Heating Ventilation and Air Conditioning

RICHARD NICHOLLS

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REVIEWERS

Book reviews are an important tool for ensuring the validity of textbooks. This book has been reviewed by industry specialists. Their training, experience and knowledge of current trends place them in an ideal position for this task. I would therefore like to thank the following for agreeing to review, suggest changes and contribute, to sections of this book;

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C O N T E N T S

H E A T I N G - S Y S T E M S

V E N T I L A T I O N

A I R - C O N D I T I O N I N G

I N D U S T R Y . P A N E L S

E N E R G Y . E F F I C I E N C Y . A D V I C E

Keeping Tabs on Energy Efficiency (KTEE) Panels

A D D I T I O N A L . I N F O R M A T I O N

Information Panels (IP)

Q U E S T I O N S

R E F E R E N C E

Heating.Ventilation.and.Air.Conditioning

INTRODUCTION

Building services is not a theoretical academic subject. It is a living, developing field of endeavour which touches everyone's lives. You are probably reading this in a heated (or air conditioned?) room right now! This book reflects the closeness between the academic study of building services with its practical application in its format. A traditional textbook is presented on the right hand pages and additional details including information on commercially available products and their suppliers is given on the left. By linking the theoretical descriptions with systems which can be seen around us in everyday life learning will be enhanced.

CONTRIBUTION FROM INDUSTRY

This publication represents a new way of supplying textbooks to students studying courses which have strong industrial links. It has been issued free of charge. All costs have been paid by members of the building services industry who, as professionals, are pleased to contribute to the education of the next generation of Architects and Building Services Engineers. The book can also be purchased by those outside the free circulation list at £19.99 from the publishers.

AIMS

- To give students access to a basic text at no cost to themselves.
- To introduce students to the basic concepts and components of heating, ventilation and air conditioning systems.
- To improve uptake and understanding of the subject by presenting photographs of commercially available equipment alongside the textbook description.
- To enhance the link between education and practice.
- To make students aware of the existence of companies and the range of products and services they offer at an early stage in their careers.

ACKNOWLEDGEMENTS

I would like to thank the many building services and environmental science lecturers throughout the country who have provided information on student numbers and have agreed to receive these books and distribute them to their students. As such a lecturer myself I know that the increased work load due to rising student numbers, reductions in funding, course development and research responsibility make any additional tasks difficult to accommodate.

I would like to thank all of the companies whose advertisements appear in this book and in particular the marketing managers and reviewers with whom I have liaised.

ABOUT THE AUTHOR

Richard Nicholls is a senior lecturer in the department of Architecture at Huddersfield University. He teaches environment and services on the Architecture degree and postgraduate diploma pathways and is pathway leader for the MSc. in Sustainable Architecture. He has experience of research as a research assistant investigating low energy housing in the department of Building Engineering, UMIST and industrial experience as a local authority Energy Manager. His most recent publication is a chapter on water conservation in the book "Sustainable Architecture" edited by Professor Brian Edwards

PUBLISHERS NOTE

The information given in this book is for guidance only. It is not intended to be exhaustive or definitive. All relevant standards, regulations and codes of practice should be consulted before any work is carried out.

1 Keeping tabs on energy efficiency

Energy efficiency advice

The main source of energy efficiency advice relating to buildings is the Government's Energy Efficiency Best Practice programme.

The programme covers both the management and improvement of existing buildings and the design of new ones. It runs seminars and produces publications, including Case Studies and Energy Consumption Guides.

For building designers, the programme's most important activity is the Design Advice Service. This provides professional, independent and subsidised advice on the energy-efficient and environmentally conscious design of buildings.

In this book eight information boxes dealing with energy efficiency issues have been sponsored by the Energy Efficiency Best Practice programme (see contents page for details). They will give you a flavour of the advice that is readily and freely available.

Energy Efficiency Best Practice programme publications are available to students, in response to specific requests, but Design Advice is intended for live projects.

Examples of some key design points promoted by the programme are as follows.

Lighting

- Make good use of daylight.
- Light to appropriate levels but not more.
- Use efficient electric lighting and provide good controls.

Cooling

- Minimise cooling loads by shading.
- Consider design strategies that avoid the need for mechanical cooling.
- If this is not possible, use low-energy cooling systems.

Heating

- Provide adequate building insulation.
- Specify efficient equipment.
- Provide effective controls.

Ventilation

- Consider natural ventilation or low-energy mechanical ventilation first.
- Keep duct air velocities low.
- Provide effective controls and choose efficient fans.

Further information

Further information on building-related energy-efficiency measures is available from the Energy Efficiency Best Practice programme on the Environment and Energy Helpline 0800 585794

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

1.0 Introduction

During the heating season, from early autumn to late spring, the weather becomes too cold for comfort. The building fabric protects us from the climatic extremes to an extent, but not enough to provide the comfort levels that modern society has grown to expect. Comfort can only be guaranteed using a space heating system. Most buildings in Britain require some form of space heating for the majority of the year. Heating not only gives thermal comfort to the building occupants but also ensures their health and, in a working environment, contributes to their productivity. Finally, heating protects the building fabric from deterioration by driving away moisture and preventing frost damage.

A requirement parallel to the need for space heating is the need for a method of providing hot water for washing and bathing. Unlike the seasonal requirement for space heating, hot water is required all year round.

The basic principle behind heating systems is very simple. Heat is released by burning fossil fuels or by passing an electric current through a wire. This heat is used to warm the occupants by radiant or convective means (see IP9). Whilst the principle is simple the functions must be carried out in a manner that ensures the following are satisfactorily considered;

- Economy - There are various costs associated with heating that must be minimised. These are, initial capital cost, maintenance costs and running costs. During a typical twenty year life of a heating system running costs will outweigh the initial capital costs many times over.

- Safety - Heating systems use combustible fuels, operate at high temperatures and release asphyxiant flue gases. These hazards must be managed so that they do not present a risk to the building or its occupants.

- Comfort - (see IP5) It is not possible to make all the occupants of a building satisfied with the internal temperatures at the same time. This is because personal preferences vary. However the system should aim to make the majority of the occupants comfortable. To achieve this the heating system should provide design temperatures and then control them within a narrow band of variation during occupancy hours.

- Environment - (see page 8) The combustion of fossil fuels releases gases which contribute to global warming and acid rain. To limit the damage, the amount of pollutant gasses released per unit of heating must be minimised. Type of fuel used, combustion characteristics, control and efficiency all contribute to minimising the volume of gas released.

Heating systems can be categorised into one of two main types these are; indirect heating systems and direct heating systems. The differences between the two systems will be outlined below. Section 1.1 considers indirect heating and section 3.0 considers direct heating.

Direct heating systems use individual stand alone heaters in each room where heating is required. The most common form of direct heating is the use of gas, coal or electric heaters in a domestic property. The capital and installation costs of any heating system are determined by size and complexity. For small systems direct heating has a low initial cost and can be easily expanded at a later date. Control of individual heaters is simple to achieve but group control, because of the physical separation, is more complex. Each heater must be provided with its own fuel supply and flue. Direct heating is extensively used as a cost effective form of heating in domestic, industrial and commercial buildings.

Indirect heating systems are known as central heating systems in houses because they generate heat at a central location, the boiler. The heat must then be removed from the boiler and delivered to each room. It is carried there by a heat transfer medium, which can be water, steam or air. Pipes are used to direct the flow of steam and water and ducts guide the movement of warm air. Heat emitters such as radiators (section 1.4) are required in the rooms to "hand over" the warmth from

IP1 - INSULATION.OF.DISTRIBUTION.PIPEWORK

Pipework is required to carry fluids as hot as 150°C (hthw) and as cold as -20°C through both heated and unheated spaces. The outcome of this is heat loss from hot pipes and heat gain by and condensation on cold pipes. Both conditions eventually result in a lack of system control and thermal discomfort.

HEAT LOSS FROM HOT PIPES

The heat loss rate from a pipe depends predominantly on its surface area (length of pipe run and pipe diameter), the temperature difference between it and its surroundings and the thermal conductivity of the pipe and any insulation materials surrounding it. Given that the pipe length, diameter and fluid flow temperatures are fixed by heating system design considerations, the element we can modify to reduce heat losses is the level of insulation around the pipe. This is recognised by the building regulations and water bylaws which lay down regulations governing the use of pipe insulation.

Increasing the thickness of the layer of insulation increases its resistance to the flow of heat. However, the cost also increases. The cost effective thickness of insulation must be determined from a knowledge of system design characteristics, fuel costs and insulation costs. In addition to insulating pipes it is necessary to insulate valves and other pipe fittings such as suspension rods. Specialist jackets are available for this purpose or sheet materials can be used by cutting and forming them into an appropriate shape.

Inadequately insulated pipework causes energy wastage, condensation risks, thermal discomfort and lack of system control

CHILLED WATER PIPEWORK

Heat gains by chilled water pipework must be considered in a similar manner to heat losses. However an additional feature which must be considered is the possibility of condensation forming on the cold pipework. To avoid this moisture laden air must be kept away from the cold surface of the pipe or any layer within the insulation which is at or below the dew point temperature. This is achieved using closed cell insulation products which have a high resistance to the passage of water vapour and by sealing any joins made in the material.

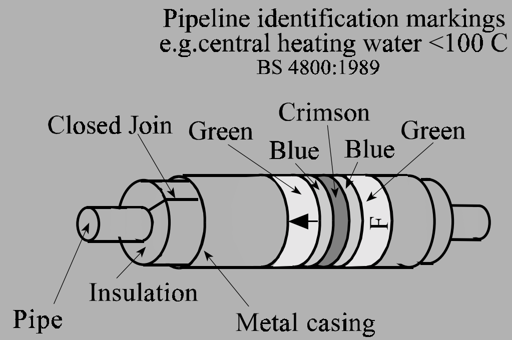


Figure IP1: Pipe insulation and identification

CONTROL AND COMFORT

Pipework is required to carry hot or cold fluids from plantroom to location of use such as a heating or cooling coil. Any heat lost or gained by the pipework will change the temperature of the fluid. As a result temperature sensor readings located early in the pipework may no longer reflect delivery temperatures. The absence of reliable sensor information makes control difficult. In addition to this thermal discomfort may be created as rooms overheat due to unregulated heat lost from pipes running through occupied spaces.

THE OZONE LAYER

chlorofluorocarbons (CFCs) (see IP15) are no longer used to make foamed pipe insulation as they damage the ozone layer. Environmentally responsible manufacturers now use ozone benign blowing agents such as air or carbon dioxide.

the heating system to the room air.

The advantages of indirect heating systems arise from the fact that most of the equipment is concentrated at a single location. This means only one flue and one fuel supply are needed to satisfy the entire building. This centrality means it is also possible to achieve a high level of control over the entire system.

There are many types of building with various functions such as domestic, retail, industrial, educational and commercial. Within each of these categories there are different forms, fabric and heat loadings. Because of this it is impossible here to describe suitable heating systems to suit all buildings. This book will simplify matters by referring to two basic types of building: *domestic* which refers to housing and *commercial* which are buildings larger than domestic such as offices. In section 1.1 the components which make up an indirect heating system will be described using domestic central heating as a basis. Detail will also be given on how the domestic system is modified to satisfy the heating demands of large buildings.

