Sanitary Systems

HOT WATER AND SUPPLY SYSTEMS

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Expansion of Water

Water expands with changes in temperature. At 4 C water is at its most dense. At temperatures below 4 ƒ C down to zero or freezing, water expands about 9% (approximately 1/10) by volume. This is why underground supplies require adequate ground cover and externally exposed water pipes require insulation to prevent damage. At temperatures between 4 C and 100 C or boiling, water expands by about 4% (approximately 1/25) by volume and is significantly less dense see table below. This degree of expansion and reduction in density is the principle of convective water circulation in elementary hot water

systems.

Temperature (°C)	Density (kg/m^3)
0	999·80
4	1000·00
10	999·70
20	998·20
30	995·00
40	992·20
50	987·50
60	983·20
70	977·50
80	971·80
90	965·60
100	958·00

$$E = C \times (\rho_1 - \rho_2) \div \rho_2$$

Where: E = expansion (m^3)

C = capacity or volume of water in system (m^3)

ρ_1 = density of water before heating (kg/m^3)

ρ_2 = density of water after heating (kg/m^3)

Example

Example: A hot water system containing $15 m^3$ of water, initially at 10°C to be heated to 80°C.

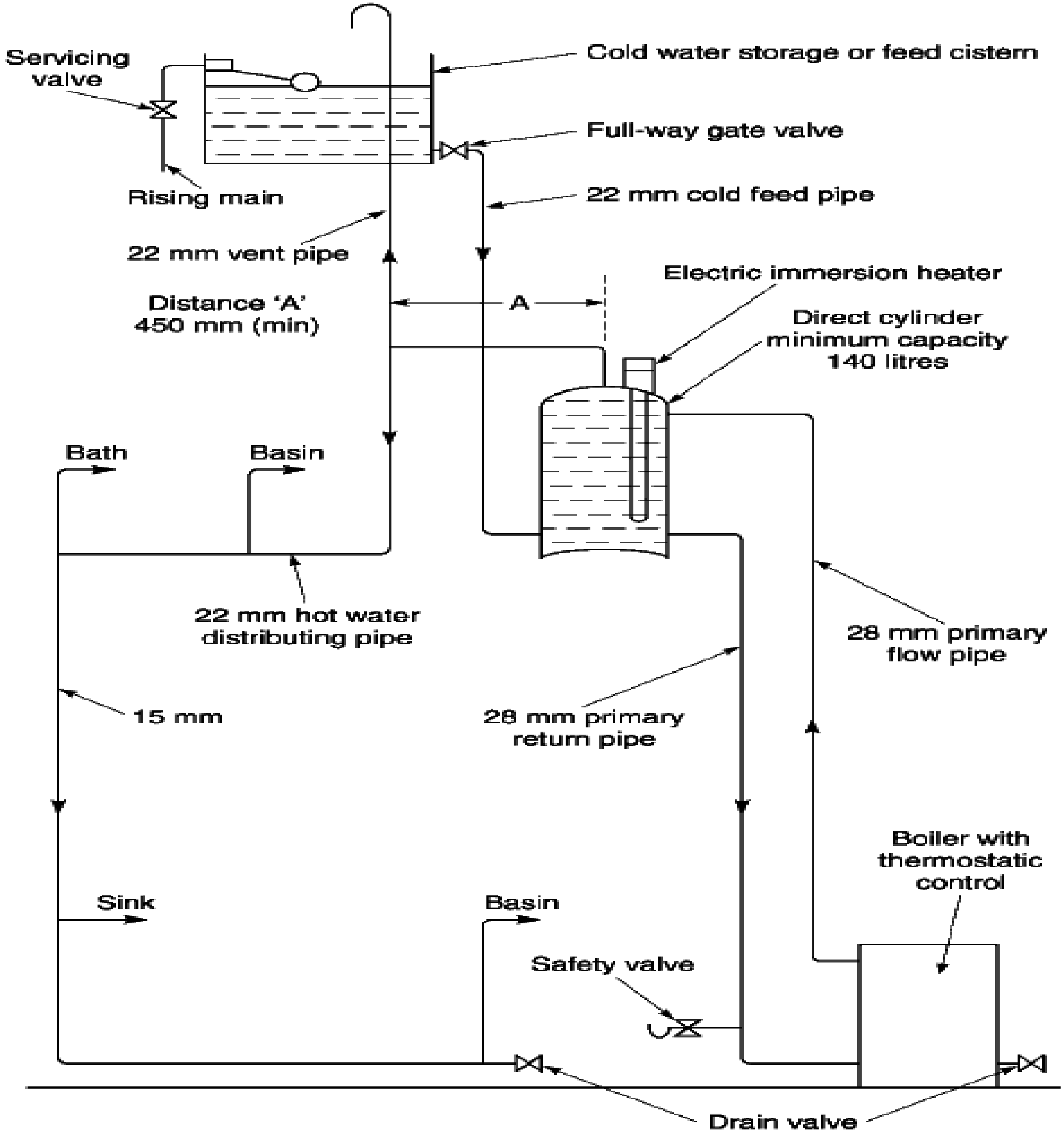
$$E = 15 \times (999{\cdot}70 - 971{\cdot}80) \div 971{\cdot}80$$

$$E = 0{\cdot}430 \; m^3$$

Hot water and heating systems must incorporate a means for accommodating expansion. A fail safe mechanism must also be provided should the initial provision malfunction.

Direct System of Hot Water Supply

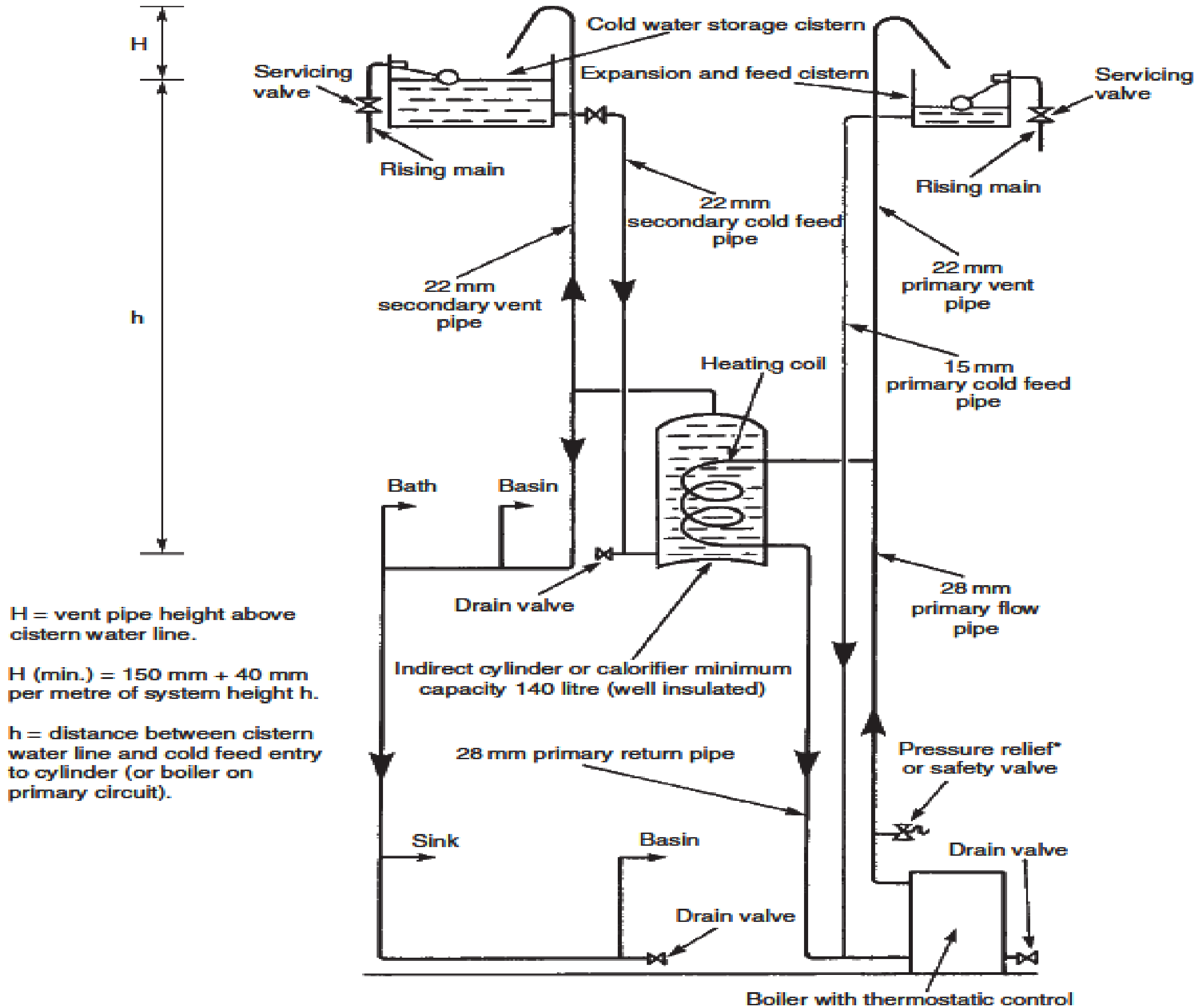
The hot water from the boiler mixes directly with the water in the cylinder. If used in a `soft' water area the boiler must be rust-proofed. This system is not suited to 'hard' waters, typical of those extracted from boreholes into chalk or limestone strata. When heated the calcium precipitates to line the boiler and primary pipework, eventually `furring up' the system to render it ineffective and dangerous. The storage cylinder and associated pipework should be well insulated to reduce energy losses. If a towel rail is fitted, this may be supplied from the primary flow and return pipes.



