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Forest Research
The Research Agency of the Forestry Commission
TECHNICAL DEVELOPMENT

WOODFUEL BURNING SYSTEMS

Introduction

This Information Note is one of a series produced for a Technical Development Branch (TDB) Outdoor Workshop (ODW) and is produced as a guide to part of a harvesting system suitable for use in small-scale woodlands. ODWs are a TDB initiative designed to offer practical advice to practical people through presentation, demonstration and user guidance. The ODW programme will involve repeating trials and introducing new systems around Great Britain so that a wide range of sites, systems and practitioners can be included.

This Note collates currently available information on woodfuel burning systems and identifies the fuel specifications for each.

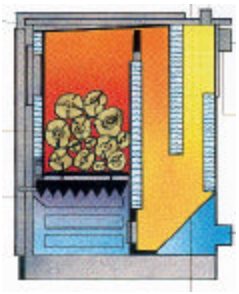
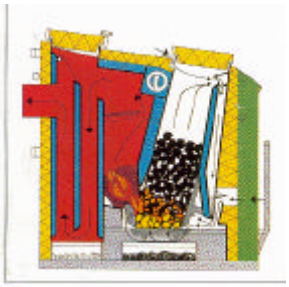
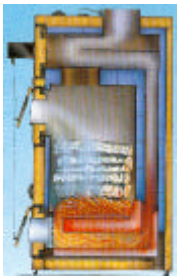
The coverage is complete, from small, simple warm air systems up to modern commercial sized systems producing heat, electricity, pure power or a combination of energy outputs.

Descriptions have been kept as clear and straightforward as possible, notwithstanding the many complexities of modern larger, commercial woodfuelled power stations.

Illustration of boiler or system type Domestic sized systems. Traditional appliances			
Name	Box Stove	Tiled Stove	Cooker/Boiler
Brief description	Fire is within a freestanding metal container with adjustable air inlets. May have a water boiler incorporated.	Intense, intermittent firing within a large ceramic or stone heat store. Slow release of stored heat between firings.	A 'Range' cooker that also supplies 'wet' central heating.
Fuel type(s)	Prepared wood logs, i.e. cut to length, split, and dried. (coal options).	Prepared wood logs.	Prepared wood logs, (coal options).
Combustion type and maximum efficiency guide	Simple 'over-burning'[1] technology *c.* 65 - 70%.	Simple 'over-burning' technology *c.* 85 - 90%	Simple 'over-burning' technology *c.* 50 - 60%.
Heat output range	2 to 20 kW	up to 10 kW	10 to 25 kW
End-use suitability	Small domestic, direct air heating or supplementary to other background heat.	Small/medium domestic, direct air heating. High aesthetic appeal.	Small/medium domestic, cooking and CH/DHW[2] supply.

[1] This is where the fire burns up through the fuel, placed on top.
[2] CH = central heating; DHW = domestic hot water

Name	Box Stove	Tiled Stove	Cooker/Boiler
Particular service requirements.	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Some operational expertise.
Installation parameters - notes	Insulated chimney. Direct heat protection.	A large and heavy construction.	Insulated chimney. Large hot water storage.
'Best practice' fuel characteristics[3] & other requirements	Length, thickness specifications and moisture content *c*. 20 to 25%. An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c*. 20 to 25%. An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c*. 20 to 25%. An assured supply of suitable fuel.