1.1 Wet Indirect Heating

A wet indirect heating system uses water as the heat transfer medium. The main components of a wet indirect heating system are shown schematically in figure 1.1. Each of these components will be discussed more fully in sections following the numbering on the diagram.

In domestic properties it is likely that the boiler is accommodated in the kitchen either floor standing or wall mounted. In commercial buildings where the quantity of heating plant is greater it is necessary to have a purpose built plant room. The plant room must be well ventilated and have sufficient room for the equipment and access to it for maintenance. Plant rooms are usually situated on the ground floor where the weight of the heating system can easily be supported. Ventilation air for the plant room is typically provided through an access door leading to the outside which has louvered openings. Initial estimates of plant room size are based on rules of thumb, usually a small percentage of the total floor area. The actual percentage varies depending on the complexity of the heating system. As well as space for the plant room allowance must also be made for horizontal and vertical service distribution runs throughout the building [see IP7].

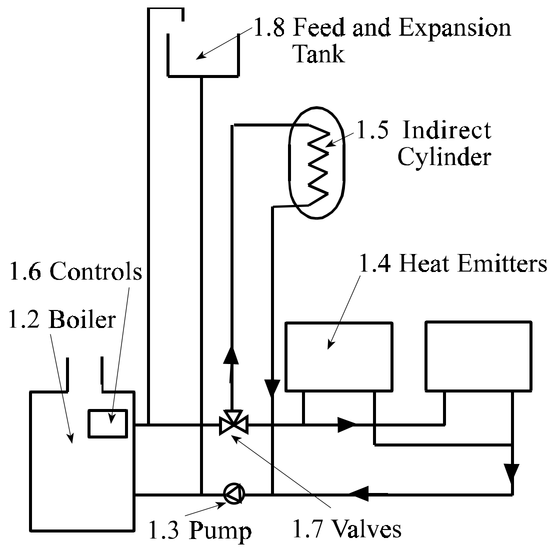


Figure 1.1 Wet indirect heating system

A number of companies produce packaged plant rooms which are delivered to site pre-assembled resulting in savings in both time and costs. These units may be accommodated within the building or are containerised for locating outside the building or on the roof top.

1.2 Gas Boiler

The heart of an indirect space and water heating system is the boiler. This section will concentrate on gas boilers however it should be remembered that oil fired boilers are available using liquid instead of gaseous fuels. The disadvantage of oil boilers is that oil deliveries must be organised and space allocated for oil storage. Electric boilers are also available, here the system water circulates over an electrical heating element. Electricity is more costly than gas or oil per unit of energy but the system has the advantage of small physical size, no requirement for a flue and ability to function where no gas supplies exist.

A gas boiler is a device which burns gas in a controlled manner to produce heat. This heat is transferred, using a heat exchanger, to water which circulates

around the heating circuit.

Boilers are specified in terms of their power measured in kilowatts (kW). A boiler for a typical four bedroom detached house would be rated at approximately 15 kW. A small flat or low energy house may need a boiler as small as 5 kW. Large buildings would need several hundred kilowatts of boiler power.

The main components of a boiler are shown in figure 1.2 and are described below.

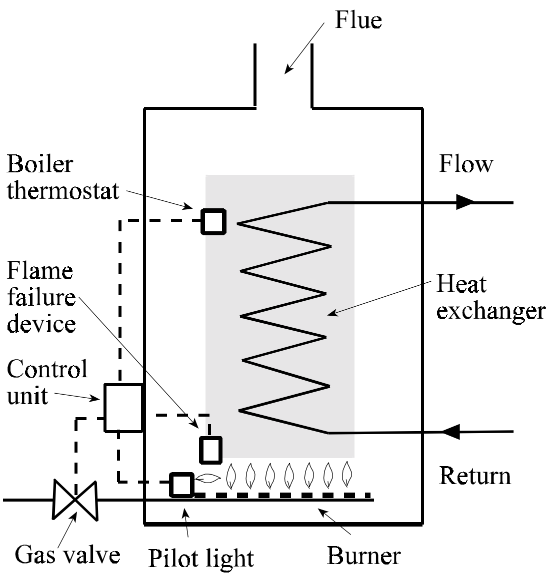


Figure 1.2 Parts of a boiler

Gas Valve. This valve is normally closed. It is opened by a solenoid allowing gas to flow into the burner if there is a call for heat and safety conditions are satisfied. If there is a loss of power or a signal indicating a fault is sent from the control unit then the valve will automatically close.

Pilot Light. This is a small flame which burns continually. Its function is to ignite the gas/air mix as it leaves the burner. An alternative is to use electronic spark ignition. Electronic ignitions have a greater degree of technical complexity but give improved boiler economy by eliminating the gas used by the pilot light at times when the boiler is not required to fire.

Burner. For optimum performance all of the gas that enters the boiler must be burned. To achieve this the burner must mix the gas with the correct quantity of air. This is known as a stoichiometric mix of gas and oxygen. Insufficient air would result in incomplete combustion with carbon monoxide being produced and dangerous unburnt gas building up. Too much air and the combustion gases will be diluted and cooled. The burner is designed to mix gas and air to give the most safe and efficient combustion possible. Atmospheric burners use the pressure of gas in the mains and buoyancy in the flue to draw combustion air into the burner. Forced draught burners use a fan to input combustion air. This allows a greater degree of control over the combustion process resulting in reduced boiler sizes.

In commercial buildings large amounts of fuel are used so it is important to buy it at the lowest price. To help in fuel purchasing boilers supplying large buildings can be fitted with dual fuel burners. These can use either gas or oil. It is possible to switch between fuels to use the fuel which at that time is the cheapest.

Amongst the combustion products of gas or oil are various nitrous oxides collectively known as NO_x. NO_x is a polluting gas and so European regulations exist to limit the amount of NO_x produced by burners for a given heat output. In response to this burner manufacturers have updated their products to meet and often exceed the requirements of this legislation.

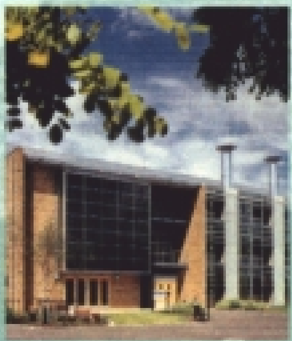
Flame Failure Device (FFD). Flames are detected by this unit and if present gas is allowed to enter the burner. If the flames are extinguished for any reason the gas valve will be closed. This avoids a dangerous build up of unburnt gas within the boiler.

Control Unit. This is an electronic device which receives signals from the FFD and Thermostats. Using this information it controls the operation of the gas valve, pump and ignition systems. Time control is also carried out by this unit to make sure that the heating system only operates when it is required. Each type of boiler has its own control strategy, individual boiler manufacturers should be consulted for further details.

Boiler Thermostat. This is a temperature sensor which is used to control the boiler flow temperature. Boiler

2 Keeping tabs on energy efficiency

Environmental effects of energy consumption



The combustion of fossil fuels creates a number of pollutant gases. The quantity emitted depends on the amount and type of fuel being burned. The gases are carbon dioxide (CO_2), one of the main contributors to global warming; sulphur dioxide (SO_2), which contributes to the problem of acid rain; and nitrous oxides (NO_x). NO_x is a collective term for the oxides of nitrogen, mostly nitric oxide (NO) (a cause of ozone depletion) and nitrogen dioxide (NO_2). NO_2 is a lung irritant which reduces air quality.

Fuel type	CO_2 g/kWh	SO_2 g/kWh	NO_x g/kWh
Electricity	684	9	1.7
Oil	313	0.59	0.26
Gas	226	0	0.22

Pollution output of various fuels

Global warming

Heat from the sun can easily pass through the atmosphere to warm the Earth's surface. However, the heat re-radiated from this surface is absorbed by gases in the atmosphere, such as CO_2. This causes the atmosphere to be warmed (global warming).

Some global warming is essential for life on Earth. However, recent decades have seen an increase in the concentration of CO_2 in the atmosphere as a result of fossil fuel burning. Scientists now generally agree that increased heating of the atmosphere will occur due to the effects of global warming.

Acid rain

Some of the particulates and gases produced during combustion are acidic and combine with rain to create acid rain. This damages the environment in three ways.

- It harms trees – many European forests are showing signs of leaf damage due to acid rain.
- It collects in freshwater lakes and rivers, increasing the acidity which endangers freshwater life.
- It erodes stone buildings and statues, degrading the beauty of historic buildings.

The role of the building professionals

The first stage in reducing the problem is to minimise the consumption of fossil fuels while maintaining acceptable standards of comfort. Energy use in buildings accounts for approximately 45% of the UK CO_2 output.

Further information

Further information on building-related energy-efficiency measures is available from the Energy Efficiency Best Practice programme on the Environment and Energy Helpline 0800 585794

BEST PRACTICE PROGRAMME
ENERGY EFFICIENCY

flow temperature is the temperature of water leaving the boiler. It is this which determines the radiator temperature. The hotter the water the greater is the heat output of the radiators. It is usual to set the boiler thermostat higher in winter than summer because of this. This process is carried out manually on domestic boilers however commercial boilers are fitted with a device called a compensator which carries out the function automatically. Compensators are discussed more fully on page 35. A separate overheat thermostat provides a safety function by cutting out the burner if the temperature should increase too much. Thus avoiding overheating of the boiler.

Heat Exchanger. Made of materials such as cast iron, steel and aluminium the heat exchanger is designed to give maximum thermal contact between the hot combustion gases and the circulating water. The heat exchanger of large boilers may be delivered to site in sections which are then bolted together. There is a variety of heat exchanger forms. Some are positioned over the burner and the hot flue gases rise up through the heat exchanger. Other heat exchangers surround the burner and the combustion gases have to pass through channels in the heat exchanger to escape. This means the flue gases have to pass the heat exchanger twice thereby improving the transfer of heat into the heating circuit.

Flue. When gas is burnt in air carbon dioxide, carbon monoxide, nitrous oxides and water vapour are produced. Carbon monoxide is an asphyxiant and would kill the occupants of any room in which it accumulated. To avoid this, it is necessary to have a flue which carries away the waste products of combustion and safely discharges them outside of the building. A flue is essentially a duct connected to the boiler combustion chamber, terminating outside of the building. The flue run should be as straight as possible to avoid unnecessary restriction to the flow of flue gas. Horizontal runs should be avoided to allow flue gases to rise continuously. It should terminate at a location where the flue gases cannot re enter the building. Hence, for example, flues cannot discharge near windows. The flue will also have a terminal unit which acts to keep the outlet of the flue open by, for example, excluding the entry of nesting birds. Flue gases are hot and so the terminal should not be located in a position where it could be touched by anyone passing by. The movement of flue gases in atmospheric burners is by natural buoyancy. Forced draught boilers use fans to discharge the products of combustion

There are various arrangements of flue. However, each one exhibits the common functions of safely exhausting flue gases whilst at the same time preventing the burner flames being blown out by excessive draughts through the system. One method of preventing this is to use a draught diverter (figure 1.3). Upwardly moving flue gases pass up and around a baffle plate. If wind causes the direction of flow to reverse then the plate causes the flue gases to temporarily spill over into the boiler house rather than enter the boiler. The draught diverter also prevents excess air being pulled through the boiler should there be excess suction from the flue itself due to wind or buoyancy effects.