Servicing valve
Cold water storage or feed cistern
Full-way gate valve
Rising main
22 mm cold feed pipe
22 mm vent pipe
Electric immersion heater
Distance 'A' 450 mm (min)
A
Direct cylinder minimum capacity 140 litres
Bath
Basin
22 mm hot water distributing pipe
28 mm primary flow pipe
15 mm
28 mm primary return pipe
Boiler with thermostatic control
Sink
Basin
Safety valve
Drain valve

Indirect System of Hot Water Supply

This system is used in 'hard' water areas to prevent scaling or 'furring' of the boiler and primary pipework. Unlike the direct system, water in the boiler and primary circuit is not drawn off through the taps. The same water circulates continuously throughout the boiler, primary circuit and heat exchange coil inside the storage cylinder. Fresh water cannot gain access to the higher temperature areas where precipitation of calcium would occur. The system is also used in combination with central heating, with flow and return pipes to radiators connected to the boiler. Boiler water temperature may be set by thermostat at about 80°C.



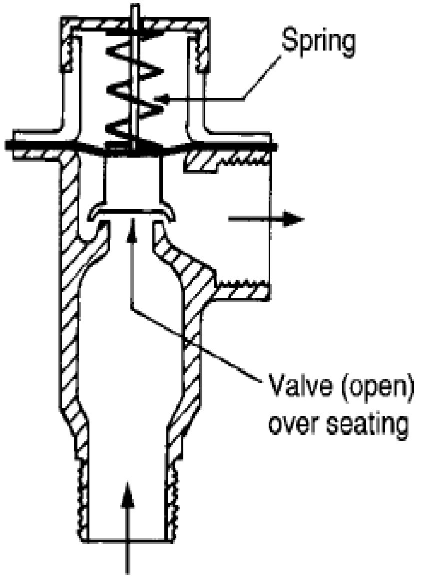
*A safety valve is not normally required on indirect open vent systems, as in the unlikely occurrence of the primary flow and vent becoming obstructed, water expansion would be accommodated up the cold feed pipe.

Hot water system components

1. Expansion valve

Expansion devices in hot water systems are designed as a safe means for discharging water when system operating parameters are exceeded, i.e. in conditions of excess pressure and/or temperature.

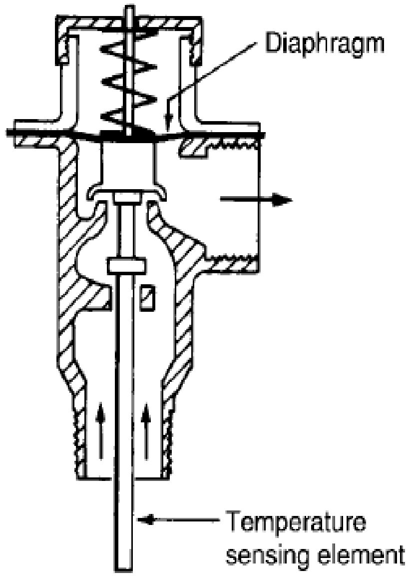
Expansion valve : Care should be taken when selecting expansion or pressure relief valves. They should be capable of withstanding 1.5 times the maximum pressure to which they are subjected, with due regard for water mains pressure increasing overnight as demand decreases.



Expansion valve

2. Temperature relief valve

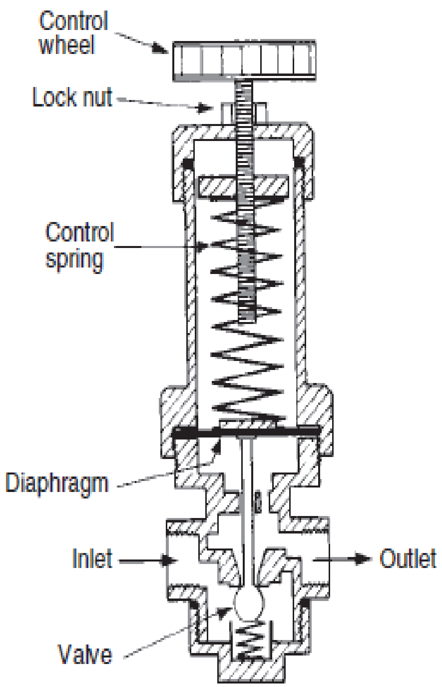
These should be fitted to all unvented hot water storage vessels exceeding 15 liters capacity. They are normally manufactured as a combined temperature and pressure relief valve. In addition to the facility for excess pressure to unseat the valve, a temperature sensing element is immersed in the water to respond at a pre-set temperature of 95 C.



Temperature relief valve

Pressure Reducing Valve

Pressure reducing valves are otherwise known as pressure regulators. PRV's can be applied to many different piped services including gas, compressed air, water and steam. These applications may range from relatively simple installations such as mains water supplied domestic unvented hot water storage systems, to larger scale industrial steam and district heating schemes.

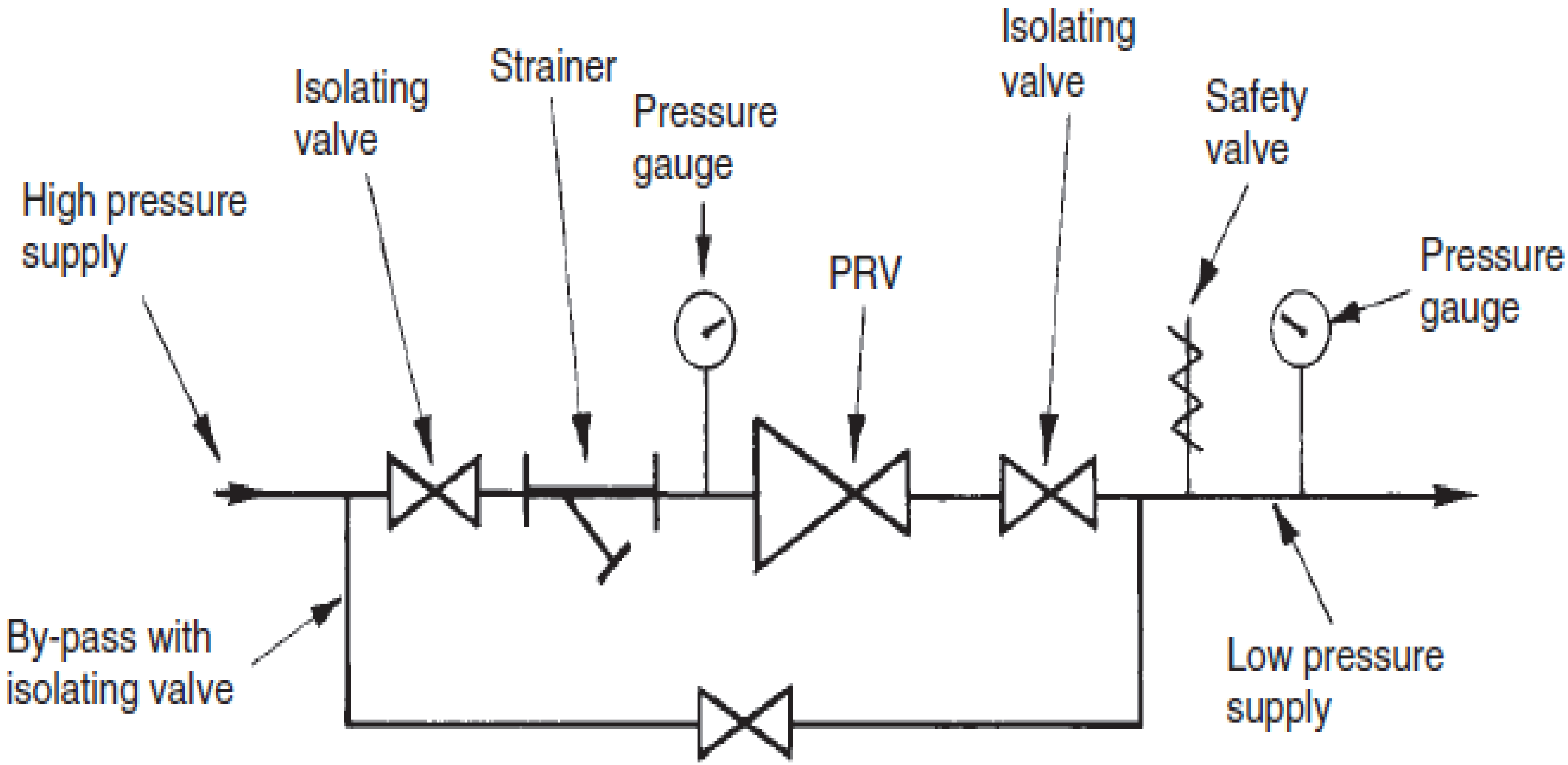


Typical PRV

Pressure Reducing Valve (cont….)