Illustration of boiler or system type Domestic sized systems. Free-standing boilers, log fired			
Name	Freestanding boiler. 'Over-fired' type	Freestanding boiler. 'Under combustion' type	Freestanding boiler. 'Reverse combustion' type
Brief description	Top or side loading boiler unit	Top or side loading boiler unit	Top or side loading boiler unit
Fuel Type(s)	Prepared wood logs	Prepared wood logs. Options for supplemental oil/gas burners.	Prepared wood logs. Options for supplemental oil/gas burners
Combustion type[4] and maximum efficiency guide	Simple 'over-burning' technology *c*. 60 - 70%	Efficient under combustion design *c*. 65 - 75%	Very efficient reverse combustion design *c*. 75 - 90%
Heat output range	11 to 30 kW	15 to 200 kW	15 to 75 kW
End-use suitability	Small/medium domestic or small commercial premises	Small/medium domestic or small commercial premises	Small/medium domestic or small commercial premises
Particular service requirements	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Some operational expertise.
Installation parameters - notes	Insulated chimney. Large CH hot water storage tank, usually incorporating DHW provision + additional electric immersion heater.	Insulated chimney. Large CH hot water storage tank, usually incorporating DHW provision + additional electric immersion heater.	Insulated chimney. Large CH hot water storage tank, usually incorporating DHW provision + additional electric immersion heater.
'Best practice' fuel characteristics[5] and other requirements	Length, thickness specifications and moisture content *c*. 20 to 25% An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c*. 20 - 30% An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c*. 20 - 30% An assured supply of suitable fuel.

[3] See later reference to European Fuel Standards

[4] Under-combustion is where the fire burns sideways and away from the fuel, placed on top. Reverse combustion is where the fire burns downwards and away from the fuel, placed on top.

[5] See later ref. to European Fuel Standards

Illustration of boiler or system type Domestic sized systems. Freestanding boiler variants log fired.			
Name	Multi-fuel boilers	Combination boilers	Wood pre-burners
Brief description	A boiler designed to run on a wide variety of fuels	A main wood, plus a separate oil/gas boiler in one unit	A wood pre-burner furnace designed to convert another, e.g. a fossil fuelled boiler
Fuel Type(s)	Primarily wood logs, but also coal, coke, and wood or peat briquettes. Also supplementary oil or gas burner options.	Wood logs mainly, plus the programmable fossil fuel option.	Prepared wood logs, (NB. Certain quality fuel characteristics).
Combustion type and maximum efficiency guide	Under or reverse combustion type. *c.* 60 - 65% woodlogs; c. 60 - 80% fossil fuel alternatives.	Under or over combustion type, *c.* 60 - 70% woodlogs *c.* 75 - 85% fossil fuel alternative.	Reverse combustion, up to 90% efficient.
Heat output range	20 to 600 kW	15 to 25 kW	20 to 50 kW
End-use suitability	Small/medium domestic or small commercial premises.	Small/medium domestic or small commercial premises.	Small/medium domestic or small commercial premises.
Particular service requirements	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Some operational expertise.	Woodfuel storage capacity. Operational expertise required.
Installation parameters - notes	Insulated chimney. Large CH hot water storage tank.	Insulated chimney. Large CH hot water storage tank.	Insulated chimney. Large CH hot water storage tank.
'Best practice' fuel characteristics[6] and other requirements	Length, thickness specifications and moisture content *c.* 20 - 30% An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c.* 20% An assured supply of suitable fuel.	Length, thickness specifications and moisture content *c.* 20%, (fuel quality is critical). An assured supply of quality fuel as per manufacturer's specification.

Other Log Fuelled Variants

Although not represented by anything currently available in the UK, some Canadian and North American domestic systems have a separate boiler house to the dwelling. These are log-fuelled and have larger fuel capacities and comparably longer log lengths (e.g. 2 m) than anything in the above table. Detailed operational information is scarce but boiler design is broadly similar to efficient modern parameters, e.g. the under-fired design principle with multi-pass heat recovery systems.

Modern, efficient boiler designs have also developed to cope with the traditional French log fuel of split 1 metre firewood lengths, (usually sold in unit quantities called 'Stère'). Some currently available boiler units for this type of fuel incorporate the most efficient reverse fired principle, and have unusually large fuel hopper capacities for long unattended periods of operation.

[6] See later reference to European Fuel Standards

Illustration of boiler or system type Domestic to Medium sized systems. Free-standing boilers, chip fired			
Name	Pre-furnace burner	Stoker-burner	Inclined moving grate
Brief description	Consists of a hopper and a feeder tube to a small ceramic lined burner. Flames are injected into a separate boiler unit. Basically a 'chip fired blowlamp'.	A similar hopper and feed tube, but into a small containment vessel placed inside the boiler. Combustion air is supplied via a separate pipe.	A similar hopper and feed tube, but onto an inclined moving grate which lies inside the boiler, at its base. Combustion air is supplied from beneath the grate.
Fuel Type(s)	Fuel grade wood chips	Fuel grade wood chips	Fuel grade wood chips
Combustion type and maximum efficiency guide	Turbulent air combustion[7]. Up to 85% (maybe greater for larger units).	Over fired combustion with air feed from sides, 70 to 85%.	Over fired combustion with air feed from beneath, 70 to 85%.
Heat output range	20 to 300 kW	30 to 300 kW	20 to 500 kW
End-use suitability	Domestic up to large commercial.	Large domestic up to large commercial.	Domestic up to large commercial.
Particular service requirements	Appropriate hopper size and reliable fuel deliveries. Suitable fuel quality. Operational expertise.	Appropriate hopper size and reliable fuel deliveries. Suitable fuel quality. Operational expertise.	Appropriate hopper size and reliable fuel deliveries. Suitable fuel quality. Operational expertise.
Installation parameters - notes	Requires professional installation to ensure safety and efficiency.	Requires professional installation to ensure safety and efficiency.	Requires professional installation to ensure safety and efficiency.
'Best practice' fuel characteristics[8] and other requirements	'Super' or 'fine' grade wood chips. Moisture content maximum 30% on small to *c*. 40% on large units.	'Super' or 'fine' grade wood chips. Moisture content maximum 30% on small to *c.* 40% on large units.	Can run on 'coarse' grade chips and with more moisture content, up to *c*. 50%.

[7] This is where the fuel mixes up with the air whilst burning.
[8] See later reference to European Fuel Standards

Illustration of boiler or system type. Domestic to Medium sized systems. Re-constituted fuels - pellets			
Name	Small domestic space heating	Central heating boilers	Retrofit pellet burners for boilers
Brief description	A 'stand alone' unit similar in appearance to a modern 'box stove' design. The fire is electrically ignited and thermostatically controlled, so heating can be electronically programmed.	Small boilers have an integral hopper, which is usually manually filled. Larger boiler units have an attached hopper similar to a chip unit. If large enough the hopper can be filled by a fuel delivery tanker, like an oil-fired system.	Units designed to replace external burner equipment on fossil fuel boilers, (e.g. oil). Units are similar to a pre-furnace type chip unit. If large enough the hopper can be filled by a fuel delivery tanker, like an oil-fired system.
Fuel Type(s)	Quality grade extruded pellets.	Quality grade extruded pellets or lower grade 'rolled' pellets for larger units.	Quality grade extruded pellets or lower grade 'rolled' pellets for larger units.
Combustion type and maximum efficiency guide	Automatic fuel feed from integral hopper, usually dribbled down a small feed spout from above fire[9]. High efficiency, (up to 90%+) due to dense and very consistent fuel.	Automatic feeding from a hopper, (see footnote). High efficiency, (up to 90%+) due to dense and very consistent fuel.	Automatic feeding from a hopper, (see footnote). High efficiency, (up to 90%+) due to dense and very consistent fuel.
Heat output range	2 to 12 kW	60 to 185 kW	40 to 400 kW
End-use suitability	Small dwellings/single rooms.	Domestic and commercial central heating systems.	Domestic and commercial central heating systems.
Particular service requirements	Undemanding, due to the high fuel quality.	Undemanding, due to the high fuel quality.	Undemanding, due to the high fuel quality.
Installation parameters - notes	As for other 'box' stoves.	Similar to fossil fueled boilers.	Similar to fossil fuelled boilers.
'Best practice' fuel characteristics	Essential to keep stored fuel dry. Poorer quality pellet supplies are characterised by pellet disintegration and woody dust.	Essential to keep stored fuel dry. Poorer quality pellet supplies are characterised by pellet disintegration and woody dust.	Essential to keep stored fuel dry. Poorer quality pellet supplies are characterised by pellet disintegration and woody dust.

[9] Pellet fuel feeds are one of three types across all the range; feeding by spout from above, auger feed from the side, and auger feed from below, i.e. 'welling up'

Illustration of boiler or system type District Heating Systems		
Brief description	A small pre-fabricated or larger site constructed system that provides piped heat to a community or part of a larger community. Individual dwellings and businesses can draw upon the circulated district heat via metered heat exchangers. In that way, retaining control of their heating and hot water use. The district heating plant may also produce electricity by a co-generation system, (see below).	
Fuel Type(s)	Some form of comminuted fuel, e.g. wood chips or shredded woodfuel, suitable for medium to large scale automated feeding systems	
Combustion type and maximum efficiency guide	A variety of combustion systems may be used, either singly or in combination to increase overall efficiencies, (see commercial boilers below). Efficiencies up to 90% may be attained for some systems.	
Heat output range	From about 100 kW up to several megawatts. The upper limit depends on the distribution pipework length, more by economics than heat loss.	
End-use suitability	Piped heat is supplied as a 'service' to customers, like gas or electricity.	
Particular service requirements and Installation parameters - notes	The system gives several advantages to the consumer but requires a large initial investment, and a few specialist people to run and maintain it. If combined with electricity generation, heat supplies may be particularly competitive with other systems. Problems may arise from low summer heat loadings, but can be designed out if suitably recognised at the initial stages.	
'Best practice' fuel characteristics and other requirements	Larger scale boiler plant tends to dictate its own specifications of woodfuel supply. It is then advantageous for potential suppliers to fit in with this. Also larger plant can be designed to be less sensitive to variations in fuel quality.	

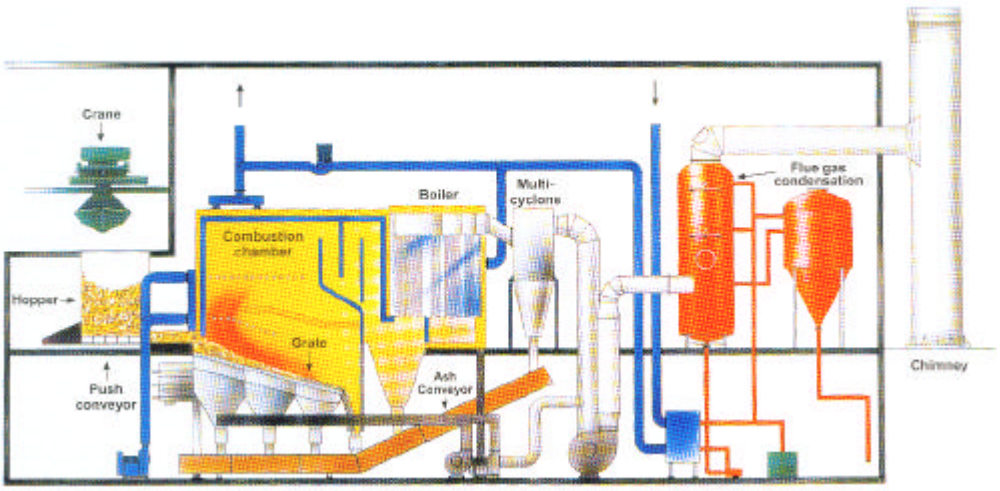


Diagram of a 4 MW district heating plant with an inclined grate burner 'Forest' type wood chips are supplied at c. 50% moisture content, so the flue gas condenser contributes c. 0.8 MW to the overall heat output.

Commercial Sized Boiler Types

Boilers of the larger, commercial sizes are more likely to be built to a unique site specification, from a set of standardised components, rather than from a production run of identical units. Therefore categorisation by boiler type is difficult. As there are only a certain number of ways in which these boilers are made, it is possible to detail them according to the differences in their main components. Types of woodfuel burner arrangement and differences in energy output arrangements are the main variables.

Types of Burner Arrangement

Variations in burner arrangements mainly cover the type of burner grate, and the fuel feeding mechanism.

Types of burner grates are:

- **Solid, inclined grate:** This is the simplest arrangement. The amount of incline is specific to the fuel type and allows for its movement from the upper section, down to the grate end during combustion.

  Cooling/drying air is usually supplied upwards through the grate bars and at the grate end for combustion. Combustion control is achieved mainly via the air supply and partly fuel feed rate. Combustion air supply also acts to partly pre-condition the fuel, especially if it is pre-heated.

  This design type is simple and basic but is relatively inflexible in terms of accommodating variations in fuel type and/or fuel moisture content. Some designs might incorporate a moving end-grate, which is usually set at a flatter incline than the first part of the grate. This allows a greater area for combustion than the simpler design.

- **Plane grate:** This older form of flat, fixed grate is not at all common nowadays, although some quite efficient designs remain in use. The most common may be seen in chip fuelled systems where the fuel is pushed into the firebox by a hydraulic ram.

  In large-scale commercial use the most usual type is where fuel is fed by an auger from beneath into the centre of a circular, boiler retort. This causes the fuel to well up centrally and burn as it is pushed slightly down and outwards towards the edge of the retort.

  Primary combustion air is fed in from beneath, and secondary air from vents further up the walls of the retort to effect complete and efficient combustion of gases. Combustion control is by modulating the air supply and fuel feed, although not all fuel types may be auger fed. A specific variation of this boiler has ceramic firebox walls and pre-heated primary air for the efficient combustion of wet fuels.

- **Moving grate**: Movement of the grate bars acts to transport the fuel, and therefore allows a flatter grate incline throughout. As the fuel is moved along it tends to mix, allowing a more consistent pre-drying from the air fed in from beneath. Controlling the movement of the grate bars allows greater accommodation for fuel types as the fuel movement time may be adjusted for complete combustion.

  A disadvantage of the moving grate system is that small fuel pieces and ash fall through it more easily. The ash removal system is usually therefore more complicated and expensive. Often incorporating a water treatment system to eliminate ash fires. Another small disadvantage is that air control can be more difficult, resulting in a slight over-supply when the boiler is at partial load conditions.

  Some designs of moving grate are horizontal. In these the grate is a type of endless conveyor, perforated for the air supply from beneath. Fuel is either fed in at one end or is sprinkled over the grate from above. Ash falls through and is removed at the other end of the grate.

- **Fluidised bed systems:** These very efficient systems were originally developed for solid fossil fuels and have been adapted since for comminuted woodfuel. One pre-requisite is that the fuel is comminuted to a fairly fine particle size (e.g. < 2 mm.).

  There are several type variations within this context but the overall design feature is that fuel is burnt within a matrix of hot inert material, usually a mixture of sand and ash. This inert material is kept hot and relatively fluid by the introduction of pre-heated combustion air from below. Other chemicals and minerals may be added to aid ash removal and absorption of undesirable emission elements (e.g. sulphur).

  Type variations are ‘solid bed’; ‘bubbling bed’; ‘turbulent bed’; or ‘circulating bed’, depending on the relative amounts of bed movement incorporated into individual designs. The names are in order of the relative increase in the velocities of supplied combustion air to the amount of inert bed material.

  In a ‘solid bed’ the air velocity only just enables the inert bed particles to behave like a fluid.

In a 'circulating bed' the air supply carries the burning material upward during combustion, and it is then returned to the burner base afterwards. In all types the action of the moving inert material grinds the fuel particles smaller as they burn resulting in a very fine ash which is removed efficiently by other processes. Combustion control is effected by the fuel feed and the air supply in combination, to maintain the same oxygen content in the exhaust gases.

A variation of the fluidised bed process is when two beds are arranged in series, usually vertically, giving a 'multi-bed combustion'.

Types of fuel feeding mechanism are:

- **Auger feeding**: Sometimes called 'screw feeding' This is the most common feeding type for all comminuted woodfuels. Auger design has made great progress to the point where it is now very reliable but the mechanism can still have problems with poorly comminuted fuel. Long wood slivers and sections of twigs are the main cause of blockage problems, especially in the smaller sized equipment.

- **Ram feeding**: Whereby a hydraulic ram acts to push a charge of fuel into the burner.

- **Pneumatic feeding**: Whereby the fuel is carried into the burner by airflow. (This type is only associated with fluidised bed systems).

- **Rotary gate**: Fuel falls by gravity onto a quarter section of a rotary drum. As the drum is turned each section empties onto the firegrate from above.

- **Spreader-stoker**: Fuel falls by gravity onto a spinner, which throws it over the surface of the firegrate.

All fuel-feeding systems incorporate specific design features to prevent fuel from burning back along the feedpipe.

Energy Output Arrangements

- **Steam turbine generator**: The most traditional and formerly the most common way of getting electricity from heat was to first turn it into steam, then use that to drive a generator via a steam turbine. This technology is not new and was perfected to a high degree at the time of coal fired power stations.

  One big drawback is the losses incurred every time energy is converted from one form to another. In these power plants energy is converted several times. Once into heat, then into steam pressure/volume, then into rotary turbine motion, and finally into electricity via a generator.

  A modern condensing power plant achieves an overall efficiency of about 50%. Compare this to its heat generation stage, which on its own has a typical efficiency of 90%.

- **Co-generation (or combined heat and power)**: This is a system whereby heat and electricity are produced simultaneously by the same plant.

  The advantage here is that where there is a demand for these two forms of energy, e.g. a district heating scheme combined with a grid distributed electricity supply. Another use is where an industrial process can use the rotary energy, with the turbine exhaust heat energy supplied to a District Heating scheme. Depending on the balance of arrangements a co-generation plant may achieve up to 85% overall efficiency.

  Disadvantages of this system occur when there is an insufficient heat load, e.g. during a low district heating demand in summer. During these periods efficiencies can drop, unless there are alternative heat loads available, eg, industrial uses.

- **Gasification**: This is a system whereby the fuels' energy is converted into a gaseous form. Once in this form and suitably cleaned it may be used to drive generators via either a modified internal combustion engine, or a gas turbine, i.e. similar to a jet engine.

  In simple terms the woodfuel is turned into a char, which is either partially burnt or externally heated to release the gas.

  Woodfuel gasification for a small internal combustion engine generator is suitable for relatively small-scale electricity generation (5 to 50 megawatts) but some problems remain to be solved, particularly the removal of tar compounds from the gas before it is fed to gas turbine generators.

  However, gasification can be a solution for the use of certain problem biofuels, e.g. bark, sawdust and wood residues, when the resultant gas may be fed directly into a boiler as an additional fuel. With this system gas contaminants do not matter a great deal.

- **Integrated Gasification Combined Cycle Generator**: A power plant that combines a gas turbine generator and a steam turbine generator from the gas turbine exhaust heat. A process that combines two of the above types.

  Potential efficiency benefits of this dual generation system are attractive, but to date problems with the hot gas cleaning process remain. Without effective hot gas cleaning, gas turbines can not work reliably, as the turbine blades are sensitive to contaminants from the biofuel.

The above descriptions are meant as an easily understandable summary of systems and processes involved in the commercial burning of woodfuel for energy. Actual processes are much more complicated and involve a high degree of professional engineering expertise.

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Develops, evaluates and promotes safe and efficient equipment and methods of work, maintains output information and provides advice on forest operations.

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