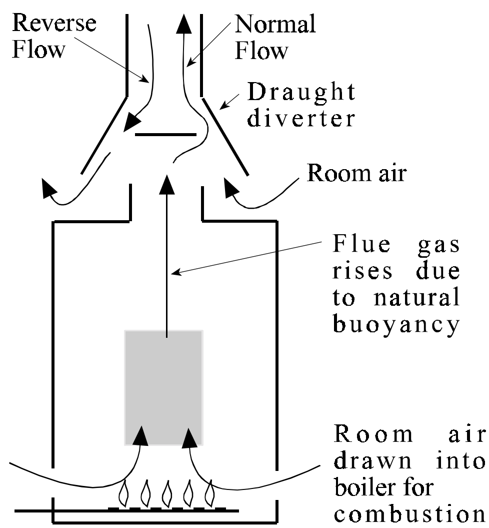


Figure 1.3 Flue draught diverter

The Balanced Flue (Figure 1.4) is a dual function flue which takes combustion air from outside the building and supplies it to the burner. The same unit discharges the flue gases outside. The benefit of this flue is that any wind pressures act on the inlet and outlet equally. As a result flows through the flue will be stable ensuring the burner flames will not be blown out. Because both the combustion air and flue gases enter and leave the boiler without making contact with the room air the boiler is known as a "room sealed" appliance.

IP2 - TEMPERATURE, ENERGY. AND. POWER

Three terms commonly used in building services studies are temperature, energy and power. The latter two can easily be confused. This information panel aims to clarify the definition of these terms and give examples related to buildings.

TEMPERATURE

The scale of temperature commonly used in building studies is the Centigrade scale. This is a scale set between the temperature of melting ice and the temperature of boiling water. These temperatures are zero degrees centigrade (0^oC) and one hundred degrees centigrade (100^oC) respectively. Typical temperatures encountered in buildings are;

Design outside air temperature, -1^oC
Average annual outside air temperature, 6^oC
Chilled water flow temperature, 6^oC
Room temperature (active e.g. gymnasium), 16^oC
Room temperature (sedentiary e.g. office), 21^oC
Human core body temperature, 37.5^oC
Boiler flow temperature, 82^oC
Boiler return temperature, 70^oC
Max. temperature of radiant tube heater, 450^oC

Another scale of temperature used by building scientists, and one which you may encounter, is the Kelvin scale of temperature. The divisions on this scale are exactly the same as on the centigrade scale i.e a change (D) of one degree centigrade is equivalent to a change of one degree Kelvin (D1^oC ° D1K). The kelvin scale starts at 0K which equals -273^oC so 0^oC would therefore be equivalent to 273K.

ENERGY

Energy is thought of as the ability to do work. There are various forms of energy, for illustration they can be described in relation to a CHP unit (page 17). The forms of energy are; *chemical energy* as is contained in fuels such as coal, oil or gas, *mechanical energy* which is held by rotating objects such as the flywheel of a CHP unit, *thermal energy* (Heat) that is released by burning fuels and *electrical energy* which is produced by the CHP unit generator. Note that thermal energy is often simply referred to as heat

The amount of energy held in any of the above forms can be quantified. To do this we need units of energy. The basic scientific unit of energy is the Joule (J). But this unit is too small for describing the quantities of energy used in buildings. Instead we normally use the unit, Watt hour. This is still small so we use thousands(kilo (k)) of Watt hours i.e. kilowatt hour (kWh). 1kWh is equivalent to 36,000,000 Joules! or 0.036 Gigajoules (GJ). Typical energy values encountered in buildings are;

Energy used by a 1 bar electric fire each hour = 1 kWh
Energy used to heat a house for one year, 40,000kWh
Energy contained in $1m^3$ of gas = 10.5 kWh
Energy contained in 1kg of coal = 9.02 kWh
Energy contained in 1 litre of oil = 10.4 kWh

Note when heat is added to an object its temperature increases. When heat is removed from a body its temperature decreases.

POWER

Energy cannot be created or destroyed but it can change from one form to another. The rate at which this change occurs in a system is called the *power* of the system. For example, a gas boiler is a machine to convert chemical energy (gas) to thermal energy (heat). This conversion is not instantaneous, it occurs over time. If, in a given time, a boiler converts more gas to heat than a second boiler, then the first boiler has a greater power.

The unit of power is the Watt (W) (1W=1Joule/second). Once again this is a small unit so we often use kilowatts (kW). Typical power values encountered in buildings are;

Light bulb =	100W
1 bar electric fire =	1 kW
Boiler for a low energy house =	4kW
Boiler for a detached house =	12 - 18 kW
Commercial boiler =	150kW
Domestic refrigerator =	150W

Typical split A/C unit = 0.8 to 3kW (electrical input)
giving 2.4 to 9kW of cooling

Ventilation and combustion air is required in rooms where non room sealed combustion appliances are operating. It is needed to supply sufficient air to allow complete and safe combustion of the gas. In large installations ventilation also helps to disperse unwanted heat build up. In housing, purpose provided ventilation for small (less than 7 kW) and room sealed appliances is not required. However for non room sealed and larger appliances purpose built air vents should be provided connecting the room to the outside air. There are exceptions and reference should always be made to current regulations and manufacturers data.

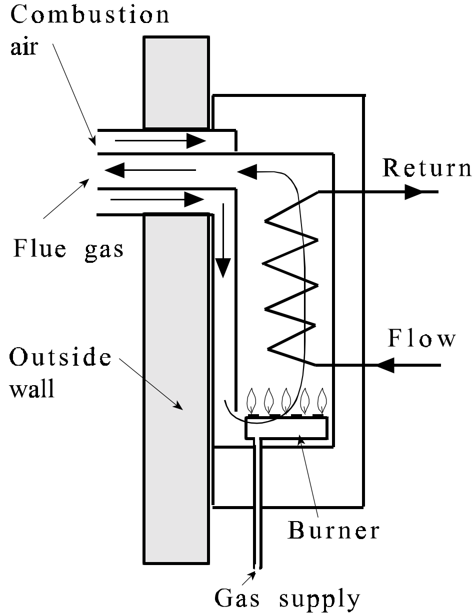


Figure 1.4 Balanced flue

In commercial buildings ventilation is usually provided through ventilation openings in the plant room walls or door. It can also be supplied to internal plant rooms using a fan and ducting running from outside to the plant room. Sensors in the ducting are interlocked with the boiler controls. These interlocks switch off the boilers if the ventilation air supply is stopped for any reason such as failure of the ventilation fan.

Fan Dilution is a flue system which cools and dilutes the flue gases so that they may be discharged at low level. The system works by drawing air from outside the building along a horizontal duct (figure 1.5). The boiler discharges its combustion gases into this airflow and so they become cooled and diluted. It is then possible to discharge the flue gases into a well ventilated area such as above the rear exit of a building. Dilution air inlet and flue gas outlet should preferably be on the same side of the building to avoid draughts blowing through the system.

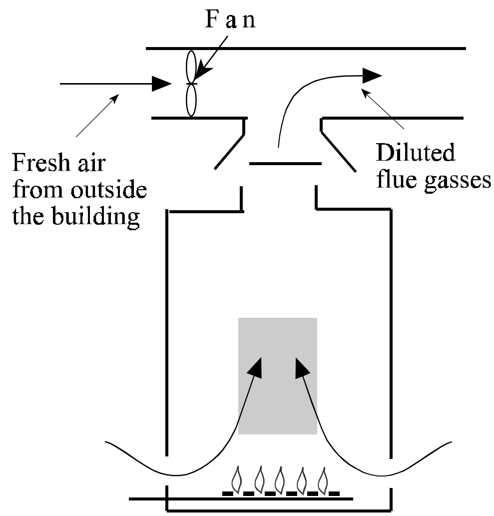


Figure 1.5 Fan dilution system

1.2.1 Boiler Efficiency

The efficiency of a boiler is a measure of how well it converts fuel to heat.

Boiler heat input is in the form of gas or oil. When this is burnt the aim is to transfer all of the heat that is released into the heating circuit. A system that achieved this aim would be 100% efficient. For safety reasons waste combustion gases must be cleared from the boiler. This is carried out by allowing the natural buoyancy of the hot flue gases to carry them up and out of the flue. Unfortunately the heat contained in these gases is lost to the system. As a result any flued combustion appliance can never operate at 100% efficiency. When selecting a boiler reference is made to manufacturers information contained in product data sheets. Figures for efficiency are usually given but if not it can be easily worked out from quoted heat input and output values (figure 1.6).

NOTES

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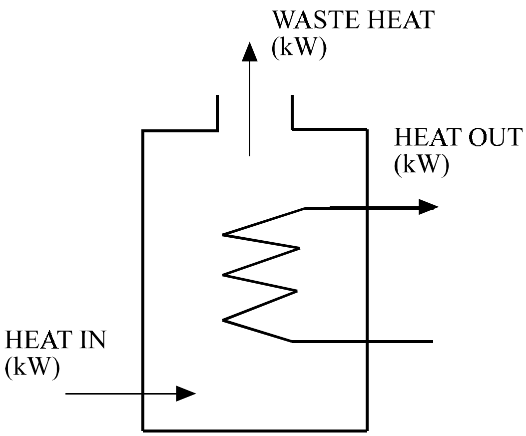
Three classes of boiler efficiency can be identified;

Standard Boilers. A standard boiler is one which provides good quality utilitarian heating but has no cost increasing features that would enhance its efficiency. The efficiency of all boilers varies with the amount of work they are required to do, known as the boiler load. For this reason the average efficiency of a standard boiler over the heating season is usually given as the seasonal efficiency. For a standard boiler this is typically 75%. The variation of efficiency with load is discussed more fully in a later section.



$$\text{EFFICIENCY}(\%) = \frac{\text{HEAT OUT}}{\text{HEAT IN}} \times 100$$

Figure 1.6 relationship between efficiency and heat output and input.

High Efficiency Boilers. These boilers are more costly than standard boilers because they include features such as a larger heat exchanger, additional casing insulation, electronic ignition and flue dampers (fig 1.7). These features; absorb more heat from the flue gases, reduce casing heat losses, stop gas usage when there is no call for heat and prevent convective loss of heat when the boiler finishes firing respectively. As a result the seasonal efficiency is improved to approximately 85%

Condensing Boilers. These boilers have a high operating efficiency. This is due to their large heat exchanger which extracts so much heat out of the flue gases that the vapour in them condenses onto the heat exchanger (hence the name). In this way the heat exchanger recovers both sensible and latent heat from the flue gases. To ensure that the boiler condenses the return water temperature must be below 53^{o}C. Seasonal efficiencies are as high as 92%. This mode of operation does however, present design challenges. Firstly the cooled flue gases lose their buoyancy and are generally cleared by a fan (figure 1.8). Secondly the flue gas condensate is slightly acidic and so the heat exchanger must be made of none corrosive materials such as stainless steel. The condensate itself must be collected and drained away. All of these features add about 50% to the cost of a condensing boiler in comparison to a standard boiler for the same rating. However their high efficiency makes them economical with the extra capital costs typically being recovered in the value of energy savings within three years.