High pressure is needed to overcome the resistances of long lengths of pipe distribution, changes in direction, valves, etc. For local distribution, the pressure must be reduced to:

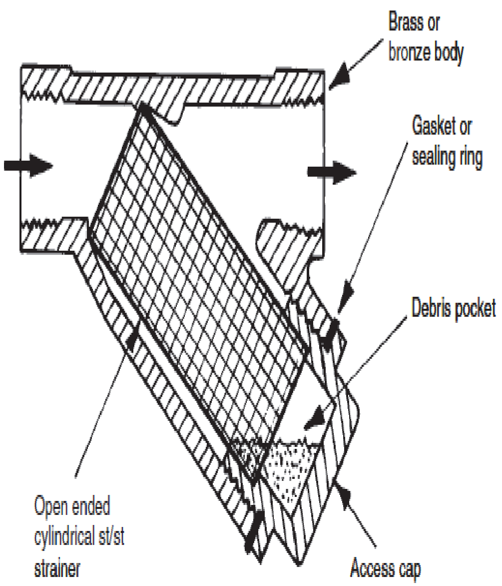
- **Prevent undue wear and damage to the lighter gauge fittings and fixtures at the end use.**
- **Provide a maximum safe working pressure to prevent injury to end users.**
- **Regulate supplies at a constant value or desirable secondary pressure, irrespective of inlet pressure variations and changes in demand.**



Installation to an industrial situation

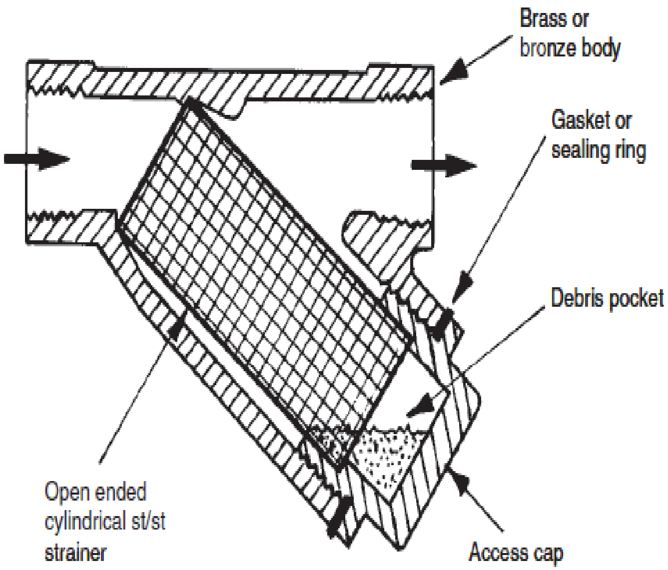
Strainers

A strainer is used to filter out and trap fluid suspended deb pipe scale and carbonate deposits from hard water. This fa is essential to prevent component wear by erosion and abrasion, and interference with the efficient operation of p system controls. Strainers are a standard installation on processing plant and other industrial applications. There h been little need or strainers in domestic systems, until the of items such as thermostatic mixing valves, shower mixer check valves and pressure reducing valves have become standard.

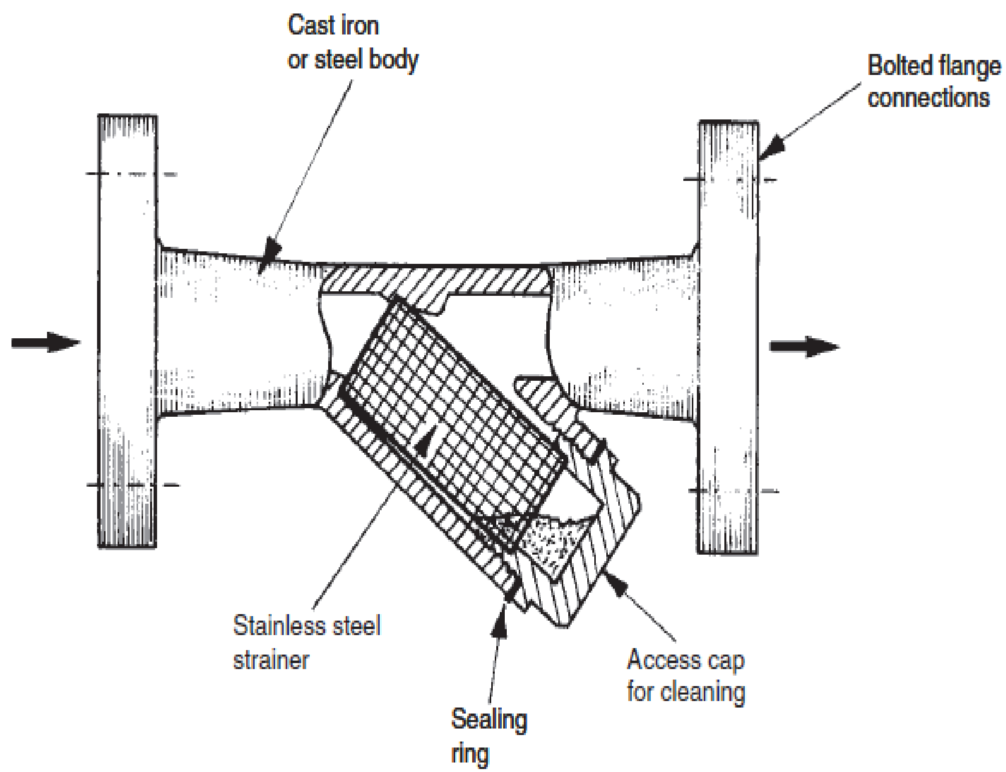


Threaded for domestic and light industrial services

Strainers



Threaded for domestic and light industrial services



Flanged for industrial applications

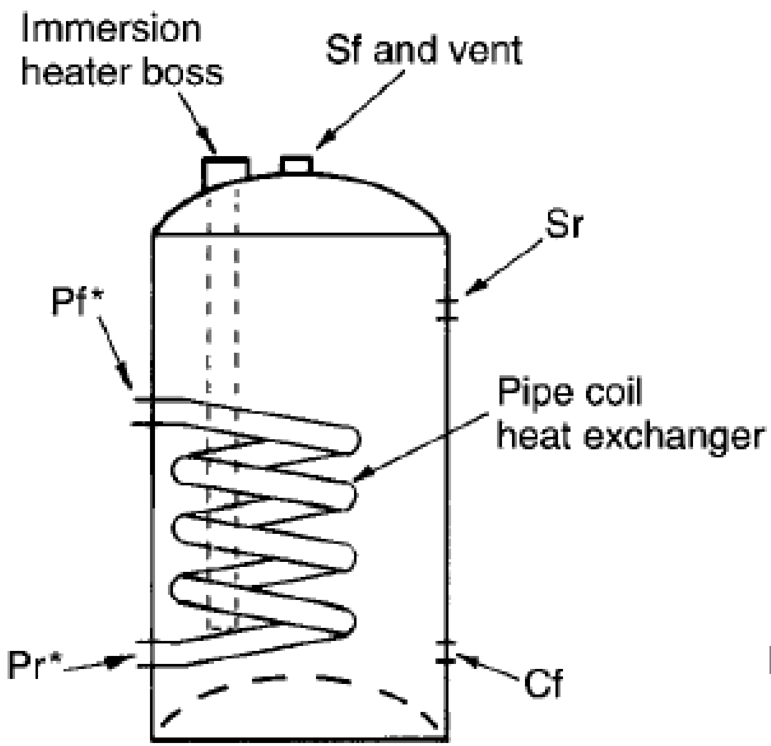
Hot Water Storage Cylinders

BS 1566-1: Copper indirect cylinders for domestic purposes. Open-vented copper cylinders. Requirements and test methods.

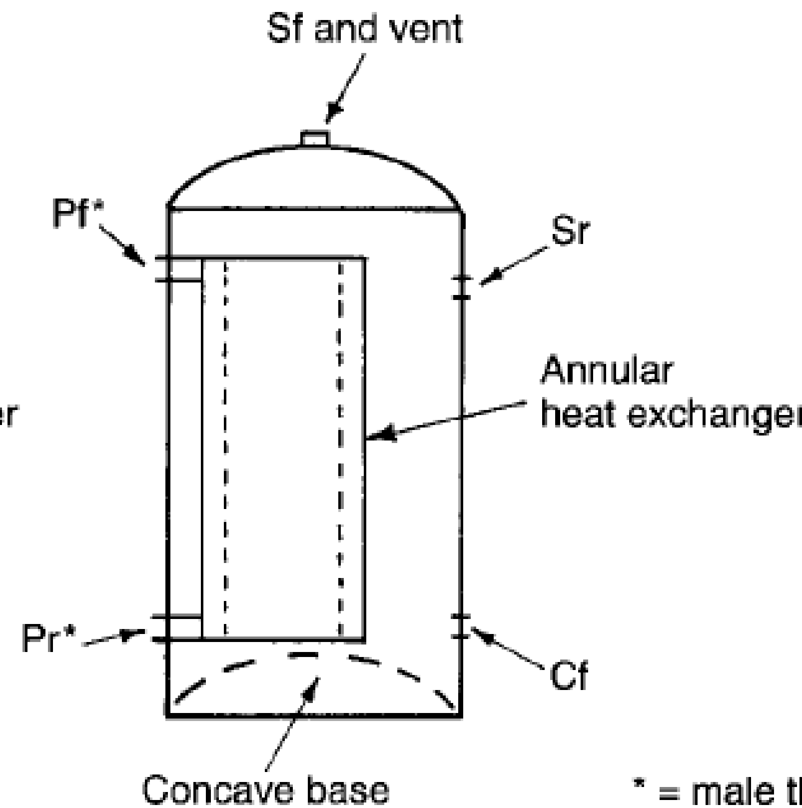
BS 1566-2: Copper indirect cylinders for domestic purposes. Specification for single feed indirect cylinders.

BS 417-2: Specification for galvanised low carbon steel cisterns, cistern lids, tanks and cylinders.

Hot water storage cyl.



