

# 4 Heating

## Learning objectives

Study of this chapter will enable the reader to:

1. state the applications for hot-water radiators, natural and fan convectors, embedded pipe radiant panel systems and overhead radiant panels;
2. discuss the use of centralized and decentralized forms of heating system;
3. state the applications for electrical heaters such as radiators, convectors and thermal storage radiators;
4. demonstrate the use of under floor and ceiling heating systems utilizing electrical energy;
5. apply appropriate heat emitters to the user's needs;
6. explain the use of warm-air heating methods;
7. understand the low-, medium- and high-pressure classifications and applications for water heating systems;
8. understand schematic pipe layouts and pump positioning;
9. design hot-water pipe systems;
10. understand the requirements of oil-firing equipment;
11. have an understanding of combustion;
12. describe flues for oil boilers;
13. calculate the room air temperature to be found during a commissioning test on a heating system;
14. understand the principles of electrical power generation and the use of combined heat and power plant;
15. describe the uses of district heating system;
16. understand the uses of a BEMS and its terminology;
17. differentiate between local control and overall supervision;
18. understand how a computer system enhances the engineer's work.

### Key terms and concepts

absorption heat pumps 115; building energy management system (BEMS) 111; building management system (BMS) 112; ceiling heating 90; chemistry of combustion 103; chimney 102; class of oil 102; combined heat and power (CHP) 108; combustion air 103; computer-based control 111; dedicated 109; digital signal 112; district heating 109; duct 91; efflux velocity 105; electrical power generation 108; embedded pipe system 90; energy management system 111; equivalent length 98; evacuated tube radiant system 92; exothermic reaction 103; expansion vessel 95; fan convactor 88; flue gas constituents 103; free-standing flue 102; geothermal heating system 114; grille 89; groundwater 114; heat exchanger 115; heating system performance testing low-, medium- and high-pressure hot water 106; microbore 95; microprocessor 111; modem 112; natural convactor 88; neutral point 93; oil storage and handling 102; one-, two-, three- and four-pipe heating systems 93; outstation 111; panel and column radiators 87; Pascal 98; plant management system 112; plant status 112; pressure drop rate 99; programmable logic controller 111; pump head 98; pump performance curve 99; radiant panel 88; radiator 87; radiator temperature correction factor 97; Redwood oil viscosity 102; sealed system 95; skirting heater 89; storage heater 87; supervisor 112; thermal storage 88; turbulence 103; under floor heating 90; wall-flame, vaporizing and pressure jet burners 103; warm-air system 93; water flow rate 97; water velocity 97.

### Introduction

Terminal heat emitters, such as radiators, convectors and warm-air methods, pipework layouts, and pipe and pump sizing are discussed. Oil-firing equipment is described and the combustion process is analysed. Basic flue arrangements are shown.

Heating systems only operate at their design heating duty when the outside air temperature coincides with that used for heat loss calculations; the commissioning engineer needs to relate heating performance on the day of test to the design figures. Such calculations are shown.

Electricity is generated at the expense of usable energy discharged to the atmosphere or the sea. The plant needed to convert this surplus into saleable heat for district heating is outlined. Interest in this subject will develop for various reasons, and the UK lags behind other European countries in the employment of combined heat and power stations.

The control and operational monitoring of heating, air conditioning and other building services has been enhanced by the use of computer-based techniques known as building energy management systems (BEMS). These are explained and clear links with other services are shown.

### Heating equipment

A wide variety of heating equipment is available that can heat the occupied space either directly by combustion of a fuel or indirectly by utilizing air, water or steam as a heat transfer fluid. The cost of electricity reflects the complexity of its production and distribution, but from the user's point of view it is a refined source of energy, which can be converted with 100% efficiency. Electrical energy purchased at night can be used to heat water, concrete or cast iron in insulated containers. This stored heat is released when needed.

An economic balance is sought between capital and running costs for each application, bearing in mind the building's use. Automatic controls can monitor water and air temperatures, operational times and weather conditions to minimize fuel and electricity consumption. In order to take maximum advantage of a building's thermal storage capacity, optimum-start controllers are used to vary start and stop times for systems that are used intermittently. Computer control is

employed in large buildings, where the capital cost can be offset by reduced energy consumption and personnel savings.

Heat emitters can be classified as follows.

### **Radiators**

Heat emitters providing radiation come into this group. A steel single-panel radiator emits about 15% of its total heat output by radiation and the remainder by convection. Radiant output from multiple panel and column types may be a lower percentage of the total. Electric, gas and coal appliances produce large amounts of convection and are partly convectors.

Types of radiator are:

Hot water: single-, double- or triple-panel column radiators, skirting heaters, recessed panels, banks of pipes.

Electricity: off-peak storage heaters, radiant appliances, convectors, radiant ceiling systems.

Gas, coal and oil: radiant appliances; Fig. 4.1 shows a gas-fired domestic radiant and fan convective appliance often suitable for the elderly or infirm even when central heating provides air heating around the occupants. Air heating alone is not always enough warm for very sedentary residents.

The main characteristics of radiant, also providing convective heat output, appliances are as follows:

Steel single panels: Neat appearance, high heat output per square metre of surface area, easy to clean, narrow.

Steel double panels: Greater heat output per square metre of wall area used, difficult to clean, protrude into the room, more costly. Anti-corrosion chemicals needed in heating water for all steel materials.



4.1 Gas radiant and fan convector room heater.



4.2 Electrically heated oil-filled column steel radiator.

Cast iron panels: Heavy and more obtrusive, low heat output, very long service period.

Steel and cast iron columns: High heat output per square metre of wall area used, bulky, heavy, often mounted on feet, difficult to clean except the hospital pattern which are smooth finished; Fig. 4.2 shows an example.

Radiant panels: Flat cast iron or steel plates with water pipes bonded to their back. They are often mounted at high level in industrial workshops and require a large surface area.

Banks of pipes: Bare steel or copper pipes fitted at skirting level in rooms or storage areas to provide an inexpensive heating surface. Can be installed in floor trenches beneath a decorative floor grille allowing indoor foot traffic to use the floor space unrestricted. Traditional churches often have these and modern buildings have them at the foot of floor-to-ceiling glazed areas to counteract downdraughts.

Off-peak storage: Thermal storage heaters taking electricity at night during less expensive charging periods. The heat is stored at high temperature in cast iron or refractory bricks in an insulated casing. Heat is released continuously into the building unless the heater is fitted with a thermostatically controlled fan and a time switch that determines its operating period. The only other control is over the length of the charge period; this requires estimating the following day's weather pattern. Heaters are bulky and their weight requires attention to the floor structure to ensure sufficient strength.

### **Convectors**

There are two types of convector, natural and fan.

### Natural convectors

Natural convectors rely on gravity convection currents produced by the heater. Skirting heaters have a finned pipe inside a sheet metal casing as shown in Fig. 4.3. Their heat emission is about 480 W per metre run, they are light and easily handled and they are less obtrusive than taller equipment. Long lengths of unobstructed wall space are needed. Where they run behind furniture, the finned element is omitted and a plain pipe is installed to reduce heat output. They are always fitted onto two-pipe systems and the return pipe can be fitted inside the casing. Valves and air vents are enclosed in accessible boxes at the ends of continuous lengths. Natural convectors produce a uniformly rising current of warm air around the perimeter of the room and this is effective in producing a comfortable environment. There is negligible radiant heating.

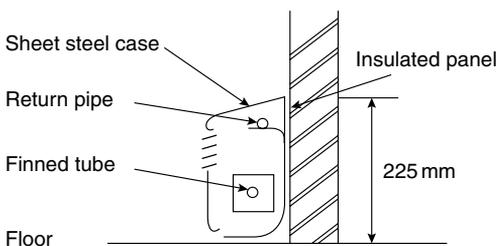
Other natural convectors are either 1 m high or extend up to room height, as shown in Fig. 4.4. They create strong convection currents with little radiation and are particularly suitable for locations where elderly, very young or disabled people are being cared for as there are no hot surfaces that may cause skin burns or start fires.

Natural convectors have high heat outputs and can be built into walls, cupboards or adjacent rooms to improve their appearance. Electricity or low- or medium-temperature hot water can be used as the heating medium. The heating elements need periodic cleaning. Such heaters are used in locations where quiet operation and the lack of draughts or intense radiation are important design considerations, such as libraries, art galleries and antique furniture stores.

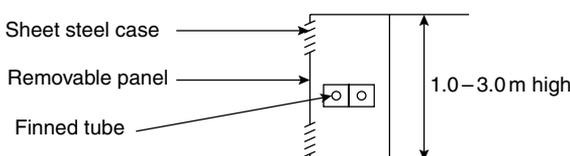
### Fan convectors

Fan convectors have a similar construction to natural convectors with the addition of one or more centrifugal fans and an air filter. Heat output can be very high and fans may be operated at various fixed speeds or from variable-speed motors. Figure 4.5 shows a typical arrangement. Fan operation is controlled from built-in thermostats or remote temperature sensors.

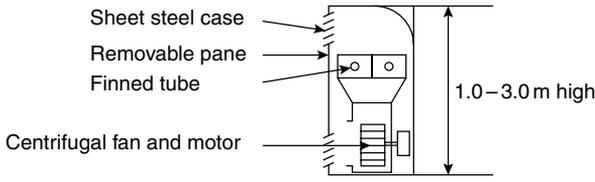
Installation can be at low or high level and the heated air stream is directed away from sedentary occupants. Fan convectors can be usefully sited at doorways to oppose incoming cold air and rapidly reheat entrance areas.



4.3 Skirting convector heater.



4.4 Natural convector heater.



4.5 Fan convector.



4.6 Balanced-flue gas-fired fan convector.

A two-pipe circuit must be used, and fan convectors are installed on separate circuits from hot-water radiators as their control characteristics are different. Constant-temperature hot-water is supplied to them, whereas radiators may have variable water temperatures to reduce heat output in mild weather.

Figure 4.6 is of a gas-fired balanced-flue fan convector that can be used when a central piped water circulation heating system is not practical. Figure 4.7 is of the outdoor balanced-flue terminal.

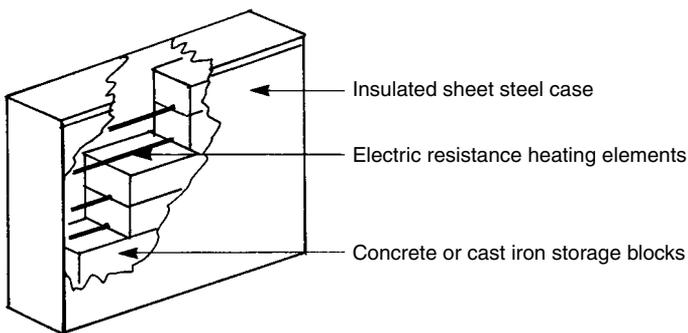
Figure 4.8 shows a typical electric off-peak storage heater, which may be a natural or fan convector.

**Embedded pipes and cables**

Low-temperature hot-water heating pipes or electric heating cables are buried in concrete walls, floors or ceilings to provide a large low-temperature surface that is maintained at a few degrees above room air temperature. Floor-to-ceiling air temperature gradients tend to be less than those



4.7 Balanced-flue terminal.

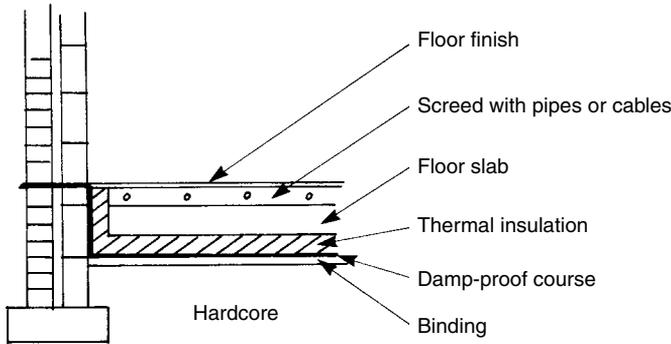


4.8 Off-peak electric storage heater.

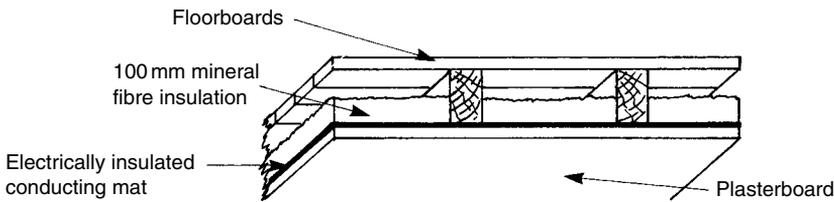
obtained with more concentrated forms of heat emission and a uniform distribution of comfort is produced. An example is shown in Fig. 4.9.