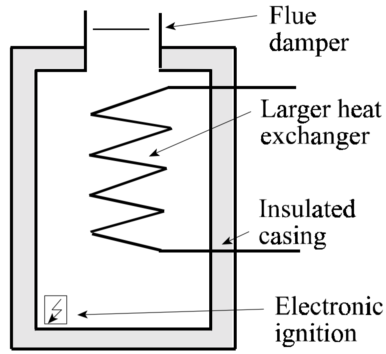


Figure 1.7 Features of a high efficiency boiler

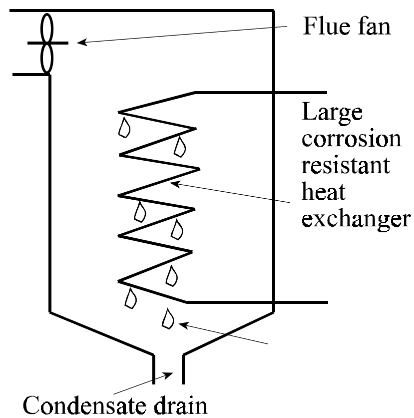


Figure 1.8 Features of a condensing boiler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BOILER LOAD AND EFFICIENCY

The efficiency of a boiler varies with the load upon it. High load is when the boiler is being asked to do a great deal of work. For example, first thing in the morning when the building and domestic hot water are both cold. In this situation the boiler will fire continuously and the flue and casing losses will be small when compared to the heat being input to the rooms. An example of a low load situation is at the end of the day when the building has warmed through and the tanks are filled with hot water. The boiler will be cycling, that is firing for short periods then stopping just to keep heat levels topped up. Almost as much heat will be lost by convection up the flue as is given to the heating system. Hence efficiency will be low. Figure 1.9 shows a graph of efficiency against proportion of full load for the three types of boiler discussed previously.

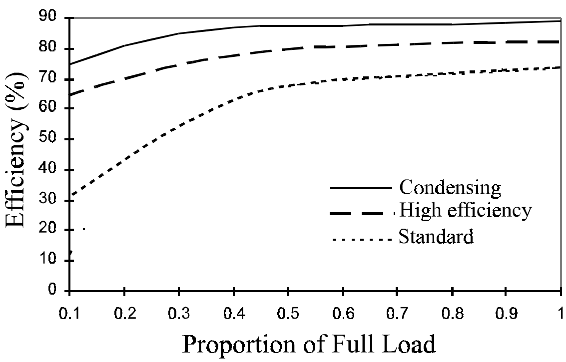


Figure 1.9 Graph of efficiency vs load

From the graph it can be seen that whilst standard boilers are effective when operated at high loads their efficiency falls off when the load on them decreases. The efficiency can fall as low as 35%. In comparison, the high efficiency boiler has a higher efficiency overall and has improved low load efficiencies. The condensing boiler has high efficiencies at all loads. The efficiency at low loads remains high at 75%. Higher efficiencies mean lower fuel costs and less pollution.

MULTIPLE BOILERS

In non-domestic buildings one way of ensuring that boilers fire near their high load rating is to operate them as part of a multiple system of boilers. This is recognised by the building regulations (L4) which require specific controls for heating systems over 100 kW rating. As an example, a multiple system of boilers used to satisfy a 100 kW load is shown in figure 1.10. It can be seen that the 100 kW load is provided by four 25 kW boilers feeding heated water into a common flow pipe and supplied by a common return. The first benefit of this arrangement of boilers is that there is back up if one of the boilers should fail. It can be isolated and heating can still be provided, albeit at a reduced capacity, by the other boilers. The second benefit is that the boilers are fired in a progressive manner to satisfy the load. So for example in the morning when there is a high load situation all of the boilers will fire. Later in the day when the building has started to warm through. Boilers 1 and 2 will fire continuously with boilers 3 and 4 shut down. At the end of the day when top up heating only is required only boiler 1 will be firing. The progressive mode of operation means that each boiler will only be firing near its full output rating. The system as a whole will therefore maintain a high efficiency even though the load is decreasing.

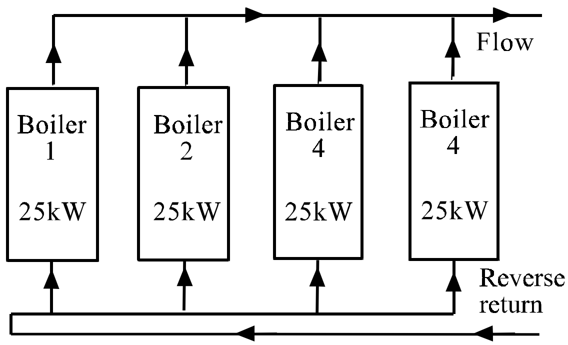


Figure 1.10 Multiple boilers for a 100 kW load

Progressive operation of the boilers requires a control process known as boiler step control. It is based on boiler flow temperature. If this falls it is an indication of increased demand for heating. As a result more boilers will be made to fire. Boiler 1 will be required to fire for more hours than any other boiler since it will operate during both high and low load situations. The boiler which is the first to fire up and last to switch off in any heating period is known as the lead boiler. To avoid unbalanced wear on the boilers the lead boiler will be cycled each week. So in week one boiler 1 will lead, in week two boiler 2 will lead and so on until after four weeks boiler one will once again be the lead boiler.

3 Keeping tabs on energy efficiency

Combined heat and power

Combined heat and power systems have the potential to greatly reduce primary energy consumption and carbon emissions by simultaneously providing heat and electricity.

However, to be financially viable, there needs to be simultaneous demand for these services for a substantial part of the year. Leisure complexes with swimming pools and hospitals are typical applications. Where individual buildings do not provide a suitable load pattern, linking several buildings together may do – especially if they have different usage: offices and homes, for example. Community heating (district heating) is one example of this.

Usually a CHP unit is sized to provide the 'base load' of heat demand, with a conventional heating system providing additional heat at times of peak demand.

For a variety of technical, operational and financial reasons, the optimal design of CHP systems is rather more complex than for most other energy efficiency measures, and specialist advice will usually be needed.

Guidance on the implementation of CHP and related issues is available from Energy Efficiency Best Practice programme documents and the programme also provides site-specific advice.

Guidance documents cover such issues as:

- Good Practice Guides on implementation, operation and maintenance issues
- Case Studies and Good Practice Guides for a range of building types
- the use of CHP with community heating

Further information

Further information on building-related energy-efficiency measures is available from the Energy Efficiency Best Practice programme on the Environment and Energy Helpline 0800 585794

BEST PRACTICE PROGRAMME
ENERGY EFFICIENCY

1.2.2 Combined Heat and Power

Combined heat and power (CHP) units are an additional source of heat for some buildings. CHP units are based on internal combustion engines similar to car or tractor engines (figure 1.11). They have spark plugs an engine block and cylinders. The first difference to a vehicle engine is that instead of running on petrol or diesel they run on gas (natural, biogas or bottled). Secondly rather than drive a set of wheels the motive force generated by the engine is used to drive an electricity generator. This is the "power" part of the output. Instead of a radiator to exhaust the waste heat from the engine to atmosphere the CHP unit has a heat exchanger which transfers this heat into the heating system circulation. CHP units are also based on gas turbine technology giving increased heat and power outputs.

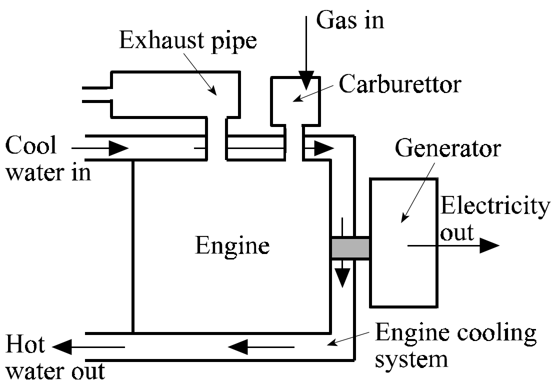


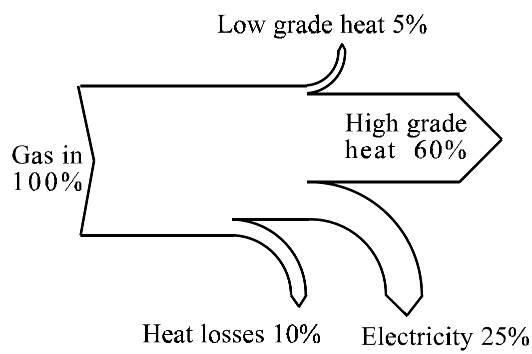
Figure 1.11 Combined heat and power unit

The efficiency of the CHP unit at producing heat is lower than that of a gas boiler at approximately 60%. This can be increased by 5% if an extra heat exchanger is used to recover additional heat from the exhaust pipe and oil cooler. This gives a heating efficiency which is still lower than a gas boiler. However, when the heat output is combined with the energy value of the electricity output the efficiency is greatly increased, to approximately 85%. This is illustrated in the energy flow diagram for the CHP unit shown in figure 1.12.

There are environmental benefits to be obtained from the use of CHP units. These are derived from replacing power station generated electricity by CHP generated electricity. For example, the efficiency of a coal fired power station at producing electricity is approximately 35%. 65% of the energy value of the coal is lost as waste heat in the flue and cooling towers of the power station and in transmission losses in the grid cables. A CHP unit has comparable electricity production efficiency but the waste heat is used in the buildings heating system.

The economics of CHP units is complex and involves a balance between savings in energy bills against capital and running costs. CHP units produce electricity at a unit cost which is much cheaper than can be purchased from the grid. But for the savings from this to pay back the capital cost of the installation the CHP unit must run for the maximum number of hours possible. Balanced against this is the fact that the CHP unit, like any engine, requires periodic routine maintenance. This involves changing oil, filters and spark plugs. CHP maintenance costs are high.

Figure 1.12 Energy flow diagram for a CHP unit



To maximise the running hours, which is necessary to save energy and pay back the capital and maintenance costs, the following three stranded strategy must be followed.

Firstly the CHP energy output must be matched to the building in which it is installed. A unit must be selected whose output satisfies the base heating and electricity demand which occurs all year round. If the CHP gives out more heat than is required the system controls will

4 Keeping tabs on energy efficiency

Holistic low-energy design

For a building to consume the minimum amount of energy while maintaining acceptable levels of thermal comfort it must be designed holistically. All of the elements that have an impact on a building's energy consumption must be considered.