Indirect copper,
72 – 440 litres (domestic)



Indirect galvanised steel,
109 – 455 litres (domestic)

* = male thread
key: see next page

Hot water storage cyl.(cont……)

Direct cylinders have no coil or annular heat exchangers. They can be identified with female pipe threads for the primary flow and return connections. For domestic use: copper - 74 to 450 litres capacity, galvanised steel - 73 to 441 litres capacity. Direct and indirect cylinders for industrial and commercial applications are manufactured in copper and galvanised steel in capacities up to 4500 litres.

Types of Boiler

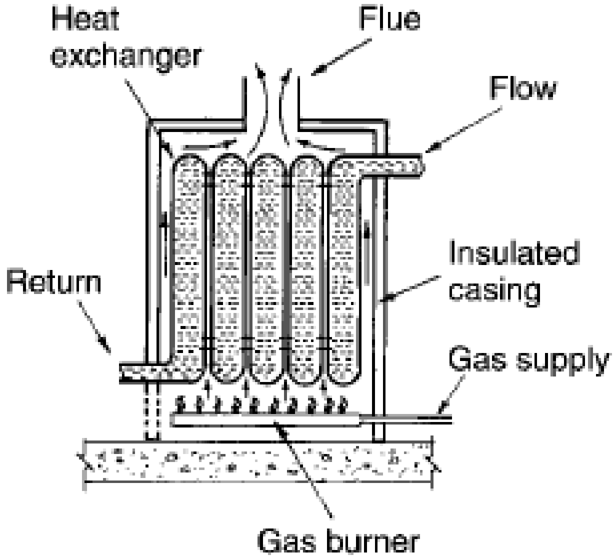
Cast iron sectional † made up of a series of hollow sections, joined together with left- and right-hand threaded nipples to provide the heat capacity required. When installed, the hollow sections contain water which is heated by energy transfer through the cast iron from the combusted fuel. Applications: domestic to large industrial boilers.

Steel shell, fire or flame tube † hot combusted fuel and gases discharge through multiple steel tubes to the extract flue. Heat energy from the burnt fuel transfers through the tube walls into cylindrical waterways. Tubes may be of annular construction with water surrounding a fire tube core. Uses: commercial and industrial buildings.

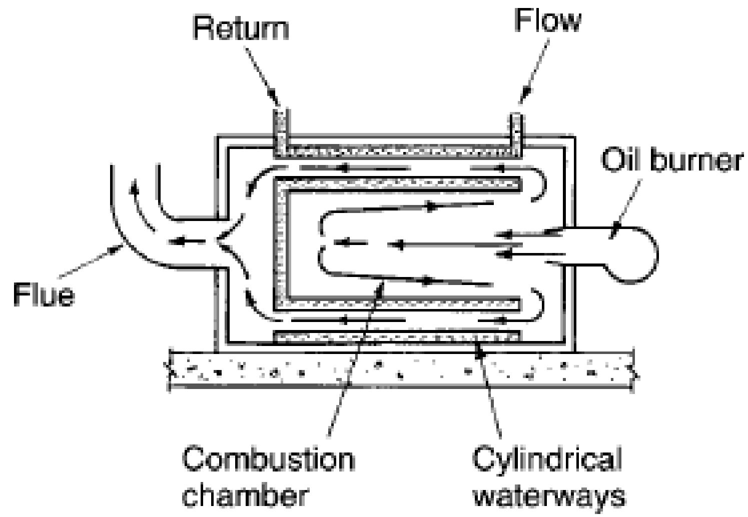
Boilers (cont…)

Copper or steel water tube † these reverse the principle of fire tubes.

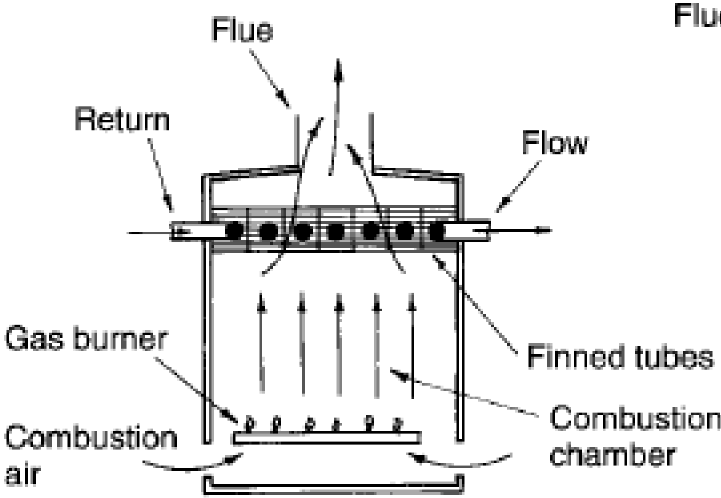
Water circulates in a series of finned tubes whilst the combusted fuel effects an external heat transfer. These are typical of the heat exchangers in domestic boilers.



Cast iron sectional boiler



Fire tube boiler

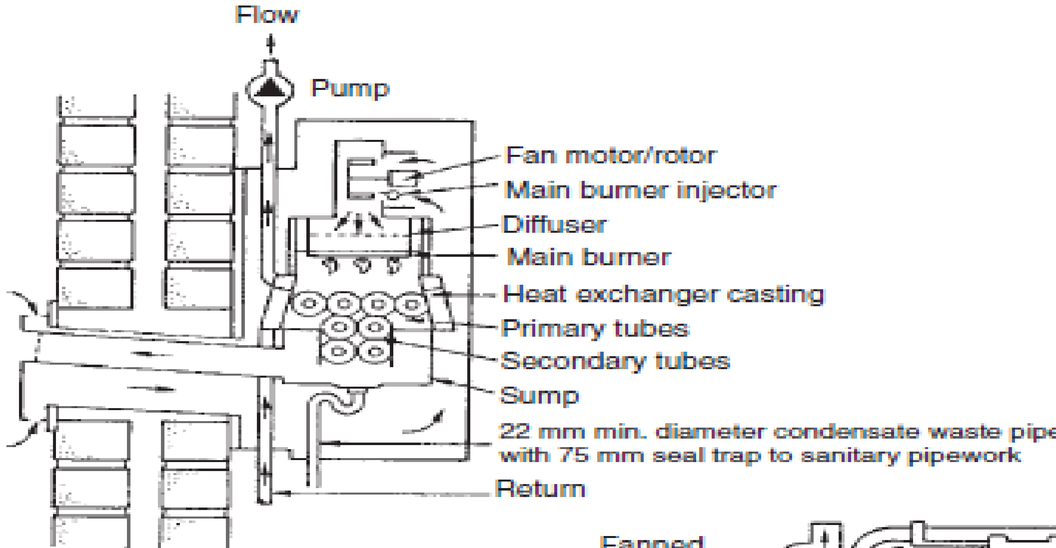


Water tube boiler

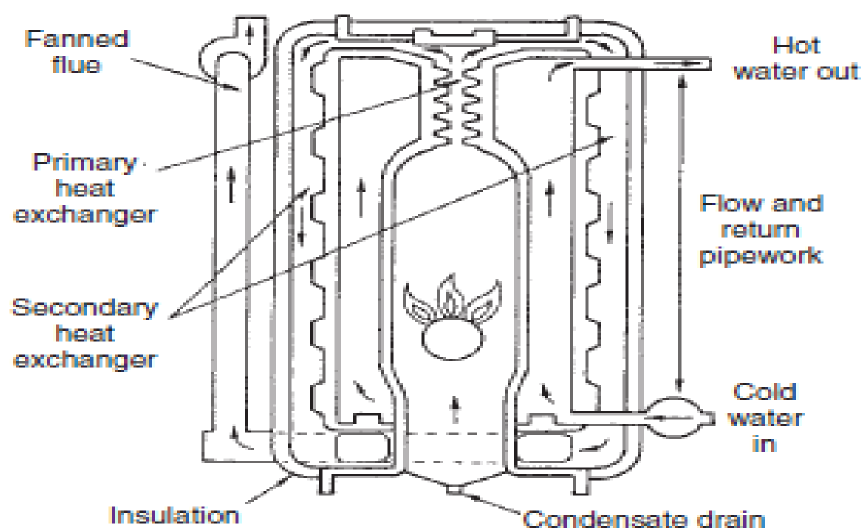
Condensing Gas Boilers

Condensing boilers have a greater area of heat transfer surface than conventional boilers. In addition to direct transfer of heat energy from the burning fuel, heat from the flue gases is used as secondary heating to the water jacket. Instead of the high temperature (200–250°C) flue gases and water vapour discharging to atmosphere, they are recirculated around the water jacket by a fan. This fan must be fitted with a sensor to prevent the boiler firing in the event of failure. Condensation of vapour in the flue gases is drained to a suitable outlet. The overall efficiency is about 90%, which compares well with the 75% expected of conventional boilers. However, purchase costs are higher, but fuel savings should justify this within a few years.

Condensing Gas Boilers (cont…



Balanced flue condensing boiler



Conventional flue condensing boiler

Condensing Gas Boilers – Characteristics (1)

Otherwise known as high efficiency boilers.

Originally developed in the 1930s. Lack of technological advances and less concern about effect of consuming fuel limited interest until the

fuel crises of the 1970s.

Introduced to the domestic market in the early 1980s. Slow to

establish due to relatively higher purchase cost. From 2005, virtually compulsory for new installations, to satisfy SEDBUK efficiency bands A and B. Extracts heat from flue gases to gain from the secondary heating effect.

Condensing Gas Boilers – Characteristics (1)

Heat exchanger must be corrosion resistant, i.e. stainless steel or aluminium to resist the acidity of condensate. Cast iron and copper are only suitable in non-condensing boilers with high flue gas temperatures which are unaffected by condensation.