Soft copper pipes are laid in position on the concrete floor slab and held by clips, and the ends are connected to header pipes in service ducts. Joints are avoided for the under floor sections. Steel or plastic pipes may be used in some situations. Thermal expansion and contraction of the pipework must be accommodated and the floor surface temperature is limited to avoid damage to the structure, surface finishes or occupants. This is done by enclosing the pipe in a hard asbestos sleeve on water pipes operating at  $85^{\circ}\text{C}$  or by controlling water temperature to  $45^{\circ}\text{C}$  with a mixing valve system. Pipes are buried in the floor screed. Heating elements are evenly distributed to provide uniform radiation and convection to the occupants.

Electric ceiling heating can consist of buried cables or a flexible conducting mat fixed between the ceiling joists and plasterboard, as shown in Fig. 4.10. The mat is electrically insulated from the structure and connected to 240 V 50 Hz supplies to rise to a surface temperature of  $40^{\circ}\text{C}$ .



4.9 Embedded panel heating.



4.10 Radiant ceiling heating.

### **Radiant panels**

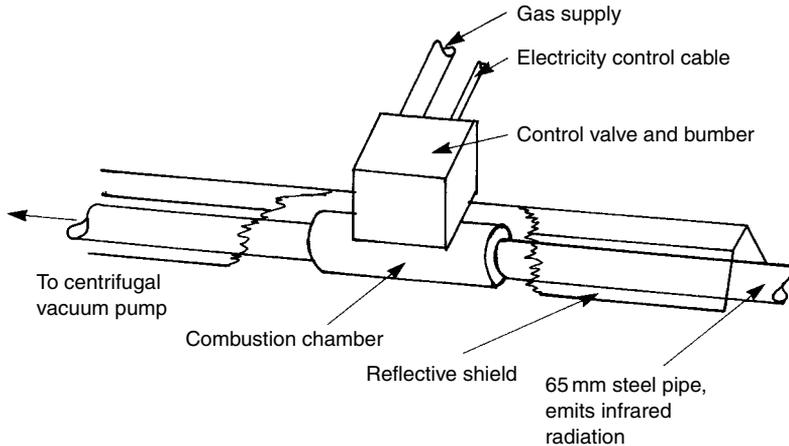
Radiant panel systems employ either a high- or a low-temperature surface to transmit heat by radiation directly to the occupants, and to other unheated surfaces, producing an elevated mean radiant temperature. Comfort conditions can be maintained with lower air temperatures than with convective systems. This should result in economical running costs.

Convection heat output from the hot radiant source is minimized by placing thermal insulation over the reflector. High-temperature radiation is generated using gas combustion close to ceramic reflectors, which emit some heat in the visible part of the infrared region and consequently are seen to be contributing to a feeling of warmth. Domestic gas fires and industrial heaters are in this category. Covered pedestrian areas of shopping precincts can be warmed from recessed units in canopies.

The effect of using high-temperature panels is to produce a series of localized 'sun spots' over a small floor area. Careful siting is necessary to avoid overheating of people or objects.

Low-temperature systems utilize hot water, air or flue gas to heat a metal sheet or pipe, which emits long-wave infrared radiation outside the visible band. They can be installed in factory or office environments and produce a uniform overall warmth, assisted by re-radiation and convection from surfaces heated by the radiant source. Unlike convective systems, they are not adversely affected by room height. Complete systems can be suspended from the ceiling, leaving floors uncluttered.

An evacuated tube system is shown in Fig. 4.11. Flue products from the gas burners are drawn along steel pipes by a vacuum pump and discharged to the atmosphere.



4.11 Overhead industrial radiant tube heating system.

### **Warm air**

Recirculated room air is heated either directly or indirectly by the energy source. Direct firing of combustion gases into the air is permissible only in large well-ventilated factory premises. All other applications require a fuel-to-air heat exchanger where the combustion products are enclosed in a sheet metal passageway. Room air is passed over the outside of this heating surface.

Heated air is passed through ducts to the occupied space. It is diffused into the room through a grille, which mixes it with room air convection currents and avoids draughts. Each grille has a damper to regulate the air flow. Extract grilles and ductwork return the air to the heater. Care is needed not to extract air directly from kitchens and bathrooms, as this would lead to odours and condensation in living areas.

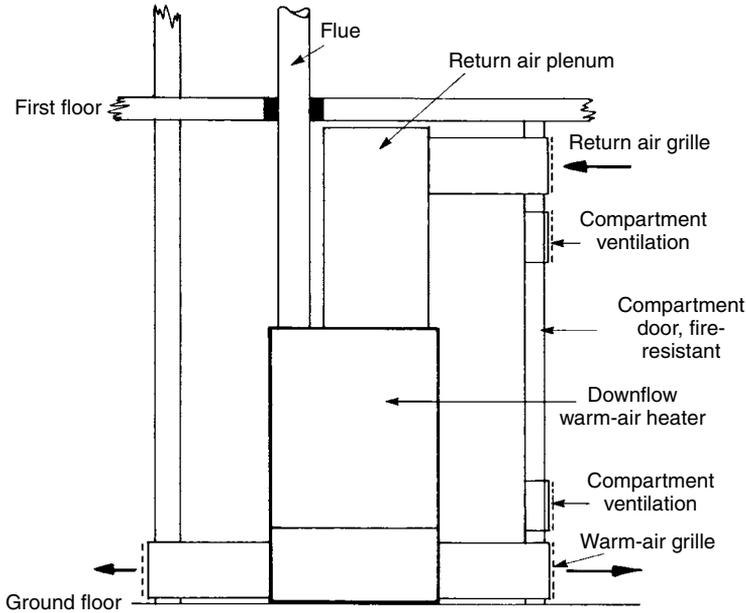
The main advantage of warm-air systems is quick heating up and response to thermostatic control. A source of radiant heat is needed in the sitting room to complement the otherwise purely convective heating. A typical domestic installation is shown in Fig. 4.12, where the heater is fitted in a cupboard which is centrally located with respect to all the rooms. Stub ducts are used to connect the heater to the supply and recirculation grilles.

### **Hot-water heating**

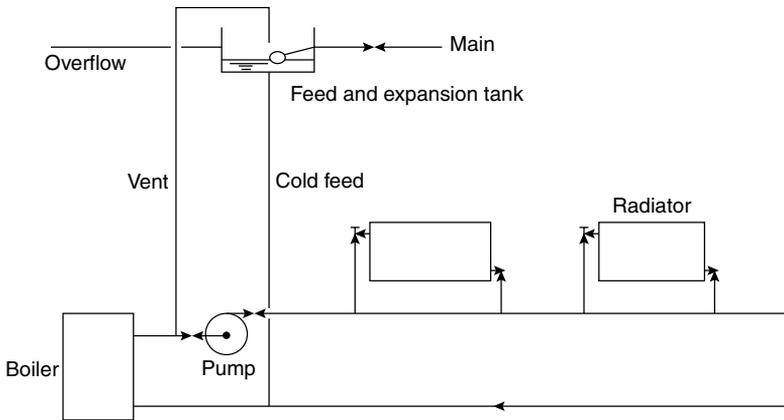
The basic arrangements of the various hot-water heating systems are shown in Figs. 4.13–4.16. Hot-water heating systems are classified by the temperature and pressure at which they operate (Table 4.1).

The pump position relative to the cold feed and vent pipe connections is important in systems with an open expansion tank. The water pressure rise across the pump can be considerable, and if the arrangement is incorrect water can be pumped up the vent pipe and discharged into the open tank. The connection of the cold-feed pipe to the circulation system is known as the neutral point, Fig. 4.18. It is here that the water pressure is always equal to the static height of water above it, with the pump exerting no additional pressure.

A satisfactory arrangement is shown in Fig. 4.18. The hydraulic gradient shows the variation of total water pressure throughout the circulation, that is, the sum of the static head and the pump head, some of which generates suction pressure between the neutral point and the pump inlet.



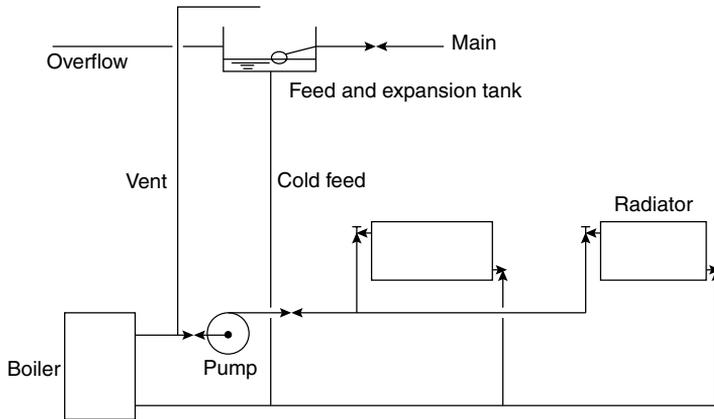
4.12 Ducted gas-fired warm-air heater installation.



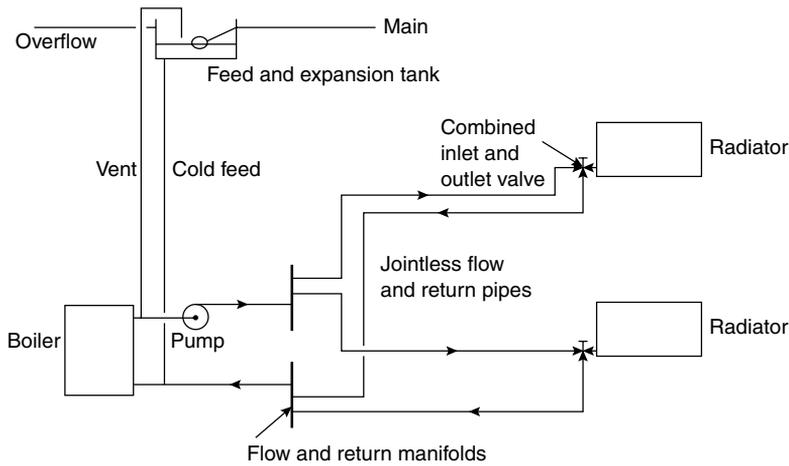
4.13 Low-temperature hot-water one-pipe heating system.

The design of a pumped heating system is approached in the following way.

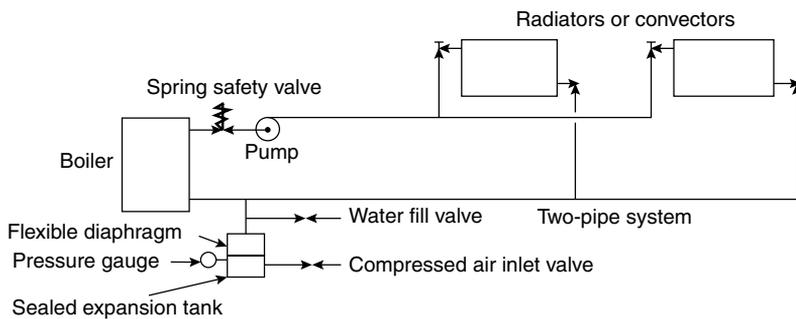
1. Calculate room heat losses.
2. Decide radiator and convector positions and then their sizes from manufacturers' literature.
3. Calculate the water flow rate for each heat emitter.
4. Design the pipework layout.
5. Mark the water flow rates on the pipework drawing and add them up all the way back to the boiler from the furthest heater, marking the drawing with each value.