When considered holistically, passive solar strategies can provide approximately 10% of the space heating energy use of a typical dwelling. Inadequate consideration can increase energy usage and create discomfort through overheating and glare. Passive solar heating is seldom of use in commercial properties, such as offices, since substantial heat gains already occur from lighting, occupants and office equipment. Solar gains would simply add to these and cause overheating.

Element	Design issue
Siting	Exposed sites, solar/daylight access
Form	Surface area, volume, internal layout
Fabric	Insulation levels, sealing, workmanship
Ventilation	Uncontrolled infiltration, mechanical ventilation, heat recovery
Daylight	Window design, daylight penetration, internal surfaces
Artificial light	Lighting design, efficiency of lamps/luminaires, control
Passive solar heat	Collection systems, thermal mass, distribution of heat
Mechanical heating	System selection, efficiency of components, control
Cooling	Passive cooling, system selection, efficiency of components, control
Services	Fans, pumps, lifts, renewables, etc
Post-occupancy	Monitoring and targeting, energy management

Factors in low-energy design

Further information

Further information on building-related energy-efficiency measures is available from the Energy Efficiency Best Practice programme on the Environment and Energy Helpline 0800 585794

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switch it off to avoid over heating, cutting down the running hours. If the CHP gives out more electricity than is required by the building it will have to be used by other buildings on the site or exported to the grid. The export of electricity requires the installation of extra meters and unfortunately the price paid by the electricity companies for electricity deposited into the grid is low. It can be seen therefore that a high and consistent base demand is required for economic operation of the CHP unit. This tends to make them more suitable to buildings such as leisure centres and hotels with swimming pools.

Secondly, the CHP unit will be part of a heating system incorporating gas boilers to provide the above base heat demand. To make sure the CHP has maximum chance to run it must be the first heating device the system return water encounters on its way back to the plant room. In other words the CHP must be in series with the boiler heating system.

Thirdly, the CHP must undergo routine maintained at the specified intervals. In addition, many units are fitted with sensors, control devices and modems that allow them to auto dial a maintenance company if the CHP should stop running due to the occurrence of a fault. This will allow rapid attendance by a service engineer to rectify the fault.

1.3 Pumps

It is the job of the pumps to make the water circulate between the boiler and heat emitters within the heating system pipe work.

The three main components of a pump (figure 1.13) are an electric motor, an impeller and the casing. The electric motor is directly coupled to the drive shaft of the impeller. Water on the inlet side enters the pump in the centre of the impeller. The impeller rotates driving the water out towards the casing by centrifugal force. The water outlet is situated off the centre axis of the pump. As a result the pump casing must be cast to arrange the inlet and outlet flows to be along the same centre line. The pump is then known as an "in-line pump".

In domestic heating systems a single pump will suffice. However commercial heating systems contain a large volume of water which may have to be pumped great distances. In this situation high capacity twin head pumps are required. Twin pumps are required to give stand-by capacity if one of the pumps should fail. This is because a loss of pump power in a commercial building would result in an unacceptable loss of heating.

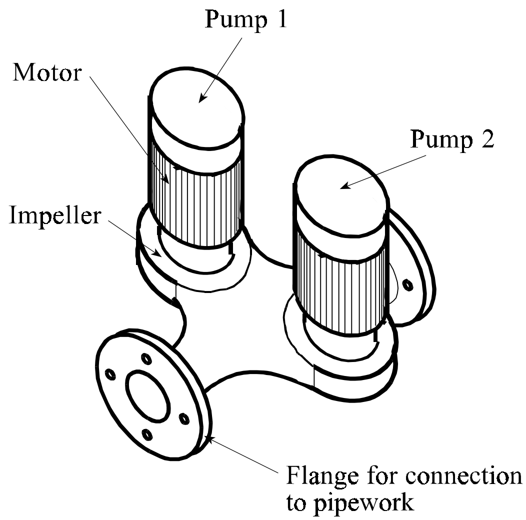

Figure 1.13 Twin head pump

Only one pump runs at a time, this is called the duty pump, the other acts as a stand-by. It is usual to run each pump for 1500 hours then change over to the other to even out the wear on them. This process can be carried out manually via the pump control panel. However in modern systems this is carried out automatically using a building energy management system (BEMS) (section 1.6). As well as routine cycling of pumps a BEMS can detect pumps failing if they are fitted with a suitable sensor and automatically isolate it and start up the stand-by pump.

Variable speed pumps. An energy saving development in pump technology is the variable speed drive pump. This system does not run at a fixed speed but varies its speed and hence pumping power depending on the work it is required to do. For example, if a heating zone is warm enough valves will close isolating its heat emitters from the heating flow. As

I P 3 - M O T O R S . A N D . D R I V E S

Electric motors are everywhere in building services. They drive fans, pumps, lifts escalators and process machinery. In a typical prestige air conditioned office, fans and pumps account for 20% of the total electrical consumption (1). For comparison refrigeration only consumes 11% of the total. Motors are, therefore, key services components and major consumers of energy.

ELECTRIC MOTORS

Most electric motors used in building services are of the AC induction type. Single or three phase alternating current is fed through copper coils in the stator creating a magnetic field. This magnetic field induces another in the rotor. This causes the rotor to spin in the same way that like poles on bar magnets push apart. This spin can be used to drive the impellers of pumps (section 1.3) and fans (section 4.3).

> Electric motors are everywhere in buildings. They are key components and major consumers of energy.

HIGH EFFICIENCY MOTORS

Motors are machines that convert electricity into movement. Like most machines their efficiency is less than 100%. The wasted proportion is seen as heat, arising from overcoming friction and created as a result of resistance in the windings of the motor. The efficiency of a typical 3kW motor is approximately 81%.

It is possible to increase the efficiency of motors by using low loss electrical steels and by increasing the thickness of wires used in the motor construction. This reduces resistive and inductive heating in the windings. As a result the motor cooling fan can be made smaller which adds to increased efficiency. These modifications increase the 81% motor efficiency by 4% i.e. up to 85%. This does not seem a large improvement but when you consider motors run for up to 24 hours a day the cumulative savings are very large. The additional cost of a high efficiency motor (about 25% more than a conventional motor) will typically be paid back within the first year of operation. Some manufacturers now offer high efficiency motors as standard

DRIVE SYSTEMS

The majority of motors run at a fixed speed. Variations in demand are usually satisfied using flow control devices. For example in a warm air heating system as the demand for heating falls the supply of warm air to the space will be reduced by closing a damper. The fan motor continues to operate at fixed speed.

There is a rule affecting motors, known as the cube law, which states that electricity savings are proportional to the cube of reductions in speed. This means that cutting the motor speed by 20% will give a 50% saving in electricity consumption. From this it can be seen that even modest reductions in motor speed will result in considerable energy savings. There are three types of variable speed drive (VSD). These are(2);

A two stage motor i.e. fast/slow/off operation. This is cheap and gives reasonable savings.
Electromechanical systems. Using gears, drive belts and slip disks to vary drive speed. These are robust but do not give maximum savings.
An inverter. This converts 50Hz mains electricity to DC. It then re converts it to AC at a frequency dependent on load. Increasing the frequency in response to increasing load increases the speed of the motor and vice versa. This system gives maximum flexibility and so maximises savings.

Additional benefits from VSDs are reduced maintenance costs and reductions in electrical standing charges.

Further information

1. Energy Efficiency Office. Energy Consumption Guide 19: Energy Efficiency in Offices. HMSO 1992.

2. Energy Efficiency Office. Good Practice Guide 2:Guidance notes for Reducing Energy Consumption Costs of Motor and Drive Systems. HMSO 1993.

a result less water will need to be pumped around the heating circuit. A variable speed pump will sense this and slow down. This is illustrated in Figure 1.14 which shows that the energy consumption of a fixed speed pump remains constant as the demand for water flow falls. The variable speed pump slows down to match demand resulting in a fourfold reduction in electricity consumption for each halving of pump speed.

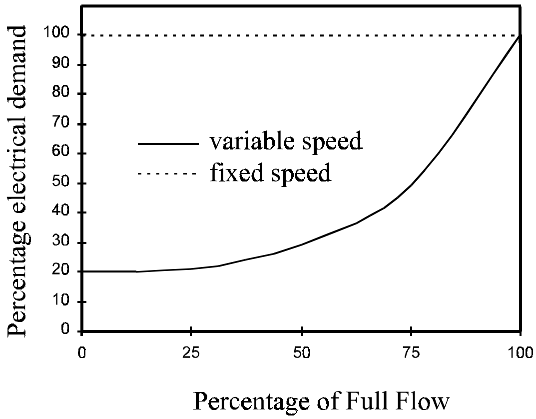

Figure 1.14 Graph of pump electrical use against percentage of flow

By exercising variable speed control of the pumps considerable amounts of energy and hence money can be saved. Using less energy also gives a reduction in the output of pollutant gases from power stations (see IP3).

1.4 Heat Emitters

Heat emitters transfer the heat from the heating system to the rooms requiring warming. This is usually carried out by convection and radiation from a surface heated by the hot water flowing through the heating circuit. To avoid overheating the room some method of control is required. This is usually achieved by restricting the flow of heated water into the heat emitter using a valve.

In most domestic buildings heat is emitted to the rooms using radiators. Water heated to 80°C by the boiler flows into the radiator, raising its temperature. The radiator warms the room by losing heat to it. The radiator gives out heat partly by radiation but mainly by convection. Convection occurs when the radiator heats up the room air in contact with it. The air becomes less dense and so rises to the ceiling where it mixes with the rest of the room air. Cooler air from beneath the radiator is drawn up to repeat the process. Because it has lost heat to the room, water leaving the radiator and returning to the boiler is typically 10°C cooler than the flow temperature. In order to achieve this temperature drop the flow of water through all the radiators in the system must be regulated during commissioning. This is carried out by opening or closing lock shield valves fitted on the radiator outlets to increase or decrease the flow rate respectively.

For a given boiler flow temperature the heat output of a radiator is determined by the size of its surface area for convection. The single panel radiator (figure 1.15) is the simplest pattern. It is two pressed steel panels sealed by welding on all sides. Its shape gives it an internal void, which fills with hot water, and surface convolutions which increase its surface area. The single convector radiator has this same basic panel but has an additional corrugated plate spot welded to its back surface. This plate increases the effective surface area over which convective heat loss can take place. Two other patterns are shown which also increase heat output by increasing surface area further. The heat outputs of each of these radiators is given for a 600 mm high by 1000 mm long radiator. It can be seen that in comparison to the single panel radiator the heat outputs of the single convector, single panel / single convector radiators and double convector radiators are 43%, 112% and 170% bigger respectively.

The benefit of increased heat output is that the physical size of the radiator can be reduced for a given heat output. A feature which is useful in confined spaces such as where sill heights are low. However it must be remembered that the cost and depth of the radiators also increase with increasing heat output

Radiators are usually positioned beneath windows. This is a useful location as it is unlikely that furniture will be positioned here and also the heat output of the radiator will counteract the cold down draughts from the glazing. Radiators are rated in terms of their heat output which should be matched to the peak heat loss

IP4 - SIZING.BOILERS.AND.HEAT.EMITTERS

Manufacturers produce a range of boiler and heat emitter sizes to satisfy the needs of various buildings. Before you can buy a boiler and connect it up to the heat emitters you need to know how much heat is required by each room which in turn informs you of the size of the boiler. Over sized boilers should be avoided since they will rarely operate at peak load and so will have low efficiencies. Under sized boilers will not give the required output and so room temperatures cannot be maintained against low outside temperatures.

> Undersizing of boilers means temperatures cannot be maintained, oversizing results in low efficiencies.

HEAT EMITTER SIZING

Heat Emitters must be sized to supply the peak heating demand of a particular room. This is determined by calculating the peak fabric and ventilation heat loss rates of the room. Examples of how to do this are given in building science text books. The ambient conditions assumed for the calculation use -1^{o}C for the outside air temperature along with the design indoor temperature. For a room occupied by people engaged in a low level of physical activity, such as an office or living room, the indoor temperature is assumed to be 21^{o}C. The air change rate and fabric thermal properties are also required

The outcome of the heat loss rate calculation described above for a living room might give a heat loss rate of 2000Watts. This means that when it is 21^{o}C inside and -1^{o}C outside the room will be losing heat at a rate of 2000W. To maintain the internal temperature heat must be supplied to the room at the same rate. This is anologous to water pouring out of a hole in a bucket. To maintain the required water level (21^{o}C) water must be poured into the bucket at the same speed at which it is leaving through the hole (the heat loss rate). For this reason the heat emitter for our example room should be sized at 2000W. Trade literature for heat emitters gives a range of useful information such as dimensions and mounting details. It also gives information on heat outputs. A suitable heat emitter can be chosen from these tables.

One difficulty of heating large rooms is to get adequate heat distribution throughout the room. Unless some kind of forced convection system is used, heat tends to be concentrated near the heat emitter. One way of achieving better distribution is to divide the heat input into the space using two or more heat emitters distributed evenly through the room.

BOILER SIZING

The process used to determine the fabric and ventilation heat loss rate for the individual room must be repeated for all rooms. If an indirect heating system is being used. The source of heat, usually a boiler, must be able to supply the total heating requirement of the heat emitters in all the rooms. For the four roomed house shown in figure IP4 it can be seen that the boiler power needs to be 3.3kW. If hot water is to be derived from this boiler an allowance (typically 3kW) must also be added for this purpose.

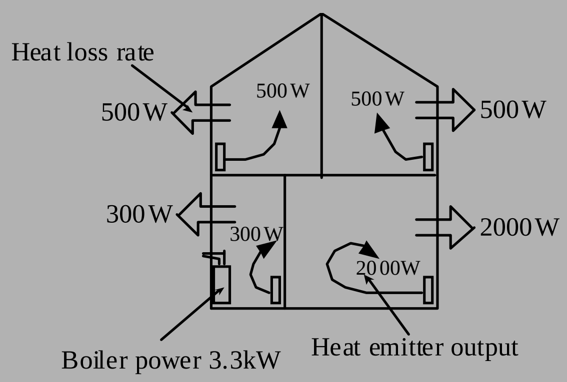

Figure IP4. Heat losses from room counteracted by appropriately sized heat emitters

In large buildings where the heat output of the boilers is measured in hundreds of kilowatts a multiple system of boilers must be used (section 1.2.1) to maintain high operating efficiencies.

rate of the room in which they are situated (see IP4). In large rooms the radiator output should be split and more than one radiator used. This will distribute the heat more evenly throughout the room.

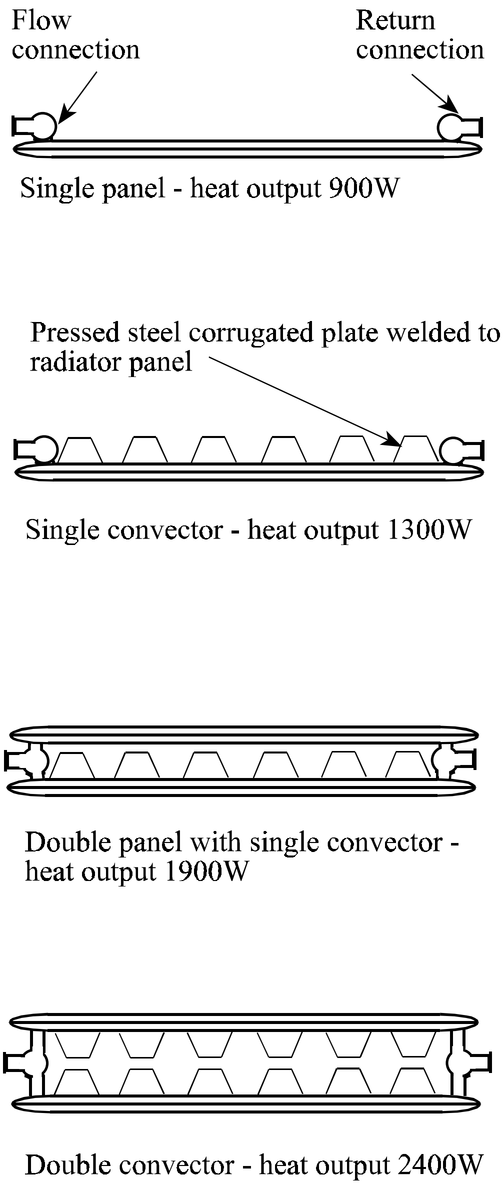

Figure 1.15 Radiator patterns - plan views

COMMERCIAL HEAT EMITTERS.

As with domestic buildings, radiators are used in commercial buildings but in addition, a wide range of other heat emitters are encountered.

Low Surface Temperature (LST) Radiator. This is a radiator which is encased to prevent touching of the hot surfaces (figure 1.16). A top grille allows heat to leave the unit. LST radiators are suitable where high surface temperatures could cause burning. Examples are aged persons homes or nursery schools.

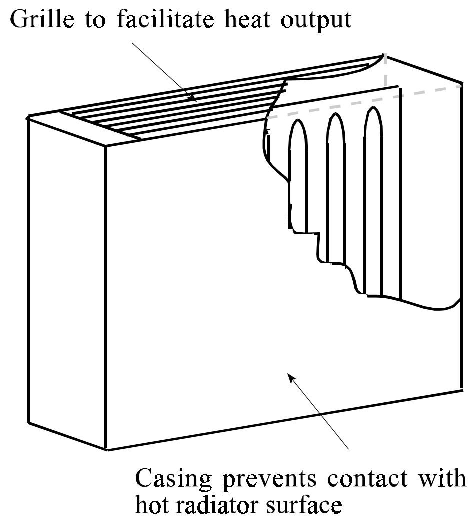

Figure 1.16 Low surface temperature radiator

Perimeter Radiator. This radiator is constructed from a tube which has had fins added to increase its surface area for heat output (figure 1.17).

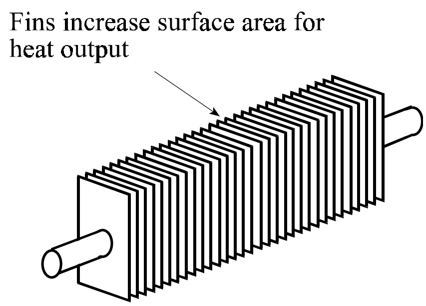

Figure 1.17 Perimeter radiator

5 Keeping tabs on energy efficiency

Home energy ratings

The energy efficiency of homes can be summarised by a Home Energy Rating. The Government's procedure for calculating home energy ratings is the Standard Assessment Procedure (SAP). It uses a scale of 1 to 100 – the higher the rating the better the energy efficiency.

The SAP rating takes account of a number of features, including:

- building insulation
- building design
- solar heat gains
- building ventilation
- heating and hot water efficiency and controllability.

SAP

All new dwellings and conversions are required by Building Regulations to have a SAP rating. SAP can also be used to rate existing homes and to show the impact of possible improvements.

The national average SAP rating is about 40. However, new housing can easily achieve ratings of over 80, and the ratings are often used in the marketing and promotion of new developments to prospective purchasers.

SAP ratings can be obtained from organisations authorised by the Government to assess properties and issue SAP certificates.

There is currently no equivalent rating system for non-domestic buildings, though a number of computer models exist that can model the temperatures and energy flows in these buildings. The BREEAM rating system includes energy performance among other environmental criteria.

Further information

Further information on building-related energy-efficiency measures is available from the Energy Efficiency Best Practice programme on the Environment and Energy Helpline 0800 585794

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The unit may only be 150mm high but it is long in length. Perimeter radiators are typically used along the entire outer edge of highly glazed spaces. Here their heat output counteracts cold down draughts from the glazing. Its low height makes it unobtrusive. A modification of perimeter heating is to recess the radiator into the floor depth and cover it with a grille to form a perimeter convector heater.

Convector Heater. Convector heaters are constructed from a cabinet in which there is a finned coil heated by water flowing through it from the heating system (figure 1.18). Air inside the casing is heated by contact with the heating coil causing it to rise up through the convector and out of the upper grille to heat the room. The convection current carries on this cycle by drawing cool room air into the cabinet via the lower grille. A filter behind the inlet grille removes dust from the airstream.

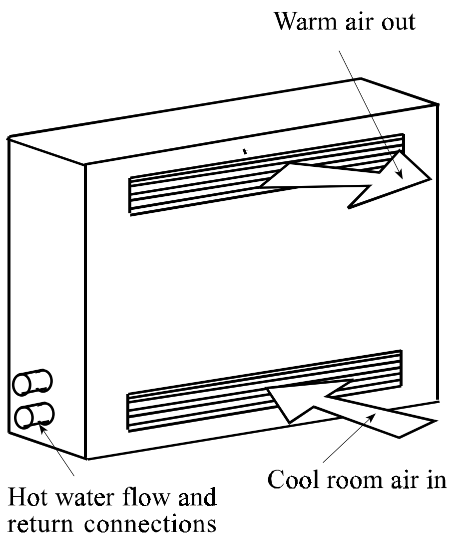

Figure 1.18 Convector heater

The heat output of the unit can be increased and the time taken to heat the room reduced by fitting a fan into the casing to drive the circulation of air through the heater. The heater is then known as a fan convector. Fan noise can be a problem in some quiet locations but heat output can be regulated more effectively by switching the fan on and off as required.

Radiant Panel. These heat emitters are composed of copper tubes welded onto metal plates (figure 1.19). Flexible connectors are then used to connect a series of these plates together. The panels, which in offices are perforated and painted, are hung to form part of the suspended ceiling. Water from the heating system is passed through the tubing causing the temperature of the panels to increase. The space below is then heated by convection and radiation.

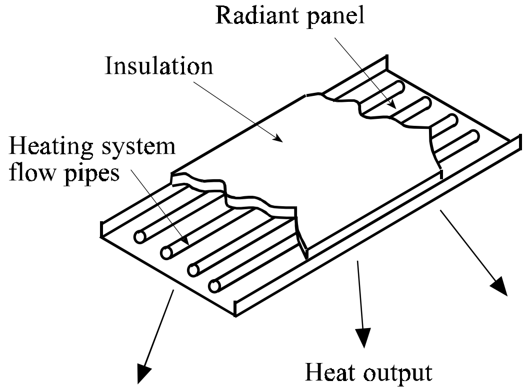

Figure 1.19 Radiant panel

The advantages of radiant panels is that they do not take up any wall space and their heat output will not be affected by furniture such as filing cabinets or desks pushed up against walls.