Non-corrosive plastic condensate waste pipe required. Waste usually connected to a siphon which discharges condensate in one go from a 150 ml sump. This reduces the possibility of a drip discharge freezing. Least efficient condensing boiler has about the same efficiency as the most efficient non-condensing boiler.

Condensing Gas Boilers – Characteristics (1) (cont….)

About 80% energy exchange occurs as combusted gas at temperatures above 200 C effect the primary heat exchange. The secondary heat exchange adds about another 5% as the fanned flue gases reduce to about 55 C as they pre-warm the returning system cool water. With this temperature reduction the flue gases condense, dew point occurs (steam turns to water) adding about another 5% in latent energy transfer.

Condensing Gas Boilers – Characteristics (1) (cont….)

The gas burner has to impart less energy to raise the temperature at the primary heat exchange, hence fuel savings and less CO 2 and NO x emissions from the flue.

Controls

Non-condensing boilers are efficiently controlled with thermostatic valves, thermostats and an interlock facility.

The boiler is switched on and off relative to internal air temperature. High temperature water is delivered to emitters.

Condensing Gas Boilers – Characteristics (1) (cont….)

Condensing boilers are at their most efficient when enabled to run for sustained periods with a moderate flow water temperature and low return water temperature. They are ideally suited to modulating, weather compensated control systems.

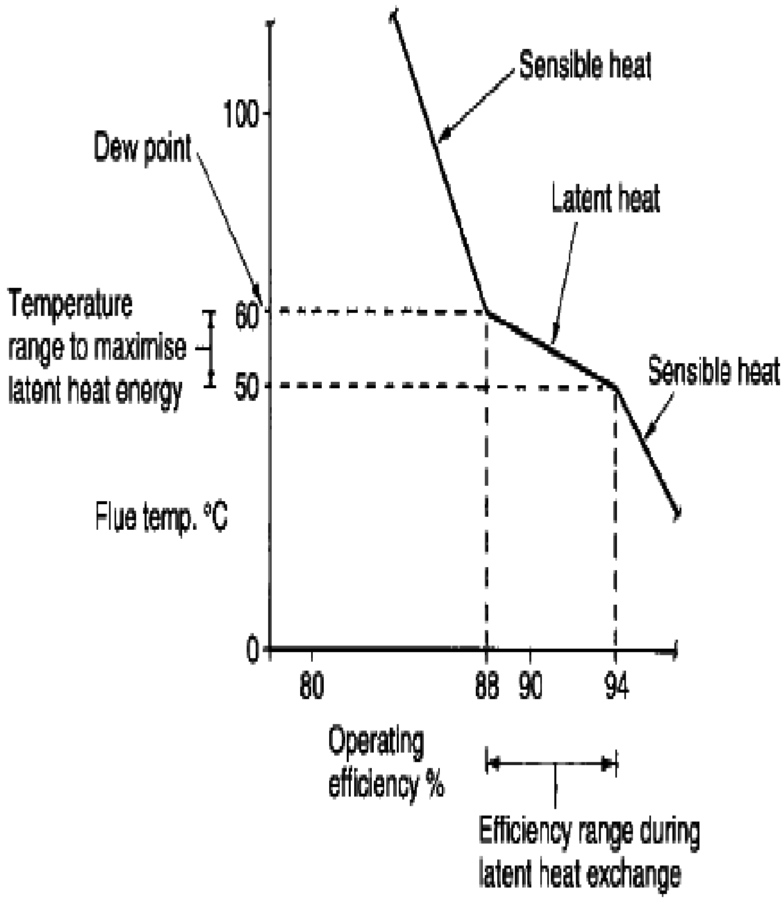
Flue discharge has a distinct plume or cloud of moisture droplets. May be a problem with neighbouring properties. Flue slopes back slightly towards the boiler to discharge any condensation from the flue duct into the condensate drain. Typical SEDBUK factors:

Modern condensing boiler 88%

Modern non-condensing boiler 75%

Older boiler 58%

Condensing Gas Boilers – Characteristics (1) (cont….)



Condensing boiler efficiency

Approximate number of households in UK = 14 million.

Typical annual household production of CO_2 with a non-condensing boiler = 5 tonnes.

Total potential CO_2 emissions = 70 million tonnes.

Typical annual household production of CO_2 with a condensing boiler = 3 tonnes.

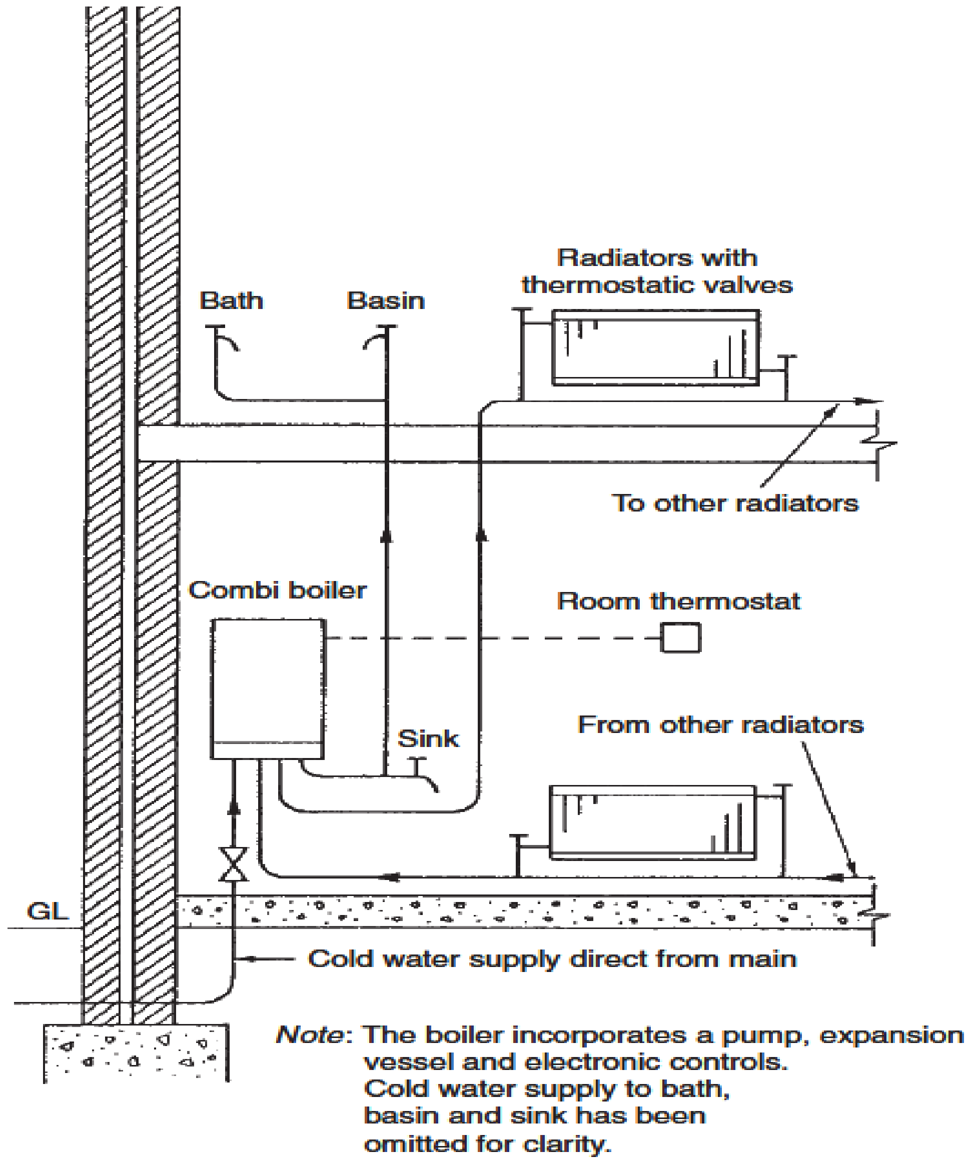
Total potential CO_2 emissions = 42 million tonnes.

Therefore, in addition to fuel savings, condensing boilers represent a potential for an annual reduction in polluting or greenhouse gases of 28 million tonnes.

Combination Boiler

This system saves considerably in installation time and space, as there is no need for cisterns in the roof space, no hot water storage cylinder and associated pipework. The ` combi ' gas boiler functions as an instantaneous water heater only heating water as required, thereby effecting fuel savings by not maintaining water at a controlled temperature in a cylinder. Water supply is from the mains, providing a balanced pressure at both hot and cold water outlets.

Combination Boiler (cont…..)



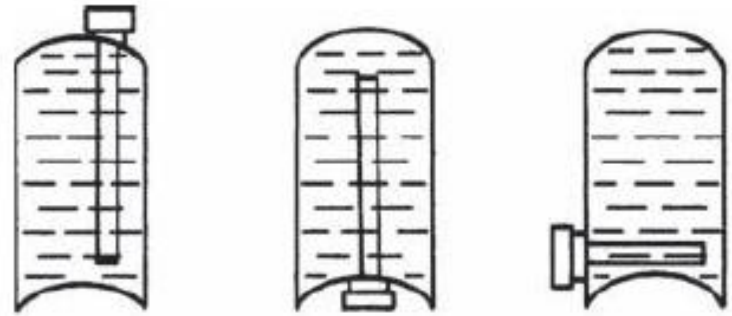
Electric Water Heaters – 1

An electric immersion heater may be used within a conventional hot water storage cylinder. Alternatively, individual or self-contained open outlet heaters may be located over basins, baths or sinks. Combined cistern-type heaters can be used to supply hot water to several sanitary appliances. Energy conservation is achieved with an integral thermostat set between 60 and 65 C. This temperature is also sufficient to kill any bacteria.

