors in addition to the ‘U’ value: Surface Factor (F), Admittance Factor (Y-value) and Decrement Factor (f).

Design temperatures

The temperature sensed by a body depends upon the surrounding air temperature and the mean radiant temperature (MRT) of all the surrounding surfaces - a similar level of comfort can be achieved with a high air temperature and low MRT, or with a lower air temperature and higher MRT.

To only consider air temperature when carrying out heat loss calculations may give unsatisfactory results, so either ‘environmental’ or ‘dry resultant’ temperatures are normally used, which take into account both air and mean surface temperatures.

For normal situations, where air movement is low, the dry resultant temperature is used, and recommended values for various situations are given in the CIBSE Guide, NPIBC Guide and BS5449

In domestic situations it is necessary to consider whether designing for adjacent areas to be at considerably varying temperatures is reasonable. In practice, communicating doors are frequently left open, and so to calculate on the basis of one room being at 21 °C and an adjacent communicating room being at 16°C may be unrealistic - with the door open the adjacent room temperature is likely to stabilise at around 18°C-19°C.

The environmental temperature is weighted in favour of the mean surface temperature and is generally used in dynamic heat transfer calculations, where the heat exchange between the surfaces and the enclosed space is considered.

Air change rates

In a building of normal construction there will be air infiltration occurring at various points through the building structure (e.g. window and door frames) and this has to be allowed for in the heat loss calculations. Actual infiltration rates may vary considerably, depending upon the age of the building, level of insulation and exposure. Empirical values of air change rates for various situations are given in the FIVCA/CIBSE/IoP Domestic Heating Guide. The procedure for calculation is straightforward - the volume of the room is calculated (V) and multiplied by the air change rate (N), the specific heat of air (0.33 W/m3oC) and the inside/outside temperature difference.

Modern buildings are increasingly being constructed with higher standards of insulation and draught proofing and as a result, the air change rate can drop to considerably less than that required to adequately control moisture and odour build-up. Under these circumstances, some form of mechanical extract and/or supply ventilation should be considered.

The provision of mechanical extract from domestic kitchens, bath/shower rooms and some toilets is now mandatory under the Building Regulations (reference Approved Document F) and literature from domestic fan manufacturers gives guidance on requirements.

In commercial properties it is also necessary to take into account the number of occupants and ensure that an adequate supply of fresh air is available. The recommended fresh air supply rate in offices, where there is minimal or no smoking, is 5-8 l/s per person.

Installation of a fresh air ventilation system may be required. Alternatively, the use of through-wall heat recovery ventilator units, could be considered.

Wherever mechanical ventilation is used, its effect on the heat loss must be considered and allowed for.

Heat loss calculations

Accurate heat loss calculation is essential for efficient operation. Using 'rule of thumb' methods or a simple disc calculator will invariably result in system oversizing, with increased capital and running costs. A number of radiator manufacturers now offer free of charge heat loss programmes which can be run on a PC, but it is essential to understand the 'manual' method of calculation, if only to do 'spot checks'.

Examples of design calculation worksheets can be found in the HVCA/CIBSE/IoP Domestic Heating Design Guide.

It must be remembered that the calculation of heat losses is not an 'exact' science, since there are many variables involved, such as variations in standard of construction and in the constructional materials and their moisture content (e.g. bricks)

The heat losses are calculated a room at a time and for rooms over 5m height a percentage addition is made to the calculated heat loss, dependent upon the type of system (convective/radiant).

The calculated heat loss for each room forms the basis for the sizing of the heat emitters and the total of all the calculated heat losses forms the basis for sizing of the primary heat source. However, whilst the individual room heat losses all include for the effect of air infiltration, the rooms into which air will be infiltrating at any given time will depend upon the wind direction. Air will infiltrate into rooms on the windward side, pass through the building and exit the building from the rooms on the leeward side, thus the air infiltrating into the leeward side rooms, will have already been heated by its passage through the rooms on the windward side. The fact that the air entering the leeward side rooms has been pre-heated cannot be taken into account in the sizing of heat emitters for the rooms - a change in wind direction may reverse the situation - but it can be considered when sizing the primary heat source. With a property having two or more exposed elevations and internally partitioned, the primary heat source basic load can be reduced by up to 50% of the calculated ventilation heat loss.

The actual reduction allowed will be dependent upon the building configuration - if a domestic property has a through lounge, exposed at both ends to the outside, then a 50% reduction in respect of this room would not be appropriate, but it may well be in respect of bedrooms at first floor.

Types of heating system

Heating systems generally fall into one of four categories - wet, dry (warm air), radiant and electric storage and a building could have a combination of any of these.

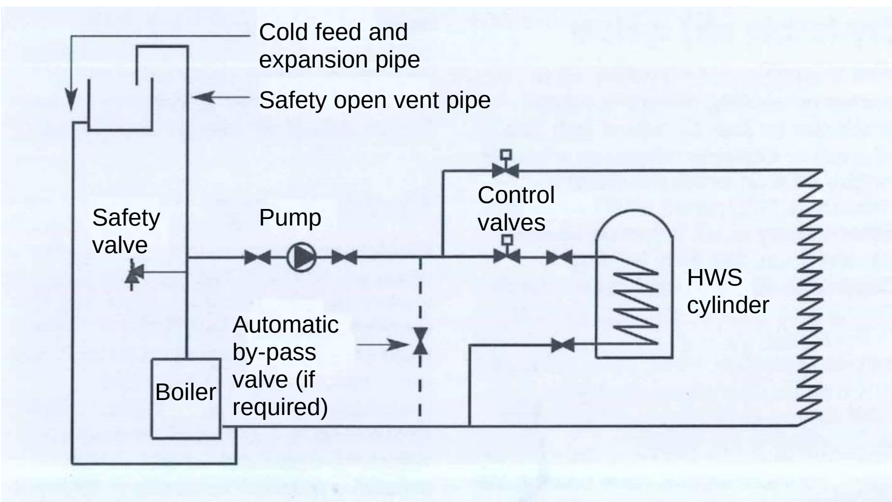
Wet system

In a wet system, the heat source is invariably a boiler burning gas, (natural or LPG), oil or solid fuel, or an electric storage boiler. Water is heated in the boiler and then pumped via a piping distribution system to the heat emitters, where the heat is given out. The cooled water then returns to the boiler for re-heating. Wet systems are adaptable, extendable (subject to capacity) and fully controllable and in domestic situations they usually also provide domestic hot water heating via an indirect cylinder.

Heat emitters are usually radiators or natural or fan assisted convectors, or underfloor heating may be installed, in which hot water is circulated through a network of underfloor pipes. This gives a very even level of heating, with no heaters to occupy wall space and the maintenance requirement and potential leakage risk is reduced. Underfloor heating can be installed within new floors and over all types of existing floors and offers proven energy consumption reductions in the order of 15-20%, compared to normal wet heating systems. The installation is usually carried out by specialist contractors.

Wet systems can be either open vented or sealed. With an open vented system a feed and expansion (F & E) cistern is located at least 1 m above the top of the highest heater or section of circulating pipework and connected to the system by a cold feed and expansion pipe.

Figure 2 Typical open vented system



The purpose of the cistern is to keep the system topped up with water and to accept the increase in system water volume as it heats up. The F & E cistern capacity to waterline should be not less than 18 litres plus 1/20th of the water content of the system, and the cold feed pipe should ideally be sized to contain the expansion volume of the system (usually means 22mm minimum size) and connected to the circulating part of the system with an anti-gravity loop. Terminating over the F & E cistern is the safety open vent pipe which must have an unobstructed path back to the heat generator and the function of which is to vent any air liberated from the heat generator and provide a relief for any steam produced as a result of a boiler thermostat failure.

With an open vented system the positioning of the pump in relation to the safety open vent and cold feed connections is very important if problems of pumping over, open vent aeration or suction leaks are to be avoided. As a general rule, position the pump on the flow after the safety open vent connection. In low head situations a combined safety open vent and cold feed is permitted, provided the boiler has a high limit safety thermostat. Always fit a diaphragm type safety valve if there is a risk of freezing.

A sealed system has no F & E cistern, cold feed or safety open vent pipe. The system is usually filled direct from the mains via a filling loop incorporating a double check valve, isolating valve and, ideally, a pressure reducing valve, to a pressure of approximately 0.5 bar above the static head from the fill point to the highest point in the system.

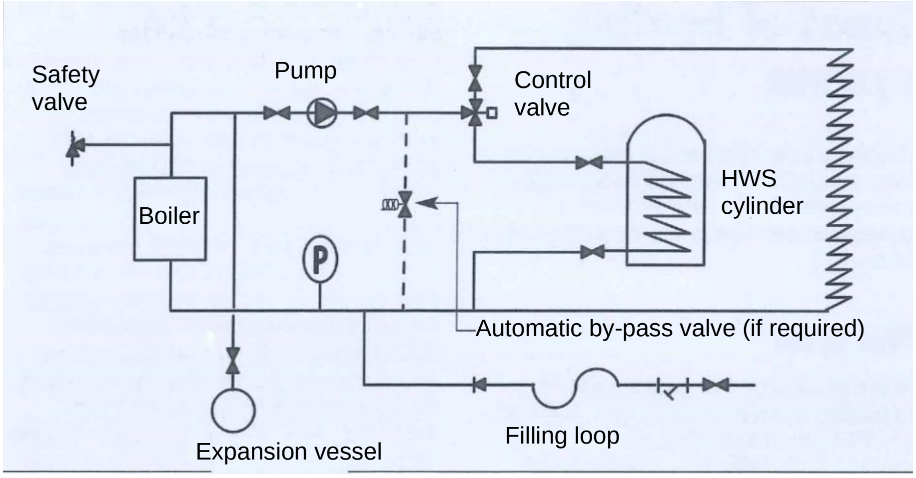


Figure 3 *Typical sealed system*

To accommodate the expanded water volume as the system heats up, an expansion vessel is connected to the system, which must also be fitted with a non-adjustable safety valve (diaphragm type) set at 3 bar. All boilers connected to sealed systems must have high limit thermostats. All gas combination boilers are of the sealed type, with the expansion vessel, safety valve and high limit thermostat all built into the unit and a number of ordinary boilers are now available as 'system boilers' with all necessary sealed system components built in.