4.14 Low-temperature hot-water two-pipe heating system.



4.15 Low- or medium-temperature hot-water microbore heating system.

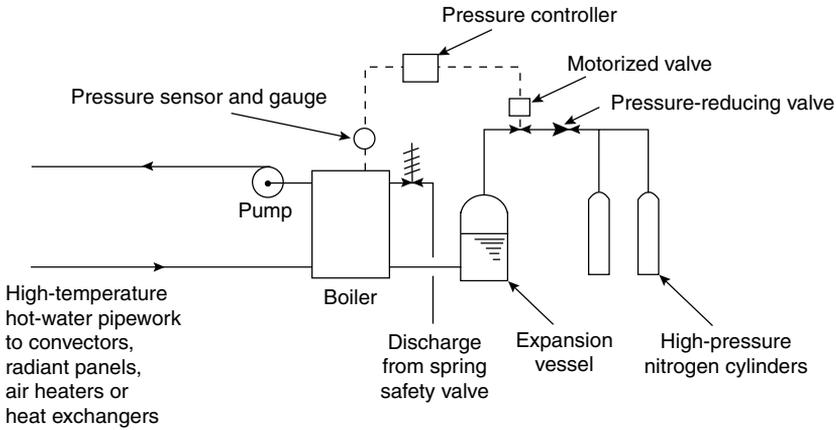


4.16 Low- or medium-temperature hot-water heating system using a sealed expansion tank.

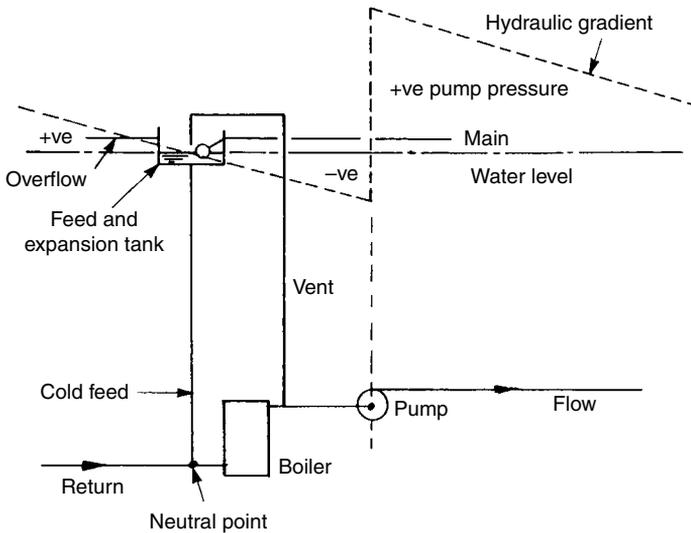
Table 4.1 Classification of hot-water heating systems.

Type	Flow temperature (°C)	Pressure
LTHW	80	Open to atmosphere, 1 bar
MTHW	120	7 m head above atmosphere, 2 bar
HTHW	Over 120	In excess of 7 m head, 3 bar

Note: LTHW, low-temperature hot-water; MTHW, medium-temperature hot-water (refer to Fig. 4.17); HTHW, high-temperature hot-water.



4.17 Pressurization equipment for a high-temperature hot-water heating system.



4.18 Neutral point in a heating system.

6. Choose pipe sizes from a chart or data, using an estimate of pressure loss rate and maximum allowable water velocity.
7. Calculate the pump head and water flow rate; compare with the pump manufacturer's stated performance curves and choose a suitable pump.

The temperature of water flowing through a heat emitter or along a pipe will drop from its flow temperature  $t_f$ °C to its return temperature  $t_r$ °C and lose heat  $Q$  W. If there is one heater in a room,  $Q$  will be equal to the room steady-state heat loss. Heat losses from distribution pipework may initially be assumed to be 10% of the room heat loss, and the radiator water flow rate should be increased by this amount.

The specific heat capacity ( $SHC$ ) of water is 4.19 kJ/kgK. The heat balance equation is:

$$\text{heat lost by water} = \text{radiator heat output } Q + \text{pipe heat loss}$$

or

$$\text{water flow rate } q \times SHC \times \text{temperature drop} = Q + 10\% \times Q$$

$$\text{water flow rate } q = \frac{1.1 Q}{SHC(t_f - t_r)} \text{ kg/s}$$

The radiator manufacturer's heat output data will be for a fixed temperature difference between the mean water temperature and the room air temperature. Usually a figure of 55 K is used. Comparison of design conditions and literature data can be made using the following equations:

$$\text{radiator mean water temperature } MWT = \frac{t_f + t_r}{2}$$

$$\text{radiator heat output at 55 K difference} = \frac{\text{room heat loss}}{\text{temperature correction factor}}$$

where:

$$\text{temperature correction factor} = \left[ \frac{((t_f + t_r)/2) - t_a}{55} \right]^{1.30}$$

and  $t_a$  is the room air temperature (°C).

#### EXAMPLE 4.1

A double-panel radiator is to be installed in a room where the air temperature is 22°C and the heat loss is 4250 W. Water flow and return temperatures are to be 82°C and 71°C respectively. An extract from a radiator manufacturer's catalogue for a temperature difference of 55 K is given in Table 4.2. Select a suitable radiator and find the water flow rate through it.

Table 4.2 Heat output from steel double-panel radiators of 500 and 700 mm height.

Radiator length (m)	Heat output (kW) for 55 K difference		
	500 mm	700 mm	900 mm
1.720	2.00	2.60	2.90
1.920	2.30	2.90	3.30
2.200	2.60	3.25	3.75
2.400	2.85	3.60	4.25
2.600	3.10	3.90	4.80

$$\begin{aligned} \text{temperature correction factor} &= \left[ \frac{(82 + 71)/2 - 22}{55} \right]^{1.30} \\ &= 0.988 \end{aligned}$$

$$\text{radiator heat output at 55 K difference} = \frac{4250 \text{ W}}{0.988} = 4302 \text{ W}$$

The 2.6 m × 900 mm radiator is needed. Verify that the wall space is available and that there is not a clash with furniture and furnishings in the room. The water flow rate is:

$$\begin{aligned} q &= \frac{1.1 \times 4.25}{4.19 \times (82 - 71)} \\ &= 0.1014 \text{ kg/s} \end{aligned}$$

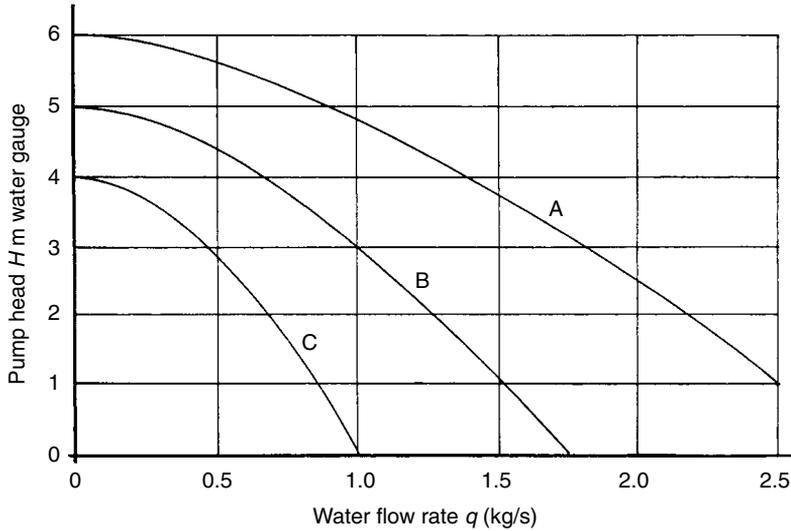
A first estimate of pipe sizes can be made using an average pressure loss rate  $\Delta p/EL$  for the whole system ( $EL$  is the equivalent length). Either an arbitrary figure of say 300 N/m<sup>3</sup> is chosen, or a figure is evaluated from the expected pump head. The index circuit length is found from the total flow and return pipe length from the boiler to the furthest radiator. Pipe fittings increase frictional resistance and an initial 25% increase in measured pipe length is made in order to find the equivalent length of the system:

$$\text{pump head } \Delta p \frac{\text{N}}{\text{m}^2} = EL \text{ m} \times \frac{\Delta p}{EL} \frac{\text{N}}{\text{m}^3}$$

This is often converted into head  $H$  m water gauge:

$$\begin{aligned} \text{pump head } H &= \Delta p \frac{\text{N}}{\text{m}^2} \times \frac{\text{m}^3}{\rho \text{ kg}} \times \frac{\text{kg}}{\text{g N}} \\ &= \frac{\Delta p}{9.807 \times 1000} \text{ m} \\ &= \frac{\Delta p}{9807} \text{ m} \end{aligned}$$

Water flow rate through the pump is the sum of all the radiator water flow rates. Figure 4.19 shows typical pump performance curves. The allowed pressure loss rate can be assessed from



4.19 Pump performance curves.

the pump characteristic curves. For example, if pump B is to be used at a flow rate of 1 kg/s, the corresponding head developed is 3 m. This is equal to a pressure:

$$\begin{aligned}\Delta p &= 9807 H \\ &= 9807 \times 3 \text{ m} \\ &= 29421 \text{ N/m}^2\end{aligned}$$

As,

$$\begin{aligned}29421 \frac{\text{N}}{\text{m}^2} &= EL \text{ m} \times \frac{\Delta p}{EL} \frac{\text{N}}{\text{m}^3} \\ \text{allowed } \frac{\Delta p}{EL} &= \frac{29421}{EL} \text{ N/m}^3\end{aligned}$$

If the measured index circuit is 50 m of pipework:

$$\begin{aligned}EL &= 50 \text{ m} \times 1.25 \\ &= 62.5 \text{ m}\end{aligned}$$

and,

$$\frac{\Delta p}{EL} = \frac{29421}{62.5} = 471 \text{ N/m}^3$$

This would be the maximum pressure loss rate, averaged over all the pipework, and pipe sizes would be read from the 460 N/m<sup>3</sup> line in Table 4.3 to ensure that the available pump head was not exceeded (Moss, 1996).

Table 4.3 Flow of water in copper pipes of various diameters.

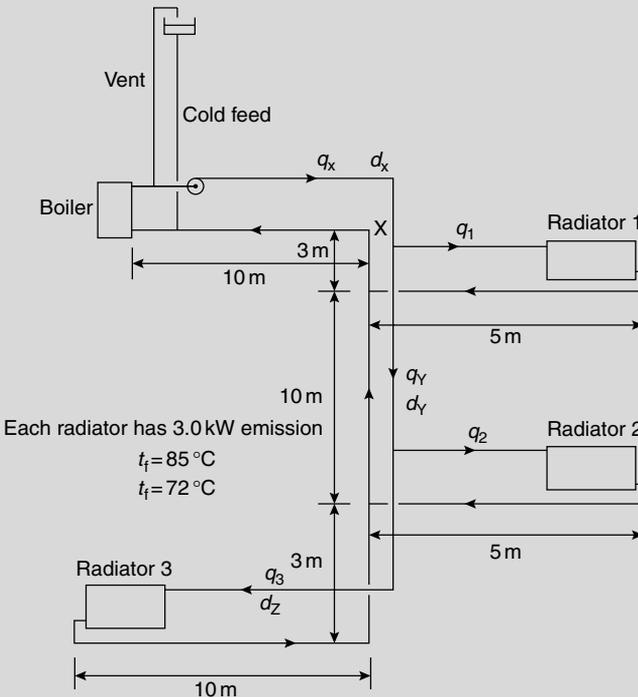
$\Delta p/EL$ ( $N/m^3$ )	Water flow rate $q$ (kg/s) for diameters of					
	6 mm	15 mm	22 mm	28 mm	35 mm	42 mm
200	0.013	0.065	0.174	0.381	0.656	1.060 $v = 1.0$
260	0.015	0.075	0.202	0.441	0.760	1.230
300	0.016	0.081	0.219	0.478	0.823	1.330
360	0.018	0.090	0.242	0.529	0.910	1.470
400	0.019	0.096	0.257	0.561	0.965	1.560
460	0.020	0.104	0.278	0.607	1.040	1.680 $v = 1.50$
500 $v = 0.50$	0.021	0.109	0.291	0.635	1.090	1.760
560	0.023	0.116	0.310	0.677	1.160	1.880
600	0.024	0.120	0.323	0.703	1.210	1.950
660	0.025	0.127	0.340	0.741	1.270	2.050
700	0.026	0.131	0.352	0.766	1.320	2.120
760	0.027	0.138	0.368	0.802	1.380	2.220
800	0.028	0.142	0.379	0.825	1.420	2.280

Note:  $v$ , water velocity (m/s);  $\Delta p/EL$ , rate of pressure loss due to friction.