Electrical water heaters (cont…..)

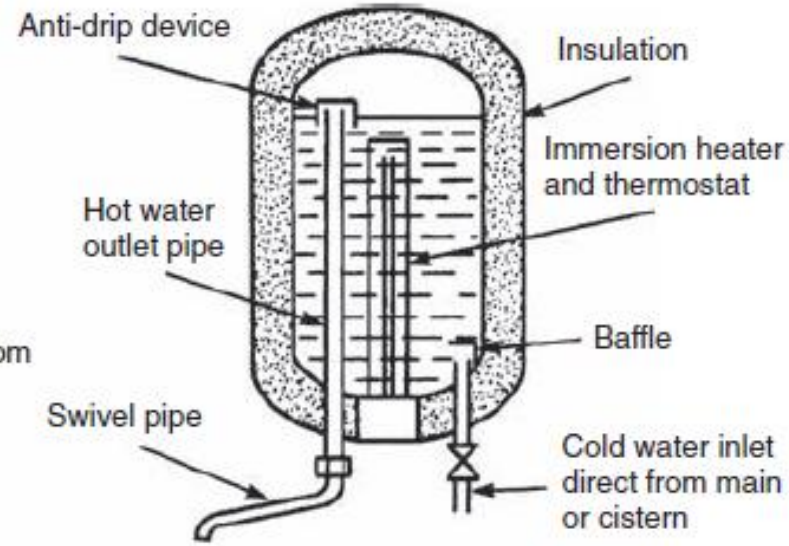
This temperature is also sufficient to kill any bacteria. The immersion heater must be electrically earth bonded and the cable supplying the heating element must be adequate for the power load. A cable specification of 2.5 mm^2 is normally adequate with a 20 amp double pole control switch supplied direct from the consumer's unit or fuse box. Overload protection at the consumers unit is a 16 amp fuse or circuit breaker for a 3 kW

element and 20 amp for a 4 kW element.

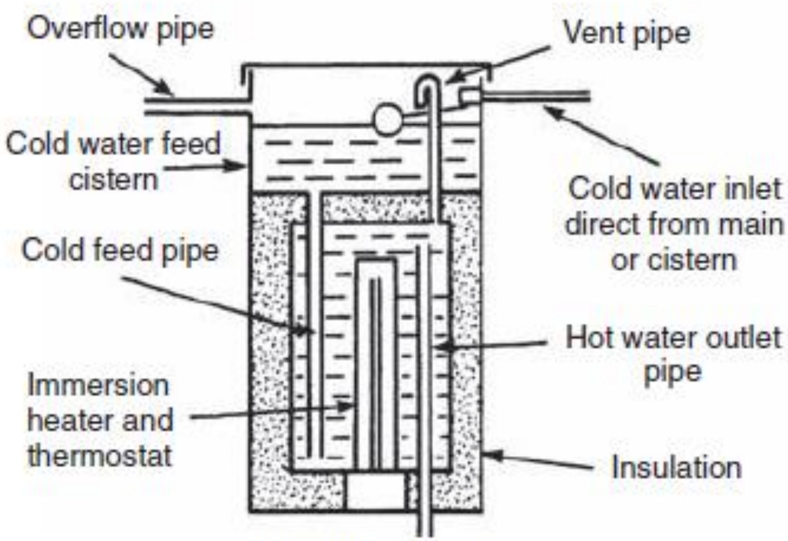


(a) Vertical top entry (b) Vertical bottom entry (c) Horizontal bottom entry

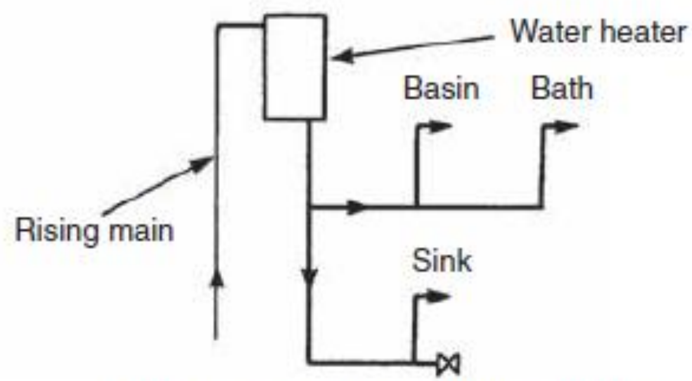
Positions of electric immersion heater inside cylinder



Self-contained open outlet heater



Cistern-type heater

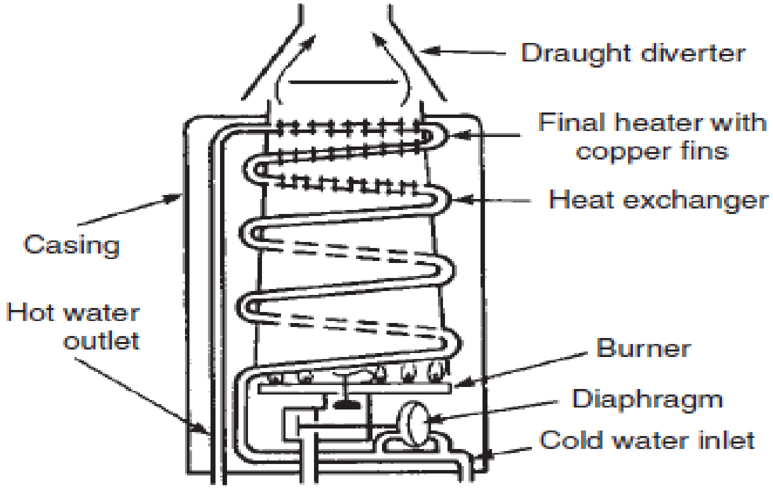


Installation of electric cistern-type heater

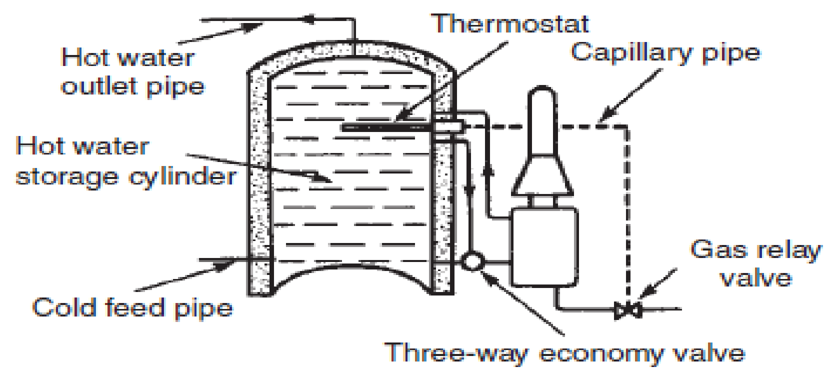
Gas Water Heaters – 1

When the hot water outlet is opened, cold water flows through a venturi fitting. The venturi contains a diaphragm which responds to the flow differential pressure and this opens the gas valve. A pilot flame ignites gas flowing through the burner which heats the water as it passes through the heat exchanger. Installation can be direct from the water main or from a cold water storage cistern. A multipoint system has the hot water outlet supplying several appliances.

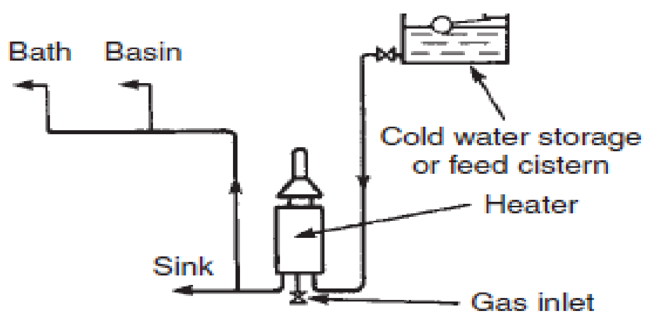
Gas water heater



Instantaneous gas water heater



Installation of gas circulator



Installation of instantaneous gas water heater

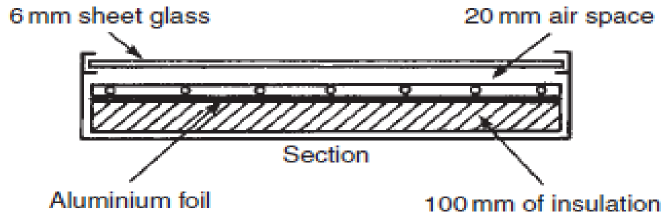
Solar Energy – Flat Plate Collector

Solar energy can contribute significantly to hot water requirements. In some countries it is the sole source of energy for hot water. In the UK its efficiency varies with the fickle nature of the weather, but fuel savings of about 40% are possible. For domestic application, the collector should be 4 to 6 m^2 in area, secured at an angle of 40 degrees to the horizontal and facing south. The solar cylinder capacity of about 200 litres is heated to 60 C.

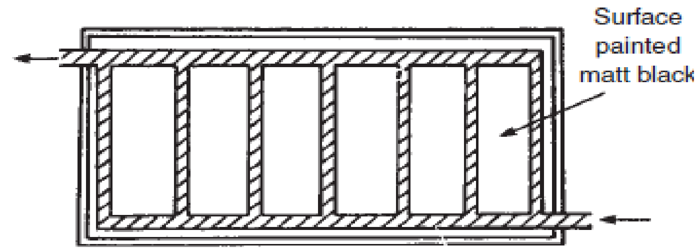
Solar energy

The cylinder and associated pipework must be very well insulated and the solar part of the system should contain a blend of water and non-toxic anti-freeze.The pump is switched on when the temperature of water at point X exceeds that at point Y by 2 to 3 C. The solar cylinder and the conventional cylinder may be fitted on the same level, or to save space a combined solar/ conventional cylinder can be obtained from specialist suppliers.