A sealed system avoids the risk of freezing of the F & E cistern and associated pipework; overcomes problems associated with positioning of the cold feed and open vent connection to the system - a particular problem with low water content boilers - and drastically reduces the corrosion problems due to oxygenation of the system.

With any wet heating system, the pipework requires protection from damage/frost.

Dry (warm air) system

With a dry (warm air) system, air is heated by passing through a heater, which can be directly heated (e.g. gas or oil fired) or indirectly heated by a heater battery through which hot water is circulating. The heated air is discharged, either directly or via a ducting system, into the areas requiring heating. Depending upon the application, the air having given up its heat, may pass back to the heater, via a ducting system or by natural ventilation paths, to be re-heated, or it may be discharged to outside (e.g. toilet extract system) and fresh outside air supplied to the heater.

Warm air systems give rapid heat up but may lack control flexibility (particularly domestic) and ducted systems may be difficult to extend without major building works.

Commercially, ducted systems can be zoned, possibly with individually controlled heaters for each zone and/or motorised zone dampers and mixing boxes, but in domestic situations, due to cost limitations, they only offer a limited degree of control and separate provision has to be made for domestic hot water heating.

Radiant heating

Radiant heating systems are suited to situations with very high ceiling levels, or very high air change rates, with heaters usually of the gas fired 'radiant plaque' or 'tube' type.

Gas-fired radiant heating systems can be highly efficient and economical, with running costs of between 20% and 40% lower than alternative types of system. However, to realise these savings it is essential to correctly control the heaters (non-adjustable black bulb type thermostat) and consideration of access to the heaters for maintenance purposes must always be considered when evaluating the economics. The potential savings in running costs could be negated by the cost of installing a tower to give access for maintenance/repair.

Electric storage

Electric storage heating is possibly the cheapest to install, but lacks the inherent control flexibility of wet systems and is therefore invariably less efficient, unless used only for 'background' heating. They are suited to very well insulated properties with a heat loss around 4kW or less and refurbishment in properties where the installation of gas could present a potential hazard (e.g., high-rise flats). Most modern heaters incorporate charge and output controls and some electricity supply companies have tariffs which provide a mid-afternoon boost, as well as radio controlled charging periods.

Heat sources

With wet heating systems the heat source is invariably a gas or oil fired boiler, although solid fuel boilers may be found in areas without a natural gas supply.

Solid fuel boilers

Solid fuel boilers can be quite economical, especially the 'smoke eater' type units, which can burn bituminous coals in smokeless zones, but usually much more expensive to operate for heating the domestic hot water only during the summer - use electric heating for summer DHW, unless large quantities required. They need frequent maintenance, plus fuel storage facilities and, since the heat cannot be turned on and off in the same way as with gas or oil, they must have 'heat-sink'. They are not suited to fully automatic control.

The suitability for use of an existing chimney must be checked. Flue gas temperatures from solid fuel boilers will be considerably higher than with gas boilers and flues must be capable of withstanding these temperatures (around 1,200°C if any tar deposits catch fire) - suitable types are twin wall S/S insulated (some with additional ceramic lining) and refractory block flues. Existing chimneys must be checked for suitability for use - can be lined with insulating refractory concrete liners of 'cast-in-situ' refractory liner - single skin flexible liners must not be used. Consult a specialist if in doubt.

Gas fired boilers

Gas fired boilers, both natural gas and LPG fired, are available as floor or wall mounted models with conventional or balanced flues. Balanced flue boilers can be located in any room, and fan assisted balanced flue boilers do not have to be located on outside walls - some flues can be extended by up to 30m. There are limitations in the siting of conventionally flued boilers, particularly in relation to bathrooms, shower rooms and sleeping accommodation and reference must be made to the current Gas Safety (Installation and Use) Regulations. There are also restrictions on under stairs installation of boilers, as there are in relation to the manner and positioning of flue terminations.

For domestic and commercial boilers with atmospheric burners (flue gas temperatures up to 260°C), flues can be of single wall or flexible stainless steel type. To comply with the Gas Safety Regulations, one should never, generally, connect a new appliance to an existing flue liner - the liner should always be renewed at the same time.

For solid fuel boilers, commercial boilers with pressure jet burners and certain DFE fires, where flue gas temperatures can be up to 540°C, flues must be twin wall insulated or of refractory block/liner.

In commercial situations a ‘Monodraught’ type flue or fan diluted flue system can overcome problems of boiler location and fluing. The choice of system depends on location and it is advisable to seek the manufacturers advice relating to design/installation requirements.

Oil fired boilers

Oil fired boilers are available as conventional or balanced flue units, both floor standing or wall mounted. They require the provision of an oil storage tank (accessible for filling) plus connecting pipework to the boiler and safety controls. For conventional flues, check with boiler manufacturer for correct type, as this will depend on flue gas temperature - aluminium/ceramic/ clayware are not normally suitable.

See Building Regulations (Part J) and BS 5410 for detailed installation requirements.

Electric boilers

Some electric boilers are similar to a normal night storage heater, but incorporate a pump, heat exchanger and pipework for connection to the central heating distribution system. Since all the heat is stored in one unit the distribution of the heat output is far more flexible than with individual storage heaters and, provided any ‘boost’ consumption at the higher general tariff rate can be kept to an absolute minimum, although economical to run, they can be quite bulky and heavy.

Condensing boilers

Conventional boiler efficiencies are limited to around 80% to 83%, to keep the flue gas temperatures around 220°C and prevent condensation occurring in the boiler or flue. The annual efficiency of a conventional boiler will be around 67% (with a badly controlled system this can easily drop to well below 60%) compared to 87% for a gas fired condensing boiler, rising to at least 94% when fully condensing.

The only major difference between a condensing boiler and a fan assisted balanced flue boiler is that the condensing boiler has a corrosion resistant aluminium or stainless steel heat exchanger, with a very high heat exchange surface area, and a condensate collection and drain point. Installation is no more difficult than for a conventional boiler, the only additional requirement being a plastic drain pipe to a suitable drain connection. Do not run the condensate piping in copper, or connect it to copper or lead piping, since the condensate is mildly acidic and will corrode copper and lead. When the condensing boiler is working at its most efficient, ‘flue pluming’ is most prevalent.

System design is to normal parameters, as with a conventional boiler. Oversizing of heat emitters is not economically justified - 50% oversizing only improves efficiency by 2.4%. Even without entering the condensing mode, the boiler will still achieve an efficiency of around 87% compared to around 77% for a modern floor standing unit. With the cost of boilers steadily reducing, the increased capital cost can be quickly recovered through reduced running costs.

Condensing boilers are also available for operation with LPG (Propane), and oil.

Direct fired air heaters

Direct fired air heaters are available as balanced flue gas fired room heaters; conventional or balanced flue gas fired unit heaters; oil fired conventionally flued heaters and radiant gas heaters. There are numerous variations to suit different applications and they are usually quite efficient, due to them being individually controlled.

Note that in garages/workshops the combustion air supply to the burners should be ducted from outside.

Electric quartz radiant heaters, operating on normal tariff rates, will be very expensive to run, although they may be the ideal solution in certain areas requiring localised and intermittent heating.

Alternative heat sources

Three alternative primary heat sources which could be considered are: heat pumps, combined heat and power (CHIP) units and solar heating.

Heat pump

A heat pump operates in the same way as a domestic refrigerator, but in reverse - heat is removed from some ‘inexhaustible’ source (e.g. outside air, ground water) and discharged into the heating system, in the same way that heat is removed from the icebox and given out at the condenser coil at the back of the refrigerator cabinet.

CHP units

CHIP units are usually gas-fired and comprise of a gas driven internal combustion engine linked to an electrical generator. A high percentage of the energy that would otherwise be wasted as heat from the engine unit can be used to power the heating system, giving an operational efficiency in excess of 85%. For a client with a fairly constant electrical and heating demand, this can be an extremely efficient method of electrical generation.

Solar heating

Although fairly high levels of solar radiation are available in the UK, even in cloudy winter days, solar heating will only provide what is generally termed a ‘low grade’ heat source, such as is suitable for pre-heating domestic hot water and for heating of swimming pools.

All the above alternatives offer a variety of permutations and combinations, and it is essential to obtain independent and unbiased professional advice if any of these options are being considered.

Combustion air

With any fuel burning appliance it is vital that there is an adequate provision for combustion, cooling and flue dilution air. Full details of requirements are given in the Building Regulations, Gas Safety (Installation and Use) Regulations and relevant British Standards - the following summarises the basic requirements.

Unflued appliances

The concentration of carbon dioxide must not exceed 2800ppm where people may be present and ventilation must be provided by natural ventilation via permanent openings at high and low level, or by mechanical ventilation with airflow safety interlock.