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**EXAMPLE 4.2**

Figure 4.20 shows the arrangement of a two-pipe low-temperature hot-water heating system serving three radiators. The pipe dimensions indicated apply to both flow and



4.20 Low-temperature hot-water heating system.

return pipes. The frictional resistance of the pipe fittings amounts to 25% of the measured pipe length. Flow and return water temperatures at the boiler are to be 85°C and 72°C respectively. Each radiator is situated in a room air temperature of 20°C. The heat outputs of radiators 1, 2 and 3 are 1, 2 and 3 kW respectively. Pump C of Fig. 4.20 is to be used. Find the pipe sizes for the system.

For radiator 1:

$$q_1 = \frac{1.1 \times 1}{4.19 \times (85 - 72)} = 0.02 \text{ kg/s}$$

Similarly, for radiators 2 and 3:

$$q_2 = 0.04 \text{ kg/s}$$

$$q_3 = 0.06 \text{ kg/s}$$

Water flow in the distribution pipework will be:

$$q_X = 0.12 \text{ kg/s}$$

$$q_Y = 0.10 \text{ kg/s}$$

Water flow rate through the pump is:

$$q_X = 0.12 \text{ kg/s}$$

Available pump head, from Fig. 4.19, is:

$$H = 6 \text{ m}$$

Pump pressure rise is:

$$\begin{aligned} \Delta p &= 9807 \times 6 \text{ N/m}^2 \\ &= 58\,842 \text{ N/m}^2 \end{aligned}$$

The index circuit is from the boiler to radiator 3; thus the measured pipe length is:

$$2(10 + 3 + 10 + 3 + 10) \text{ m} = 72 \text{ m}$$

Therefore,

$$\begin{aligned} EL &= 1.25 \times 72 \text{ m} \\ &= 90 \text{ m} \end{aligned}$$

and,

$$58\,842 \frac{\text{N}}{\text{m}^2} = 90 \text{ m} \times \frac{\Delta p}{EL} \frac{\text{N}}{\text{m}^3}$$

maximum available  $\frac{\Delta p}{EL} = \frac{58\,842}{90} \text{ N/m}^3$

$$= 653.8 \text{ N/m}^3$$

Thus, from Table 4.2, using  $\Delta p/EL = 600 \text{ N/m}^3$ , the pipe sizes are:

$$d_x = 15 \text{ mm}$$

$$d_y = 15 \text{ mm}$$

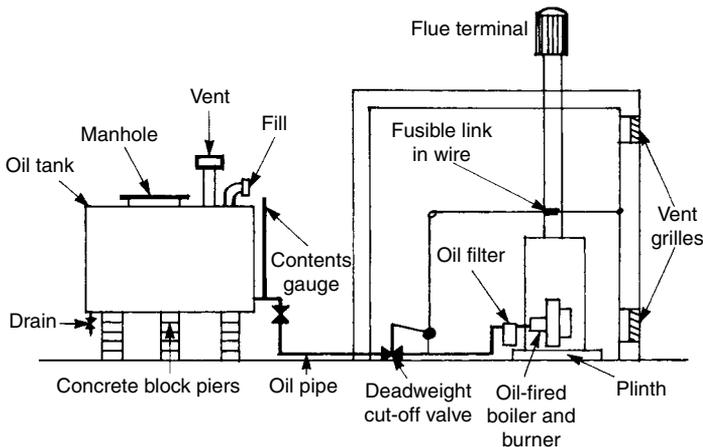
$$d_z = 15 \text{ mm}$$

Note that the pressure loss rates in pipes Y and Z are  $460 \text{ N/m}^3$  and less than  $200 \text{ N/m}^3$  respectively. Not all the allowable pump head of 6 m will be absorbed in pipe friction losses. A gate valve beside the pump will be partially closed to increase the resistance of the system. Each radiator has two hand wheel valves, one for temporary adjustments by the occupant and the other for flow regulation by the commissioning engineer.

### Oil-firing equipment

Fuel oil is graded in the Redwood no. 1 viscosity test according to its time of flow through a calibrated orifice at  $38^\circ\text{C}$ . Vaporizing and wall-flame burners in boilers of up to 35 kW heat output use 28 s oil, pressure jet burners use gas oil class D (35 s), and industrial boiler plant uses grade E (250 s), grade F (1000 s) and grade G (3500 s). Power stations may use 6000 s residual oil, heated to make it flow. This is the tar residue from crude oil distillation and can only be burnt economically on such a large scale.

Figure 4.21 shows a typical domestic oil storage and pipeline installation. In the UK domestic oils can be stored in outdoor tanks. Grades E, F and G require immersion heaters in the tank and pipeline heating to ensure flow.



4.21 Oil storage tank installation.

Wall-flame burners have a rotating nozzle, which sprays oil onto peripheral plates around the inside of a water-cooled vertical cylindrical combustion chamber. An electric spark ignites the oil impinging on the plates, establishing a ring of flame around the walls of the boiler. Correct oil flow rate from the reservoir is controlled by a ball valve.

Vaporizing burners consist of a vertical cylinder that is heated by the flame and evaporates further oil fed into its base from the reservoir flow control.

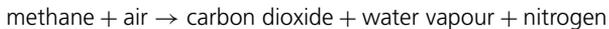
Pressure jet burners are usually confined to boilers in plant rooms as they produce more noise. Oil is pumped at high pressure through a fine nozzle, forming a conical spray in the furnace. Combustion air is blown into this oil mist from a centrifugal fan. The turbulent interaction of oil and air causes further atomization of the oil droplets, and the mixture is ignited by an electric spark.

## Combustion

Combustion is an exothermic chemical reaction that liberates heat. Fuel must be intimately mixed with sufficient oxygen and raised to a temperature high enough for combustion to be maintained. All the carbon and hydrogen in the fuel are burnt into gaseous products that can be safely vented into the atmosphere. Hydrocarbon fuels are highly energy-intensive. They require little storage volume and their combustion is controllable.

The constituents of dry air are 21% oxygen, 79% nitrogen and less than 1% other chemicals such as carbon dioxide, carbon monoxide, nitrous oxides and rare gases, measured by volume. Nitrogen is inert and takes no part in the chemistry of combustion, but it is heated in its passage through the furnace. Typical chemical compositions of fuels are given in Table 4.4.

The quantity of air required for complete combustion and the composition of the products can be evaluated from the fuel chemistry. For methane ( $CH_4$ ) the complete volumetric analysis would be



The chemical symbols for these are as follows: oxygen,  $O_2$ ; nitrogen,  $N_2$ ; carbon dioxide,  $CO_2$ ; water vapour,  $H_2O$ . Therefore (after complete combustion) we have

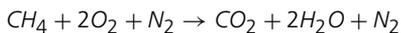


Table 4.4 Fuel data.

	<i>Anthracite</i>	<i>Gas oil</i>	<i>Natural gas</i>
Moisture (%)	8.0	0.05	
Ash (%)	8.0	0.02	
Carbon (%)	78.0	86.0	
Hydrogen (%)	2.4	13.3	
Nitrogen (%)	0.9		2.7
Sulphur (%)	1.0	0.75	
Oxygen (%)	1.5		
Methane (%)			90.0
Hydrocarbons (%)			6.7
Carbon dioxide (%)			0.6

Source: Reproduced from *CIBSE Guide* by permission of the Chartered Institution of Building Services Engineers.

This means that one volume of  $CH_4$ , when reacted with two volumes of  $O_2$  during complete combustion, will produce one volume of  $CO_2$  and two volumes of water vapour. All measurements are at the same temperature and pressure. It is assumed that the water vapour is not condensed.

Some condensation is inevitable, however, and when sulphur ( $S$ ) is present in the fuel, it combines with some of the  $O_2$  to form sulphur dioxide ( $SO_2$ ). If the gaseous  $SO_2$  comes into contact with condensing water vapour and further  $O_2$ , weak sulphuric acid ( $H_2SO_4$ ) may be formed in the flue. Coagulation of liquid  $H_2SO_4$  and carbon particles from chimney surfaces leads to the discharge of acid smuts into the atmosphere, causing local damage to washing, cars and stonework. Acidic corrosion of the boiler and chimney greatly reduce their service period. The flue gas temperature is kept above the acid dew-point of about  $50^\circ C$  to avoid such problems.

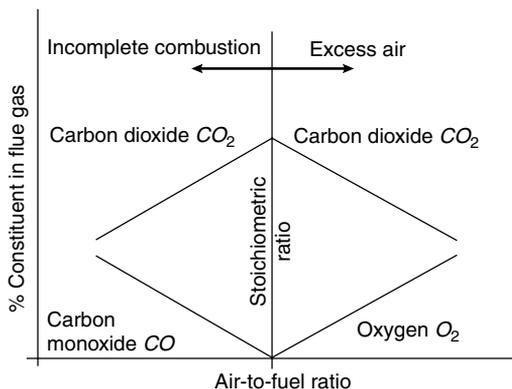
It can be seen from the methane combustion equation that  $2\text{ m}^3$  of  $O_2$  are required to burn  $1\text{ m}^3$  of  $CH_4$  completely. This  $O_2$  is contained in  $2/0.21 = 9.52\text{ m}^3$  of air, and this air contains,  $9.52 - 2 = 7.52\text{ m}^3 N_2$ .

In order to ensure complete combustion under all operating conditions and to allow for deterioration of boiler efficiency between servicing, excess air is admitted. This ranges from 30% for a domestic pressure jet oil burner down to a few per cent in power station boilers where continuous monitoring and close control are essential. Excess  $O_2$  from the excess air appears in the flue gas analyses. Measurement of  $O_2$  and  $CO_2$  levels reveals the quantity of excess air.

The presence of carbon monoxide ( $CO$ ) in the flue gas indicates that some of the carbon in the fuel has not been completely burnt into  $CO_2$  and that more combustion air is needed. The theoretically correct air-to-fuel ratio is the stoichiometric ratio. Figure 4.22 shows the variation of flue gas constituents with the air-to-fuel ratio.

The  $CO_2$  content of oil-fired boiler plant flues will be about 12% at 30% excess air, the combustion air volume required per kilogram of fuel burnt will be about  $14.6\text{ m}^3$  and the flue gas temperature leaving the boiler will be about  $200^\circ C$ . For domestic natural-draught gas-fired boilers, excess air may be 60%, the flue gas temperature will be  $165^\circ C$  and the  $CO_2$  content will be around 7.5%.

Samples of flue gas taken during commissioning and routine servicing are tested for  $CO_2$  and  $O_2$  content by absorption into chemical solutions. The Orsat apparatus is typical. The smoke content is measured by drawing a sample through filter paper and comparing the discoloration with known values.