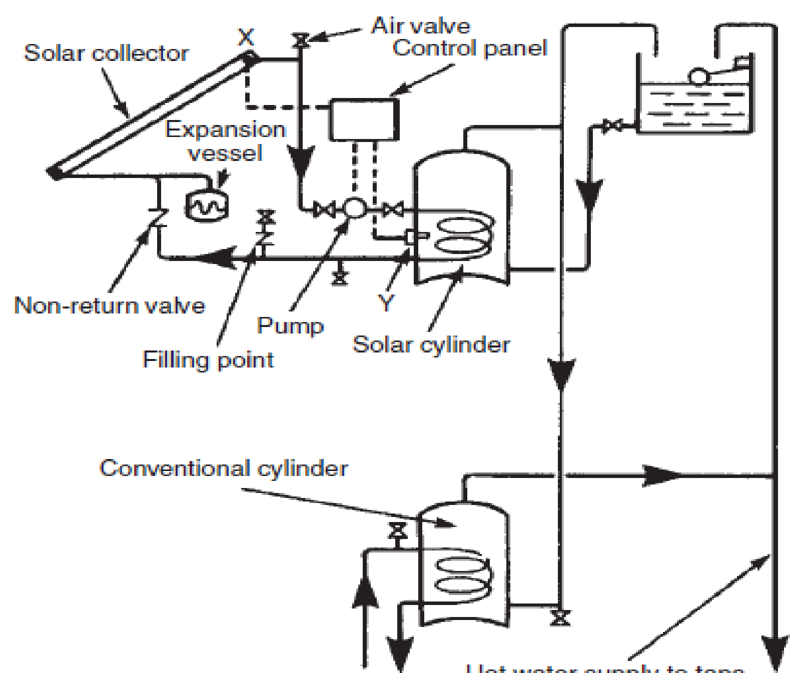
Solar energy (cont….



Detail of flat plate solar collector



Elevation

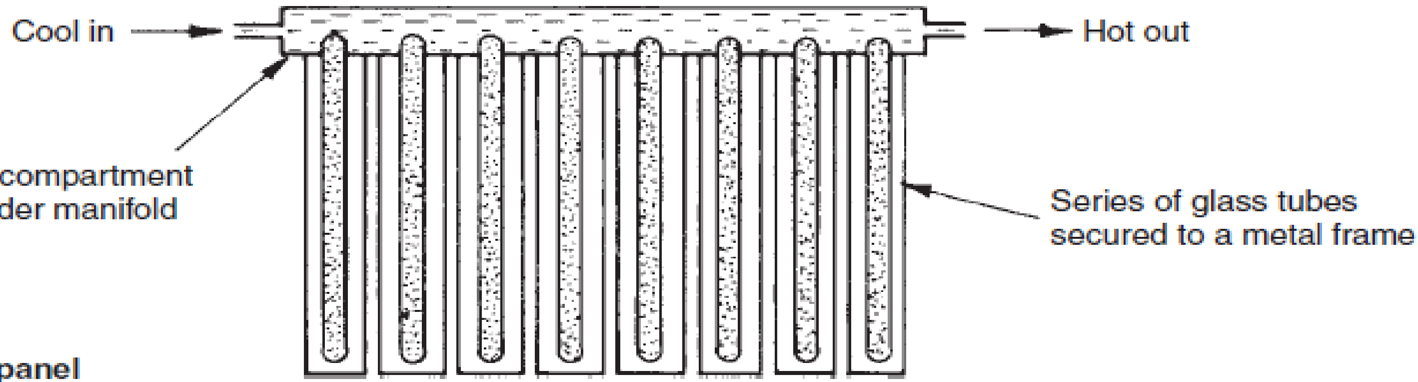


Detail of system

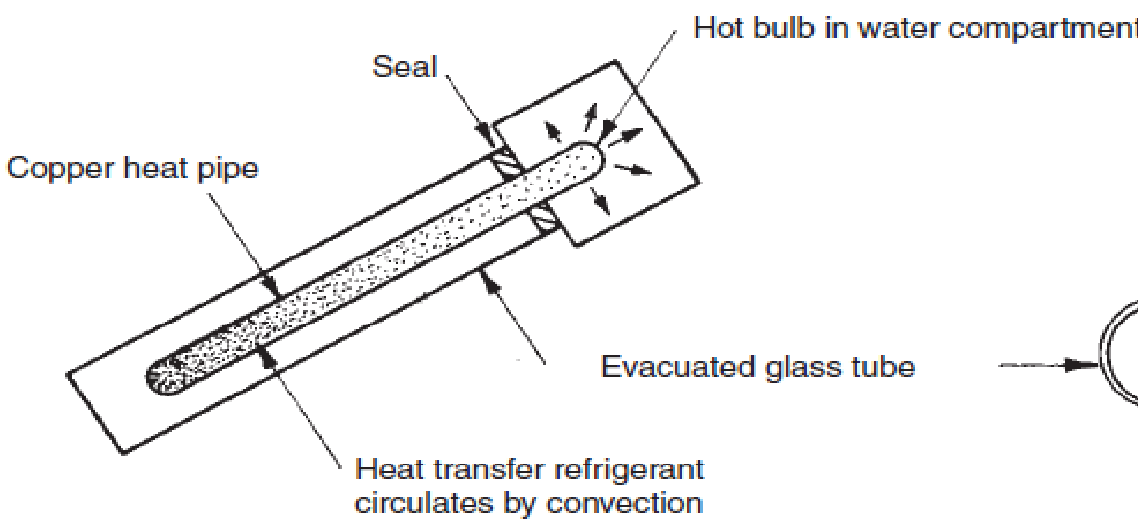
Solar Energy – Evacuated Glass Tube Collector

The evacuated glass tube collector functions differently from a flat plate collector. The panel is made up of a series of refrigerant charged copper tube elements as heat exchangers or heat pipes contained concentrically within individual vacuum sealed glass tubes. The advantage is that a refrigerant is more responsive than water, with better performance in low light conditions. The outer glass tubes provide for greater

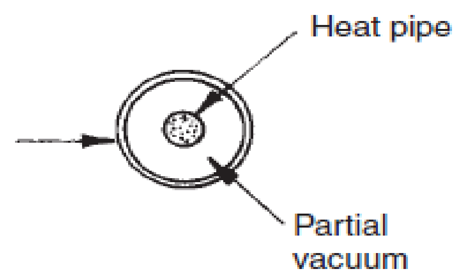
efficiency at high temperatures.



Solar panel



Longitudinal section



Lateral section

Properties of Heat – Hot Water

The heat energy properties of water are fundamental for determining pipe sizes and component dimensions in hot water and heating systems.

HEAT is a form of energy, otherwise known as thermal energy.

The standard unit of energy is the joule (J).

1 joule = amount of energy supplied by 1 watt (W) in 1 second (s).

Other units of energy found in older textbooks and product references include:

1 British thermal unit (1Btu) = 1·055kJ
1 calorie (1 cal) = 4·187J
1 kilowatt hour (1kWh) = 3·6MJ
1 therm (1 therm) = 105·5MJ

POWER is a measure of work rate.

Power (W) = heat energy (J) ÷ time in seconds (s)

Thus, 1W = 1 joule/second

Hot Water Storage Capacity

For most buildings the following table can be used as guidance:

Building purpose	Storage capacity (litres/person)	Energy consumption (kW/person)
Dwellings:		
single bath	30	0·75
multi-bath	45	1·00
Factory/Office	5	0·10
Hotels	35*	1·00
Hostels	30	0·70
Hospitals	35*	1·00
Schools/Colleges:		
day	5	0·10
boarding	25	0·70
Sports pavilions	35	1·00

*Average figures

E.g. A student hall of residence (hostel) to accommodate 50 persons.

Capacity: $50 \times 30 = 1500$ litres

Energy consumption: $50 \times 0{\cdot}70 = 35$ kW

Hot water supply calculations
Boiler Rating

Rating can be expressed in terms of gross or net heat input into the appliance. Values can be calculated by multiplying the fuel flow rate (m^3/s) by its calorific value (kJ/m^3 or kJ/kg). Input may be gross if the latent heat due to condensation of water is included in the heat transfer from the fuel. Where both values are provided in the appliance manufacturer's information, an approximate figure for boiler operating efficiency can be obtained, e.g. if a gas boiler has gross and net input values of 30 and 24 kW respectively, the efficiency is

$24/30 \times 100/1 = 80\%$.

Boiler power

Calculation of boiler power:

$$\text{kW} = \frac{\text{kg of water} \times \text{S.h.c.} \times \text{Temp. rise}}{\text{Time in seconds}}$$

where: 1 litre of water weighs 1kg

S.h.c. = specific heat capacity of water, 4·2kJ/kgK

K = degrees Kelvin temperature interval

Temp. rise = rise in temperature that the boiler will need to increase the existing mixed water temperature (say 30°C) to the required storage temperature (say 60°C).

Time in seconds = time the boiler takes to achieve the temperature rise. 1 to 2 hours is typical, use 1·5 hours in this example.