Open flued appliances

These require permanent ventilation openings, either directly to outside or via adjacent room(s). Vents must be non-closable; must not incorporate any screens that could be blocked by dirt, insects, etc. and must not be positioned where they could be blocked by leaves, snow, etc. Vents through cavity walls must be sleeved. Always check effect of any extract ventilation fans on the operation of the flue. To correctly size the grilles, check the manufacturers' information on the percentage of 'free area'.

Balanced flue (room sealed) appliances

The design of these appliances places the air inlet and flue discharge in the same pressure zone. The only ventilation requirement may be for cooling purposes if the appliance is located in a compartment - some appliances do not require compartment ventilation - see manufacturers' requirements.

Inadequate ventilation can be lethal, particularly with gas fired appliances, it is the installer's responsibility to ensure that the complete gas installation and connected appliances are safe to use. A contractor working on a gas installation would be committing a criminal offence if he does not belong to a class of persons approved for the time being by the Health and Safety Executive.

Carbon monoxide poisoning causes cherry red appearance in victims face - remove victim from contaminated area and ensure continued breathing - administer oxygen if possible. See Table 1.

Table 1

% Saturation of haemoglobin with carbon monoxide	Symptoms
0.005	Threshold value
0.01	Slight headache in 2-3 hours
0.02	Mild headache, dizziness, nausea and sleepiness after 2-3 hours
0.04	Frontal headache and nausea after 1-2 hours; risk of death after 3 hours
0.08	Severe headache, dizziness, convulsions after 45 minutes; unconsciousness within one hour; risk of death after 2-3 hours
0.16	Headache, dizziness and nausea within 20 minutes; unconsciousness, risk of death after 1-2 hours
0.32	Headache, dizziness and nausea in 5-10 minutes; risk of death after 15 minutes
0.64	Severe symptoms after 1 to 2 minutes; death within 10-15 minutes
1.28	Immediate symptoms; death within 1 to 3 minutes

Boiler sizing

Boiler size is normally based upon the calculated heat loss plus 10% (or 15%), but with intermittently occupied buildings a margin of 20-25% may be more appropriate. If there is a great amount of pipework which is not giving off useful heat (e.g. beneath suspended or intermediate floors or passing through unheated voids or cupboards) an additional allowance must be included.

In domestic situations an additional 2 or 3kW is often added to the boiler load for domestic hot water heating, but with a well-insulated domestic dwelling this could represent around 30% of the total load and seriously reduce the boiler efficiency.

In the average domestic situation, with a well-controlled system and with a low capacity very high recovery cylinder (at least 20kW heat transfer capacity) and hot water priority, the inclusion of an additional hot water heating margin is unnecessary.

With the full boiler output switched to hot water heating, the short period of loss of space heating will not be noticed.

Where there is a requirement for a high performance shower, the domestic hot water heating load will be greater and is likely to constitute the largest element of the total boiler heating load. Calculation of DHW storage capacity is therefore a matter of achieving an economic balance between storage capacity and boiler reheat capacity, assuming a very high recovery cylinder with heat transfer capacity >boiler output capacity.

The following can be used to evaluate requirements:

Specific heat of water = 4.18kJ/kg°K.

1 Joule = 1 Watt for 1 sec.

1 kW/h = 3,600kJ.

Assumed cold water supply at 10°C and mixed water temperature at 40°C.

Useful energy stored in cylinder (H1 kJ.):

H1 = storage volume (litre = kg.) x (storage temp. - 40)°C x 4.18kJ/kg°K.

Re-heat potential from boiler (H2kJ.):

H2 = boiler output (kW) x $\frac{\text{draw off duration (min.)}}{\text{60 min}}$ x 3 600kJ

Required energy (H3 kJ.) :

H3= Draw off volume (litre = kg.) x (40 - 10)°C x 4.18kJ/kg°K.

To meet load, H3 = H1 + H2

Heat emitter selection

Types of heat emitters

The common steel panel radiators are available with single or double panels and with fins welded to them to further increase output. Radiators manufactured from steel are also available in a variety of shapes and designs, as are ones manufactured from aluminium, copper, cast iron and even plastic, but they are more expensive than the steel panel type. In certain circumstances, such as with the elderly, infirm or young children, it is necessary to use low surface temperature radiators. Radiators give approx. 80% of their output by convection and 20% by radiation.

There should be at least 100mm clearance from the top of the radiator to any sill above and 150mm clearance below for the pipework and connections.

A long, low radiator will give better heat distribution than a tall one (note emission penalty) and avoid locations covered by furnishings. Natural convectors will give a quicker heat-up than a radiator and can be either wall mounted or of the skirting or under floor type.

Fan convectors will give an even faster heat up and can be time/temperature controlled. They are very compact and can be built into fitted units, bench seats or stairways; mounted at high level or recessed into floors. Significant savings can result if the operation of the fan convector can be linked to a touch activated timer control or occupancy detector. Ensure the path of the airflow is not obstructed by any furniture.

Choice and positioning of heaters

Heat is given out in two ways - by radiation and by convection. With radiant heating, the heat rays given out strike any surfaces in their path, such as people, furniture, and walls, and warm them up - these surfaces then in turn heat the surrounding air. With convective heating the heat warms the air which in turn heats the surfaces it comes into contact with, as it circulates around the room. Occupancy pattern/use of area will influence selection of emitter type.

Comfort depends not only on the air temperature but also the average radiant temperature (Mean Radiant Temperature - MRT) of all the surrounding surfaces - the lower this average temperature the higher the air temperature must be to give comfortable conditions. Around 20% of the heat output from a radiator is by radiation and the remaining 80% is given out by convection - a reasonable balance for most domestic situations, where the radiant level will balance the effect of colder external wall surfaces. With highly insulated buildings, a faster responding convective heater may be more appropriate.

If radiators are positioned on outside walls, significant savings (5-10%) can be achieved by putting reflective foil faced insulation behind the radiators.

Avoid obstructing any electrical socket outlets. If using a fan convector, ensure the path of the airflow is not obstructed by any furniture.

Heat emitter sizing

To size a heater it is first of all necessary to decide on the system flow and return water temperatures. The ‘conventional’ temperatures for low pressure systems are 82°C flow and 71 °C return (180°F/160°F) giving a mean water temperature of 76.5°C for heaters on a two-pipe system, it is worth considering basing the design on 82°C/68°C flow and return, in order to reduce pipe sizes and flow rates. There is no reason why the temperature differential cannot be even higher, but attention must be given to any limitations imposed by the boiler manufacturer, and the saving in pipe sizing may be offset by the necessary increase in radiator size.

The generally accepted method of sizing radiators is to add 10% to the calculated room heat loss and select the nearest sized radiator. With the variations in the UK Winter climate during recent years, a 15% margin may be considered more appropriate., especially if heating is very intermittent. It is not normal in domestic situations to consider internal heat gains from people and equipment, since these can be intermittent.

Prior to 1-7-97, radiator outputs were based on BS 3528:1977 which specified a mean water to room temperature difference of 60°C and pipe connections at top and bottom opposite ends (TBOE). With normal system flow and return temperatures of 82/71 °C the outputs will therefore be lower. Table 2 gives the correction factors with which the manufacturers figures must be multiplied for 82/71 °C flow and return temperatures and varying room temperatures, plus other correction factors for varying methods of installation.

All the correction factors below are cumulative, so for a radiator with a rated output of 1500W installed in an open recess in a room at 20°C with BOE connections, its output will reduce to 1500 x 0.9 x 0.85 x 0.90 = 1032W.

From 1-7-97, radiator outputs have had to comply with EN-442 which requires that quoted outputs are based on a mean water to room temperature difference of 50°C - this will result in the quoted outputs being reduced by around 20%. Also, testing has to be carried out, or quoted outputs adjusted, to equate to pipe connections at top and bottom same ends (TBSE), thus requiring a deduction of 8-9% from quoted outputs to allow for bottom opposite end connections - the normal in the UK. Virtually all UK radiator manufacturers still quote outputs based upon 60°C temperature difference, the figures shown in their catalogues being adjusted from the 50°C difference at which testing is carried out.

Oversizing will result in reduced system efficiency due to temperature overshoot. As a general guide one heater will satisfactorily cover up to 20sq. metres.

Piping system design and sizing

The most common type of heating distribution system is a two-pipe system, although there are many older single-pipe systems still in existence.

Two-pipe system

The two-pipe system will have separate flow and return pipes with the flow and return connections to each heater connected to the respective flow and return pipes.

Two-pipe systems are always pumped and have the advantage of a positive (pumped) flow of water through each heater. Copper piping systems of 15-28mm size are referred to as ‘small-bore’.

Table 2 *Correction factor for radiator outputs*

Room temperature	Correction factor for radiator outputs
16	1.00
18	0.95
20	0.90
22	0.87
Connections top bottom same ends (TBSE)	1.04
Connections bottom opposite ends (BOE)	0.85
Radiator length greater than 5 x its height	0.93
Radiator in open fronted recess	0.90
Radiator in recess with front grille	0.80 and lower
Radiator shelf above	down to 0.90
Metallic paint finish	from 0.9 to 0.8

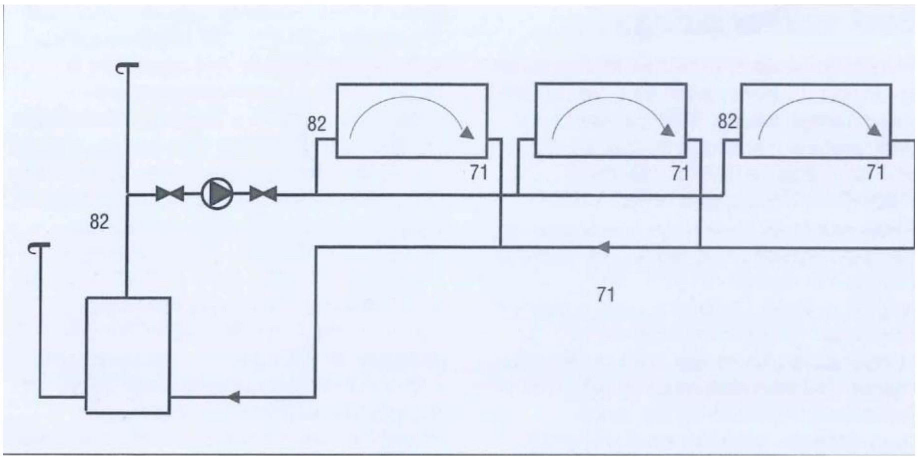


Figure 4 *Two pipe circuit circulating temperatures °C*

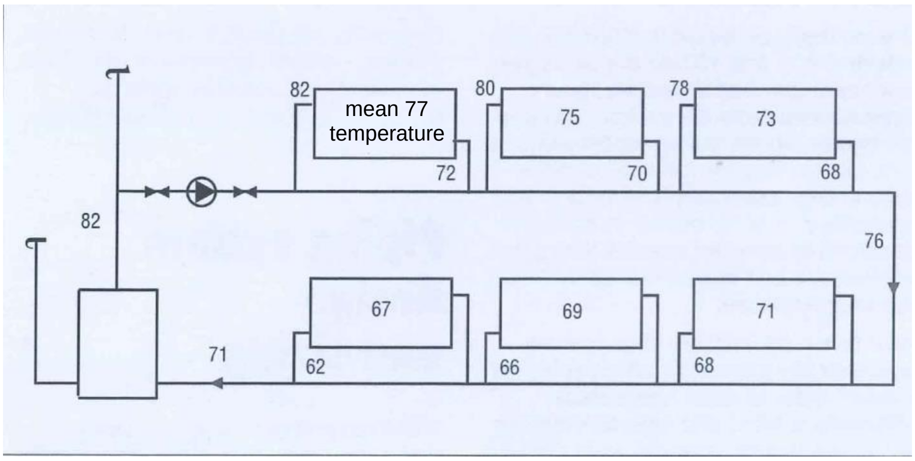


Figure 5 *Single pipe circuit circulating temperatures °C*

An option (usually for domestic situations) is a 'microbore' system in which the main flow and return from the boiler, connect to manifolds from which the radiators are individually connected by 8mm or 10mm pipes. Being flexible, the pipes can be 'threaded' between floor joists etc. in much the same way as electrical cables, so avoiding having to use fittings. Installation is simplified, but the system has to be very carefully designed and a more powerful pump is needed to circulate the water through the small pipes as well as specially designed 'twin- entry' radiator valves.

There are several variations for commercial installations, including 'ladder' or 'reverse return' configurations.

Single pipe systems

With single pipe systems, water circulates around one or more single pipe loops with the radiator flow and return connections connected from the same pipe loop, the return connection being downstream of the flow. Whilst circulation is usually pump assisted, the circulation of water through each radiator is primarily by gravity, although it can be aided by the use of diverter tees, and connections must be top/bottom opposite ends (TBOE).

Although there is less pipework to install, a single-pipe system must be carefully designed and it cannot be used with convectors, which must have a pumped flow of water through them to achieve the rated output.

Since the water temperature around the pipe loop(s) will progressively drop as it passes each radiator, the radiators towards the end of the circuit will have to be larger than they would be for the same output on a two-pipe system, where there would be little variation in flow temperature from one end of the system to the other.

A variation on the basic single pipe system is the 'loop-in' system whereby the pipework loops in and out of a single two connection valve on each radiator - the valve incorporates a by-pass so that some of the water enters the radiator whilst the remainder goes through the by-pass and is joined by the cooler water leaving the radiator - and the mixed water leaves the valve through the second connection and passes to the next radiator on the circuit. This gives a more positive flow through each radiator.

Pipe layout and sizing

Before sizing a piping system, it is necessary to decide upon the position of heaters etc. in order that pipe routes can be decided, with due regard to the constructional details of the building and any client requirements. If installing a heater in a bathroom, it is a good idea to connect it from the outlet side of the pump before any control valves. It will then heat up whenever the boiler comes on and not be dependent on the remainder of the house requiring heating. If installing a solid fuel boiler, at least one heater must be connected on a separate gravity circuit from the boiler to provide a 'heat sink'. If most of the heaters can be picked up on one or two pipe loops, then it may be worth considering a single pipe system. Heaters will have to be sized to take account of the reducing water temperature, and they must be connected top bottom opposite ends and always with the return connection downstream of the flow. Convectors and hot water cylinders cannot be put on a single pipe circuit. Mixing microbore and smallbore is quite permissible, provided the pipework and pump are correctly sized.

Always connect a hot water cylinder primary return to the combined heating and DHW return pipe downstream of the last heating return connection, to avoid possible reverse circulation problems.

Correct pipe sizing is essential if problems of insufficient water flow to the farthest radiators on the system are to be avoided. Having determined the piping layout, the heating load on each section can be calculated and the provisional pipe size can be determined from Table 3, which is based on a flow rate corresponding to an 11°C. system temperature drop and also shows the heat loss from uninsulated and insulated pipe.

For domestic systems it is generally unnecessary to carry out a detailed pipe sizing, with proportioning of mains losses, etc., as one would do for a commercial situation. However, it is a good idea to carry out an accurate pressure drop calculation, in order to check the adequacy of the pipe sizing and check the pump duty.

The procedure for this can be summarised as follows:

1. Total heating loads in each pipe section and convert to flow rate in l/s (same as kg/s). The following conversion formula can be used:

Table 3 Heat losses

Pipe diameter (mm)	Maximum load (watts)	Heat loss/m	
		Bare (watts)	Insulated (watts (9mm thick))
6	650	20	4
8	1300	27	6
10	2100	32	7
15	5500	46	10
22	11000	63	12
28	18000	78	14
35	28000	95	15

Load in kW x $\frac{0.23825}{\text{Design temp drop K}}$ = flows in l/s

2. Measure length of each section of pipe and add allowance for equivalent length of fittings.

NOTE:
This is a simplification of the procedure of multiplying the pipe equivalent length at a particular flow rate by the fitting velocity pressure loss factor.

3. Determine pressure drop in Pa/m for the flow rate in the pipe size concerned and multiply by the total length from 2x2 (flow & return) - this gives the pressure drop in that section of pipe. If the resultant velocity >1m/s or pressure drop >400Pa/m, then increase pipe size.

4. Total all calculated pressure drops from the boiler to the radiator at the end of each of the distribution circuits, adding the resistance of the boiler and any control valve - some circuits may have common sections of piping. The circuit with the highest resistance is the Index Circuit and gives the required pump head at the system flow rate - the pump selection can then be made.

A reduction can be made in the heater sizing for each metre run of exposed copper pipe, based on the outputs in the preceding table. These figures will vary depending upon room and water temperatures, etc. but are sufficiently accurate to be used with the normal range of water and room temperatures. If the pipe emission is too high, the efficiency of the system control could be adversely affected.

Gas and oil piping installations

Gas piping systems must be designed and installed in accordance with the requirements of either BS 6891:1998 Installation of low pressure gas pipework up to 28mm. in domestic premises' or Institution of Gas Engineers publication IGE/UP/2 'Gas installation Pipework, Boosters and Compressors on Industrial and Commercial premises'. The requirements for LPG is covered in the CITB Study Notes Publication ME 210.

Oil supply systems should be in accordance with BS 5410:Part 1:1977- CoP for Oil fired installations up to 44 kW output or Part 2 for above 44kW.

Domestic hot water - types of system

Vented (storage) systems

In domestic premises with a heating system, the normal method of providing domestic hot water is via an indirect hot water storage cylinder, with the cold water supply from a cold water storage cistern. The efficiency of such a system will vary considerably - it is essential that the cylinder is very well insulated . Building Regulations require the use of factory applied insulation. Primary heating pipework between the boiler and cylinder must also be insulated.

A very basic system, with time switch control, gravity circulation to the cylinder coil, and no controlling thermostat on the cylinder to shut off the boiler when the temperature of the stored water is hot enough, may have an efficiency as low as 30% during 'hot water only' heating. If the primary heating pipes are uninsulated, even lower efficiency will result.

The efficiency will improve with the addition of full thermostatic control.

The efficiency of a fully pumped system can be considerably increased by installing a cylinder with a low storage capacity which has a very high recovery rated coil cylinder, far in excess of a normal BS cylinder.

With low storage capacity and very high heating coil surface area (heat exchange capacity up to 30kW or more), heat is transferred to the stored water as fast as the boiler can provide it. The boiler does not cycle 'on' and 'off' during the heating period and a hot water only system efficiency of well in excess of 75% can be achieved. The use of a high recovery cylinder enables the boiler input to be taken into account when calculating domestic hot water storage requirements since it will be re-heating the water to a significant extent, even during a relatively short draw-off period.

With a typical 60 litre cylinder and a gas fired boiler of 17kW output, the entire contents will be heated from cold to 60°C in around 15 minutes if the boiler is hot to start with, and 18 minutes if starting from cold. With a 22kW boiler, these times reduce to 10 minutes and 17 minutes The very fast recovery means baths can be run at around 10-15mins. intervals, but use with a 'hot water priority' control system. The inclusion of a pump over-run thermostat to transfer residual boiler heat to the cylinder, will further increase the system efficiency, by around $^1/_2$-1%.

Advantages

i. Large quantities of hot water available quickly

ii. Once heated, availability of water unaffected by gas or electric supply failure.

Disadvantages

i. Water pressure may be inadequate for a good shower

ii. Considerable re-heat time once hot water drawn off (unless a high recovery cylinder)

iii. Requires cold water storage cistern, with consequent frost protection problems if located in a roof void

iv. Wasteful heat loss from stored hot water when no demand

v. Space required for storage cylinder.

Unvented (mains pressure) systems

All cold water outlets and the hot water storage system are fed directly from the mains, giving very good outlet pressures, suitable for high resistance terminal fittings, such as single lever operation taps - balanced hot and cold pressures will result in improved mixing and less wastage of water, with consequent reduced running costs.

Water is heated directly or indirectly in a purpose designed insulated storage cylinder, either of copper or lined steel. Expansion is accommodated in a small expansion tank and a number of special safety controls are fitted. Suitable cylinders with expansion tank and safety controls are available as packaged units to serve just a few basin taps or a complete dwelling. Direct gas fired units are also available, although these would normally be used for larger installations.

Mains pressure hot water can also be provided by combination boilers, multipoint water heaters (gas or electric) and point-of-use electric heaters. If installing a combination boiler, ensure the gas supply is adequate - input can be >35kW for DHW heating. When comparing different makes, ensure you compare like with like - DHW output claims may be based on 25°C, 30°C or 35°C temperature rise.

Advantages

i. Cold water storage cistern not required
ii. Possible cheaper installation cost
iii. Removes problems of freezing of roof pipework etc
iv. Reduced running costs
v. Very good water pressure at outlets and better shower performance.

Disadvantages

i. Requires annual maintenance check of all safety controls by qualified plumber
ii. May show up defect in existing piping installations when converted to the higher pressure un-vented operation.

Mains fed instantaneous systems

Usually supplied by a wall mounted multipoint gas fired water heater or combination gas fired boiler. Some multipoint units have fan assisted flues and can be located up to 3m from the outside wall. Outputs can be up to 35kW and most units will also supply a shower, in conjunction with a suitable thermostatic mixer.

In hard water areas a water treatment unit should always be installed on the mains supply to the heater. It is also advisable to insulate any long runs of hot water supply pipework to reduce heat loss between the heater and taps.

Thermal storage system

A thermal storage system provides mains pressure hot water to all points of use, in the same way as a multipoint heater. Heating water from the boiler is passed through the shell side of the cylinder and the mains water is passed through the coil to supply all the taps - the volume of heated water is small, so all the safety devices of an ‘unvented system’ can be omitted, although the installation of a small expansion vessel to act as a ‘shock arrestor’ is advisable, as is a thermostatic mixing valve. The heating circuit is separately pumped, either from the shell side, or via the second coil. See below. Such a system may give improved boiler part load efficiency and the thermal store provides rapid response to both hot water and heating system demand. The primary circuit pump will be of a low head type and the potential for system aeration problems will be reduced. The inclusion of a pump over-run thermostat will further increase the system efficiency.

The heating circuit could be a completely separate sealed system with its own expansion vessel and safety valve, whilst the boiler remains on a low head open vented system. The latest packaged units combine both a condensing boiler and thermal store in one insulated unit, together with purpose designed controls, and have a resultant energy saving potential.

Electric water heaters

Electric mains fed instantaneous water heaters are generally restricted to supplying a single outlet and small electrically heated ‘point of use’ storage units of 7 litre capacity, capacity can be installed above or below a working surface - they require special taps to provide a vent and prevent pressure build-up. They avoid having to heat a large quantity of stored water at a time when only a small amount is required.

Inlet water treatment should be considered in hard water areas, although the majority of electric heater elements are easily removed for de-scaling.

Alternatives and design considerations

Where the points of demand are a considerable distance apart, or demand is of a low level, consideration should be given to the installation of individual ‘point of use’ heaters. In a large dwelling, with an en-suite bathroom remote from the main area of demand at the kitchen and main bathroom, consideration could be given to the installation of two independent low storage/high recovery cylinders.

Another option would be to install a single cylinder with a self-regulating electric trace heating cable on the very long dead-legs.

In the majority of small commercial situations demand is low, and can be met by local point-of-use heaters, but occasionally one is involved in a project requiring large quantities of water. Under these circumstances, a dedicated gas fired water heater may be the answer, which can be cistern or mains fed. If the high demand is on a very intermittent basis (e.g. showering) and there is a heating system installed, then another option would be to install a non-storage system with a plate heat exchanger, which is heated on a priority basis by the boiler plant.

Advantages

i. Cold water storage cistern not required (unless for c/w outlets)
ii. No space required for hot water storage (except thermal storage)
iii. Hot water always available at the turn of a tap
iv. Possibly cheaper installation cost than a storage system (except thermal storage)
v. No wasteful heat loss from stored hot water
vi. High water pressure available at outlets.

Disadvantages

i. For a gas multipoint heater an adjacent outside wall and a gas supply is required
ii. Slower delivery rate of hot water than with a storage system
iii. Electric heaters are expensive to run if quantities of water are required - they need a separate electrical supply.

When designing any mains-fed system, storage or instantaneous, it is essential that the adequacy of the cold water main supply is checked for maintenance of adequate flow/pressure under periods of high demand/drought.

Water Regulations are very explicit in their requirements to avoid wastage or contamination of water supplies and everyone who is involved with the design, specification, installation and maintenance of domestic water systems must ensure that they comply with the requirements of the various legislative documents relating to the prevention of Legionella.

Piping installation

1. Avoid placing bends or other fittings close to the inlet or outlet of pumps, as this can cause cavitation under certain conditions. If possible, aim for a 450mm length of straight pipe both sides of the pump.
2. Fittings which offer a high resistance to the flow of water can give rise to noise generation and problems of inadequate flow. Generally, compression elbows and end feed elbows have a far tighter radius than integral solder ring elbows, and therefore offer a higher resistance to flow. Note that microbore pipes are vulnerable to damage and blockage and there may also be noise problems due to high water velocities at any restrictions.
3. Always consider requirements for venting and pre-commissioning cleansing and maintenance, and include adequate provision for drainage. At least two 15mm valved full bore drain points should be provided at low points in the system to enable it to be adequately flushed through, positioning with regard to flushing paths, avoiding short circuiting.
4. Generally, the maximum safe depth for notching a floor joist is 0.15 x the joist depth, with a maximum width of 1.5 x the pipe width, and a maximum of two pipes in a single notch. The maximum diameter for a hole drilled through a joist is 0.25 x the joist depth, with the centre line between 0.25 and 0.4 of the joist depth down from the top.
5. Indicate on the floorboards with a felt marker pen the route of pipes under suspended floors.
6. Ensure all high points are adequately vented and that air vent points, compression joists and any other potential sources of water leakage are not positioned over any electrical equipment.
7. Do not use softened water to fill a system (or add washing-up liquid !!) - the high salt content can result in serious corrosion problems.
8. Only use the very minimum amounts of flux when making soldered joints and use a pre-commissioning cleanser.
9. If there is a risk of the installation being left switched off during freezing conditions, use an anti-freeze as well as a corrosion proofer or provide frost protection controls.
10. Always connect the DHW cylinder primary return as the last connection on the return pipe to the boiler, after any heating return connections to avoid reverse circulation problems.
11. Install pumps vertically, to self-purge of air, and with the shafts horizontal (not below) to reduce bearing load and wear. Fit valves each side and do not position at system low point.
12. If installing a combined cold feed and open vent, in order to comply with British Standard 5449:Pt1:1990 the boiler must be fitted with a high limit safety thermostat.
13. Do not install a new boiler or equipment into an existing system without cleansing it thoroughly. Avoid fabricated or aluminium heat exchangers if the system is not chemically cleaned. Consider the requirement for a strainer on the return to the boiler.
14. Use reflective radiator film over pipes which are immediately below floor boards to avoid degradation of floor covering.
15. Always fuse the control system at 3A and mark the plug/connection unit accordingly.
16. The electrical supply to an immersion heater must be run directly from the distribution board, and must not feed any other equipment.
17. When an existing system cannot be drained, a self-cutting tee can be used to provide a drain point.
18. Use pipe clips that completely enclose the pipe and metal strapping for suspending pipes below floor joists.
19. Use good quality lever operated quarter turn ball valves rather than gate valves for ease of future maintenance.
20. Install temporary equipotential bonds if breaking electrical continuity of existing pipework, to protect operatives and third parties.
21. Use non-dezincifiable fittings on domestic water services.

By-pass connection

For boilers fitted with pump over-run thermostats it is essential that there is always an open circuit for the water to be pumped around. If all circuits can be closed off by motorised or thermostatic valves, a by-pass is required - use an automatic pressure operated by-pass valve to avoid loss of boiler operating efficiency. If the system has a three-port motorised control valve, or if there is some other permanently open circuit, such as via a bathroom radiator (without hand-wheel valve), there is generally no requirement for a by-pass connection, but check with boiler manufacturer.

Controls

However well designed a system, its ultimate efficiency will depend upon the method of control. The basic requirement of any control system is to provide the correct amount of heat in the right place at the required time, and to ensure that the boiler is switched off when there is no system demand for heat.

The main components of a control system will usually be a programmer to enable selection of system operating times; thermostats to control the space and, where applicable, domestic hot water storage temperature and motorised valve(s) to control the circulation of heating water to the different circuits (e.g. space heating and domestic hot water heating).

Modern programmers are of the electronic type (rather than electro-mechanical) and either battery operated or mains operated with a battery reserve (alkaline or rechargeable). Some are very basic in operation, whilst others offer three or more switching cycles a day, with separate times for heating and hot water plus separate programming for each day of the week or weekdays and weekends. Such flexibility offers greater potential for energy saving, but consideration of the occupants ability to operate the unit must be taken into account.

Thermostats

Modern room thermostats can be either of the electro-mechanical type, (with either a bi-metallic strip or vapour- filled bellows) or electronic type. Electromechanical type thermostats often incorporate accelerator heaters (requiring a neutral connection) to reduce the temperature overshoot with radiator systems and some also have a night setback facility. Modern electronic room thermostats achieve much better control, with a differential of around 0.5°C. Since each 1°C rise in temperature above that required will increase fuel consumption by about 7%, the energy saving potential of the electronic thermostat is readily apparent. Cylinder thermostats are invariably of the electro-mechanical type with a differential of around 6-10°C to prevent excessive boiler cycling.

Programmable thermostats

Programmable room thermostats comprise a single channel electronic programmer and a room thermostat in one casing. They are often used where the boiler does not provide domestic hot water storage (e.g. the 'combi' type), or for zone control. Being of the electronic type, they give close temperature control and offer programming on a daily basis with as many as six timed periods a day, each at a different temperature setting. They all have battery back-up, or are battery operated. The 'off' periods are determined by selecting a timed period at a reduced temperature (e.g. 14°C), effectively giving frost protection.

Thermostatic radiator valves

Thermostatic radiator valves are simple to install, requiring no electrical supply, and can be installed to give temperature control in individual rooms. They should not be installed on all radiators as there would be no means of automatically stopping the boiler and pump when the demand in all areas is satisfied, with the valves having closed. The energy saving potential of the valves can be completely lost due to the continued operation of the pump, with water circulating via a continuously open or automatic by-pass valve controlled by-pass loop, and inefficient cycling of the boiler under the control of its thermostat. The Building Regulations require the installation of a room thermostat, to shut the boiler off when demand is satisfied. The thermostat must be located in an area that is representative of the temperatures in the property and there must be no thermostatic radiator valves in that area.

Their use should be limited to selected locations which are subject to external heat gains, or areas which require keeping at reduced temperature for long periods (e.g. spare bedrooms).

Motorised valves

Motorised valves will either be of the two-port or three-port type. Two-port valves are also called 'zone valves' and can be used to control the flow of water around individual circuits (space heating or domestic hot water heating). There may be a boiler requirement for by-pass, particularly where it has a pump-over-run thermostat, to ensure that there is always an open path for water circulation.

Three-port valves have one inlet port, connected from the boiler flow (usually via the pump) and two outlet ports. The outlet ports will, typically, connect to the hot water cylinder heating flow and the radiator circuit flow, although they could both connect to two different zone heating circuits. The valves are either of the diverting (two position) or mid-position type. A diverting valve is driven by its motor to allow water to flow to one or other of the two outlet ports, as required by the controlling programmer/thermostat - usually give priority to the hot water cylinder heating. A mid-position valve allows the water to flow to either of the outlet ports, or both at the same time. Use of a three-port valve ensures that one port will always be open to maintain a flow path for the water and may avoid the need for a boiler by-pass.

Electronic controllers

There is an increasing use of more sophisticated electronic controllers in domestic systems and these fall into three categories: compensated control; optimising time control, and boiler short-cycling control.

Compensated control

Compensated control is a method whereby the amount of heat that is put into the building is automatically varied, depending upon the outside temperature and therefore the rate of heat loss from the building. This is achieved by either varying the temperature of the water flowing around the heating circuit, over-riding the boiler thermostat, or by varying the length of the boiler 'on' periods. This method of control is more efficient than a simple room thermostat control, and overcomes the problem of siting the room thermostat in a position that is truly representative of the average conditions in the house.

Optimising time control

Optimising control is well proven in the commercial/industrial sector, and now coming into the domestic sector.

The basic principle of operation is that you programme the occupancy period and required temperature and the controller then calculates the latest switch 'on' time, based on the preceding ambient temperature. Can also provide optimum 'off' control.

Boiler short cycling

Boiler short cycling controls operate in conjunction with a normal room thermostat controlled system, and delays the boiler firing for a timed period. Some are simply electronic delay timers which delay boiler firing for a timed period, regardless of level or frequency of demand, whilst others take into account demand frequency. They have little energy saving potential and their use with certain types of systems may actually increase energy consumption.

Underfloor heating systems

There is available a complete range of low pressure hot water underfloor heating systems suitable for all types of buildings. This includes different floor constructions such as screed, concrete and timber suspended.

Systems are also available for the refurbishment market using special thin screeds and dry construction techniques.

The design principles, however, are common to all systems and need to be understood.

Underfloor systems operate by means of embedded loops of pipe connected via a manifold to the flow and return sides of the heat source. See Figure 6.

Each loop or circuit can usually be controlled and/or isolated on both the flow and return.

Systems will normally be designed to operate at low water temperatures of between 40°C and 60°C and a temperature drop of between 5 and 10°K across the system.

Virtually all systems today use non-ferrous plastic pipe instead of ferrous or copper material. By laying modern polymer plastic pipe in continuous coils without joints it is possible to avoid many of the problems associated with systems in the past. Modern polymers do not corrode or attract scale and are in many cases capable of outliving the useful life of the building.

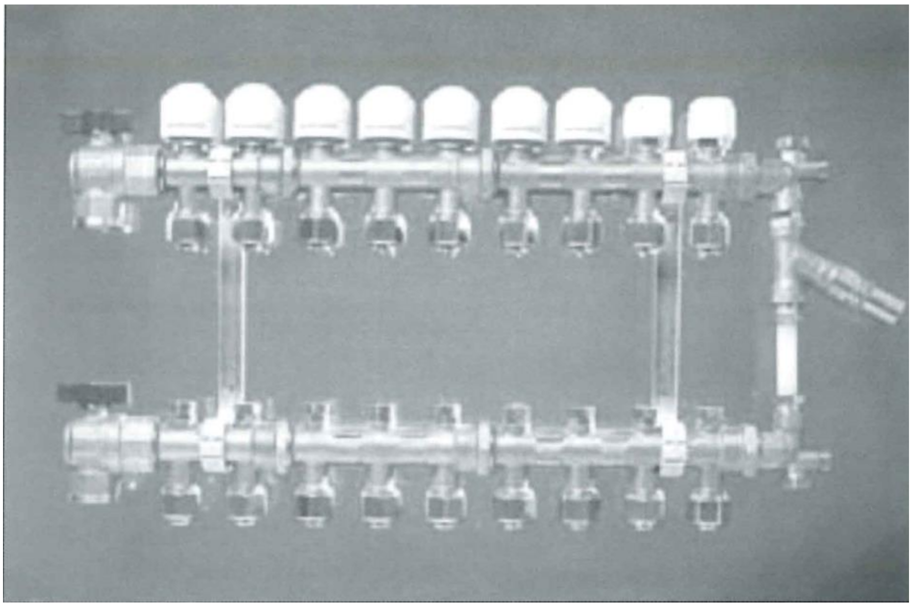


Figure 6 Typical manifold

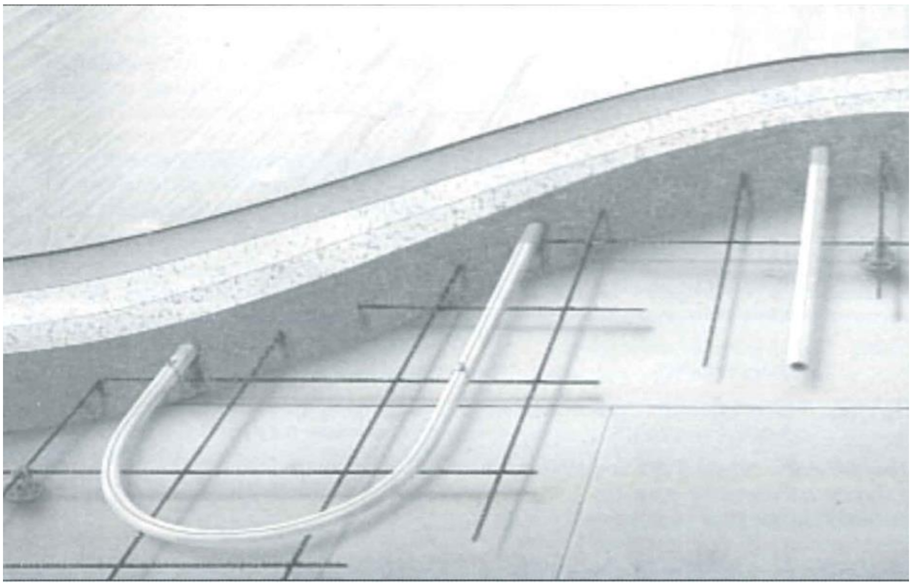


Figure 7 Solid floor construction

The most common materials in use today are:

PEX: Cross linked Polyethylene

PP: Co-Polymer of Polypropylene

PB: Polybutylene

All pipes should ideally incorporate a diffusion barrier, which can be either integral or applied to the outside of the pipe as a coating. The purpose of the barrier is to reduce the amount of oxygen that can migrate through the pipe wall. Pipes without a diffusion barrier will pass much higher rates of oxygen thereby providing a highly oxygenated water circulation around the heating system. If the heating system is not fully protected by a corrosion inhibitor, then rapid corrosion of any steel components within the heating system can occur.

Better insulation standards in our buildings have meant that most floors are now insulated as standard. This means that for most buildings the installation of the underfloor heating will be no more difficult than any other form of heating.

The basic form of floor construction in most buildings is solid concrete, floating or suspended. There are many different ways in which various underfloor heating manufacturers design their systems and it is only possible to deal with some of the standard methods of construction in this publication.

The following are typical floor sections of the three most common types.

Solid floor construction

Typical floor make up:

a. Oversite

b. Concrete slab

c. Insulation

d. Underfloor heating pipes

e. Floor screed

f. Final floor finish.

On some buildings, the insulation will be fitted below the slab in which case the pipes can be installed within the concrete slab. See Figure 7.

The above construction is used for both ground bearing and suspended slabs.

Floating floor construction

Typical floor make up:

a. Oversite

b. Concrete slab

c. Pre-grooved insulation fitted with heat emission plates

d. Underfloor heating pipes

e. Floor boarding

f. Final floor finish.

This design is often used on pot and beam construction where the finished floor is flooring grade chipboard laid over the underfloor heating system.

The specially adapted insulation, which is usually pre-grooved to accept the pipe and heat emission plates, is designed for full floor loading. The use of heat emission plates ensures that the floor temperature will be even across the whole floor area. See Figure 8.

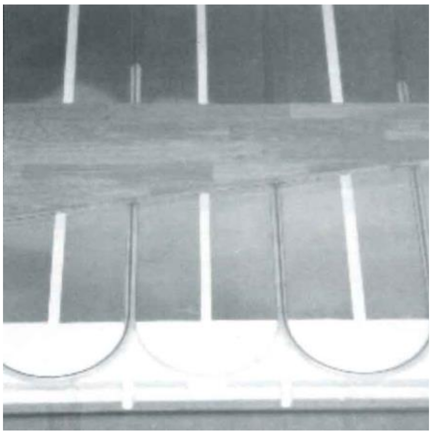


Figure 8 Floating floors construction

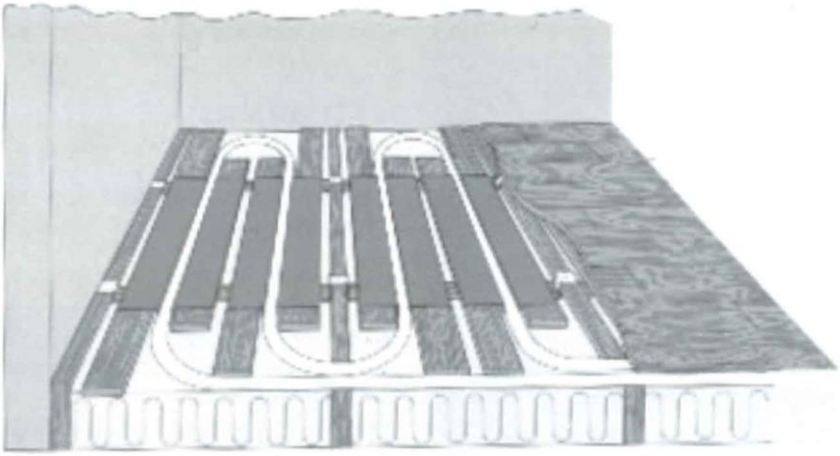


Figure 9 Suspended floors

Suspended floor construction

Typical floor make up:

1. Timber joists or battening
2. Insulation between joists
3. Cross battens
4. Heat emission plates fitted to cross battens
5. Underfloor heating pipes
6. Floor boarding
7. Final floor finish.

This design is suitable for most types of joisted or battened floors. The cross battening fitted at 90° to the joists means that a consistent pipe centre can be maintained irrespective of the joist centres. This particular system also avoids any notching of the joists.

There are many variations on all the standard floor sections and there are systems available today which can be adapted in a variety of ways to meet the building design.

Insulation would be fitted to most floors irrespective of the construction method and this would need to meet the requirements of the Building Regulations. The downward heat transmission can be calculated in several ways. For ground bearing slabs the most common formulae used is:

$$U_{slab} = \left\{0.05 + \left(1.65 \times \frac{P}{A}\right)\right\} - \left\{0.6 \times \frac{P^2}{A}\right\}$$

U_{slab} = U value of un-insulated slab W/m^{2}K

P = External Perimeter of Building m

A = Total Area of Floor m^2

By using the above formula, the ‘U’ value of the un-insulated slab can be calculated. Once this value is known the amount of insulation required to bring the floor up to the standard required can be calculated.

For an insulated slab the formula would be:

$$U_{insulated} = \frac{1}{\left(\frac{1}{U_{slab}}\right) + R_{insulation}}$$

Where :

$U_{insulated}$ = U value of an insulated slab W/m^2 K

U_{slab} = U value of un-insulated slab W/m^{2}K

$R_{insulation}$ = The thermal resistance of the insulation W/m^{2}K

The selection of a suitable insulation material will normally be made in conjunction with the architect to ensure the material will meet the floor loading requirements in addition to the level of insulation required.

For suspended floor slabs, the calculations are more complex since an enclosed air space is introduced below the slab, which can often have a high infiltration rate.

It must be remembered that with underfloor heating a solid screed or concrete floor will have a higher mean temperature than a floor constructed without underfloor heating. For this reason most floors will require a degree of insulation to be fitted to offset any downward losses.

Design considerations

The human foot is a highly effective thermostat for the whole body. In the colder areas of the world human kind has been keen to ‘take the chill off the floor’ since ancient times. The techniques used to achieve this range from the simplest rugs and skins to the more sophisticated hypocaust system of the Greeks and Romans.

Research shows that a basic temperature of 21 °C on the floor surface will give an ideal sensation of comfort. International Standards indicate that the comfortable range is between 19-26°C and dependent upon the required air temperature, floor heating systems should stay within this band.

Most areas are permitted with design floor temperatures up to 29°C. Temperatures up to 35°C are acceptable for specific areas such as pool surrounds, changing rooms, bathrooms and the first metre of space adjacent to walls with high fabric losses. This may occur where you have for instance extensive floor to ceiling glazing where it is necessary to offset as much as possible the cold down draught that occurs.

The sensitivity of the human foot will perceive a temperature above 29°C as ‘uncomfortable’ at normal room temperatures of 18-22°C and should be avoided.

Other limiting factors to the surface temperature may be the particular floor covering and for some materials such as timer the maximum manufacturers temperature should be observed.

Modern well insulated buildings no longer need high surface temperature in order to provide sufficient output to meet the heat losses of a typical building. Average floor emissions of between 50 and 75 watts per m2 will often be more than sufficient. Low temperature floor systems provide inherent, passive self-regulation. Floor temperatures generally need only be 3-5°K higher than room air. Any rise in air temperature due to solar gain or increased occupancy means the air will begin to approach the floor temperature. As this temperature difference decreases the heat emission from the floor reduces. This process is rapid and precise. Heat emission from the floor will begin to decrease as soon as air temperature rises. Given an air temperature of 20°C and a floor temperature of 23°C, heat emission from the floor will decrease by about a third for each degree of temperature that the air temperature rises.

A three degree rise in air temperature will thus be sufficient to neutralise the system. Theoretically, this inherent self-regulation makes it possible to design an underfloor heating system with no other form of room temperature control.

Design criteria

To evaluate comfort purely in terms of temperature requires consideration of the following:

1. Wet Bulb temperature
2. Dry Bulb temperature
3. Rate of air movement
4. Mean radiant temperature.

There are various accepted methods for the measurement of temperature including globe, equivalent, effective, radiant, environmental, dry and wet bulb.

The most commonly used measure of comfort for heating systems is the dry resultant temperature which in the absence of high rates of convection can give accurate indications as to the level of comfort that can be anticipated.

The dry resultant temperature is defined as:

$$t_{res} = \frac{t_r + T_{ai}\sqrt{10v}}{1 + \sqrt{10v}}$$

Where the internal rate of air movement v is less than 0.1 m/s then the above equation can be simplified as follows.

$T\ res = 0.5t_{ai} + 0.5t_r$

where:

t_{res} = dry resultant temperature °C

t_{ai} = inside air temperature °C

t_r = mean radiant temperature °C

The inside air temperature can be assumed to be the dry bulb temperature with the mean radiant temperature as a calculation derived from the shape of the room, it's area, surface emissivity and temperature.

The radiant temperature is significant to a feeling of comfort since it is the exchange of radiation with our surrounding that has the most effect on our perception of 'thermal comfort'.

With convective systems, the air temperature will always be higher than the dry resultant temperature and this difference can be as much as 5°K in buildings with high fabric losses such as glass walled structures.

Conversely in floor radiant systems the air temperature will always be lower than the dry resultant temperature and is not so affected by the rate of fabric loss.

This means that the floor radiant systems lower dry resultant temperature can safely be used for the calculation of heat losses.

This difference can account for a reduction of 5-10% for most types of buildings.

In addition, it is not necessary to allow any margins for height factors in buildings when considering the use of radiant floor heating systems.

In order to prepare a design for a building it is necessary to calculate the heat losses in an acceptable form.

Many of the modern computer programs allow for the use of resultant temperatures in conjunction with floor radiant systems. These will give a more accurate reflection of the steady state heat losses.

Once the heat losses are known and tabulated then the underfloor heating system can be designed. Since there is an upper limit on the surface temperature the maximum output from the floor is restricted.

For general purposes, a figure of 11 Watts/m_2 K can be used to determine the maximum floor emission. Where K is the difference between surface and air temperature.

For example:

Room area	10m_2
Heat loss	540 Watts
Heat required	54 Watts/m_2
Air temperature	20°C
Floor temperature	26°C
Output required	54/(26-20)
	= 9 Watts/m_2 K

In the above example, the heat required is within the design parameter of 11 Watts/m^2K.

The calculation should be repeated for each of the rooms or areas to determine whether there are any areas, which cannot be, heated within the permitted design limits of the maximum floor surface temperature.

The water flow temperature required to achieve a given surface temperature is dependent upon the following:

1. Surface temperature required
2. Type of floor construction
3. Depth of pipe below floor surface
4. Floor covering.

All of these determine the total thermal resistance above the pipe, which will determine the drop in temperature between the pipe and the surface of the floor.

To achieve a set output from a floor means that we can either vary the pitch of the pipe and operate at a set water temperature or we can fix the pipe pitch and operate at different water temperatures.

Constant water temperature is sometimes introduced into the design by choice but more often is a function of only 'one' water temperature being available regardless of different floor constructions. The main disadvantage of this approach will be encountered during installation when the installer will have to create different pipe pitches. Many projects - especially domestic ones - feature different floor structures with, for example, the ground floor being concrete and the upper storeys wooden suspended floors. Water temperature required can differ by more than 15°C between the floors and such a temperature difference is difficult to meet using constant water temperature. Altering the pitch of pipes to meet requirements from area to area also presents potential future problems when floor covering materials are replaced e.g. switched from tiles to wall-to-wall carpet. In such circumstances, the pipe pitch cannot be altered retrospectively and heat transfer may not be sufficient to achieve design temperatures.

If the pipe pitch is kept constant, it will result in varying water temperatures. This method leads to easier design and installation. It must be borne in mind that there is always an upper limit to the desirable water temperature and in extreme cases different pipe pitches and loop configurations may need to be considered. Clearly there are an unlimited number of combinations of construction methods and floor finishes, each of which will give a different overall thermal resistance.

The temperature drop across the pipe loops should be kept low i.e. approximately 5-10°K in order to maintain even floor temperatures.

Different pipe sizes also require equivalent adjustments to water temperatures however this adjustment is very small. The difference between a 15mm and a 20mm pipe result in only a 2% increase in flow temperature for the 15mm pipe.

Three main types of loop configuration are used for underfloor heating. The construction techniques used for the building will effect selection of the most suitable type for the individual project.

In general when pipe layout plans are formulated, attention should be paid to routing the supply flow to the external wall or other potentially cold areas.

Serpentine coil layout

Temperature variations within local areas are kept to a minimum. The main advantage of this configuration is that it is adaptable to all kinds of floor structures and can be easily modified for different energy requirements by altering the pitch of the pipes. This configuration is the most suitable for underfloor heating installations serving domestic premises. However, a flexible pipe is required.

Double coil layout

The characteristic of this configuration is that supply and return pipes in the layout run in parallel.

This provides an even mean temperature, but will result in a higher variation of temperature within small areas. It is suitable for heating larger areas with higher heat demands e.g. churches, hangers, or even for external use under paths and driveways.

Spiral coil layout

Supply and return pipes are run parallel, but in the form of a spiral in this variation. This approach is suitable for buildings with a higher heat demand, but is less suitable for installation in association with wooden floor structures.

Studies show that a naked human foot cannot detect a temperature variation of less than 2°C. A serpentine layout with a pipe pitch of 250-300mm keeps the temperature comfortably within this range, so that no variation in floor temperature can be detected.

A number of different approaches may be applied to the control of water temperature in underfloor heating systems.

One of the simplest means of control is to maintain a constant supply water temperature from the boiler to the system by means of self-regulating control valve and mixing circuit.

This type of circuit works by mixing some of the return water from the underfloor heating with the water from the boiler to maintain a fixed supply water temperature.

Whilst this is satisfactory for small building such as domestic housing heat demand for a building will vary principally as a function of outdoor temperature.

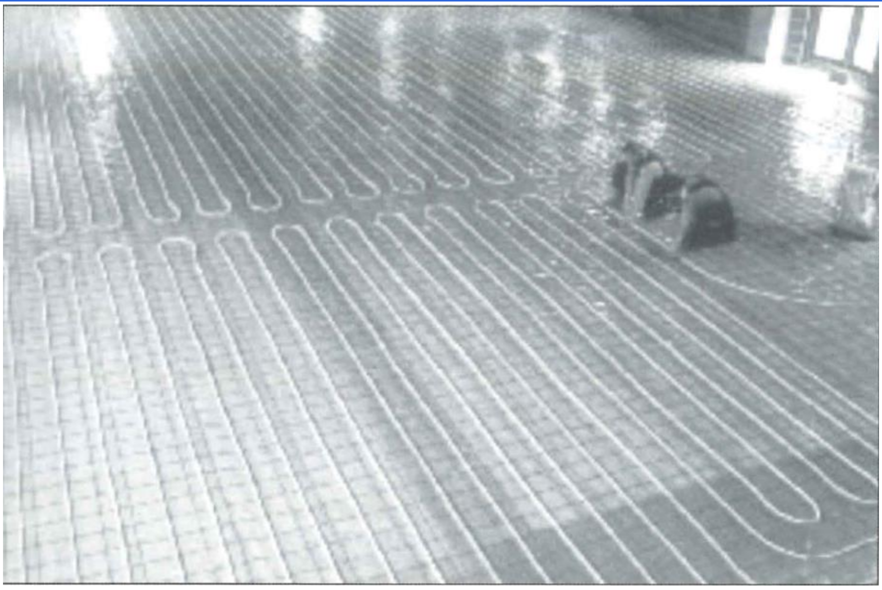


Figure 10 *Serpentine coil layout*

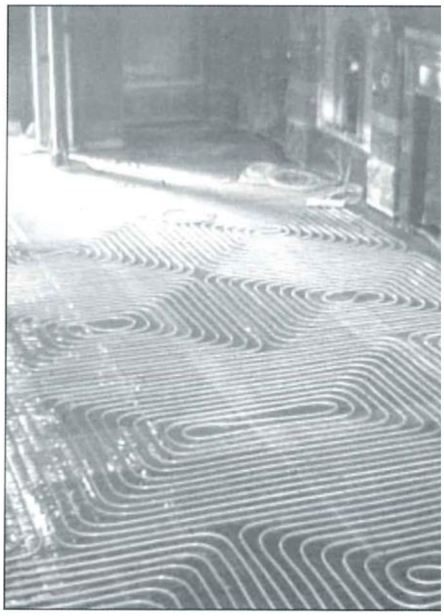


Figure 11 *Double coil layout*

One of the main advantages using outdoor temperature compensation is the shorter reaction time particularly for systems installed in concrete floors. The lower the water temperature is in the system the smaller the heat sink effect of the floor and the quicker the response, a disadvantage being the possible rapid changes in the outside air temperatures.

Maximum comfort requires room temperature control. Different areas of the building will have differing heat requirements depending upon external factors, including the orientation of the building, wind direction etc. or internal influences including open fires, number of occupants etc. Underfloor heating installations can, with the right controls, meet all of these requirements. Water circulation in each loop of the underfloor system can be controlled individually by means of actuators and room thermostats.

Figure 12 *Spiral coil layout*

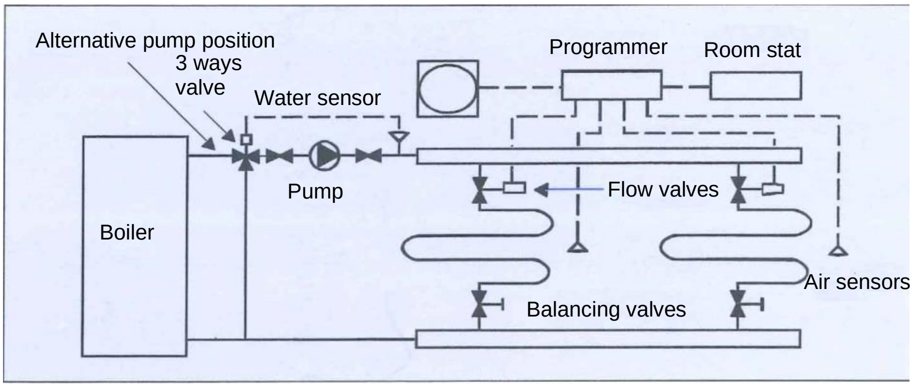


Figure 13 Control circuit for fixed supply temperature

This gives the end user individual control over each room or area.

The U value of a building directly relates to the performance of the underfloor heating system, which serves it. If the building is poorly insulated energy will be wasted and response times will be affected by the undesirable heat losses. Floor structure also affects response time. In buildings with concrete screeded floors, the screed will serve as an energy store, however by comparison a wooden suspended floor has little thermal store potential and therefore reacts much quicker.

Careful consideration should be given to the location of the manifolds at the outset of the project. They should be located as centrally as possible within the building so that the length of pipe routing between manifolds and the individual heating zones is kept to a minimum. This will help to balance the system and improve the temperature control of individual rooms. The manifolds can be concealed in cupboards, or suitable voids, so aesthetics are not a major issue.

Care should be taken however, to ensure that the manifolds are located in such a way as to provide easy access for further maintenance. Underfloor heating systems, with an oxygen diffusion barrier, can be used safely in association with other heating systems and air conditioning.

Complementary heating systems should be set up in such a way that they do not interfere with temperature control of the underfloor heating system.