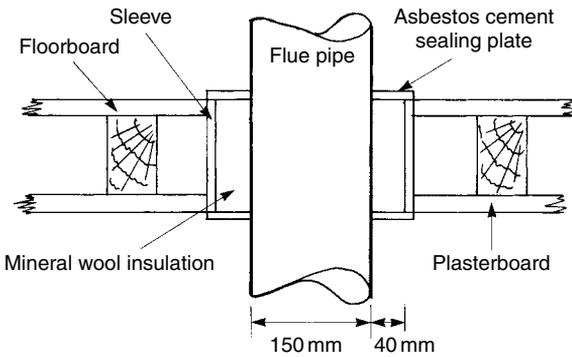


4.22 Variation of flue gas constituents with air-to-fuel ratio.

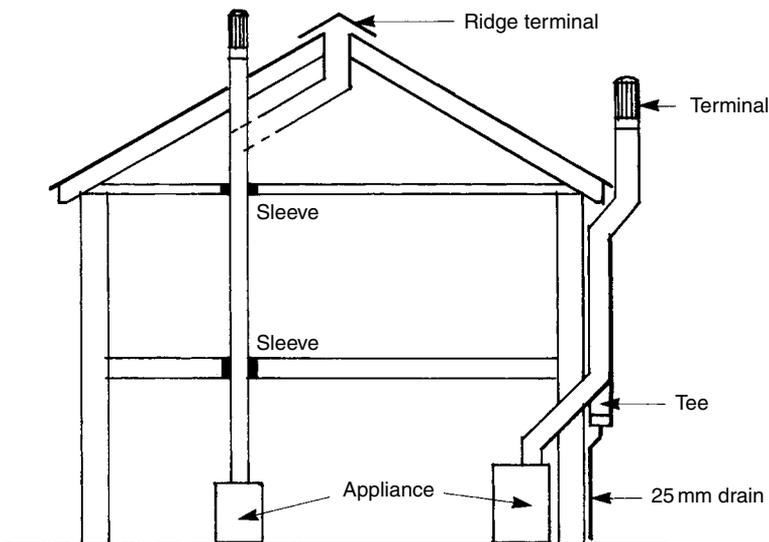
**Flues**

Flue systems for oil-fired boilers are of either the conventional brick chimney or free-standing pipe designs so as to discharge combustion products into the atmosphere and allow sufficient dilution so that fumes reaching ground level will not be noticeable. Chimneys from large boiler plant may be subject to minimum height specification by the local authority. Efflux velocity from the chimney can be increased by utilizing a venturi shape when fan assistance is used, effectively raising the chimney height.

The flue pipe diameter will be equal to the boiler outlet connection. Each boiler in a multiple installation should have its own flue. Flues must be kept warm to prevent acidic condensation, and are therefore constructed within the building. Some useful heat is reclaimed in this way. Figure 4.23 shows the necessary separation of flue pipe from combustible materials at an intersection with a floor. External free-standing pipes are constructed of double-walled asbestos or stainless steel to reduce heat loss. Figure 4.24 shows two suitable arrangements.



4.23 Separation of flue pipe from combustible materials in a floor.



4.24 Internal and external free-standing flue pipes.

### Performance testing

A radiator heating system is subjected to a water pressure test at greater than its normal working pressure prior to thermal insulation. To check its thermal performance, an assessment is made of the expected room temperature for the external conditions prevailing during the test. Careful measurements of the external air temperatures at regular intervals, the amount of solar radiation, the wind speed, the occupancy, the use of internal lighting and the sources of heat gains are needed.

Under steady-state conditions:

Heat loss from room = heat output from radiator

$$UA (t_{ei} - t_{eo}) = \text{constant} \times \left[ \frac{(t_f + t_r) / 2 - t_{ai}}{55} \right]^{1.3}$$

The radiator constant is its heat emission for a 55 K temperature difference. The room heat loss is a series of constants multiplied by  $(t_{ei} - t_{eo})$  K, including ventilation heat loss, and can be characterized by the air temperature difference  $(t_{ai} - t_{ao})$  K. Thus  $(t_f + t_r)/2$  can be replaced by the mean water temperature  $t_m$  °C. Therefore the heat balance equation simplifies to:

$$(t_{ai} - t_{ao})_1 = C(t_m - t_{ai})_1^{1.3}$$

and

$$(t_{ai} - t_{ao})_2 = C(t_m - t_{ai})_2^{1.3}$$

where subscripts 1 and 2 refer to the test day and design conditions respectively. These equations can be divided:

$$\frac{(t_{ai} - t_{ao})_1}{(t_{ai} - t_{ao})_2} = \left[ \frac{(t_m - t_{ai})_1}{(t_m - t_{ai})_2} \right]^{1.3}$$

The left-hand side of the equation represents the variation of building heat loss with temperature, and the right-hand side represents the heating system performance at various room temperatures. A graph of each side against a base of room air temperature can be drawn to find the room air temperature that satisfies both sides of the equation.

#### EXAMPLE 4.4

A radiator heating system is designed to produce an internal air temperature of 23°C at an outside air temperature of -2°C with a mean water temperature of 85°C. It was tested on a calm cloudy day, before occupation, when the external air temperature remained stable at 5°C for 2 days. Water flow and return temperatures at the boiler were found to be 88°C and 76°C respectively during the test. Room internal air temperature remained stable at 26°C. State whether the heating system performance met its design conditions.

On the test day,

$$t_m = \frac{88 + 76}{2} \text{ °C} = 82 \text{ °C}$$

and,

$$\frac{t_{ai} - 5}{23 - (-2)} = \left( \frac{82 - t_{ai}}{85 - 23} \right)^{1.3}$$

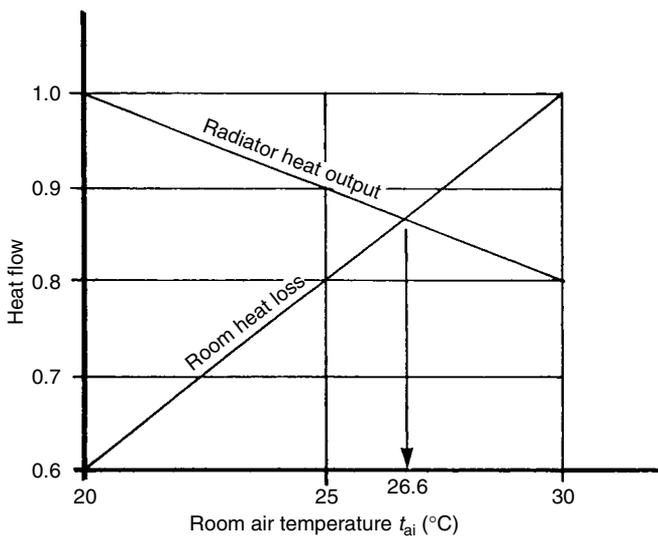
where  $t_{ai}$  is the expected internal air temperature on the test day. Then:

$$\frac{t_{ai} - 5}{25} = \left( \frac{82 - t_{ai}}{62} \right)^{1.3}$$

Assume a range of values for the internal air temperature of say 30°C, 25°C and 20°C. Evaluate each side of the equation (Table 4.5) and plot against  $t_{ai}$  (Fig. 4.25). The graphical solution reveals that an internal air temperature of 26.6°C satisfies both equations. This can be verified by substituting 26.6°C for  $t_{ai}$  in the heat balance equation. Thus the measured temperature on the test day is sufficiently close to the theoretically expected figure to say that the heating system meets its design specification.

Table 4.5 Radiator heat output test in Example 4.3.

$t_{ai}$ °C	Heat loss	Radiator heat output	
	$(t_{ai} - 5)/25$	$(82 - t_{ai})/62$	$[(82 - t_{ai})/62]^{1.3}$
30.0	1.0	0.839	0.80
25.0	0.8	0.919	0.90
20.0	0.6	1.000	1.000



4.25 Variation of room heat loss and radiator heat output with room air temperature in Example 4.3.

## Electrical power generation

Electricity is generated by alternators driven by steam turbines in power stations. The largest alternators produce 500 MW of electrical power at 33 kV. The steam is produced in a boiler heated by the combustion of coal or residual fuel oil, which could otherwise only be used for making tar. The oil is heated to make it flow through distribution pipework.

Nuclear power stations produce heat by a fission reaction and the active core is cooled by pressurized water (pressurized water reactor (PWR)), carbon dioxide gas (high-temperature gas-cooled reactor (HTGR)), liquid sodium (fast breeder reactor) or heavy water (Canadian deuterium (CANDU) system). This fluid then transfers its heat to water, boiling it into steam to drive conventional turbines.

Smaller alternators are driven by methane combustion in gas-turbine engines or by diesel engines. A large modern power station has four separate boiler-turbine-alternator sets, producing a total of 2000 MW at a maximum of 38% overall efficiency. Figure 4.26 shows the energy flows in a conventional power station.

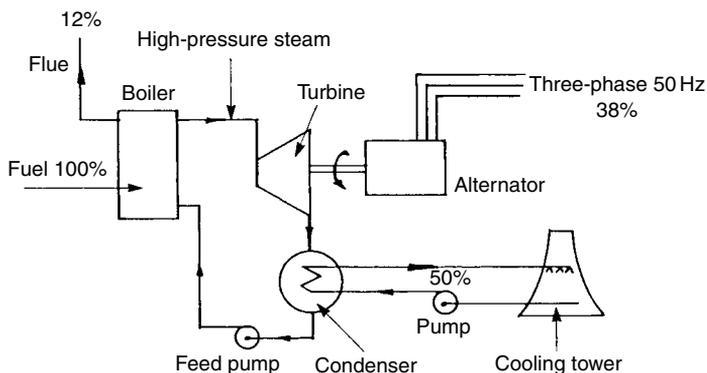
Approximately half the input fuel's energy is dissipated in natural-draught cooling towers or sea water, depending on the plant location. Steam leaves the turbine at the lowest attainable sub-atmospheric pressure so that as much power as possible is extracted from it as it passes through the turbines. The temperature of the cooling water may be as low as 35°C, which is of little practical use unless a mechanical heat pump is employed to generate a fluid at 60°C–90°C. The heat could then be pumped to dwellings. Power stations are normally sited away from centres of population and heat transport costs are high.

During the next 25–100 years, the UK is going to have to make more efficient use of its indigenous hydrocarbon reserves, extend nuclear power generation capacity and develop alternative production methods such as tidal, wave, solar, wind, geothermal and hydroelectric plants.

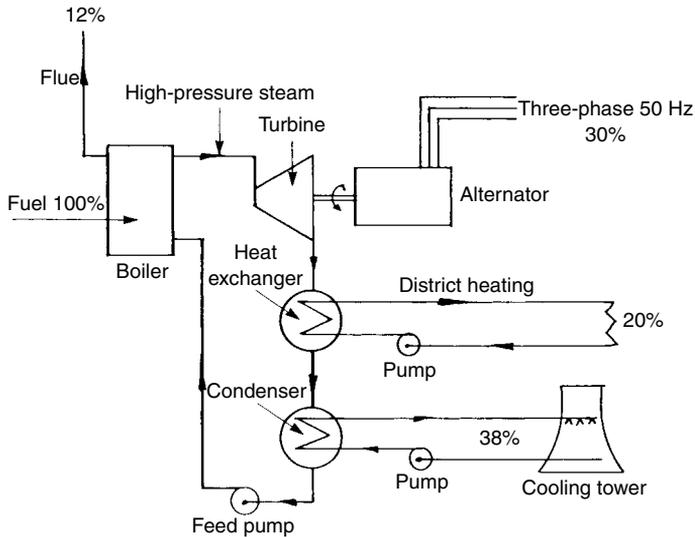
## Combined heat and power

Existing power stations generate electricity only, at as high an efficiency as possible. Combined heat and power (CHP) stations produce less electricity and more heat but improve overall fuel efficiency to about 50%, as indicated in Fig. 4.27.

Future CHP plants will be smaller than the present electricity-only plants and will be sited close to centres of industry and population. Coal-fired boilers will be used where practical. Fuel and ash will be mechanically handled and flue gases filtered to remove dust and impurities (Horlock, 1987).



4.26 Conventional 2000 MW power station.



4.27 Combined heat and power plant.

### District heating

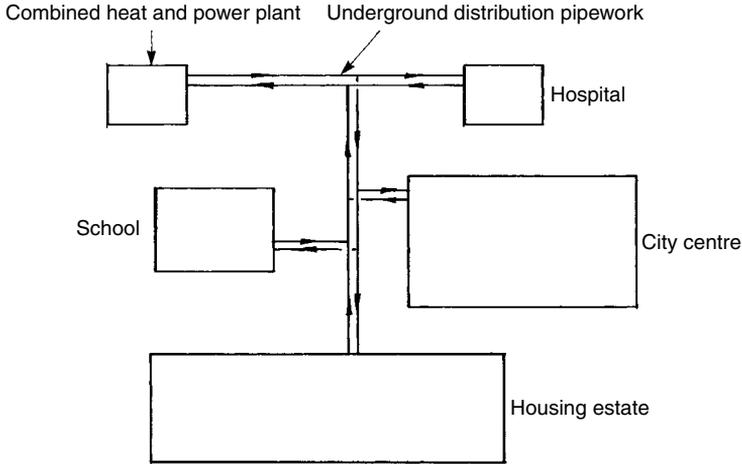
District medium- or high-pressure hot-water heating, employing two-, three- or four-pipe underground distribution systems, will provide heat primarily to the largest and most consistent users, such as hospitals, factory estates and city centres. Further custom will be won from existing buildings by straight price competition. The street distribution layout is indicated in Fig. 4.28. Flow and return pipes will be well-insulated and may be installed inside one large-diameter pipe, which will form the structural duct and moisture barrier.

The CHP plant generates electricity for the locality and is connected into the national grid. It should also incinerate local refuse, utilizing the heat produced, and recycle materials such as metals and glass. It will provide hot water for sanitary appliances and air conditioning and, as these will be summer as well as winter heat loads, a method of separating them from the heating system will be used. This can be done with the three- and four-pipe arrangements shown in Figs 4.29 and 4.30 to economize on pump running costs and pipe heat losses during the summer.

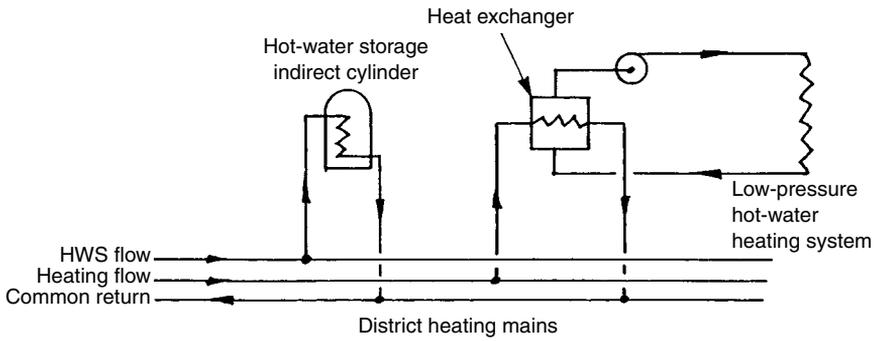
The supply of heat to each dwelling will be controlled by an electric motorized valve, actuated by a temperature sensor in the heat exchanger, which will enable existing low-pressure hot-water systems to be connected. A heat meter, consisting of a water flow meter and flow and return temperature recorders, will continuously integrate the energy used, and quarterly bills could be issued through a directly linked computer.

Medium- and high-temperature hot-water heating systems are sealed from the atmosphere. Pressurization methods involve restraining thermal expansion, charging with air or nitrogen, or making use of the static head of tall buildings. As the boiling point of water increases with increasing pressure, high flow temperatures can be used. This permits a large drop in temperature from flow to return (50 K or more), and water flow rates can be reduced compared with low-pressure hot-water open systems. Pipe sizes are smaller and the system is more economical to install when used on a large scale.

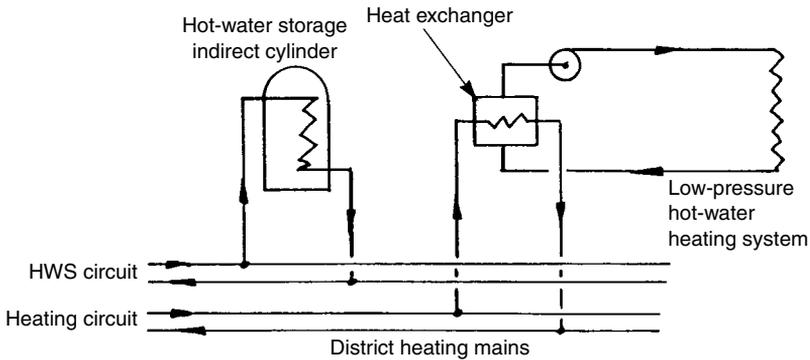
District cooling from a central refrigeration plant serving air-conditioning units in commercial buildings can be developed alongside a CHP scheme. Underground chilled-water pipework will



4.28 Medium- or high-pressure hot-water district heating system.



4.29 Three-pipe district heating system.



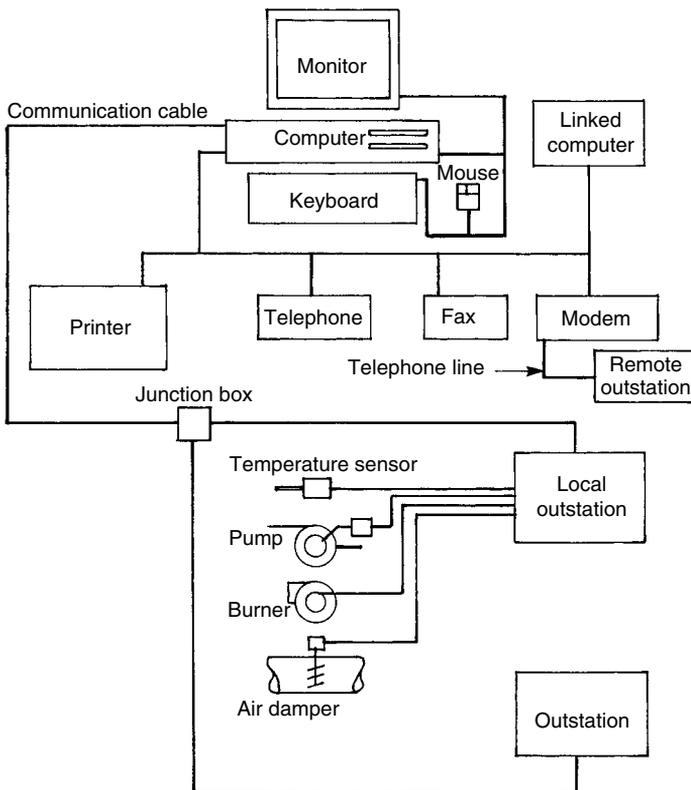
4.30 Four-pipe district heating system.

be separate from the heat network, and space, cost and acoustic advantages could be gained in comparison with individual systems. A higher standard of service should be available from centralized services, with fewer breakdowns and closer control of pollution.

### Building energy management systems

Computer-based remote control and continuous monitoring of energy-using systems, such as heating, air conditioning, electrical power, lighting and transportation, provide a higher standard of service than can be achieved manually (Fig. 4.31). The following types of control can be used.

1. The programmable logic controller (PLC) is a dedicated microprocessor programmed to operate a particular plant item such as a boiler, refrigeration compressor or passenger lift.
2. The energy management system (EMS) is a dedicated microprocessor that is linked to all the energy- and power-using systems such as heating, air conditioning, electrical power, lighting, lifts, diesel generators and air compressors. It may appear as a metal box on a wall of the plant room, having numbered buttons and a single line of screen display for maintenance staff to use for carrying out a limited range of routine changes. Such a unit may serve as an outstation that is either intelligent, having its own microprocessor, or dumb, merely passing data elsewhere.



4.31 Building energy management system.

3. A building energy management system (BEMS) is a supervisory computer that is networked to microprocessor outstations, which control particular plant such as heating and refrigeration equipment. All the energy-using systems within one building are accessed from the supervisor computer, which has hard disk data storage, a display unit, a keyboard, a printer and mimic diagrams of all the services.

Additional buildings on the same site can be wired into the same BEMS by means of a low-cost cable. Remote buildings or sites are linked to the supervisor through a telephone modem. A modem is a **modulator-demodulator** box, which converts the digital signals used by the computer into telecommunication signals suitable for transmission by the telephone network to anywhere in the world.

4. The plant management system (PMS) is used to control a large plant room such as an electrical power generator or district heating station. A PMS can be anything from a small dedicated PLC on a water chiller to an extensive supervisory computer system.
5. The building management system (BMS) is used for all the functions carried out by the building including the energy services, security monitoring, fire and smoke detection, alarms, maintenance scheduling, status reporting and communications. Types of BMS range from systems serving one small office, shop or factory to systems serving government departments and international shopping chains, which carry out financial audits, stocktaking and ordering of supplies each night utilizing telecommunications. Suppliers of, say, refrigeration equipment maintain links with all their installations in clients' buildings and are informed of faults as they occur and often prior to clients being aware of the problem.

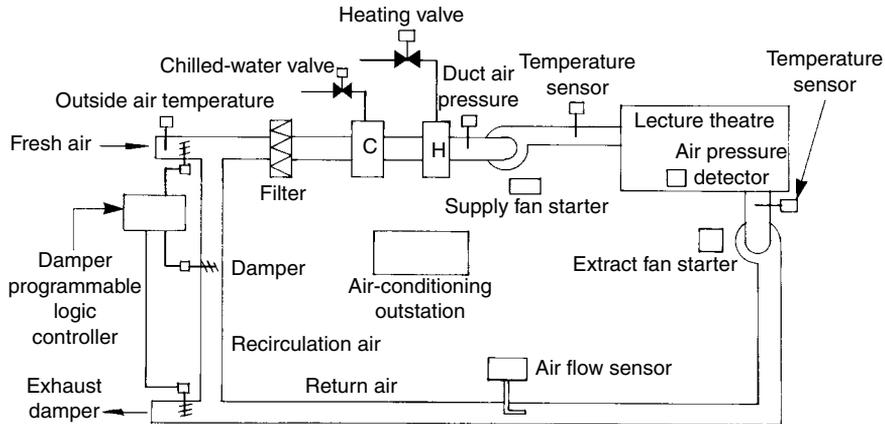
An outstation is a microprocessor located close to the plant that it is controlling and is a channel of communication with the supervisor. An intelligent outstation has a memory and processing capability that enables it to make decisions on control and to store status information. A dumb outstation is a convenient point for collecting local data such as the room air temperature and whether a boiler is running or not, which is then packaged into signals for transmission to the supervisor in digital code. Each outstation has its own numbered address so that the supervisor can read the data from that source only at a discrete time.

The supervisor is the main computer, which oversees all the outstations, PLCs and modems, contacting them through a dedicated wiring system using up to 10 V and handling only digital code. Such communication can be made every few seconds, and accessing the data can take seconds or minutes depending on the quantity of data and the complexity of the whole system, that is, the number of measurements and control signals transmitted.

The engineer in charge of the BEMS receives displayed and printed reports from the supervisor and has mimic diagrams (Fig. 4.32) of the plant, which enable identification of each pump, fan, valve and sensor together with the set points of the controllers that should be maintained. Alarm or warning status is indicated by means of flashing symbols and buzzers, indicating that corrective action by the engineer is required. Plant status, such as the percentage opening of a control valve and whether a fan is running, is recorded, but only the engineer can ascertain whether such information is correct, as some other component may have been manually switched off in the plant room by maintenance staff, or may have failed through fan belt breakage. Therefore a telephone line between the supervising engineer and the plant room staff is desirable to aid quick checking of facts.

The energy management engineer has seven main functions, which are accomplished by physical work, calculation and word processing:

1. supervision of the plant;
2. choosing the energy supply tariff;



4.32 Mimic diagram on a BEMS screen.

3. reading energy consumption meters and calculating consumption;
4. organizing maintenance work and keeping records;
5. liaising with all levels of staff and management;
6. producing energy management reports;
7. monitoring fire and security systems.

The BEMS can automate these functions as follows.

1. It can supervise the plant continually by means of analogue sensors, analogue-to-digital interfaces and communication cables.
2. It can perform remote reading of energy meters and of electricity, gas, oil and heat flow, integrate these with time to calculate total energy consumption, compare with desired values and control the plant to minimize consumption.
3. It can compare electricity and gas consumption rates with published tariffs and advise which would be most economical. It may be possible to switch off electrical loads automatically to keep to the lower-cost tariff.
4. It can continuously monitor fire detectors and security systems, such as door entry control and video camera operation, detect faults, inform about status and start alarm signals.
5. It can access BEMS control and monitor information at outstations by means of passwords, which disseminate information to, and allow restricted use by, different types of employee.
6. It can detect faults and alarm conditions as soon as they occur and display the warnings at the supervisory computer where they will be noticed without delay.
7. It can carry out normal control functions for energy-using systems and supervise what is going on.

Data which are sent to an outstation include the following:

1. measurement sensor data such as temperature, humidity, pressure, flow rate and boiler flue gas oxygen content;
2. control signals to or from valve or damper actuators;
3. plant operating status, which can be determined from the position of electrical switches which are open or closed, for example, to check whether a pump is operational.

Connections are made to an outstation by means of a pair of low-voltage cables, multi-core cable or fibre-optic cable (Haines and Hittle, 1983; Coffin, 1992; Levermore, 1992).

### Geothermal heating

The Southampton geothermal heating system removes heat from salt water (brine), which is pumped up from 1.7 km depth by a unique down-hole pump. The well has been operational since 1981 and has had pumped circulation since 1988 (Southampton Geothermal Heating Company). The well-head water temperature is 74°C, which is sufficient to provide up to 2 MW of heating and hot-water services within the city centre when working in conjunction with an absorption heat pump. This renewable energy resource is the core of the district heating system.

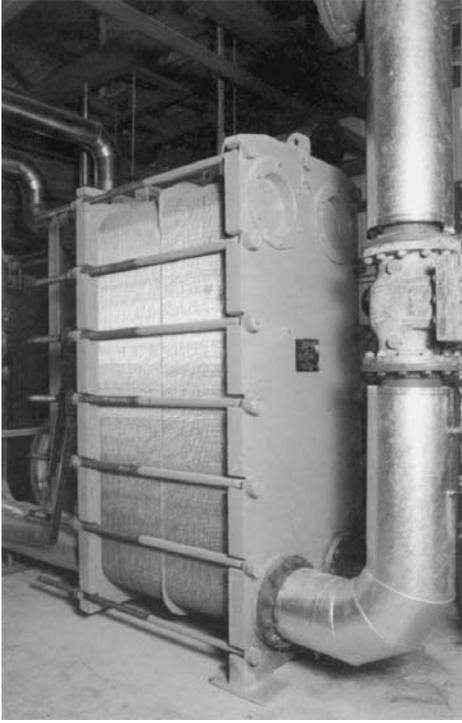
The source of the warm water is a 16 m thick layer of porous Triassic Sherwood sandstone, which is maintained at 76°C by the natural circulation of groundwater and heat flow from greater depths. The water has an acidic pH of 6.0 and high suspended solid, chloride salt and ammonia concentrations. The well is lined with a 245 mm diameter steel pipe. Water is extracted at the rate of 12 l/s by a down-hole pump that is driven from a down-hole turbine and is at a depth of 650 m. The turbine is rotated by water from a ground-level pump, which passes 31.6 l/s and consumes 192 kW of electrical power. This pump has a 250 kW three-phase electric motor, which is operated at a variable speed through a variable-frequency inverter. Figure 4.33 shows the well-head and the 250 kW pump.

The well water is passed through a titanium flat-plate heat exchanger, shown in Fig. 4.34, before being run into the storm drain at a temperature down to 30°C. This discharge water temperature fluctuates owing to the variations in the district heating return water temperature and whether the heat pump is used. The use of diverting three-port flow control valves on the heating systems within the buildings served is discouraged, as these would increase the water temperature that is returned to the heat station. The use of the absorption heat pump (Chapter 5) also influences the discharge temperature to the storm drain that directs the groundwater into the River Test estuary.

The heat station contains two 400 kW gas-fired reciprocating combined heat and power units, CHP, each generating 550 kW of waste heat which is recovered into the thermal network,



4.33 Southampton geothermal well head, brine pump and filter (reproduced by courtesy of Southampton Geothermal Heating Company).



4.34 The titanium flat-plate heat exchanger transfers heat from the brine to the district water circulating through the Southampton geothermal heating system (reproduced by courtesy of Southampton Geothermal Heating Company).

together with a much larger 5.7 MW CHP unit. This larger unit is a Wartsila 18V32DF, an 18-cylinder high-efficiency dual fuel reciprocating engine capable of operating on natural gas or light fuel oil, 35 s Redwood viscosity, as used in water heating plant. Three additional water heaters rated at a total of 7 MW burn natural gas or oil as needed. The host station also contains district water treatment and pressurization to 4 bar, district heating pumps, generator control and switchgear panels, a computerized heat monitoring and charging system and an absorption heat pump.

Heat recovered from the exhaust gas heat exchanger fitted to the larger CHP unit is matched to that required by the absorption heat pump; these can work with the geothermal well or the large-scale district cooling system. The boilers also supply high-temperature hot-water for the absorption heat pump. The heat pump lowers the return water temperature from the district circuit so that more heat can be extracted from the flat-plate heat exchanger and the brine. The heat that is removed from the district circuit is put back into it after the water has passed through the flat-plate heat exchanger. This takes place at the higher-temperature part of the heat pump, in the condenser.

A two-pipe recirculatory heating pipe system distributes heat to the Civic Centre, Southampton Institute, television studios, shops, offices and hotels. Consumers pay charges from heat meters in their building. Each heat meter integrates the water flow rate passing through that consumer's building, the water specific heat capacity, along with flow and return temperatures, to evaluate

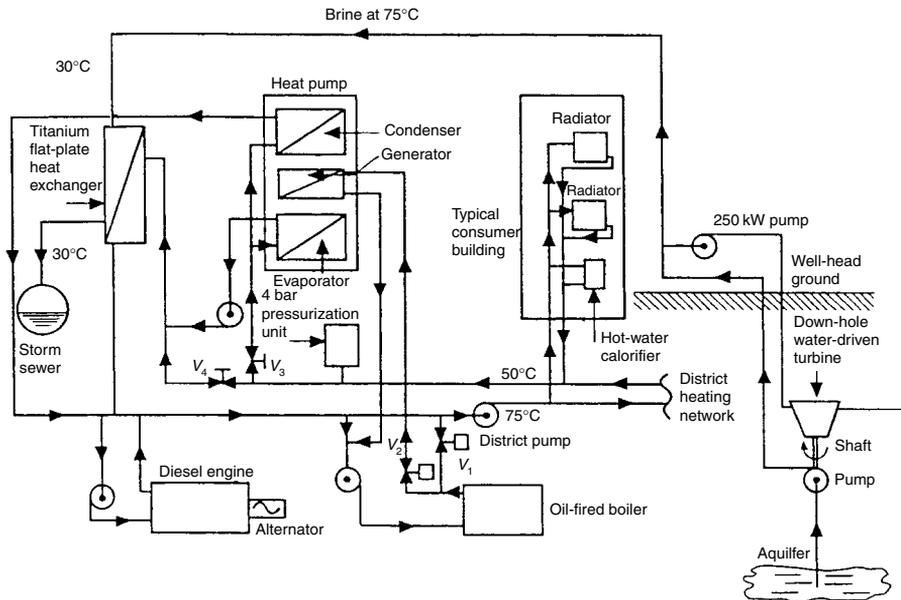
remotely the MWh consumed. The consumer pays around £37/MWh (3.7 p/kWh) for the heat energy units and a further fixed monthly charge which includes a contribution towards the overhead costs and capital repayment to the supplier. Overall, these charges are set to offer around a 10% saving against the alternative cost of on-site heating and cooling. The consumer does not pay maintenance costs for the heat service up to the heat meter, as they do with their own plant and services. Connection into the geothermal circuit may be free of capital charge to the consumer with the initial connection costs rolled into the long-term energy charges. However, commonly the consumer pays a connection charge of much less than their expected heating and cooling plant installation cost. When the existing gas and oil-fired boilers in the Civic Centre and Institute are used, the heat supply system can have a capacity of 28.9 MW. This will be sufficient for a large part of the city centre within a 2 km radius.

A recently added district cooling-chilled water two-pipe distribution system has six rotary screw refrigeration compressors of 1.2 MW cooling capacity each to supply the larger buildings close to the heat station. An ice thermal storage bank is to be added so that as much off-peak electricity as possible can be used instead of during the higher priced peak daytime hours.

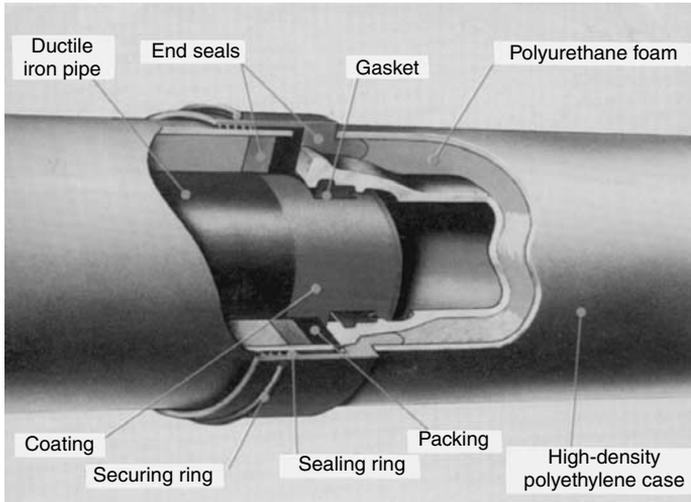
Figure 4.35 shows a simplification of the general arrangement of the heating system as it was originally installed. Recent additions of the CHP, exhaust gas heat exchanger, absorption and screw refrigeration chilled-water units have not been shown.

Figure 4.36 shows the construction of the underground cased pre-insulated pipe.

These descriptions of the heat station concept outline what can be done as alternatives to each building having its own heating and cooling plant with its attendant supervision, maintenance costs and owner responsibilities. Using a geothermal heat source greatly reduces greenhouse gas emissions as part of a sustainability initiative and is an example to us all of what can be done.



4.35 Simplified arrangement of the Southampton geothermal heating system.



4.36 Underground district heating pipe (reproduced by courtesy of Southampton Geothermal Heating Company).

### Questions

1. Sketch and describe two different types of heating system for each of the following applications: house, office, commercial garage, shop, warehouse and heavy engineering factory.
2. Why may the water in large heating systems be pressurized? Explain how pressurization systems work.
3. How do heating systems alter the mean radiant temperature of a room? Give examples.
4. What factors are included in the decision on the siting of a heat emitter? Give examples and illustrate your answer. What safety precautions are taken in buildings occupied by very young, elderly, infirm or disabled people?
5. How can radiant heating minimize fuel costs while providing comfortable conditions? Give examples.
6. Sketch the installation of a ducted warm-air heating system in a house and describe its operation.
7. List the characteristics of electrical heating systems and compare them with other fuel-based systems.
8. Outline the parameters considered when deciding whether to use a one- or two-pipe distribution arrangement for a radiator and convector-low pressure hot-water heating system.
9. Three rooms have heat losses of 2, 4 and 5 kW respectively. Double-panel steel radiators are to be used on a two-pipe low-pressure hot-water system having flow and return temperatures of 85°C and 72°C respectively. Room air temperatures are to be 20°C. Choose suitable radiators from Table 4.2 and calculate the water flow rate for each.
10. Sketch and describe a microbore heating installation serving hot-water radiators. State its advantages over alternative pipework systems.
11. A medium-pressure hot-water heating system is designed to provide a heat output of 100 kW with flow and return temperatures of 110°C and 85°C respectively. Calculate the pump water flow rate required in litres per second.
12. Find the dimensions of a double-panel steel radiator suitable for a room having an air temperature of 15°C when the water flow and return temperatures are 86°C and 72°C respectively, and the room heat loss is 4.25 kW.

13. The two-pipe heating system shown in Fig. 4.20 is to be installed in an office block where radiators 1, 2 and 3 represent areas with heat losses of 12, 20 and 24 kW respectively. Water flow and return temperatures are to be 90°C and 75°C respectively. The pipe lengths shown are to be multiplied by 1.5. Pump A (Fig. 4.19) is to be used. Pipe heat losses amount to 10% of room heat losses. The friction loss in the pipes is equivalent to 25% of the measured length. Find the pipe sizes.
14. A hot-water radiator central heating system is commissioned and tested while the average outdoor air is 3°C and there is intermittent sunshine and a moderate wind. The building is sparsely occupied. Water flow and return temperatures at the boiler are 90°C and 80°C respectively, and the room average temperature is 27°C. The heating system was designed to maintain the internal air at 22°C at an external air temperature of -1°C with flow and return temperatures of 85°C and 73°C respectively. State whether the heating system met its design specification and what factors influenced the test results.
15. List and discuss the merits of the methods used to generate electrical power.
16. Discuss the application of CHP systems in relation to density of heat usage, local and national government policy, possible plant sites, complexity of existing underground services, ground conditions, costs of competing fuels, type and age of buildings, traffic disruption during installation and better control of pollution. (The term 'density of heat usage' refers to the actual use of heat in megajoules per unit ground plan area m<sup>2</sup>, including all floors of buildings and appropriate industrial processes requiring the sort of heat to be sold.)
17. Where will a computer-based building management system usually not be found?
  1. Public hospital.
  2. Prison.
  3. Car-manufacturing plant.
  4. 500-person office building.
  5. 100-room hotel.
18. What does the term BMS mean?
  1. Building access system.
  2. Building maintenance system.
  3. Building management system.
  4. Building monitored security.
  5. Business manual security.
19. How often does the building management system communicate data with sensors and actuators?
  1. Continuously.
  2. Once per hour.
  3. Daily.
  4. Every few seconds.
  5. Annual reports.
20. What forms does building management system data not take when passing through the communications cabling?
  1. Alternating current of over 1.0 A.
  2. Light pulses through fibre-optic cables.
  3. Internet protocol data packets.
  4. Electrical direct current below 0.10 A.
  5. Voltage of 10 V maximum.

21. What is a 'point' in a building management system?
1. No such thing.
  2. Water chiller, flow control valve and temperature sensors.
  3. Water system.
  4. Air-handling unit.
  5. Printed circuit board in an outstation.
22. What opens and closes a water flow control valve or an air damper in a computer-based building management system?
1. Electric or pneumatic motor.
  2. Manually operated and wheel valves.
  3. Hydraulic actuator.
  4. Geared drive.
  5. Winding gear.
23. Which of these are 'controllers' in a building management system?
1. An engineer sat at a personal computer.
  2. The personal computer.
  3. Printed circuit boards hidden away in metal or plastic boxes in plant rooms.
  4. Water and air temperature sensors.
  5. Hand-held devices.
24. Which of these may be found in a computer-based building management security system? Choose as many as appropriate.
1. Armed guards.
  2. Intruder protection bars at windows.
  3. Digital or video camera recording.
  4. Guard dogs.
  5. Record of personnel movements.
  6. Identity badging and door swipe cards.
  7. Fibre-optic cable network communications.
  8. Telephones.
  9. Asset tracking e-tags.
25. Which of these comments are factually correct about a building management system and are not just an opinion?
1. Physical security protection is now out of date.
  2. Allows one person to control and monitor a large facility.
  3. Digital recording cameras stop illegal break-ins and escapes.
  4. Turn off the power source and it is useless.
  5. RS232 and RS484 are types of automatic control system.
26. What does the mechanical services switchboard, MSSB, do?
1. Router for all telephone calls between Property Services staff.
  2. Automatically controls all air conditioning and transportation systems on the campus.
  3. It is the manually operated switchboard for all mechanical services systems within the building.
  4. Switches all the electrical sub-circuits for the whole building.
  5. Only needed in buildings that do not have a computer-based building management system.

27. Which is not correct about the heating hot water, HHW, source:
1. Often called a boiler.
  2. A boiler is a gas-fired or electrically heated device which generates steam.
  3. HHW circulating at 75°C is steam at atmospheric pressure when it leaks out of the pipes.
  4. Is usually a gas-fired water heater at 75°C.
  5. Is a sealed water system having a thermal expansion tank.
28. Outstation and main control boxes of a building management system are normally found in:
1. Terminal air-conditioning units.
  2. Plant rooms.
  3. Computer rooms.
  4. Services shafts.
  5. The office of the building management personnel.
29. Programming and commissioning of a building management system is carried out:
1. With a screwdriver.
  2. At the server computer.
  3. Remotely through the internet.
  4. By calibrating room air temperature sensors with a thermometer.
  5. With a laptop computer communicating directly with each control box.
30. What types of cable system are used for building management system communications cables?
1. 240 V alternating current.
  2. Screened TV Aerial cable.
  3. RS485 and RS232 copper 10 V twisted pair.
  4. Mineral-insulated copper conduit.
  5. Any earthed cable.
31. What is a room-sealed gas appliance? More than one correct answer.
1. Gas-fired heater installed outside a room in the outside air.
  2. Gas-fired warm-air ducted heater installed within a sealed cupboard.
  3. Any balanced-flue gas appliance.
  4. No such thing.
  5. Gas-fired heater where combustion air enters the unit directly from outdoors through the same wall terminal where flue gas is discharged into the outdoor air.
32. What does an air curtain do?
1. Provides a security screen at an international airport flight passenger entrance.
  2. A draught to overcome prevailing wind direction at a doorway.
  3. Creates a downward or horizontal air stream across an open doorway.
  4. Makes entering a building very draughty.
  5. Wastes energy from fan power.

33. Which reports do the energy auditor want from the BMS?
1. Daily schedules of zone temperatures.
  2. Lift and security camera usage data.
  3. Zone temperatures, mechanical and electrical systems schematic drawings, detailed energy consumption, weather data, gas and electrical hourly peak demands each month and trend graphs.
  4. All fault reports.
  5. Energy auditor is too remote from day to day use of the building and does not see any reports.
34. What is the name of the generic data communication system used in BMS?
1. Open system.
  2. BACNet.
  3. LONtalk.
  4. Ethernet.
  5. GSM telephone.
35. Which communication protocol (language) passes through BMS data systems?
1. Binary 32 data bit streams.
  2. TCP/IP.
  3. HTTP.
  4. Wi-Fi.
  5. Token ring.
36. What does TCP/IP stand for?
1. Television control programming, internet post.
  2. Transmission control protocol, internet protocol.
  3. Telephone control program, internet protocol.
  4. Transmission control program, internet packages.
  5. Telephone communication package, internal protocol.
37. Which of these acronyms is not related to data communications within building management computer-based systems?
1. BACNet.
  2. LONtalk
  3. MODbus.
  4. GSMnet.
  5. ARCNet.
38. What does this formula calculate?
- $$\frac{Q}{SHC(t_f - t_r)}$$
1. Heat emission from a radiator.
  2. Supply air volume flow rate for an air-conditioned room.
  3. Average temperature of hot water in a storage calorifier.
  4. Required hot water flow rate to a heat emitter when  $Q$  represents the heat emission.
  5. Thermal transmittance of a structure from heat flow  $Q$ .

39. Which of these is the equivalent length for a pumped heating water system circulation?

1. Total length of the longest flow and return circuit.
2. Total length of all pipes in the heating system.
3. That flow and return circulation which creates the pump pressure rise.
4. Length of the longest circuit to the furthest heat emitter.
5. Total length of all pipes plus 25%.

40. Which units specify pump head?

1.  $\text{N/m}^2$ .
2.  $\text{kN/m}^2$ .
3.  $\text{N/m}^3$ .
4. bar.
5. metre water gauge.

41. Which is true about combustion?

1. All fuels contain nitrogen.
2. Air is mainly nitrogen.
3. Nitrogen is combustible.
4. Nitrogen has inertia.
5. Nitrogen in air accelerates the combustion process.

42. Which of these chemical symbols is correct?

1.  $\text{CO}_3$ , carbon trioxide.
2.  $\text{CO}$ , calcium oxide.
3.  $\text{HO}$ , hydrogen oxide.
4.  $\text{CO}_2$ , carbon oxide.
5.  $\text{H}_2\text{O}$ , water vapour or liquid.

43. Which statement relating to combustion is correct?

1.  $\text{CO}_2$  means two molecules of carbon monoxide.
2.  $2\text{O}_2$  means two molecules of oxygen.
3.  $2\text{H}_2\text{O}$  means two atoms of hydrogen plus two atoms of ozone.
4.  $\text{CO}$  is carbon oxide.
5.  $\text{SO}_2$  means sodium dioxide.

44. Which statement relating to combustion is correct?

1. Nitrogen in air assists combustion.
2. Air contains 23.2% oxygen by volume.
3. Air contains 21% oxygen by volume.
4. Outdoor air normally contains 12%  $\text{CO}_2$ .
5. Internal combustion engine traffic cleans up free hydrocarbons in the atmosphere.

45. Which of these combustion equations is correct?

1. Fuel + air + heat = nitrogen + water vapour + heat.
2. Hydrogen + oxygen = water vapour + heat.
3. Carbon + hydrogen + oxygen + nitrogen = carbon dioxide + nitrogen.
4. Hydrocarbon fuel + air = carbon dioxide + water vapour + nitrogen.
5. Carbon + oxygen + nitrogen = carbon dioxide + heat .

46. What does stoichiometric ratio mean?
1. Optimum efficiency.
  2. Maximum oxygen in flue gas.
  3. Maximum carbon dioxide in flue gas.
  4. Poor combustion.
  5. 100% excess air provided.
47. Which is not correct about combined heat and power plant?
1. Reject steam from turbine at higher pressure and temperature than in conventional plant.
  2. About 30% efficient at converting fuel energy into electricity.
  3. Must always be gas-turbine-driven generation.
  4. Can be gas-turbine-driven generation.
  5. Plant overall thermal efficiency around 50%.
48. Which is correct about conventional power generation?
1. Steam boilers work at the lowest practical pressure.
  2. Boilers generate steam at the highest practical pressure.
  3. Wet steam leaves the boilers.
  4. Modern power plant does not use steam.
  5. Steam is an out of date heating method.
49. Which is correct about nuclear-sourced conventional power generation?
1. Nuclear power stations never create any greenhouse gases.
  2. They will become the sole means of generating electricity.
  3. They are too dangerous to build.
  4. Spent nuclear fuel rods are safe to handle.
  5. Spent nuclear fuel rods remain radioactive for thousands of years.
50. Which is correct about nuclear-sourced conventional power generation?
1. Uranium is combusted to produce steam.
  2. Uranium fusion releases heat.
  3. Fission of Uranium releases heat.
  4. Uranium corrodes into lead in releasing heat.
  5. Radiation from Uranium releases heat.
51. Which is correct about nuclear-sourced conventional power generation?
1. Pressurized water nuclear reactor uses water to drive the electricity generator.
  2. Pressurized water nuclear reactor generates steam to drive turbines.
  3. Sodium gas-cooled nuclear reactors are the most popular type.
  4. Carbon dioxide gas-cooled nuclear reactors are the most popular type.
  5. Oil-cooled nuclear reactors are the most popular type.
52. Which is correct for district heating?
1. Heat supplied is charged to the consumer on a flat rate such as £/m<sup>2</sup> floor area.
  2. Heat supplied is charged at an annual fixed price to consumer.
  3. Heat supplied is charged at an annual fixed price irrespective of how much is consumed.

4. Heat supplied is charged to consumer through heat metering.
  5. Impossible to measure amount of heat energy actually supplied to any consumer.
53. Which is correct about the use of carbon dioxide sensors?
1. Detect ingress of pollution from road traffic.
  2. Used to vary the supply of outdoor air into rooms having VAV systems.
  3. Control the intake of outdoor air into an air-handling unit.
  4. Warn the fire and smoke detection systems of a fire source.
  5. Used to control underground car park mechanical ventilation systems.
54. What limits the thermal efficiency of a solar water heating panel, tube or concentrator?
1. Weak solar irradiance.
  2. Surface area of collector.
  3. Lack of thermal insulation on the back of a flat panel.
  4. Excessive water flow rate.
  5. Heat loss from heated water back to the environment.
55. Which component of a building management system controller takes input and output direct current voltages from sensors and actuators, changing them into computer data?
1. Multiplexer.
  2. The Ethernet.
  3. Analogue-to-digital converter.
  4. EPROM and RAM chips.
  5. Arithmetic logic unit, ALU.
56. Which of these statements about HTML is correct?
1. Another name for binary code.
  2. Internationally accepted standard of control system protocol.
  3. Proprietary name of open access control protocol.
  4. A mathematical program language.
  5. Language of TCP/IP.
57. What does  $N/m^3$  stand for?
1. Nanometres per  $m^2$  pressure drop per metre run of pipe.
  2. Neurons per cubic metre of room volume.
  3. Newton's per square metre pressure drop per metre run of pipe or duct.
  4. Newton's per cubic metre is a density.
  5. Nano-particles of radon gas per cubic metre of air in a building.