Underfloor Heating. This method utilises the entire floor, and sometimes the walls, of a room as a heat emitter (figure 1.20). Water from the heating system is passed through polymer pipes embedded in the floor screed. The flow temperature, at approximately 24^{o}C, is much lower than for other types of heat emitter. This is possible because of the large surface area created by utilising the floor for heat output. This is in contrast to the smaller but hotter surface area of a radiator.

There are many benefits from using an underfloor heating system. These are;

- Wall space is not taken up by heat emitters.

- large spaces which are difficult to heat evenly from perimeter heat emitters can be uniformly heated.

I P 5 - H U M A N . T H E R M A L . C O M F O R T

Human thermal comfort is determined by the way individuals perceive the temperature of their environment i.e is it too hot or too cold. This perception depends on personal preferences. As a result, within a group of people in the same room, some will feel comfortable, some too hot and some too cold. Building professionals must use their knowledge of the building fabric, heating services and human physiology to ensure that the majority of people in a space are satisfied with the temperature. There are some serious health concerns in buildings (see IP10). But lack of thermal comfort is a chronic problem which affects many people in badly designed buildings.

> Lack of thermal comfort is a chronic problem which affects many people in badly designed or serviced buildings

THERMAL COMFORT

To be comfortable a person requires a stable core body temperature of 37.5^{o}C. To achieve stability any heat inputs to the body must be balanced by a heat output. Extra heat input or reduced heat losses will cause the subject to feel warmer. Extra heat loss or reduced heat gains causes the subject to feel colder. Heat gains to and losses from the body are illustrated in figure IP5. **Convective heat** gains and losses are created when warm air moves into or out of contact with the body respectively. Convective heat transfers are strongly dependent on air movement around the body. **Conductive heat** gains and losses occur due to body contact with hot or cold surfaces respectively. Since normal contact with room surfaces is restricted to the soles of the feet this does not constitute a major component. **Radiative heat** gains and losses occur when a person is positioned next to a warm or cold surface respectively. The human body is very sensitive to radiant energy and so this component has a strong affect on comfort. In addition to the three basic forms of heat transfer there are two others related to the human body. The first is heat gain by the body due to metabolism. The body burns food to grow, repair itself and cause movement. A by-product is heat. The amount of heat gained by the body is substantial and increases with the level of activity. This is illustrated in the following table.

Activity	Metabolic Heat Output (W)
Sedentary	100
Active (light work)	150
Very Active	250

Secondly, additional heat loss arises due to evaporation of moisture from the lungs and skin. Latent heat is absorbed (see IP6) which cools the body. This cooling effect is increased in dry (low RH) environments. In high relative humidity environments evaporation is suppressed. The space is then commonly referred to as being hot and "humid".

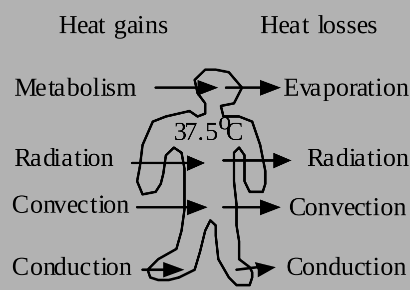

Figure IP5 Balance of body heat gains and losses

FACTORS AFFECTING THERMAL COMFORT

Anything which changes the balance of heat inputs and outputs will affect thermal comfort. For example, if air temperatures rise heat gains will increase. Turning on a fan in response causes air movement increasing heat losses. This returns the body to thermal balance and comfort. The body itself is very effective at thermoregulation e.g raising hairs for insulation, shivering for metabolic heating, variable skin blood flow to regulate body heat loss and sweating to cool evaporatively. Other variables are;

Amount of clothing	(insulation)
Temperature gradients	(differential losses)
Average surface temperature	(radiant transfers)
Relative humidity	(evaporation)

· Thermal gradients decrease from foot to head improving thermal comfort and reducing the risk of stratification.

· The low flow temperatures utilised in underfloor heating makes them ideal for use with condensing boilers (section 1.2.1). The low return temperatures will increase the tendency of the boiler to operate in condensing mode.

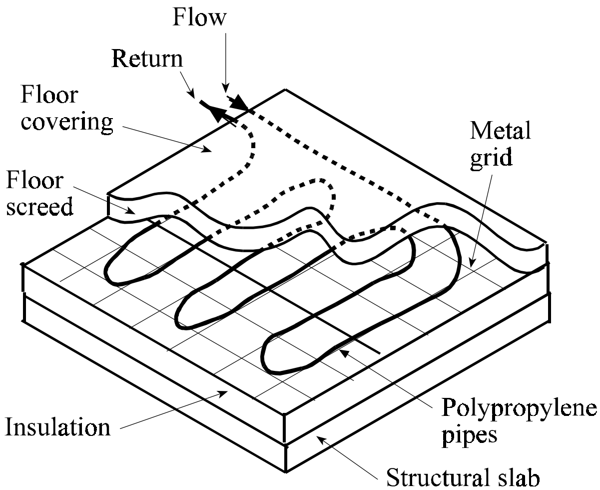

Figure 1.20 Underfloor heating system

1.5 Domestic Hot Water

Hot water is obtained from domestic central heating systems in two ways. Firstly, by the use of indirect cylinders which draw some of the heat away from the heating circuit to provide hot water. The second is to use combination ("combi") boilers which generate hot water instantaneously as it is required.

Indirect Cylinder. Some of the heated water flowing through the heating circuit is diverted, using a three way valve, through a calorifier within the hot water cylinder (figure 1.21). The calorifier is essentially a coil of copper tube through which the heating system water flows. Heat transfer from the calorifier warms up the cold water held in the cylinder. The heated water rises to the top of the tank where it is drawn off to the taps. The cold feed, which enters at the base of the cylinder, is from a mains fed tank which is often built in to the top of the cylinder to form an integral unit. Since the feed water tank is open to the air the system is referred to as a vented or non sealed system. The benefits of indirect water heating are that the central heating boiler performs two functions (space and water heating) and that there is a stored volume of hot water ready to meet peak demands.

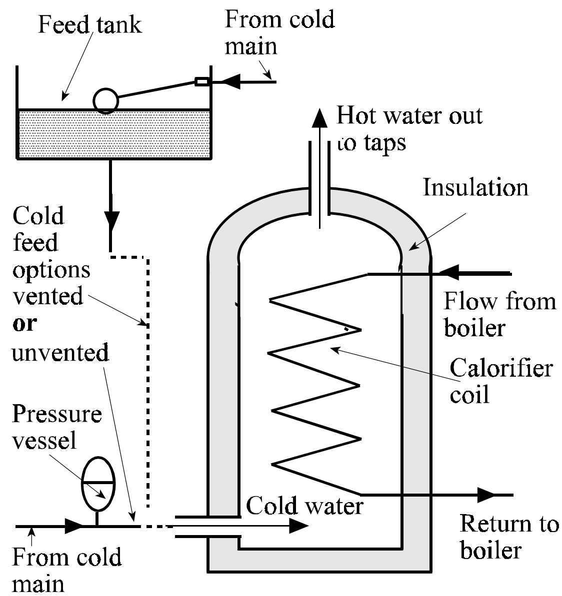

Figure 1.21 Indirect dhw cylinder

Unvented indirect cylinders are similar to the system described above in that a calorifier fed from the wet heating system is used to heat a stored volume of water. The difference is that the cold feed is from a direct connection to the cold main instead of from a tank. As a result hot water from the cylinder is fed to the taps at mains pressure. This gives a greater flow rate than a tank fed system. Since there is no opening in the system to the air it is known as a sealed or unvented system. Two of the benefits of this systems are that showers can be successfully fed from them and that the plumbing necessary for a feed tank is not required.

When water is heated it expands. The increase in pressure caused by this would damage an unvented system since the pressure cannot be released. Because of this unvented hot water storage systems are fitted with a small expansion vessel to take up the extra volume of

IP6-THERMAL.CAPACITY,SENSIBLE.AND.LATENT.HEAT

THERMAL CAPACITY

Thermal capacity is a measure of the ability of a material to absorb heat. It is usually specified in terms of the specific heat capacity of the material. This is the amount of heat, measured in Joules (see IP2), that one kilogram of the material must absorb to raise its temperature by 1^oC. The units of specific heat capacity are $J/kg/^oC$.

For example the specific heat capacity of water is 4200 $J/kg/^oC$, of air is $993J/kg/^oC$ and of stone is $3300J/kg/^oC$. It can be seen that per kilogram stone has a much greater heat carrying capacity than air and that water has a higher heat carrying capacity than stone. This has consequences for the building services industry. Air cannot carry as much heat per unit volume as water. As a consequence heat distribution systems which use air must be much larger than hydronic distribution systems to carry the greater volumes required. The relatively high thermal capacity of dense materials such as stone is used for thermal storage. One example is the use of special blocks in electric storage heaters (section3.1).

SENSIBLE AND LATENT HEAT

Sensible heat and latent heat are both forms of thermal energy. The difference in name arises as a result of what happens to a material when the thermal energy is being absorbed.

The absorption of **Latent heat** causes a change of state. One example is the absorption of the latent heat of vaporisation by water to change it from a liquid to a gas (water vapour). It should be noted that a substance gives out latent heat when the phase change is reversed. For example the latent heat absorbed by a refrigerant in the evaporator coil of a vapour compression chiller is released once more when the refrigerant condenses in the condenser.

Absorption of **sensible heat** causes an increase in the temperature of the object. The amount by which the temperature rises depends on the amount of energy absorbed, the mass of the material and its specific heat capacity (see above). Sensible energy is released by the object as it cools.

Sensible and latent heat are best illustrated using water as an example.

Figure IP6 shows what happens if a 1kg block of ice at 0^oC is placed in a beaker over a Bunsen burner. The ice absorbs heat from the flame but its temperature does not increase instead it changes state, it begins to melt. The heat absorbed is called the latent heat of fusion (units J/kg). When completely melted, further heat input causes the temperature of the water to rise. The thermal energy now being absorbed is called sensible heat. The temperature rise continues until 100^oC is reached. At this point the temperature once again stabilises and a second change of state occurs. This time from liquid to vapour. The heat absorbed is called the latent heat of vaporisation. This continues until all the liquid is converted to vapour.

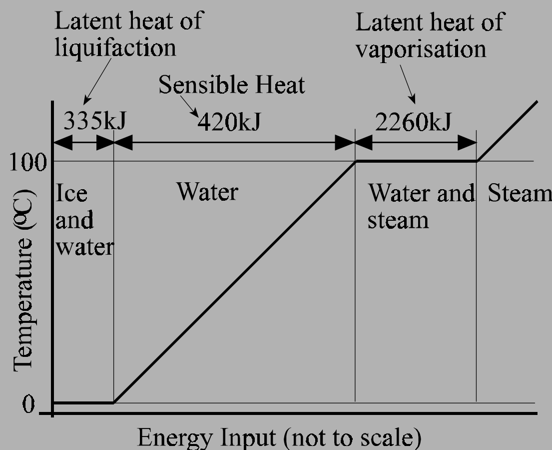

Figure IP6: Heating of ice

Consideration of figure IP6 shows some interesting features. The first is that substantially more energy is required for the phase change from water at 100^oC to steam than for the heating from 0 to 100^oC. This means that steam at 100^oC contains far more energy than water at this temperature. This is why steam is a useful heat transfer medium. It contains a lot of energy so distribution pipes can be kept small whilst transferring large amounts of heat to the heat emitters. It is also dangerous. If steam escapes and condenses onto human skin all of the latent heat of vaporisation is re released which can cause severe burns.

water created by heating.

Energy issues. In summer the low loads encountered by a central heating boiler required to generate hot water only leads to reduced boiler efficiency. It is therefore recommended that indirect cylinders are used in conjunction with a condensing boiler (section 1.2.1). The cylinder itself must be well insulated to reduce heat loss from the stored hot water. These heat losses are known as standing heat losses. The alternative approach to energy efficiency is to use a stand alone direct water heater (section 3.3)

Combi Boiler. A combi boiler is a combustion device which has two heat exchangers, one for the space heating system and one for the domestic hot water (figure 1.22). Cold water is fed into the unit directly from the mains. Turning on the hot tap allows cold mains water to flow through the boiler which in turn causes the burner to fire. Hot water is therefore generated as needed. There is little or no stored volume of water. The casing of the boiler also houses pumps, controls and a pressure vessel. A pressure vessel is required since the system is sealed and provision has to be made for the increase in pressure that occurs as water in the system is heated.

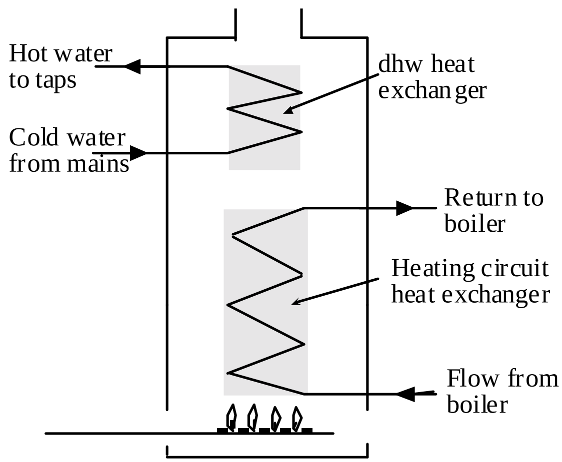

Figure 1.22 Combination boiler

One of the major benefits of this system is that it is simpler and less costly to install as the feed and expansion tank, indirect cylinder and cold water storage tank are not required. This can be seen by comparing figure 1.23 which shows a combination boiler heating system with figure 1.1 which shows an open vented heating system with indirect cylinder.

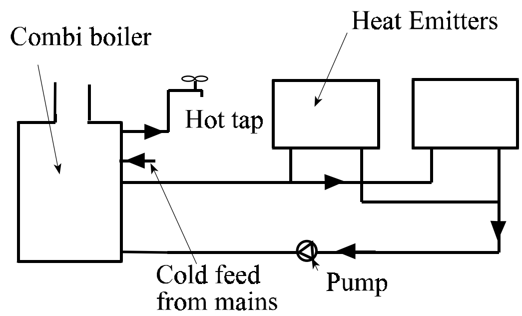

Figure 1.23 Combination boiler heating system

DHW FOR COMMERCIAL BUILDINGS.

Hot water in commercial buildings can be provided by indirect cylinders as discussed previously. The cylinders are however much bigger due to the increased demand for hot water experienced in larger buildings and are often referred to as calorifiers. Another method of dhw production is to replace the indirect cylinder with a water to water plate heat exchanger. The source of heat is still the indirect heating system.

Water to water plate heat exchangers are built from layers of convoluted thin plates (figures 1.24 and 1.25). Alternate voids created by the plates carry heating circuit and dhw flows respectively. Heat is transferred from the heating circuit flow to the dhw flow by conduction across the thin metal separating them. This process is fast enough to produce hot water instantaneously.

Plate heat exchangers have a number of advantages over storage systems;

- There are no standing heat losses since there is no stored volume of water to cool down overnight or at weekends.

- Legionnaires disease can arise where water is allowed to stand at the incubation temperature of the legionella bacteria. Since standing water is eliminated

IP7/1 - PLANT.ROOM.POSITION.AND.SIZE

Building services can represent 50% of the cost of a highly serviced building and take up to 30% of its floor area. This brings the importance of building services in the construction process clearly into view. It also illustrates the need for early allocation of space for and planning of building services. The main elements involved are plantrooms and horizontal and vertical service runs. Space allocation must take into consideration the need for adequate space and access for servicing and, if it is felt necessary, provision for flexibility and future developments. Service runs permeate throughout the entire height, length and width of a building therefore, any building services designs must be made with due regard for the structure. Integration of services with the structure is an important element in the building design process.

> Building Services can represent 50% of the cost of a highly serviced building and take up 30% of its floor area

This information panel does not have enough space to cover this subject in depth, but three main issues relating to the planning of services can be highlighted. These are space, location and distribution.

SPACE FOR SERVICES

There are many types of building and each one will have a different servicing requirement. Even within similar building types there are a range of solutions available. One example is office buildings that can be fully air conditioned, naturally ventilated or operate with both systems (mixed mode). The obvious rule is that the greater the need for building services the greater is the need for space to accommodate them. So for example a simple naturally ventilated heated office will devote 4-5% of its total floor space to plant whereas for a speculative air conditioned office this will rise to 6-9%. Highly serviced buildings such as sports centres with leisure pools may need to allocate 15-30% of the total floor area to services. For an individual building the final determinant of space requirement is the load on the heating or air conditioning system. Reducing the need for heating or air conditioning by using low energy design principles will cut down on the need for energy consuming plant and therefore on the space required to accommodate it.

At the early design stage rules of thumb will be sufficient to make an initial allocation of space. (see BSRIA Technical Note TN 17/95: Rules of Thumb, BSRIA 1995). This figure can be refined at a later stage when exact details are known.

Having arrived at a figure the space can be concentrated in one place which is usual for small to medium sized buildings. The possibility of dividing the space up and spreading it through the building depends on the layout of the building. If the building covers a large area then it may be economical to have smaller but more numerous plantrooms distributed throughout the site each satisfying individual zones or sections of the building. The advantage is that distribution runs are kept short and pipe and duct diameters can be smaller to reflect the reduced floor areas served.

LOCATION

Plantrooms can be located anywhere in the building but noise considerations, weight of equipment to be accommodated and ease of access for maintenance means that plantrooms containing heavy equipment such as boilers and chillers tend to be located on the ground floor or basement. However, modern low water content boilers (e.g. Hamworthy Wessex)are designed to be light for roof top installation. Air handling units are lightweight but bulky. This means they can be accommodated on rooftops where they are not taking up lettable space and structural requirements are not critical. The rooftop is a useful location for taking in air which is generally fresher than at ground level. The rooftop also gives the cooling system condenser access to the outside air for waste heat rejection.

Continued on page 32

with plate heat exchangers the possibility of infection is avoided.

- Plate heat exchangers are physically much smaller than indirect cylinders. This makes them useful where space is limited.

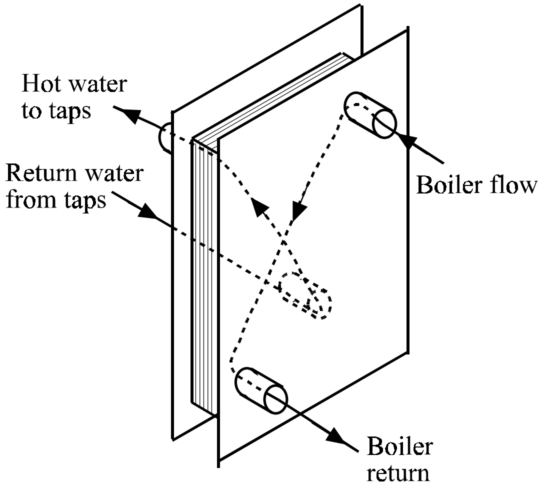

Figure 1.24 Water to water plate heat exchanger

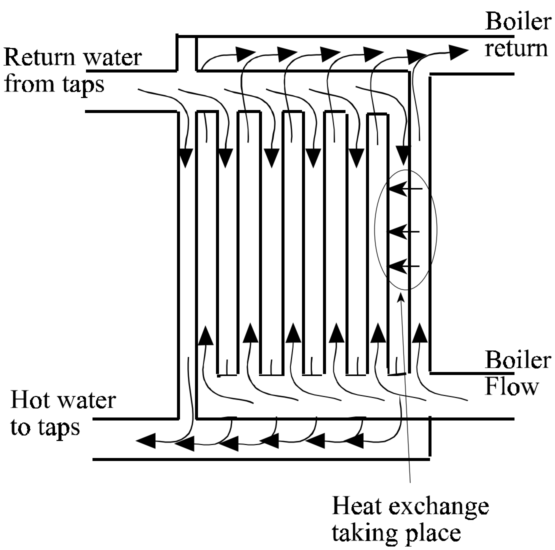

Figure 1.25 Cross sectional diagram of a plate heat exchanger

Since there is no stored hot water, which is used to satisfy demand at times of peak usage, the heat exchanger must be sized to satisfy the peak hot water demand of the building.

DHW DISTRIBUTION

A significant difference between domestic and commercial dhw systems is the way in which the hot water is distributed to the taps. In domestic properties a single pipe directs water from the cylinder to the tap. In combi systems the energy to do this comes from mains pressure. In indirect cylinder systems the water is moved by gravity. Both of these mechanisms are adequate because the pipe lengths are small. In large buildings, however, the pipe lengths become longer due to the large distances between hot water production and use. Standing heat losses from these long pipes would cool the water in them and result in tepid water being drawn off from remote taps. Running off this tepid water until hot water was obtained and the heat lost from the pipes themselves wastes energy. To ensure that hot water is always available at the tap they are usually supplied from a secondary hot water loop (figure 1.26). A secondary dhw pump continually circulates hot water from the cylinder or heat exchanger around this circuit. As a result hot water is always available at the taps. Pipe insulation ensures heat lost from the pipes is minimised (see IP1).

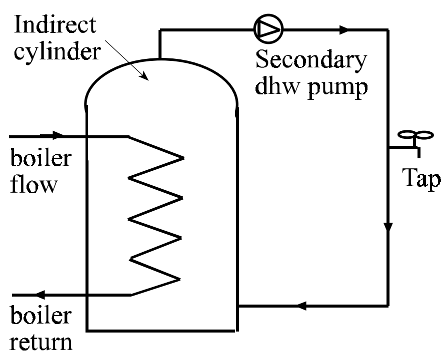

Figure 1.26 Secondary dhw circuit