Example

From the example on the previous page, storage capacity is 1500 litres, i.e. 1500kg of water. Therefore:

$$\text{Boiler power} = \frac{1500 \times 4.2 \times (60 - 30)}{1.5 \times 3600} = 35\text{ kW net}$$

Given the boiler has an efficiency of 80%, it will be gross input rated:

$$35 \times 100/80 = 43.75\text{ kW}$$

Pipe Sizing – Primary Flow and Return

The water in primary flow and return pipework may circulate by convection. This produces a relatively slow rate of movement of about 0·2 m/s, depending on pipe length and location of boiler and cylinder. Modern systems are more efficient, incorporating a circulation pump to create a water velocity of between 0·50 and 3·0 m/s. This permits smaller pipe sizes and will provide a faster thermal response.

Inside diameter of pipe	Velocity min.	Velocity max. (copper)	Velocity max. (steel)
<50 mm*	0.50 m/s	1·0 m/s	1·5 m/s
>50 mm	1.25 m/s	1·5 m/s	3·0 m/s

Exceeding these recommendations may lead to excessive system noise and possible pipe erosion.

Example

E.g. using the Copper Development Association design chart shown on the next page, with the boiler rating from the previous example of 43.75kW gross heat input and 35kW net heat input.

$$\text{Mass flow rate (kg/s)} = \frac{\text{Boiler net heat input}}{\text{S.h.c.} \times \text{Temp. diff. (pf} - \text{pr)}}$$

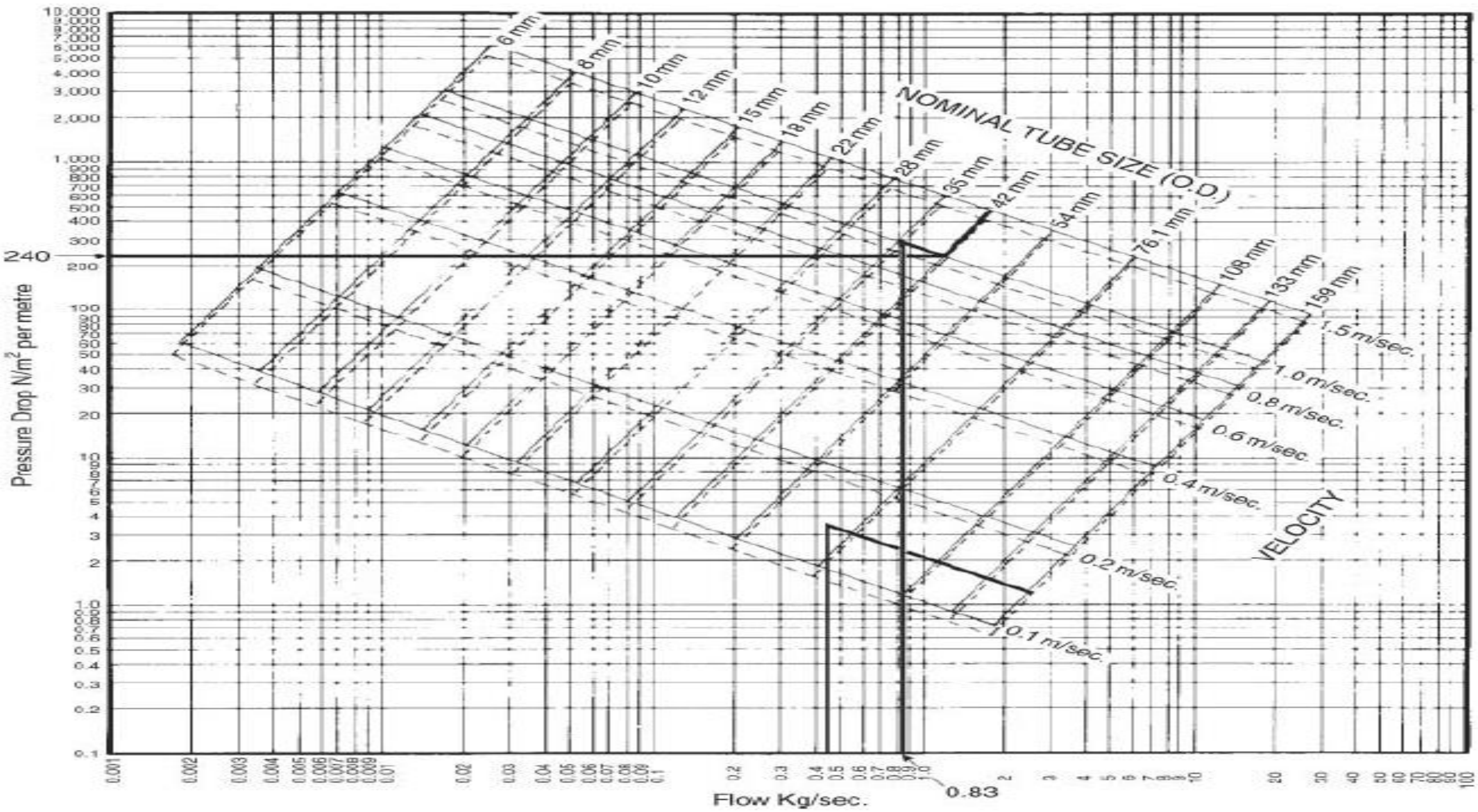
Temperature difference between primary flow (pf) and primary return (pr) in pumped water circuits is usually about 10K, i.e. 80°C − 70°C. With convected circulation the return temperature will be about 60°C.

$$\text{Mass flow rate} = \frac{35}{4.2 \times 10} = 0.83\ \text{kg/s}$$

On the design chart, co-ordinating 0.83kg/s with a pumped flow rate of 1m/s indicates a 42mm inside diameter copper tube. (35mm is just too small.)

By comparison, using convected circulation of, say, 0.15m/s and a mass flow rate with a 20K temperature difference of 0·42kg/s, the pipe size would be 76mm.

Unpressurised hot water (approx. 65°C)
Pressurised hot water (approx. 115°C)



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Circulating Pressures – Gravity Systems

Where gravity or convection circulation of hot water between boiler and emitter is used, guidance on the circulating pressure can be

determined by applying standard gravity of 9.80665 m/s^2 (generally

taken as 9.81) to the water density differential between boiler flow and return pipes. Reference to page 64 shows water density values between 0 C and boiling point.

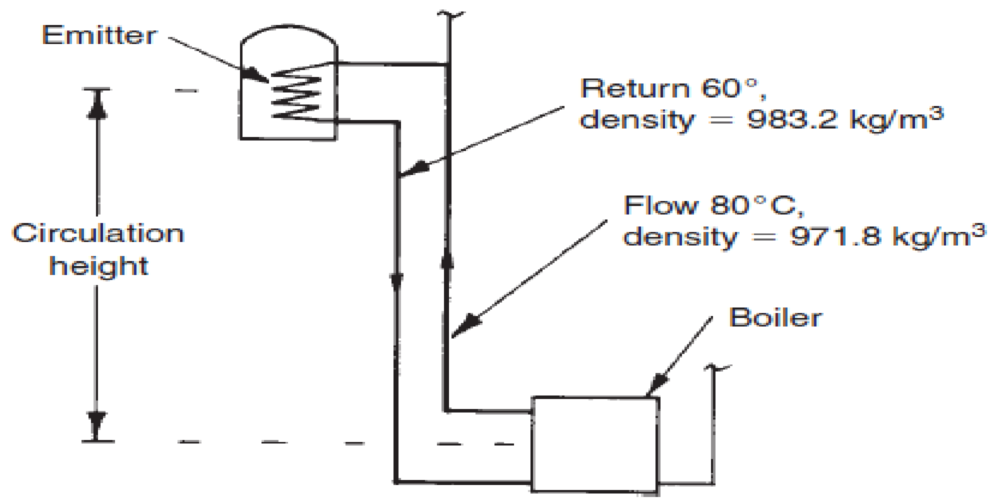
Circulating Pressures – Gravity Systems (cont….)

Formula:

CP = 9·81 × Water density differential between flow and return

CP = Circulating pressure per metre of circulation height

E.g.



Water density differential = 983·2 − 971·8 = 11·4 kg/m^3

CP = 9·81 m/s^2 × 11·4 kg/m^3 = 111·8, i.e. 112 N/m^2 per m

If for purposes of this example, the system output is rated at 8·4 kW, the mass flow rate will be:

$$\frac{8\cdot4}{4\cdot2 \times 20} = 0\cdot1 \text{ kg/s}$$ (see page 97)

With co-ordinates of 112 N/m^2 per metre and 0·1kg/s, the chart on the previous page indicates that a 22mm outside diameter copper tube could be used for the flow and return pipes. However, this does not allow for the slow circulation velocity, frictional resistance due to fittings and the need for a reasonable heat response time. A more reliable guide compares circulation velocity typically about 0·15m/s with the calculated 0·1kg/s. On the chart this indicates that a 35mm pipe would be more appropriate.

Circulation Pump Rating

Circulatory pumps produce minimal pressure in the primary flow and return, but the flow rate is considerably enhanced. The pressure can be ascertained from design charts as a pressure drop in N/m 2 per metre or pascals per metre. 1 N/m 2 equates to 1 pascal (Pa). From the design chart, circulation in a 42 mm copper tube at 1 m/s produces a pressure drop of 240 Pa per metre. An estimate of the primary flow and return effective pipe length (see page 55) is required

to establish the total resistance that the pump must overcome.

Example

example, if the effective pipe length is 20m:

240 × 20 = 4800 Pa or 4·8 kPa.

Therefore the pump specification would be 0·83kg/s at 4·8kPa.

Manufacturers' catalogues can be consulted to select a suitable pump. To provide for flexibility in installation, a degree of variable performance is incorporated into each model of pump. This range of characteristics can be applied by several different control settings as shown in the following graphic.

Pump performance chart: