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D5 Small Scale Combustion

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HANDBOOK ON COMBUSTION

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Small scale biomass combustion

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Content

Notation

w.b. … wet base

d.b. … dry base

el. … electricity

th. … thermal

w … water content of fuels related to wet fuel

u … moisture content of fuels related to dry fuel

$$w = \left(\frac{100 * u}{100 + u}\right) \qquad \text{Equation 1}$$

$$u = \left(\frac{100 * w}{100 - w}\right) \qquad \text{Equation 2}$$

CHP … combined heat and power

LHV … lower heating value

HHV … higher heating value

Nm^3 … norm cubic meter at 1,013 bar and 273,15 K

ORC ... Organic Rakine Cycle

1 Introduction and Summery

This chapter describes the combustion and thermal use of solid biomass in small scale plants. Small scale combustion plants are available in the range of 7 kW up to approx. 500 kW heat production. Those plants are predominantly used to provide households and small companies with heat. Different types of solid biomass as well different types of combustion and system techniques are available.

Especially since the 1990s the requirements on those firing systems have decreased concerning combustion efficiency, emission of particles and carbon monoxide, fire danger e. g. in timber houses, flexibility of part load, fuel use and handling comfort.

Predominantly wood based biomass is used. In addition to traditional fuels like log wood and wood chips, especially for modern low energy demanding households and small district heating plants wood pellet are of importance. In Europe since the end of the 90s wood pellet has become popular and established. Due to the discussion about the climate change and rising costs of fossil fuels also special types of biomass like straw or energy-corn are in the focus as fuel. It has to be pointed out, that straw or energy-corn requires specially adapted combustion systems because of its fuel characteristics.

Research results show, that due to the combustion of biomass particulate matter emissions (< 10 µm) are emitted with the flue gas, if no special combustion or/and filter system is used. Due to that fact emission regulation will be stronger in the future and efforts have been taken to reduce these emission by using special “small scale filters” like electrostatic filters or fabric filters.

The increase of the thermal and over all efficiency is possible due to the optimization of the combustion, the hydraulic integration and combination with other heat supply systems like solar thermal plants and the implementation of flue gas condensing systems to use latent heat, even in the small scale range. In addition combined heat and power production (CHP) and the drive of absorption chillers are possible with automatically fed plants. In the range up to 100 kW electric only a few techniques are available until now, that have presented a successfully operation behaviour.

2 Biomass Fuels

The most common and traditional fuel for small scale units are log wood with a length of 30, 50 or 100 cm and a water content w of 15–25 %. For automatically fed plants wood chips with a length of 3 to 5 cm and a water content w up to 35 %. and wood pellet with a diameter of approx. 6 mm, a length of 10–30 mm and a water content w of 8–12 % are common. For some firing systems above 200 kW thermal heat also wood chips and wood pellet with higher water content and different size are useable. The maximum particle size of the fuel is limited by the fuel feeding system. Table 1 gives an overview of these different fuels. A European wide standardization for biomass fuels is realized with DIN CEN/TS 14961. Older but valid and in practice used regulations are e.g. ÖNORM M 7133 and 7135 from Austria and DIN 51731 from Germany.

water content w (w.b.)		10 %	20 %	35 %	50 %
moisture content u (d.b.)		11 %	25 %	54 %	100 %
Lower heating value LHV kWh/kg fuel w.b.	approx.	4,5	3,9	3,0	2,2
	ash content % fuel d.b.	bulk density kg/m³ fuel w.b.			
log wood[1)]	0,5–2,5	385–570	405–590	480–700	630–910

wood chips[2)]	1,0–2,5	190–220	220–240	240–280	320–350
wood chips[2)] with bark	2,5–8,0	175–190	185–200	220–235	280–310
wood pellet	0,3–1,0	650			

Table 1: Commonly used fuels for small scale biomass combustion

[1)]stacked log wood with 1 m length, depending on soft or hard wood

[2)] predominantly containing soft wood

In addition to the fuels in Table 1 short rotating biomass energy plants and residues are of interest for the small scale combustion in the form of e. g. shavings, pulverised fuels, wood briquettes, straw bales, straw pellet, rape pellet, corn, willow, miscanthus or cottonwood chips and residues like horse manure mixed with straw and wood chips. The driving force for the use of these fuels is mainly the oil price. Until now, the combustion of these fuels occurs only in individual cases. A special combustion technique is needed to handle those fuels. In comparison to the common fuels in Table 1 such fuels can contain a much higher content of ash and higher corrosive compounds such as chlorine and sulphur. Due to that the handling (fed, combustion control, emissions, …) is more difficult and the lifetime of the firebox and the heat exchanger are reduced. Usually manufacturers do not allow to use these fuels in their common combustion plants.

3 Biomass Combustion Techniques

For the combustion, different plant systems are available which are state of the art and proved in a high number of installations. Traditional systems are open fireplaces in living areas, stoves without domestic water heating, tile stoves with a high mass of ceramic bricked walls and log wood combustors for central heating boilers. Most of them are operated with log wood, but nowadays also wood pellet can be used for stoves and even tile stoves.

Central heating boilers with an automatic feeding system are using wood chips and wood pellet mainly. The use and combustion of different fuels depends on the available combustion techniques, plant size, state regulations/laws and fuel storage possibilities. An overview is shown in Table 2.

	Fireplace	Stove	Tile stove	Central heating boiler - manually fed	Central heating boiler - automatically fed	Heating plant - e.g. district heating
size kW heat	10–40	7–10	10–40	10–200	7–200	>200
log wood	x	x	x	x		
wood chips				x	x	x
wood pellet		x	x	x	x	x
straw						x
other solid biomass fuels					x	x

Table 2: Use of fuels in different biomass combustion systems

3.1 Combustion process

There are different requirements on the time-variation of energy release or power control. Therefore in the course of time different furnace systems and designs were developed to enhance high efficiency, low emissions and a long lifetime. One basic distinctive feature for wood furnaces is the kind of fuel feed - manually or automatically. The combustion process of biomass occurs in different steps acc. Fig. 1:

- drying and heating of biomass
- pyrolysis and gasification of volatile compounds (85 weight-% of fuel d.b.)
- combustion of the remaining coal (15 weight-% of fuel d.b.)

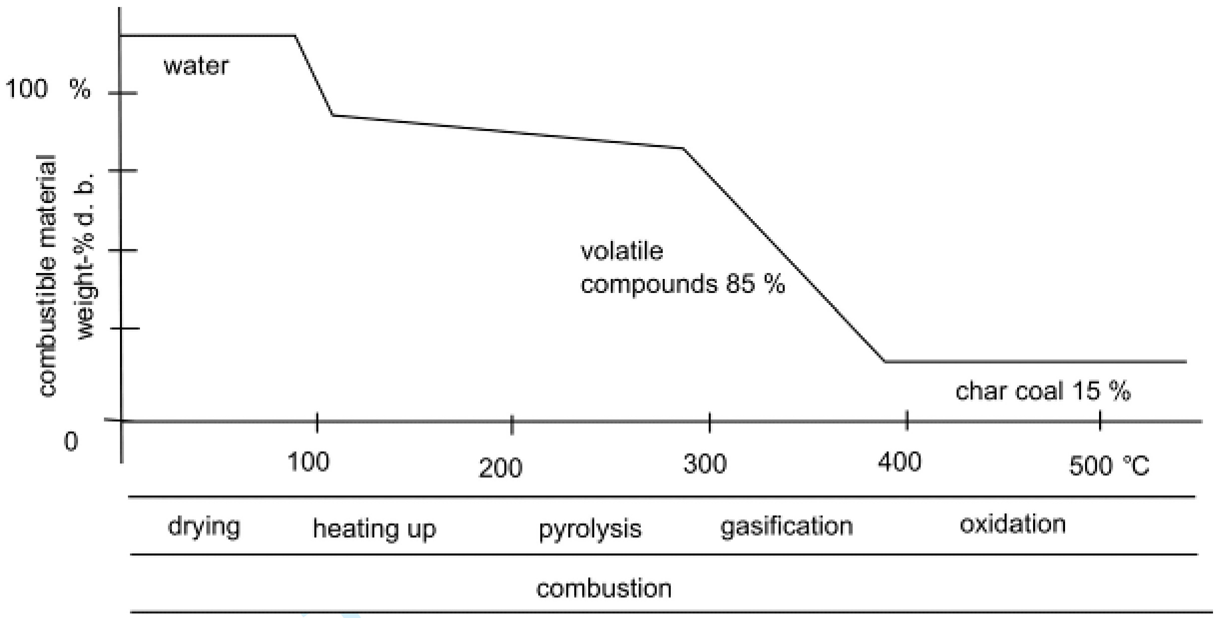

Figure 1: Combustion process of biomass [2]

For an efficient combustion a sufficient residence **t**ime of unburnt compounds in flue gas, a high **t**urbulence and mixture of flue gas and combustion air and a high combustion **t**emperature are necessary. This is known as 3T principle. Air staged gasification and oxidation of volatile compounds is state of the art and used in modern firing concepts. With that concept, the gasification and oxidation of volatile compounds occurs in locally separated combustion and reaction zones, so-called primary and secondary combustion areas.

3.2 Manually operated systems

In the range of 7–80 kW commonly and in rare cases even up to 200 kW manually operated furnace systems for log wood are used.

3.2.1 Log wood combustor systems

For log wood combustors, the following combustion principles are existing:

- updraft combustion with complete combustion
- updraft combustion with top-burnout
- downdraft combustion with bottom or lateral burnout

Updraft combustion with complete combustion

At that furnace design a grate forms the bottom of the combustion chamber. Fig. 2 shows the concept of an updraft combustion with complete combustion. The fuel is put on the grate and the combustion air is led from the bottom up through the grate and the entire fuel. The ignition normally occurs at the grate. The glowbed is located above the grate.

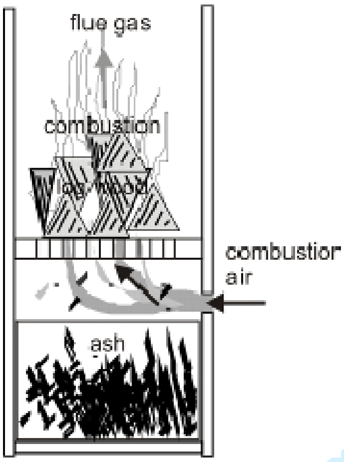

Figure 2: Updraft combustion with complete combustion principle

This causes a high fuel fumigation rate after fuel charging because the entire fuel is exposed to the heat. If the furnace is not isolated or lined with heat storage material like ceramic bricks or tiles, the temperature of the flue gas decreases and complete oxidation of unburned compounds in flue gas is not possible. In that case high emissions of unburned fuel components can be the result of such a combustion system. The periodically necessary feed with log wood causes a disturbance of the on-going combustion process. Advantages are an easy ash removal, a complete burnout of the remaining charcoal and ash and visible flames for the user in the case of single room heating concepts.

This design was original developed for coal stoves, which generate - compared to biomass - a lower amount of flue gas. The concept is used for fireplaces, simply designed stoves, central heating boilers and tile stoves with a thermal power below 20 kW. The concept is antiquated and is no longer used for modern stoves and central heating boilers. [4]

Updraft combustion with top-burnout

For a more modern firing concept the updraft combustion with top-burnout (Fig. 3) or the downdraft combustion concept (Fig. 4) is used. For both concepts a staged air combustion is possible. At the updraft combustion with top-burnout combustion air enters the combustion zone from the side and meets the glowbed directly (Fig. 3).

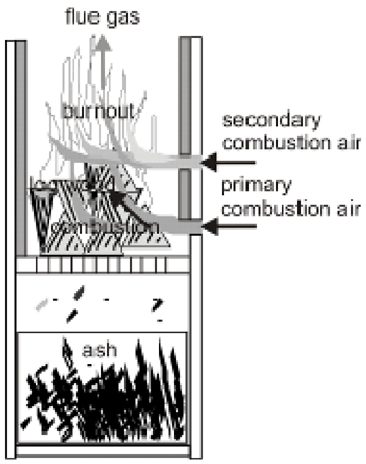

Figure 3: Updraft combustion with top-burnout

The effects of this combustion concept are a slower fuel fulmigation and lower emissions after charging of new log wood compared with the complete combustion principle.

In practise many furnaces containing elements of both concepts, complete combustion and top-burnout. Disadvantages are adverse ash removal and partially incomplete burnout of the remaining carbon. This concept is used for fire stoves, central heating boilers and tile stoves. [4]

In both concepts, complete combustion and top-burnout, the free volume for a flue gas burnout above the log wood is changing continually due to the reduction (combustion) or increase (fed) of fuel volume. Both concepts are using natural ventilation controlled by valves either manually operated or - in the case of central heating - controlled by the water temperature. This causes changes in the flue gas temperature and residues times of unburned compounds with the result of fluctuating emissions at high level. The downdraft combustion concept is used to overcome these disadvantages.

Downdraft combustion with bottom or lateral burnout

The downdraft combustion concept is the state of the art concept for the combustion of log wood. The basic attributes of this combustion design are two rigorous separated chambers, one for the fuel combustion and glowbed (primary combustion area) and one for the complete oxidation of the produced pyrolysis gases by the implementation of a second air inlet (secondary combustion area). This design is known as wood gasifier, downdraft or downdraught shaft furnace.

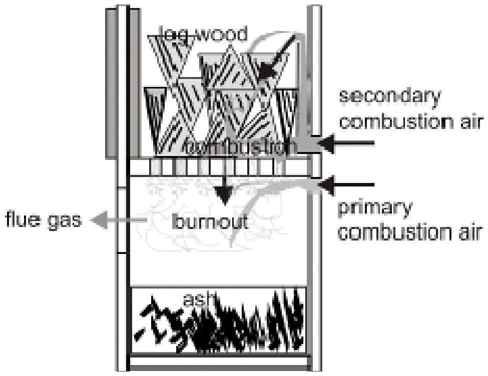

Figure 4: Downdraft combustion with bottom or lateral burnout

The glowbed is located directly above the grate. The gasification occurs in a top-down direction, which means the amount of fuel is not influencing the glowbed and the secondary combustion area as shown in Fig. 4. The result is a continuous combustion with constant high temperatures and residence time in the secondary combustion area.

The combustion is based on a bottom or lateral exit of pyrolysis gases. The burnout takes place afterwards in the hot combustion chamber, which consists of ceramic materials to hold up high temperatures. The combustion air supply usually is realised with a combustion air or a flue gas fan. Overpressure and underpressure combustion are possible. In most cases an underpressure combustion is selected. The primary air is injected directly above the grate, the secondary air is directed into the combustion chamber. Therefore only log wood on the grate reacts with primary air. The released energy in the primary combustion and the burnout is controlled by the primary and secondary air amount. This effects a smaller design of the furnace and the possibility of a high fuel shaft. The log stack over the glowbed is the fuel reserve, which is burnt continuously. The result is a combustion time of up to seven hours without manually fed with log wood. [4]

The degree of automation and control systems is high in comparison to the other combustion concepts and almost comparable with automatically fed wood chips and pellet burners. The control of the combustion occurs via sensors for flue gas temperature and oxygen contents (lambda). The amount of combustion air and power output is controlled by automatic valves and a fan with frequency changer or phase controlled modulator. This allows adjusting the combustion to low emissions and part load operation between 50 and 100 %.

Disadvantageous are high costs, a lower burnout of the charcoal at the end of a combustion interval and the possibility of fuel bridges in the shaft. Due to the costs, this technique is used only for central heating boilers from 15 kW up to 200 kW thermal output.

Special forms are e.g. furnaces for round straw bales, so-called straw bale burners or gasifiers, where round straw bales are fed via a front-endloader into the combustion chamber.

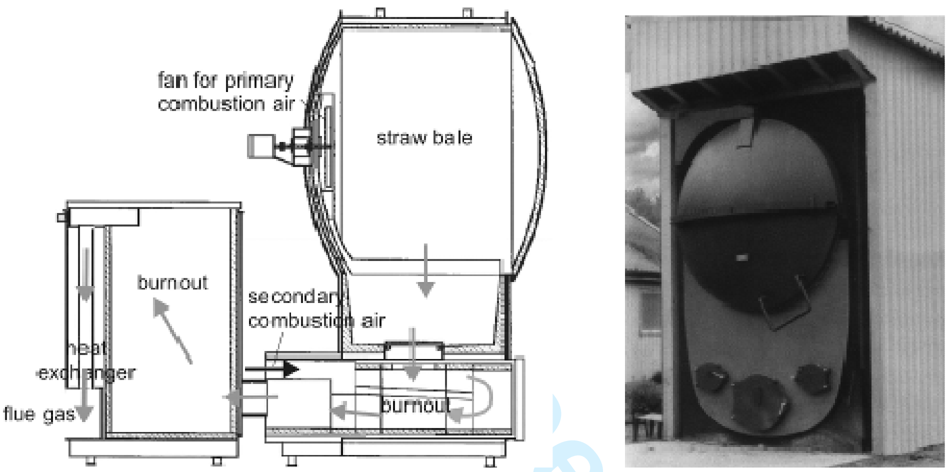

Figure 5: Straw bale combustor [5]

The straw bale combustor (Fig. 5) is available from 85 kW up to for several 100 kW thermal power.

3.2.2 Log wood fired heating systems

In this chapter, examples of manually fed log wood combustors and boilers are described.

Fireplace

The fireplace is the simplest form of the updraft combustion with complete combustion. It is available as open and closed fireplace. An open fireplace (Fig. 6) has an open combustion chamber and no possibility to regulate the combustion air. This causes a high air requirement. The effects are low burning temperatures and thereby high emissions of unburned fuel components. Because of the low burning temperatures, the main way of heat transfer goes on radiation. The thermal efficiency level is very low and in the range of 15–30 %. The combustion air is taken from the room of installation.

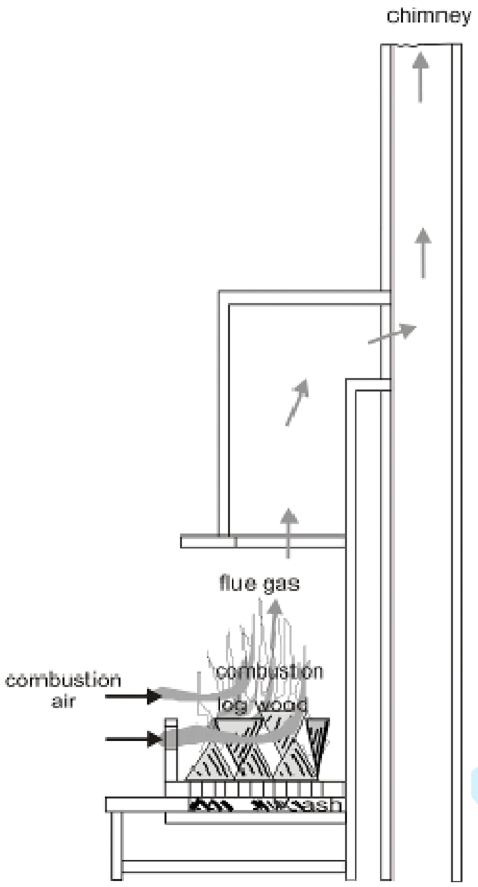

Figure 6: Open fireplace, fired with log wood

An open fireplace is hardly suitable for heating and should be replaced by more modern systems that produce lower emissions at higher thermal efficiency.

A closed fireplace (Fig. 7) is realized as closed combustion chamber with a glass panel on the front. Due to the closed combustion chamber, a limited possibility is given to control the fed combustion air to a certain extent.

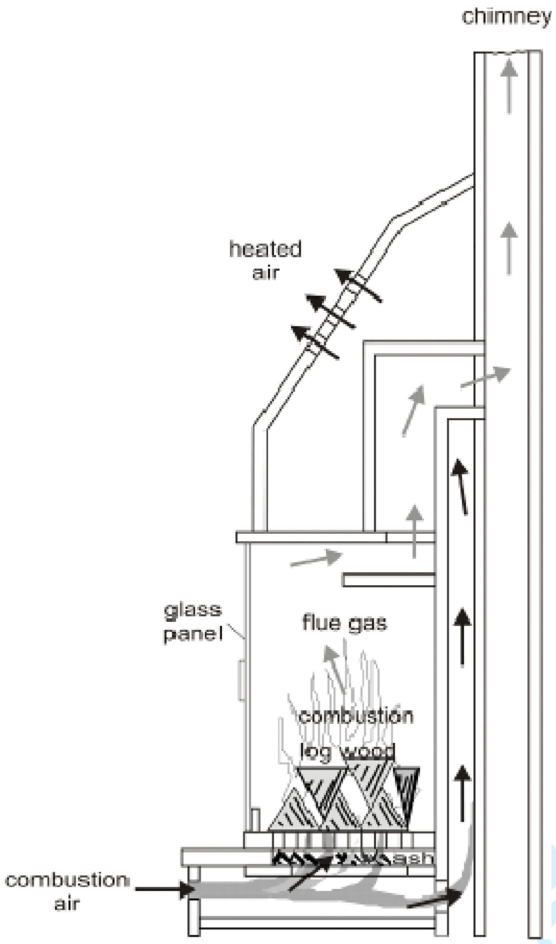

Figure 7: Closed fireplace, fired with log wood

Stoves

In opposite to a fireplace stoves are freestanding individual furnaces with a closed combustion chamber that allows the regulation of the combustion air. The combustion often is a mixed form between complete combustion and top-burnout designs as shown in Figure 8. A popular special form is the chimney stove whereby the user can watch the fire through a glass panel. Stoves normally release the heat by thermal radiation and convection. Some types are equipped with a flue gas-water heat exchanger to heat up a water circulation so they are combinations between individual combustion plants and central heating boilers. In that case the thermal efficiency level of stoves reaches 70–80 %. The usual heat output is between 5–15 kW. Its construction does not allow to accumulate much heat and the thermal power can only be regulated by the amount of the fuel charge or in some construction by the reduction of combustion air. Due to the rise in airtight passive and low-energy house constructions, some modern stoves are available as room-air independent systems. In that case the combustion air is taken from outside by an air-pipe or by a coaxial chimney. [6], [7]

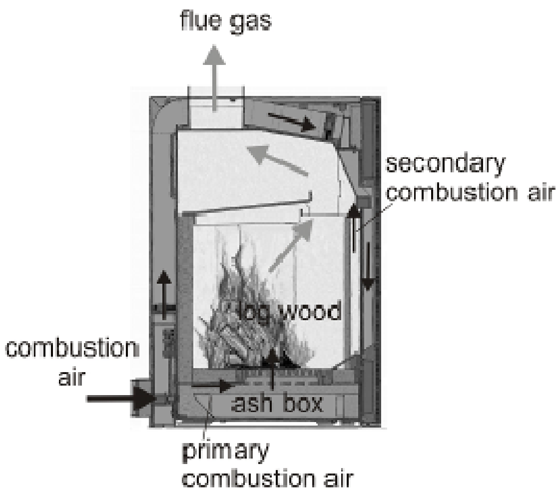

Figure 8: Log wood fired stove with 7 kW thermal power [6]

Tile stove, heat-storing stoves

Heat storing stoves or tile stoves consist of ceramic bricks and tiles or stone like soapstone. Different types are available:

- stove with ceramic bricks and tiles or stone like soapstone
- tiled base stove
- warm-air tiled stove

Tiled stoves have a very high weight from about 500 kg to more than 2.000 kg and a high heat storage capacity. The hot flue gas flows in bricked channels through the storage mass. The surface temperature ranges from 60–130 C° [4]. The origin heat-storing stove is the tiled base stove made of ceramic material and developed in the 1700s. For the tiled stove an updraft combustion with top-burnout is used. A cold tiled stove needs a long time to heat up the room because of its high heat storing capacity. However, this storage capacity is the reason for the heat radiation long after the combustion is completed.

The warm-air tiled stove shows a lower storage mass. Often a cast-iron heating element is used. This heating element is cased by bricks or fireclays. On the base of the stove slots are included where the cold room air flows through the ceramic bricks and is heated. The air rises up and leaves the stove through a grid on the top of the oven. Hereby the thermal radiation is about 60 percent and the transferred heat by convection about 40 percent of the completely transferred heat.

In some cases, especially the modern designed hot-air storage stoves are equipped with a glass front, like the chimney stoves. Some manufactures offer an external air duct for the combustion air as room-air independent combustion system. The efficiency of heat storing stoves can be higher than 80 %. The thermal power is in the range of 4–20 kW. [4]

Central heating boilers

For modern log wood combustors the downdraft combustion with bottom (Fig. 9) or lateral burnout (Fig. 10) is established. This design enables a large log wood shaft. Due to filling intervals up to 7 hours and long stationary operating modes after the combustion started, an excellent flue gas quality and a high combustion efficiency of 90 % are possible. For the operation of this central heating system, a heat storage with the capacity to receive the energy content of approx. one log wood filling is necessary. The size of the water based storage tank should be between 55 and 100 litre/kW thermal power. Due to start-ups, heat looses and part load operation the over one year thermal efficiency is in the range of 65–75 % based on fuel LHV. This is a typical range for all wood combustion systems - equal if manually or automatically fed.

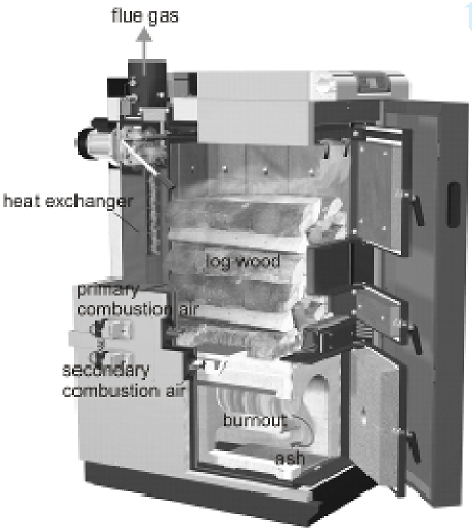

Figure 9: Log wood boiler with bottom burnout in the range of 15–60 kW [8]

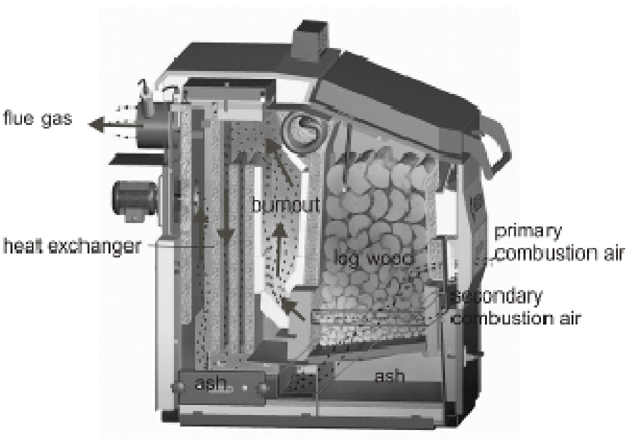

Figure 10: Log wood boiler with lateral burnout in the range of 30–50 kW [9]

Due to the need of a water based heat buffer-storage, log wood boilers are well appropriate for a combination with a solar thermal system. (Fig. 11)

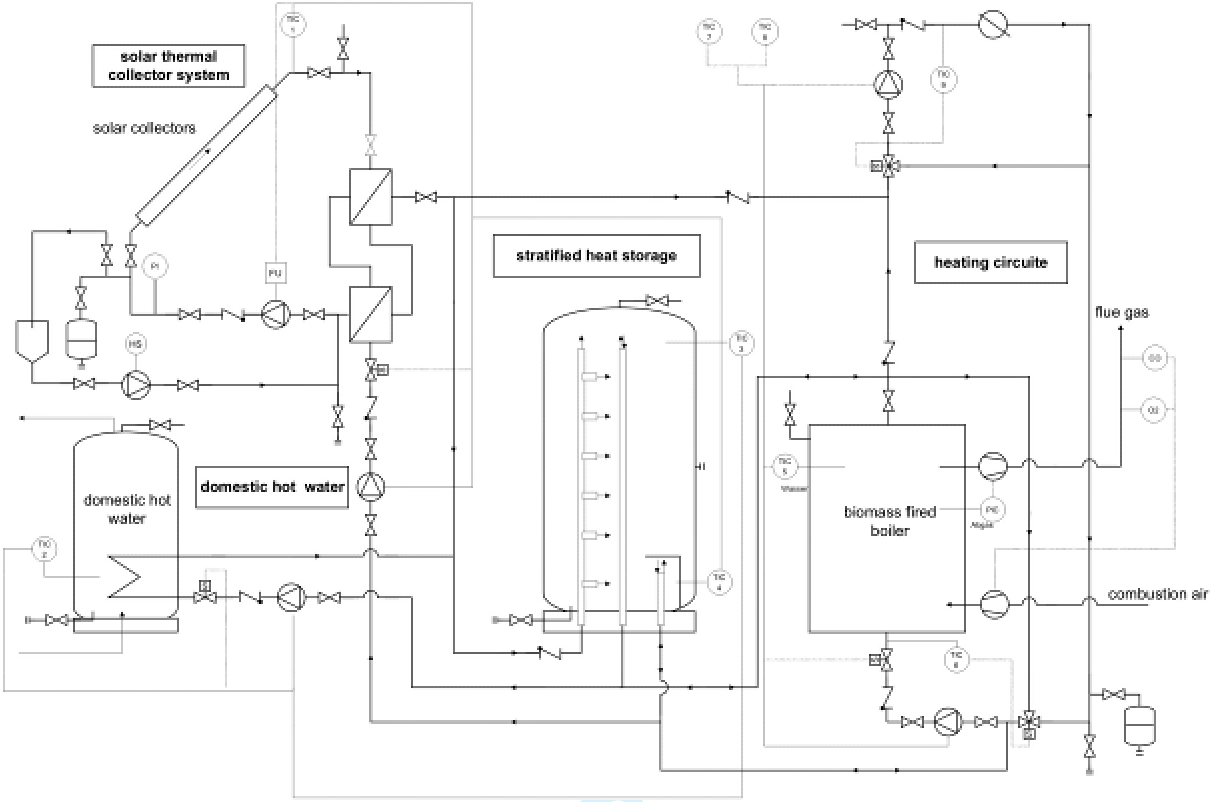

Figure 11: Hydraulic concept of a biomass fired boiler in combination with a solar thermal plant for domestic hot water and room heating. More simple hydraulic concepts of solar thermal collector plants for domestic hot water are possible.

To remove ash deposits and to increase the flue gas turbulence and the heat flux inside the heat exchanger tubes for log wood and automatically fed boilers elastic springs inside the heat exchanger tubes are common. Due to this springs, the temperature of the flue gas entering the chimney decreases at approx. 50 °C. To remove ash deposits from heat exchanger walls, this metallic springs are in addition manually or electrically operated.

3.3 Automatically fed combustors

Automatically fed combustors get their fuel like wood chips or wood pellet from fuel storage via a screw or a fuel fan. Fuel sucking fans are normally only used for wood pellets. In district heating plants hoppers, screw conveyors, hydraulic conveyors and push floors are common.

That causes a more continuously combustion with high efficiency and continuously low emissions. The common fuels are wood chips and wood pellet, but also shavings, pulverised fuels, bark, straw bales, straw pellet, energy plants like willow, miscanthus or cottonwood chips, horse manure mixed with straw and wood chips are fuels for such plants.

The fuel feeding system limits the maximum particle size of the fuel. Low ash content and a homogeneous structure of the fuel simplify the operation. Besides the automatically feeding, an automatic ash removal into an ash box is normally included. The water content w of the fuel amounts to 10–55 %. For plants below 200 kW, normally the maximum water content should be 35 %. For plants with higher thermal power, it depends on the combustion concept, if fuel with high moisture is used. In a relevant number of district heating plants in Sweden and Austria a flue gas condensation is included to use latent heat. In this plants fuels with high moisture up to 55 % are an advantage to increase the steam dew point in the flue gas, which normally amounts between 45 and 65 °C. The boiler efficiency of standard plants amounts between 82 and 93 % related to the fuel LHV. The efficiency mainly depends on the flue gas temperature at the boiler outlet (Fig. 12). The flue gas temperature should normally be between 120 and 200 °C to avoid condensation of steam in the chimney in part load operation.

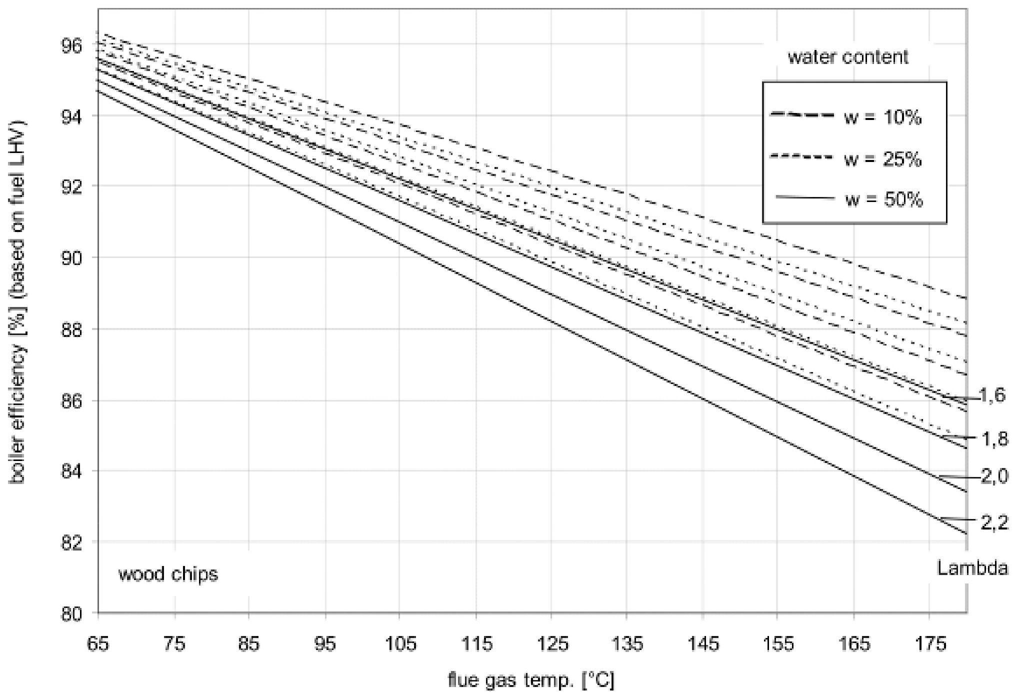

Figure 12: Boiler efficiency of wood combustor (without flue gas condensation) [10]

Due to a flue gas condensation the boiler efficiency can increase up to 115 % (Fig. 13) related to the fuel LHV. With it the flue gas cools down to approx. 40 °C by the use of the cold district heating return or heating up combustion air. Some of the air can be used for drying processes or declouding of the flue gas.

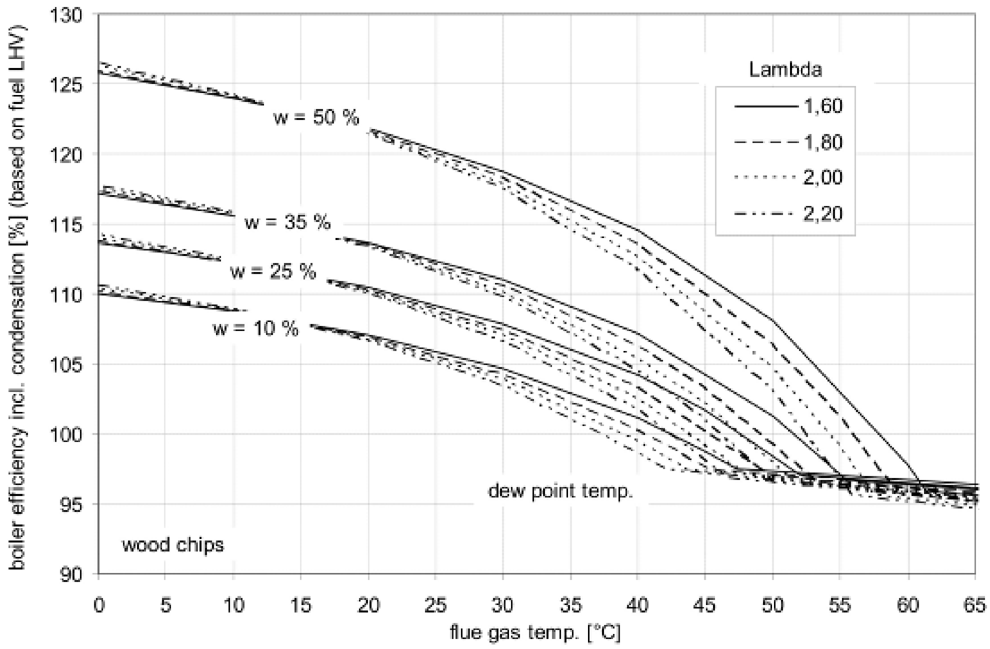

Figure 13: Boiler efficiency of wood combustor with flue gas condensation [10]

A flue gas condensation effects a reduction of solid particle emissions with 30–70 % [11], [12], [13]. In the past a flue condensation plant was used for biomass boilers > 500 kW, fired with wet biomass. Typical producers of such condensation plants are:

- Scheuch, Austria, www.scheuch.at
- V.A.S., Austria, www.vas.co.at
- Kohlbach, Austria, www.kohlbach.at
- Götaverken Miljö , Sweden, www.gotaverkenmiljo.se
- Svensk Rökgasenergi, Sweden, www.sre.se

However, condensation systems are also realized for pellet firing systems in the range of 10–50 kW (Fig. 16). Producers of such small condensers are as example:

- Bomat, Germany, www.bomat.de
- Schräder Abgastechnologie, Germany, www.schraeder.com
- Bschor GmbH, Germany, www.carbonizer.de
- SGL CARBON GmbH, Germany, www.sglcarbon.com
- Ökofen Pelletsheizung, Austria, www.oekofen.at

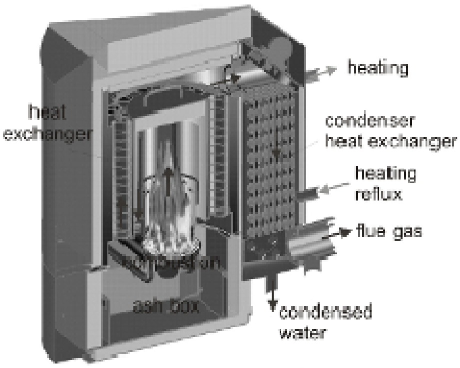

Figure 14: Pellet boiler with 12–32 kW thermal power with integrated flue gas condensation [17]

However, particles < 0,5 µm are not separated sufficiently by this technique (Fig. 15). In Europe most furnaces >100 kW are equipped with single- or multi-cyclones as part of the boiler-concept to separate course fly ash (Fig. 23).

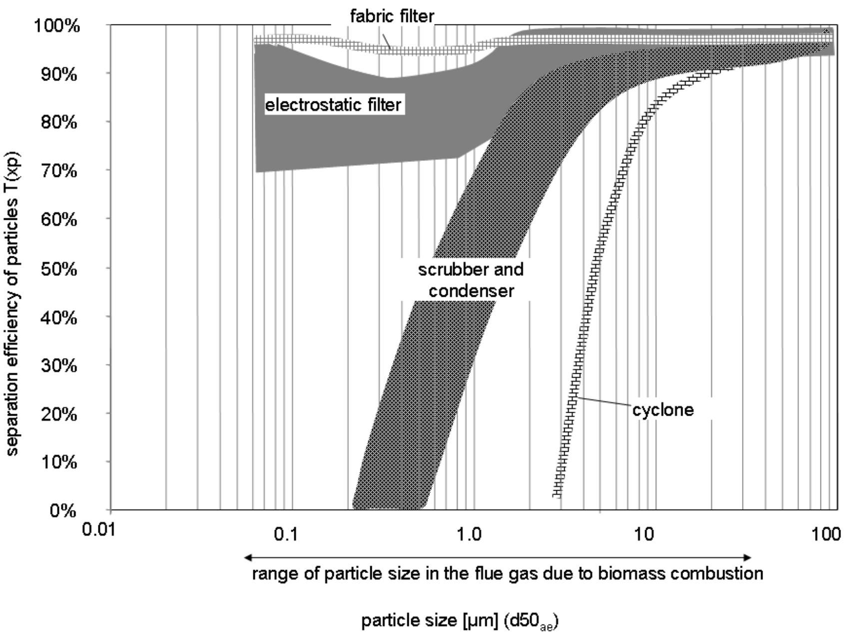

Figure 15: Separation of particles with different separation techniques [10], [14], [15]

For the separation of small particles < 0,5 µm electrostatic filters are available, even now in the range of 7–50 kW. This filter is mounted in the metallic flue gas pipe (Fig. 16).

Figure 16: Small scale electrostatic filter for wood furnaces with 7 kW–100 kW thermal power [15], [16]

Automatic operated wood pellet fed systems are available in the range of 7 kW thermal power up to several megawatt. Systems based on wood chip are available in the range of 10 kW up to several megawatt. Due to higher costs of the fed system and fuel storage in the case of wood chips, the usually essential plant size starts with 35 kW. By now also automatically fed stoves, tile stove and heat-storing stoves are available. For this furnaces mainly wood pellet are used.

The start-up is realized either manually or automatically by electrical ignition via a hot air fan or a glow plug. If a hot glowbed is available after the combustion stopped, a new start of the combustion is possible due to add on of some fuel and combustion air. The minimum part load operation is at approx. 30 % of full load. Below that 30 % of full load a start and stop mode with an automatic ignition or a so-called glowbed, control operation mode is common.

3.3.1 Combustion concepts for automatically fed firing systems

In general, there are less differences between furnaces for wood chips and wood pellet. One main different is the higher logistic effort and complexity of the handling of wood chips than for wood pellet. Automatically fed firing concepts in the small scale range can be divided into three systems:

- underfed firing
- horizontally firing with grate firing or stoker
- drop-shaft firing

Underfed firing

At underfed systems, screw conveyors from a fuel silo transport the solid fuels. A stoker screw brings the fuel from the bottom to the furnace (Fig. 17). Inside the furnace, a so-called retort is placed, where the devolatilisation and combustion occurs, separated as well in a primary and secondary combustion zone.

Due to adding of primary combustion air the drying, pyrolysis and gasification of the fuel occurs. By supply from secondary combustion air occurred a nearly complete oxidation and burnout of unburned components. Underfed furnaces are especially appropriated for fuels with low ash portion. The system shows a relative low ash slagging addiction, because of the calm glowbed and the therewith adjunctive low dust production in the combustion chamber. If a hot glowbed is available, a quick start-up process without electrical ignition is possible. [4]

This combustion type is widely used for thermal utilisation of biomass and residues. The smallest plants are realized with 10 kW thermal power for wood pellet.

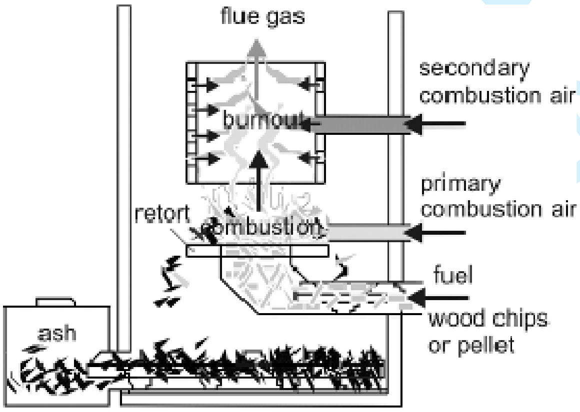

Figure 17: Principle of a underfeed furnace

Horizontally fed furnace systems or so-called stokers

Horizontally fed furnaces are available in different versions (Fig. 18), either with a simple grate, that is fixed or tiltable to remove the ash or with a pusher or moving grate in stair (Fig. 24) or flat level (Fig. 23) construction or a rotating circular designed grate (Fig. 22). The minimum power of realization of such systems is in the fixed grate version approx. 30 kW, in a simple pusher-grate version 100 kW and in a industrial-standard pusher-grate version around 1 MW. The fuel is transported sidewise to the combustion zone and moves over the grate. The combustion process is not interrupted and the fuel dries and pyrolysis. The primary combustion air ordinarily flows from below by the grate and cools the grate elements. Secondary air for a burnout is injected above the grate and the fuel. Depending on the fuel, the secondary combustion zone is partly firebrick lined or water cooled. In some cases, in addition secondary or tertiary combustion air is injected before the entrance of the heat exchanger.

The combustion concept depends on the fuel quality and ash behaviour. An ash softening and sintering results in ash deposits on the grate. With grate furnaces, the combustion temperatures can be limited due to the fuel height on the grate and the air amount. This influences the heat release rate in the fuel. Due to that, stokers as well used for herbaceous biomass such straw, corn [18], [19] or miscanthus.

Water cooled walls are common for e.g. straw firing to avoid ash sintering and melting. Due to the long residence time and the high flexibility in air amount on the grate fuels with low quality (e. g. corn, straw) and high water content (e.g. bark) are possible. Compared with underfed systems the fuel load in the furnace is grater and fast load changes and on-off-switching are not possible [3], [4]. Therefore for the improvement of horizontally fed systems, a heat storage system could be helpfully.

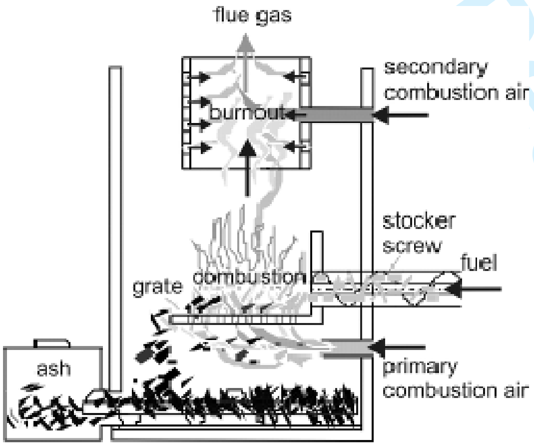

Figure 18: Principle of a stoker furnace

Special forms of stokers are furnaces for e.g. straw bales with cutting devices [24] or so-called cigar burners [25], where the bales are ignited on the front before pushed into the furnace. Especially in Denmark several plants of this type are in operation.

Drop-shaft firing

Drop-shaft firings especially designed for pellet up to approx. 30 kW. On the market 30 percent of all small scale pellet firings are drop-shaft systems and 60 percent are underfeeding systems. A stoker screw transports pellet up to a drop-shaft. The pellet fall down to a burner shell or a tiltable grate where the combustion takes place (Fig. 19). Primary and secondary air are injected into the combustion chamber on the side or the bottom of the grate.

Due to the low mass of fuel on the grate the furnace a quick start-up and load change process is possible. The combustion capacity can be modulated in a short time interval between 30 and 100 %. For a start-up electrical ignition is used. As fuel dry biomass with a water content w of < 20 % should be used.

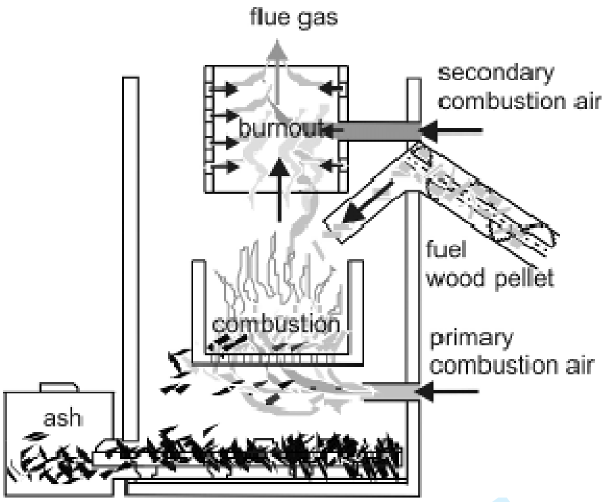

Figure 19: Drop-shaft furnace

3.3.2 Automatically operated wood chip and pellet heating systems

Stoves for the combustion of wood pellet

Pellet stoves are designed for operation in living areas. They are designed for heating of single rooms or for the connection to a heat distribution system. For low-energy houses such stoves can be used for the heating of the whole living area. The range is from 2–10 kW. The stoves are available as:

- chimney stoves (Fig. 20)
- tiled stoves (Fig. 21)

An automatically pellet feeding occurs with a stocker screw that takes the pellet from a small storage container. The storage is located elsewhere and filled manually or via a pellet fan, which transports the pellet automatically from e.g. a big bag or a storage on another floor several meters away (Fig. 21).

At stoves with a water heating system included, 50–95 % of the heat is given to the water heating system (domestic water or central heating system) and the rest is thermal radiation. The ash is collected in a small ash box. To remove the ash, manually operated ash-vacuum cleaners are available.

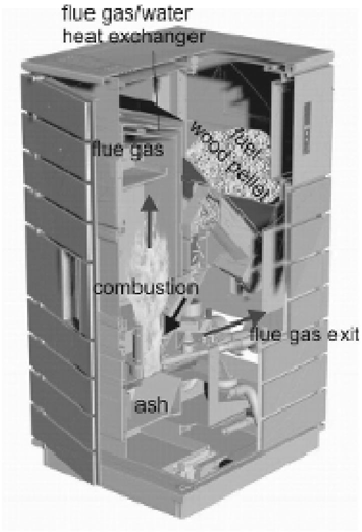

Figure 20: Pellet chimney stove for central heating with 3–11 kW thermal power, energy 5 % radiation and up to 95 % warm water, room-air independent systems [20]

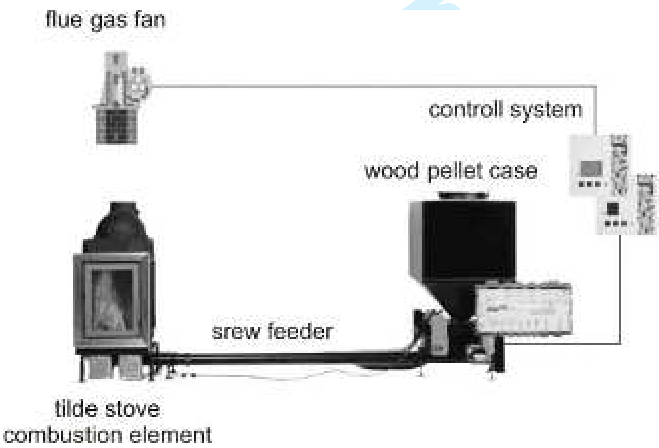

Figure 21: Tiled stove heating element with screw feeder, fired with wood pellet. In addition a big bag for wood pellet is possible [21]

Central heating boilers for wood pellet and wood chips

Automatically fed boilers for wood pellet and wood chips use the same principles. Wood chips can be burned in underfed and horizontally fed furnace systems, pellets in addition with a drop-shaft firing, which have all been explicitly described above (Fig. 22–27). The fuel transport system like stoker screws are especially designed either for pellet transport or for wood chip transport. Wood chips are more difficult in respect of transport and quality. For pellet boilers only pellet are useable, for wood chip boilers both - wood chips and pellet - are useable. Special pellet boilers (Fig. 26 and 27) are available in the range of 7 to 50 kW, above that wood chip boilers are used (Fig. 22–25).

For a change of the fuel a switch-over of the control parameter set is possible, e.g. other screw revolutions are necessary because of the higher energy density and low water content of wood pellet.

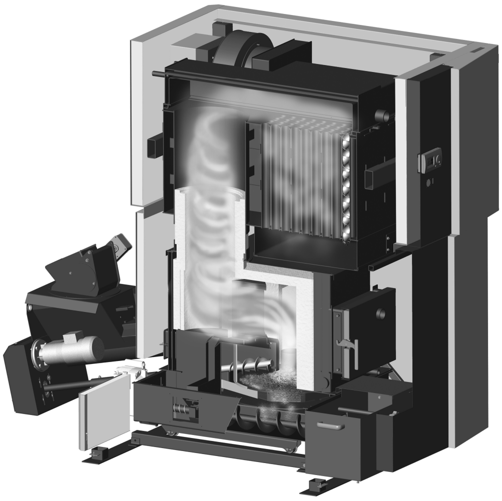

Figure 22: Wood chip and pellet boiler with a rotating circular designed grate with 150 up to approx. 300 kW thermal power [22]

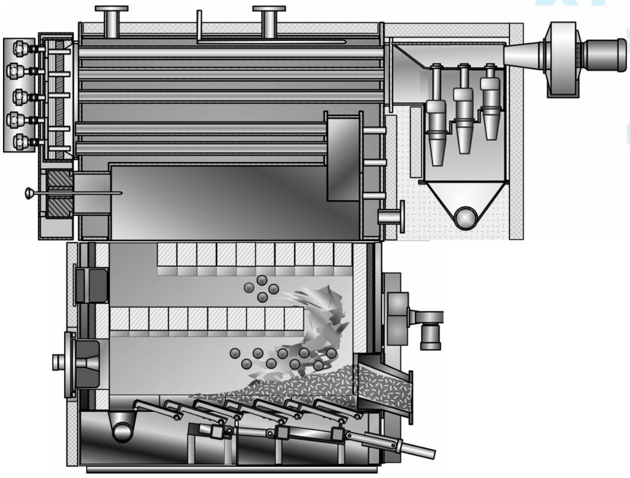

Figure 23: Wood chip boiler with moving grate in flat level construction suitable for fuels with a water content w from 30–60 % w.b. and high ash content, thermal power from several 100 kW up to approx. 5.000 kW, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]

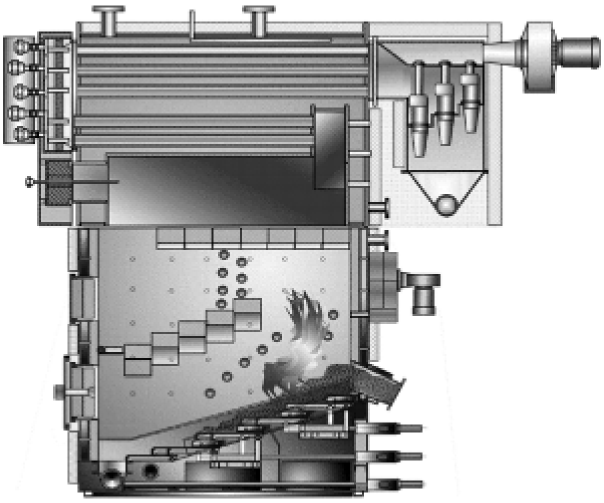

Figure 24: Wood chip boiler with moving grate in stair construction suitable for fuels with a water content w from 15–45 % w.b. and high ash content, thermal power from several 300 kW up to 5.000 kW or more, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]

At the moving grate furnace the fuel is passed into the furnace from the rear of the furnace on the grate with high-alloy casting grate bars (Fig. 23) or water-cooled grate girders (Fig. 24). The grate bars are designed that they overlap on both sides and the minimum material slips through the grate. The grate carriage has a hydraulic drive, so that the movement intervals can be automatically adjusted to the capacity. The complete combustion chamber of the example in Fig. 24 is lined with fireproof material thereby producing a high furnace temperature even in case of wet material (Fig. 23) or water-cooled and lined with fireproof material thereby ensuring the required cooling even in the case of materials that generate a high temperature in the combustion chamber (Fig. 24). In addition, full-combustion stage with furnace lining is provided above the radiation cover in the combustion room, which varies according to the material. [23]

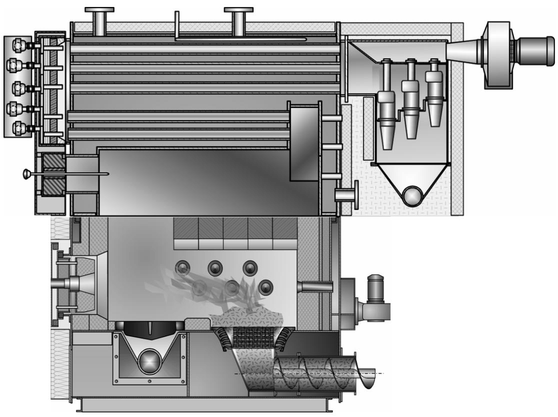

Figure 25: Wood chip boiler with underfeed furnace for fuels with a water content w from 10 %–50 % w.b., thermal power from 180 kW up to approx. 2.000 kW, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]

At the underfeed furnace the fuel is passed from below into the high-alloy casting combustion retort of the underfeed stoker furnace. In Fig. 25 the complete combustion chamber is lined with fireproof material, thereby producing a high furnace temperature even in case of wet material. A radiation cover, which varies according to the material, is placed over the combustion chamber. The primary air is passed into the combustion retort through the cast-iron bars, where a steady gasification of the combustion material commences. The secondary air that is passed into the combustion chamber leads to optimum combustion. [23]

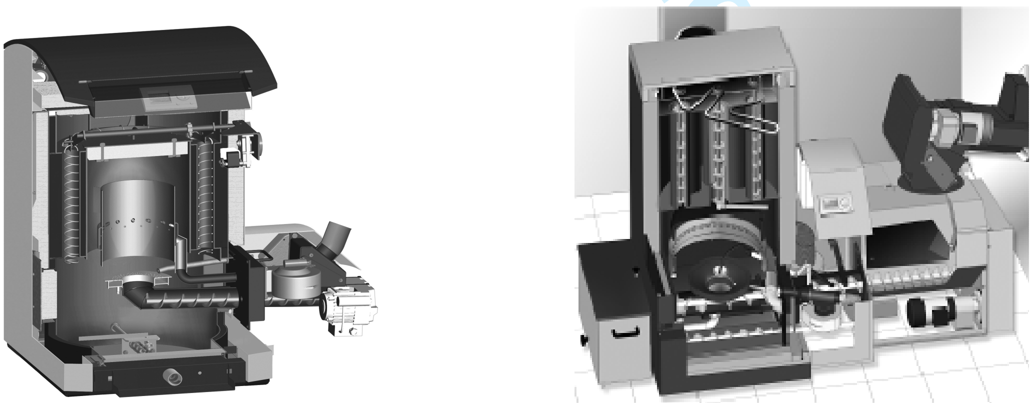

Figure 26: Left: pellet boiler with underfeed furnace, 10–30 kW thermal power, primary and secondary combustion air, two pass boiler flue, combustion air and flue gas fan. Right: wood chip boiler with underfeed furnace, up to 100 kW thermal power, one pass boiler flue, combustion air and flue gas fan [22]

Underfeed boilers according Fig. 26 are available for pellet and wood chips in the range up to 100 kW. To remove ash deposits and to increase the flue gas turbulence and the heat flux inside the heat exchanger tubes elastic springs or similar internals are installed.

Figure 27: Pellet boiler with drop-shaft furnace, 8 to 60 kW [8]

A drop-shaft furnace system for wood pellet is available from 8 up to approx. 60 kW.

Pellet boilers are used for single house-holds and so-called micro-district heating, composed of some heat consumer. Wood chip furnaces are ideally for farmhouses, communal buildings and district heating.

Pellet/log wood and wood chips/log wood burner combination are used for more flexibility and independency in the fuel input (Fig. 28). The wood chip-dual-chamber furnace with pre-oven was the original form of the small scale wood chip boiler

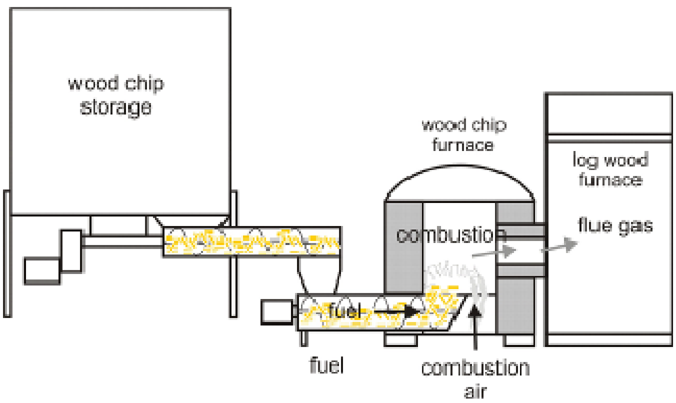

Figure 28: Wood chip-dual-chamber furnace with pre-oven [8]

The reconstruction of oil-fuelled boilers into pellet burners is difficult and not recommended due to security, problems in certification, (CE) labelling and emission reasons.

Straw bales [24] or energy-corn combustor [18], [19] are often using moving grate furnaces (Fig. 29). A special straw bale cutting device opens and ruptures the straw bales. A screw feeder transports the straw to the moving grate furnace (Fig. 30). To reduce particle emission, cyclones and electrostatic filters are common.

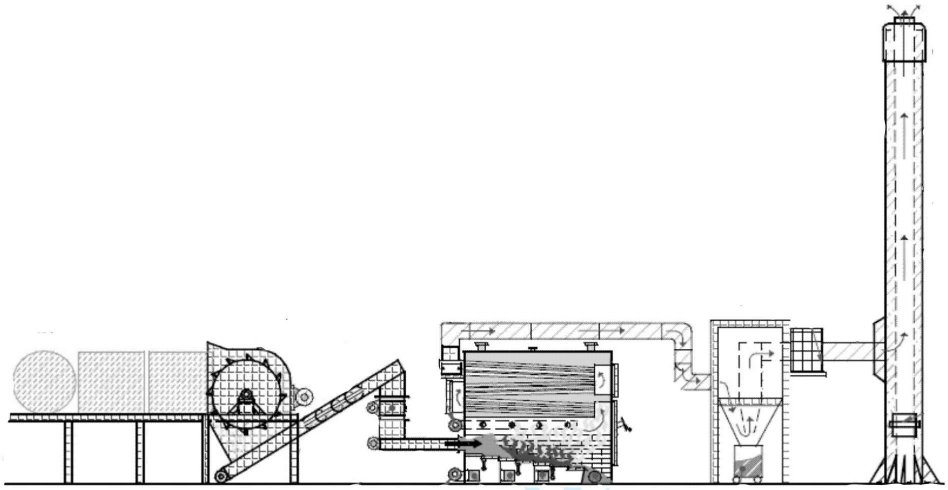

Figure 29: Straw bale firing unit with a moving grate furnace and a cyclone, thermal power 100 kW up to several 1.000 kW [24]

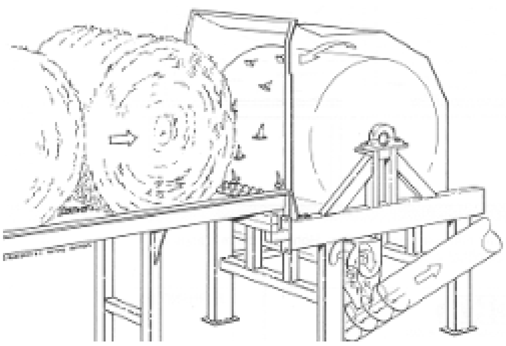

Figure 30: Straw bale cutting device [24]

4 Emissions

In respect to emissions mainly carbon monoxide (CO) and particle-emissions are of importance for the permission and operation of small scale biomass combustors. The level of emissions depends on fuel, combustion techniques and operation mode.

With a good carbon burnout, low flue gas temperature (100–150 °C) and less heat losses an thermal efficiency of 90 to 93 % (based on LHV) is possible.

For a short time period at start-up, shut-down or part-load operation, high CO emissions up to several 1.000 mg/Nm³ - even several 10.000 mg/Nm³ are possible. At modern wood boilers in full load operation, the CO emissions are in the range of 20–1.000 mg/Nm³. Particle emissions are normally in the range of 15–150 mg/Nm³. Stoves can reach higher emission values. [26], [27], [28]
Almost 90 % of the particles mass in the flue gas are smaller than 10 µm and approx. 80 % are smaller than 2,5 µm. The maximum particle number concentration is between 0,02–0,1 µm [10]. Because of the problematic of particulate matter (PM10) pollutions in Europe [51] especially in areas of high population density and in alpine regions electrostatic filters almost standard for biomass combustion plants >100 kW. It even can be expected, that this will be as well the case for smaller combustion plants in the future [16], [26]. For the relevant state regulations in e.g. Germany (1. BImschV), Switzerland (LRV) and Austria (FAV) values of 20 to 60 mg particles/Nm³ will be discussed for the future [26].

An overview about carbon monoxide and particle emission gives Fig. 31 and Fig. 32.

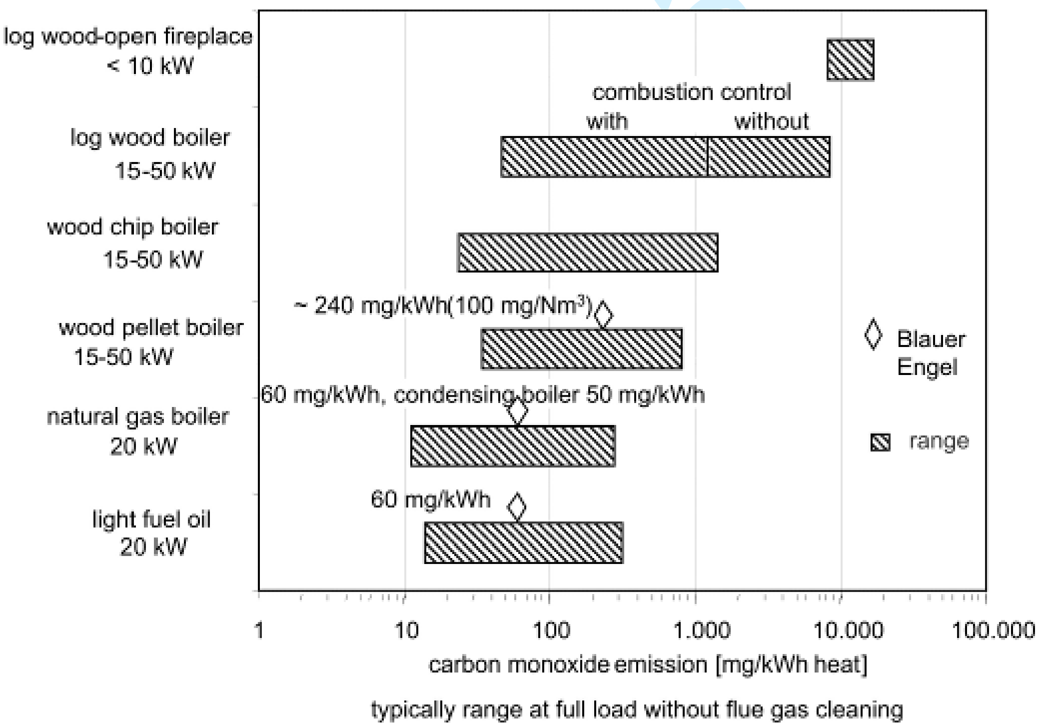

Figure 31: Carbon monoxide emissions of different combustors [10]

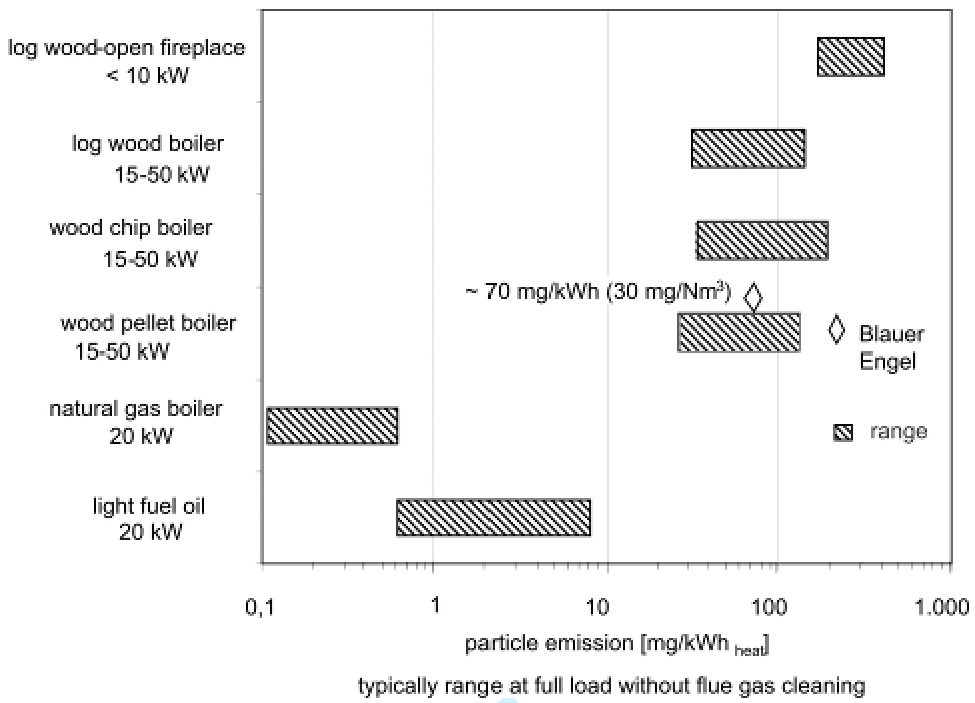

Figure 32: Particle emissions of different combustors [10]

Blauer Engel (blue angel) … Germans ecolabel for pellet stoves and pellet boilers, www.blauer-engel.de (2009)

For the conversion of different units of emissions in the flue gas at biomass combustion (wood, w = 20 %) Equation 3 an 4 can be used.

$$1\left[\frac{mg}{Nm^3{}_{\text{flue gas d.b. }13\%O_2}}\right] \approx 0{,}65\left[\frac{mg}{MJ_{fuel}}\right] \approx 2{,}34\left[\frac{mg}{kWh_{fuel}}\right] \qquad \text{Equation 3}$$

$$1\left[\frac{mg}{Nm^3{}_{\text{flue gas d.b. }10\%O_2}}\right] \approx 0{,}48\left[\frac{mg}{MJ_{fuel}}\right] \approx 1{,}73\left[\frac{mg}{kWh_{fuel}}\right] \qquad \text{Equation 4}$$

5 Electricity production and Combined Heat and Power

To produce electricity power different concepts at small scale are available which are based on solid biomass combustion. In general, automatically fed combustion systems and in addition directly and indirectly operated biomass gasifiers are used. At direct or so-called autothermal gasifiers, the heat of gasification is supplied by a partial oxidation/combustion of biomass in the gasifier. The result is a product gas with a low calorific value of approx. 5 MJ/Nm³ [30],[31]. Indirect or so-called allothermal gasifiers are heated by an external heat source. The heat is transported into the gasifier with a heat carrier, e.g. with the bed material of two interconnected fluidized bed reactors [33], [34], [35], [36]. Alternatively a heat exchanger is used for the heat transport, e.g. heat pipes [32]. In the small scale range below 500 MW thermal power, a number of direct gasifiers are in operation all over the world. Mainly solid bed co-current (downdraft) or counter current (updraft) gasifiers are used for it [33], [34]. An example of an small scale indirect gasifier is the so-called BioHPR operated with two fluidized beds, one fluidized bed as combustor and one as gasifier. The heat transfer occurs through heat pipes which are connected with both fluidised beds [32], [37]. Such a gasifier produces a H_2, CO and CH_4 rich gas with a higher calorific value of approx. 11 MJ/Nm³.

However, for the production of electricity power, the following techniques are available, sorted by the state of the art and development of the technology.

Based on biomass combustion	size kWel	el. efficiency % based on fuel LHV	Reference
organic rankine cycle	6–2.000	10–15	[38], [39], [40]
stirling engine	1–35	5–20	[22], [41], [42], [43]
steam screw engine	1–700	8–12	[44]
indirect fired hot air turbine	50–100	8–20	[45], [46]
steam piston engine	25–200	8–14	[47]

Table 3: Small scale power production based on biomass combustion

Based on biomass gasification	size kWel	el. efficiency % based on fuel LHV	Reference
gas piston engine	20–2.000	10–36	[48]
micro-turbine	30–100	8–23	[49]
SOFC/MCFC fuel cell	1–250	20–51	[32], [50]

Table 4: Small scale power production based on biomass gasification

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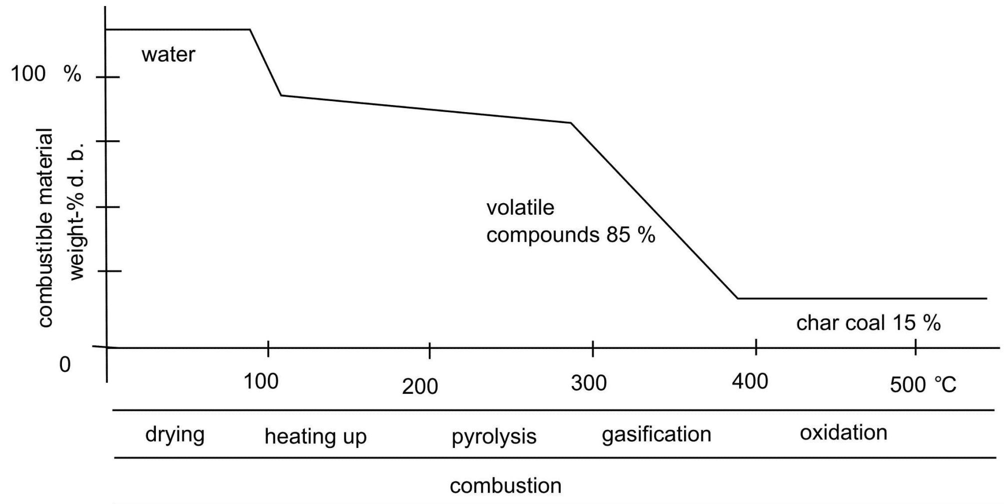


Figure 1: Combustion process of biomass [2]
191x96mm (300 x 300 DPI)

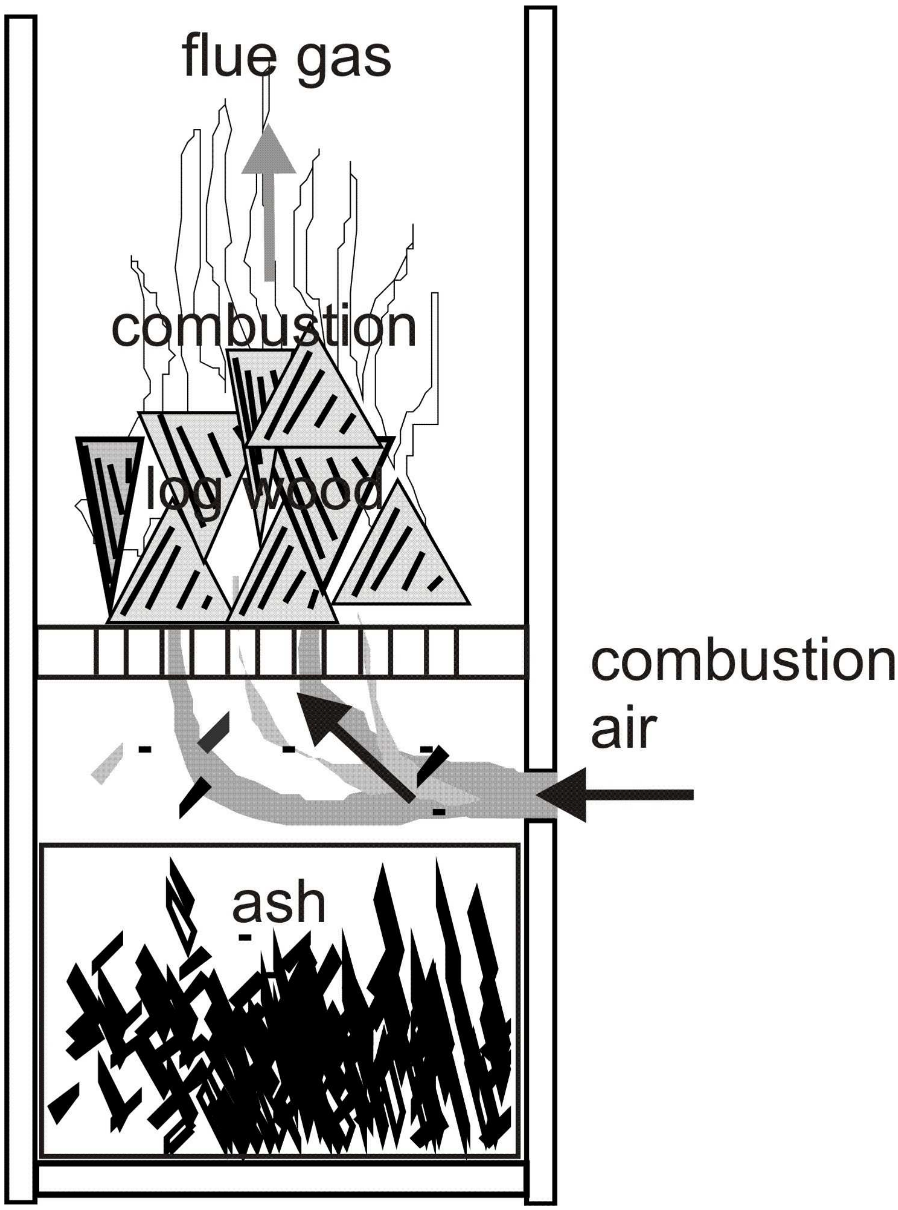


Figure 2: Updraft combustion with complete combustion principle
124x167mm (300 x 300 DPI)

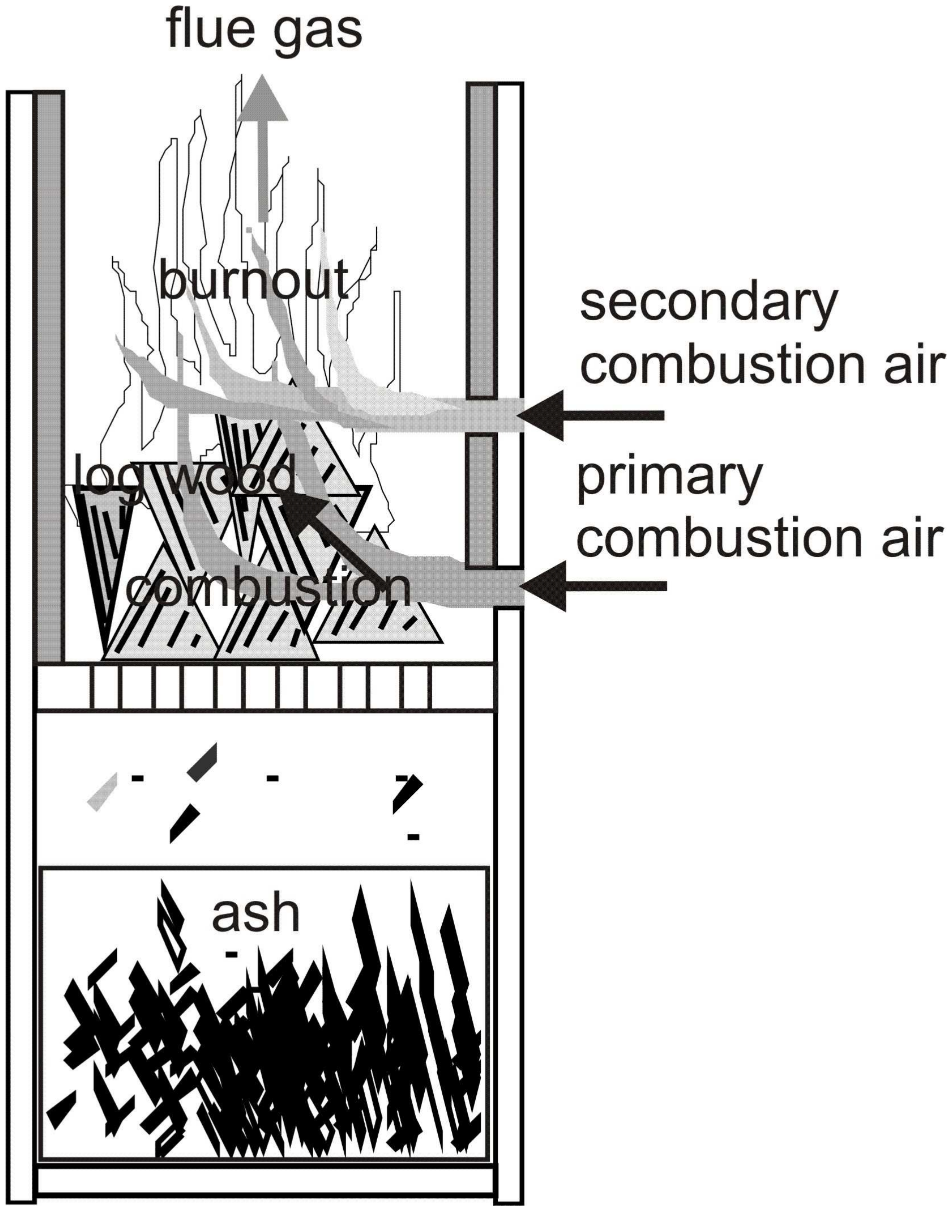
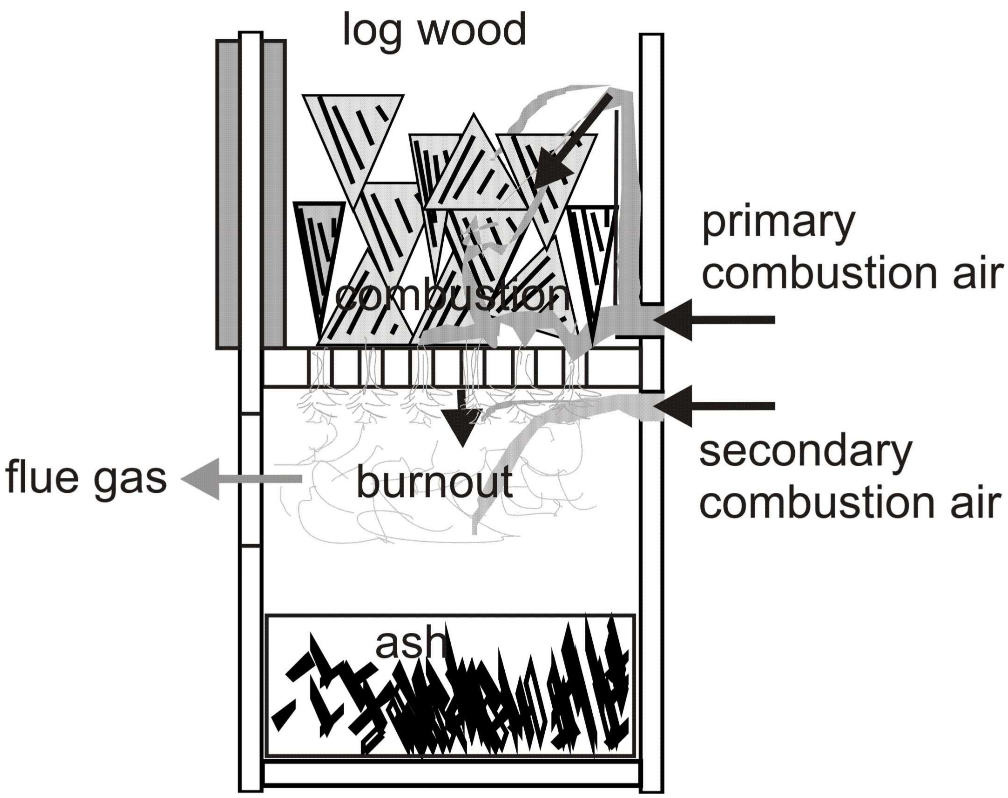


Figure 3: Updraft combustion with top-burnout
140x179mm (300 x 300 DPI)



181x142mm (300 x 300 DPI)

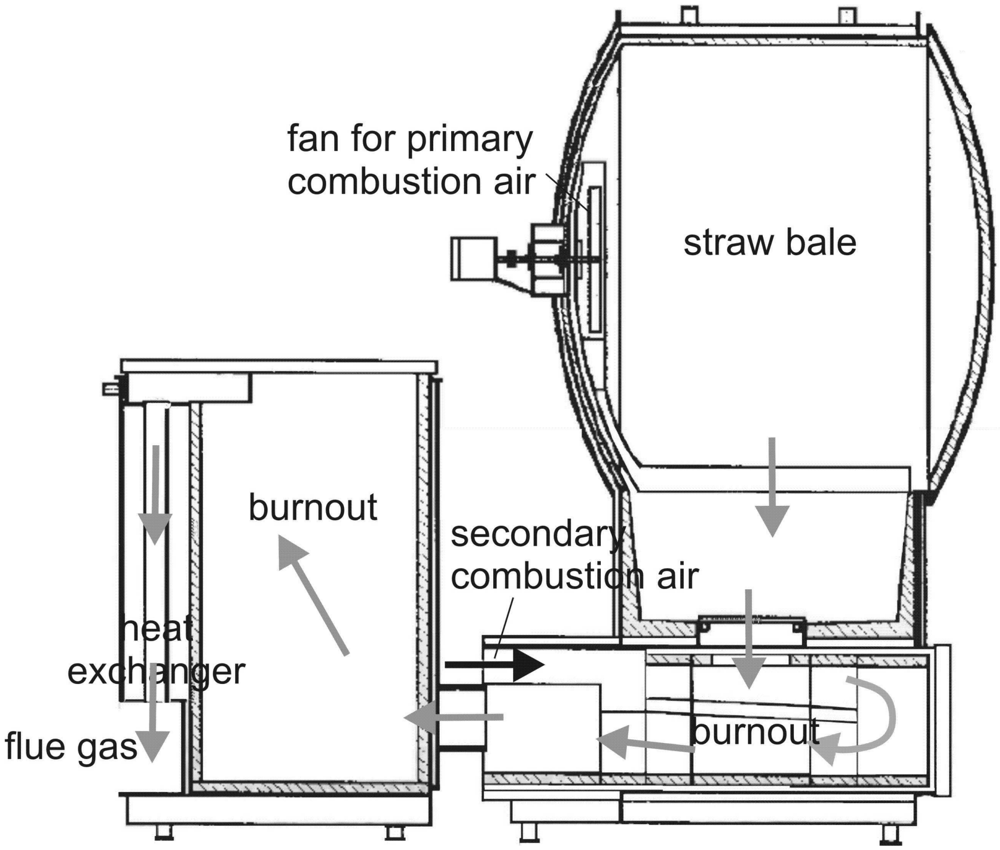
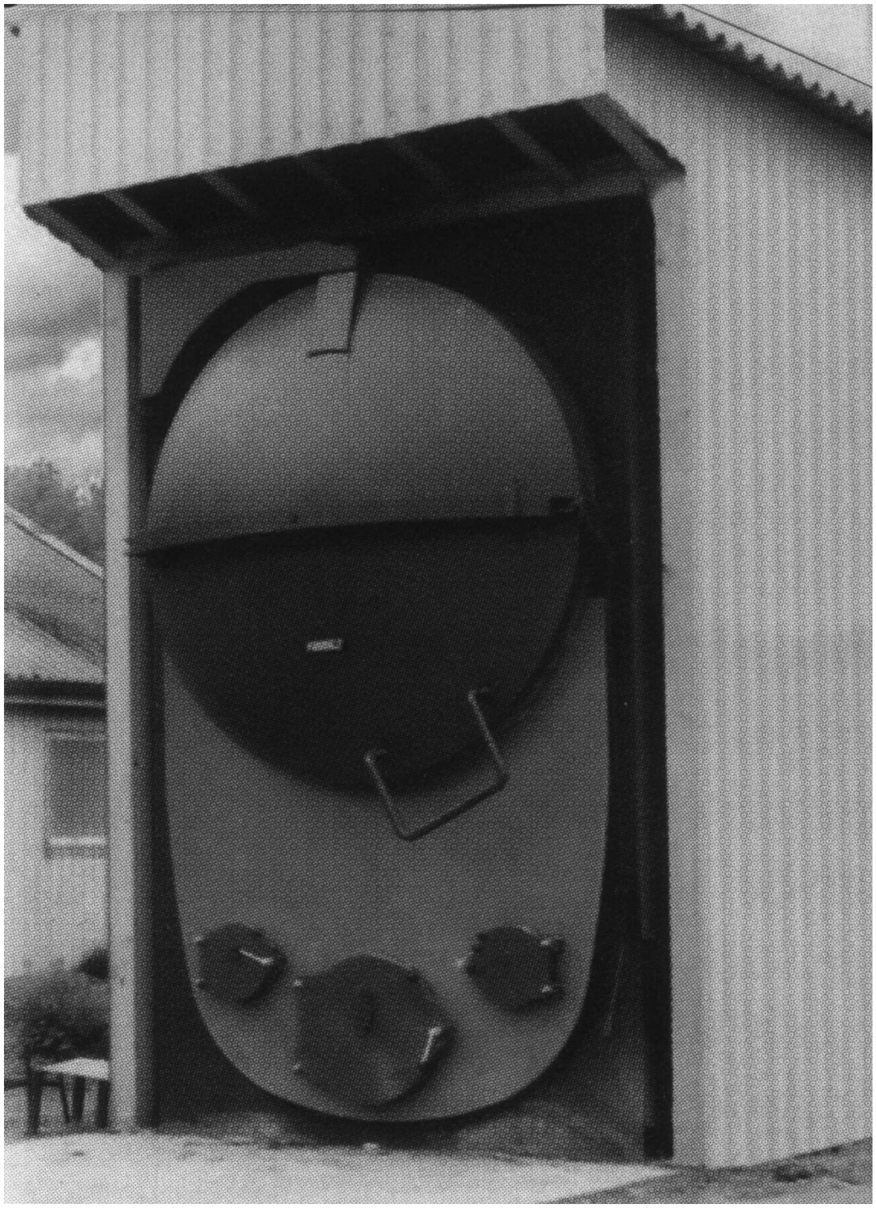


Figure 5: Straw bale combustor [5]
221x199mm (300 x 300 DPI)



809x1118mm (50 x 50 DPI)

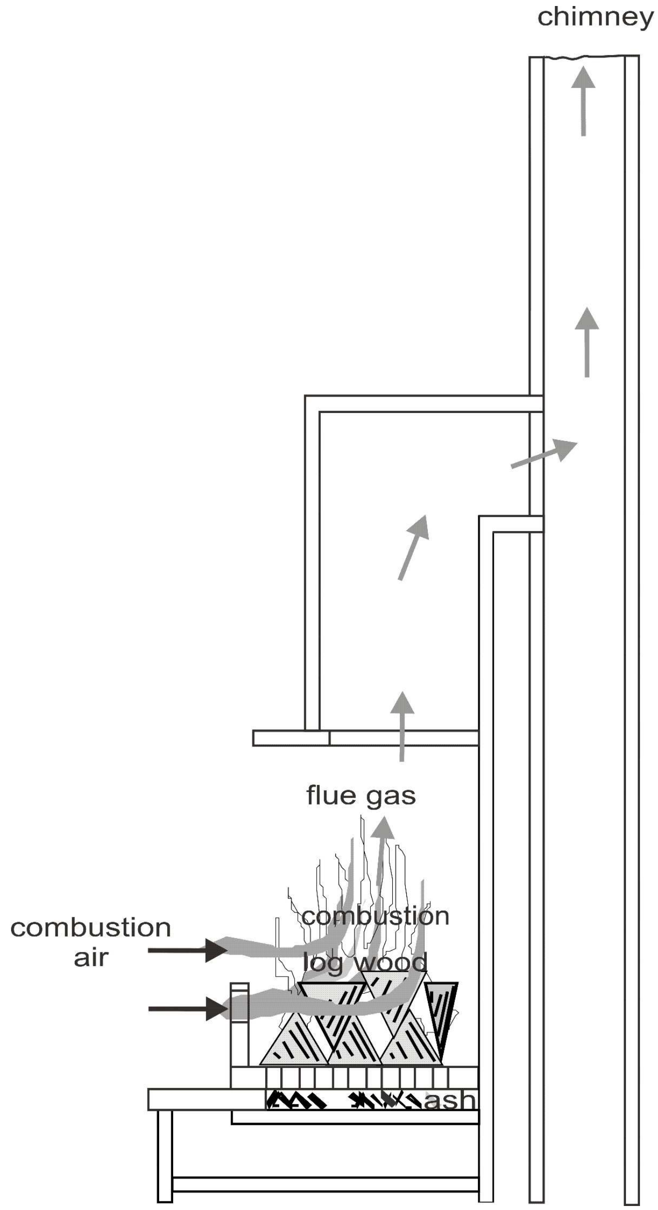


Figure 6: Open fireplace, fired with log wood
202x377mm (300 x 300 DPI)

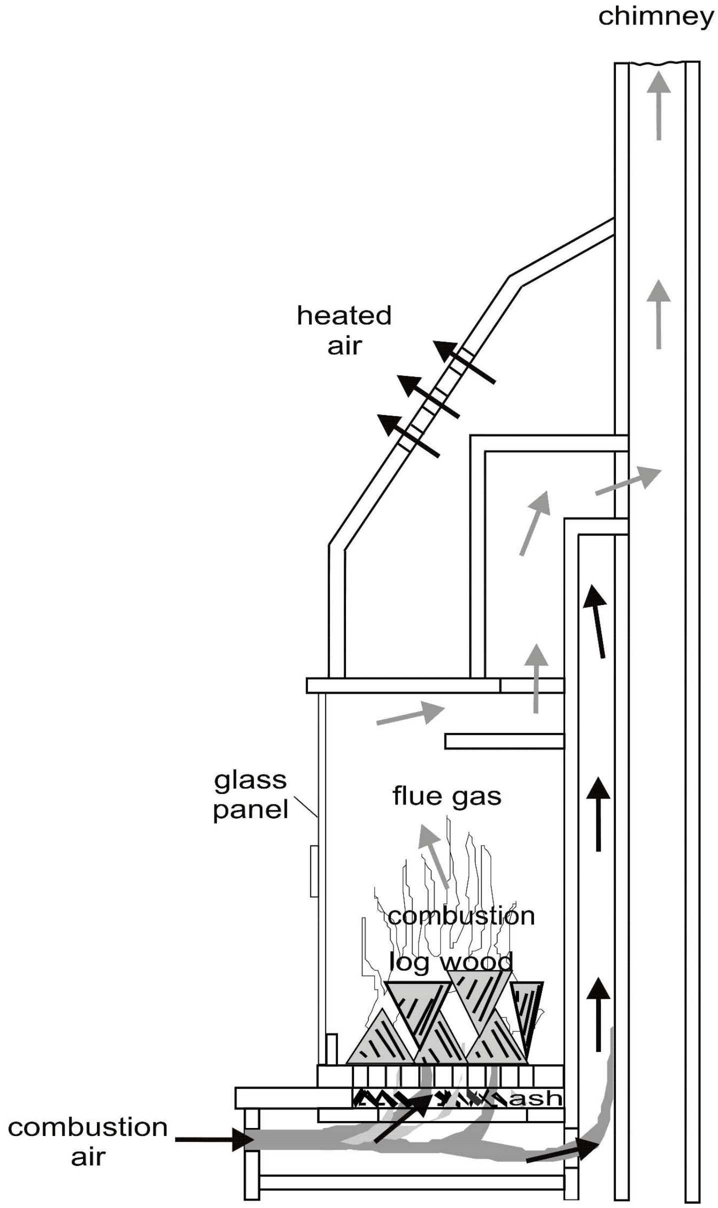


Figure 7: Closed fireplace, fired with log wood
223x379mm (300 x 300 DPI)

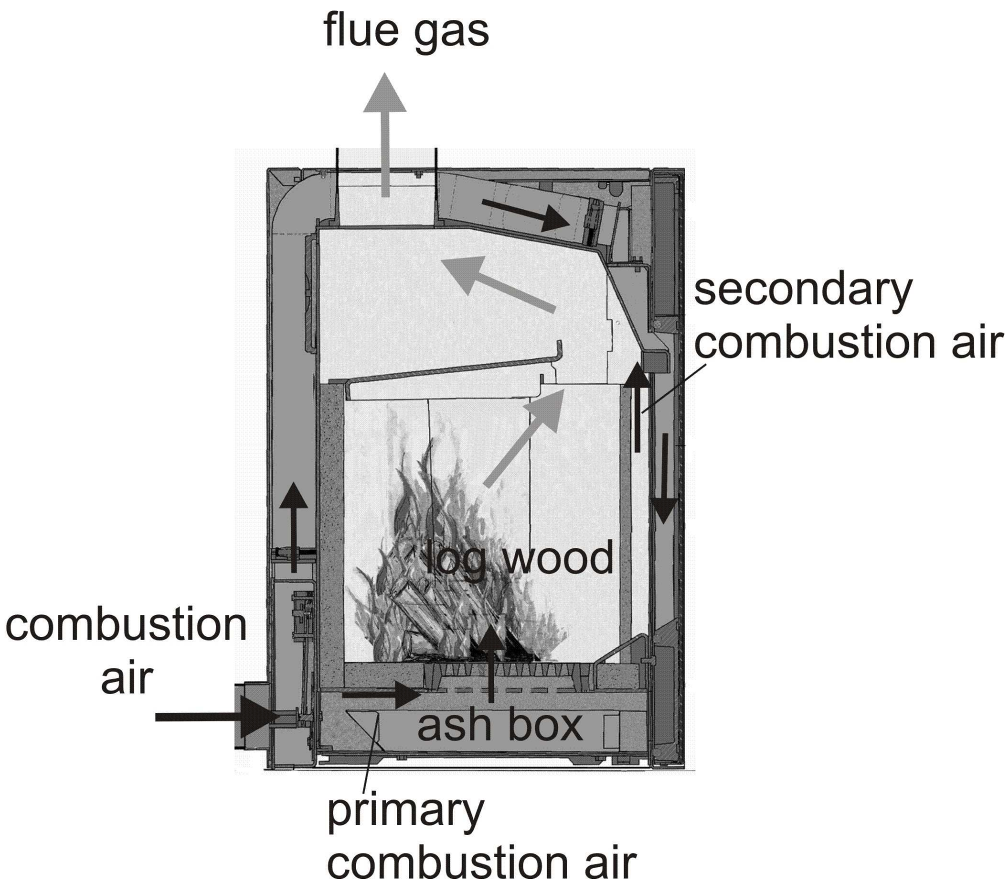


Figure 8: Log wood fired stove with 7 kW thermal power [6]
177x153mm (300 x 300 DPI)

57x98mm (300 x 300 DPI)

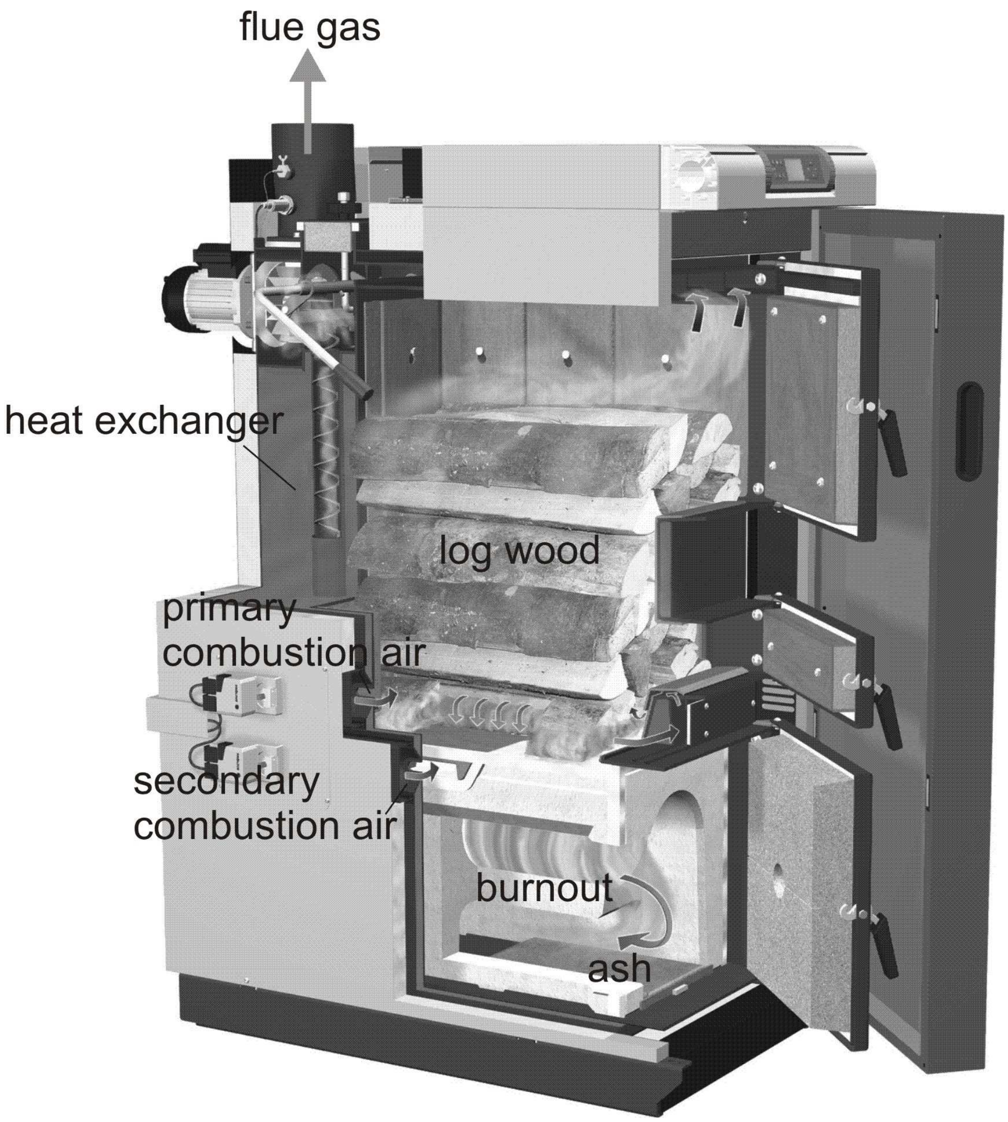


Figure 9: Log wood boiler with bottom burnout in the range of 15–60 kW [8]
146x161mm (300 x 300 DPI)

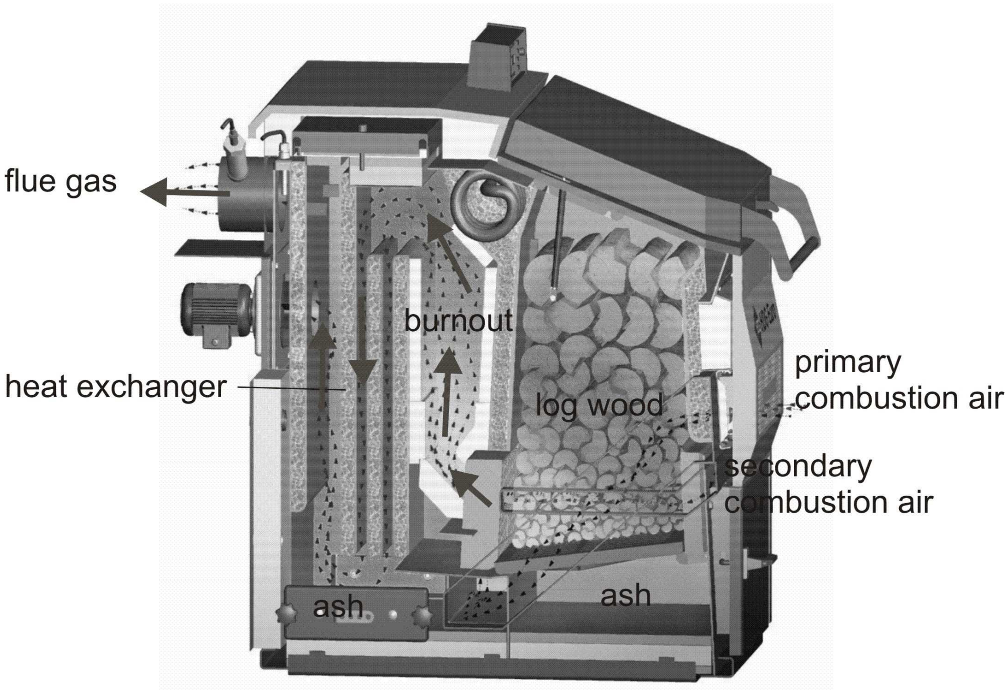


Figure 10: Log wood boiler with lateral burnout in the range of 30–50 kW [9]
183x127mm (300 x 300 DPI)

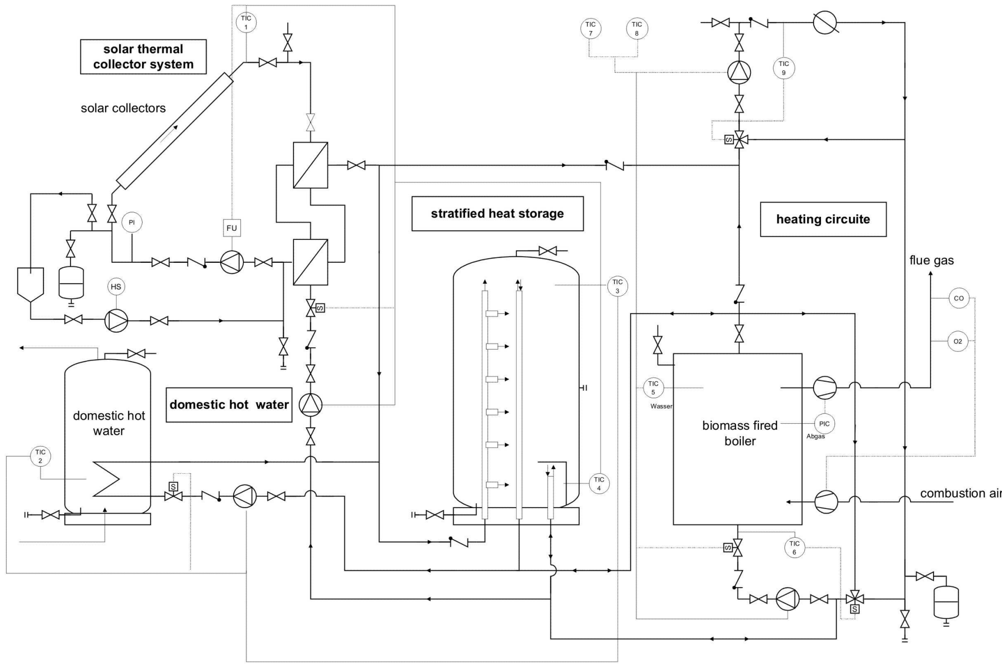


Figure 11: Hydraulic concept of a biomass fired boiler in combination with a solar thermal plant for domestic hot water and room heating. More simple hydraulic concepts of solar thermal collector plants for domestic hot water are possible.
206x136mm (300 x 300 DPI)

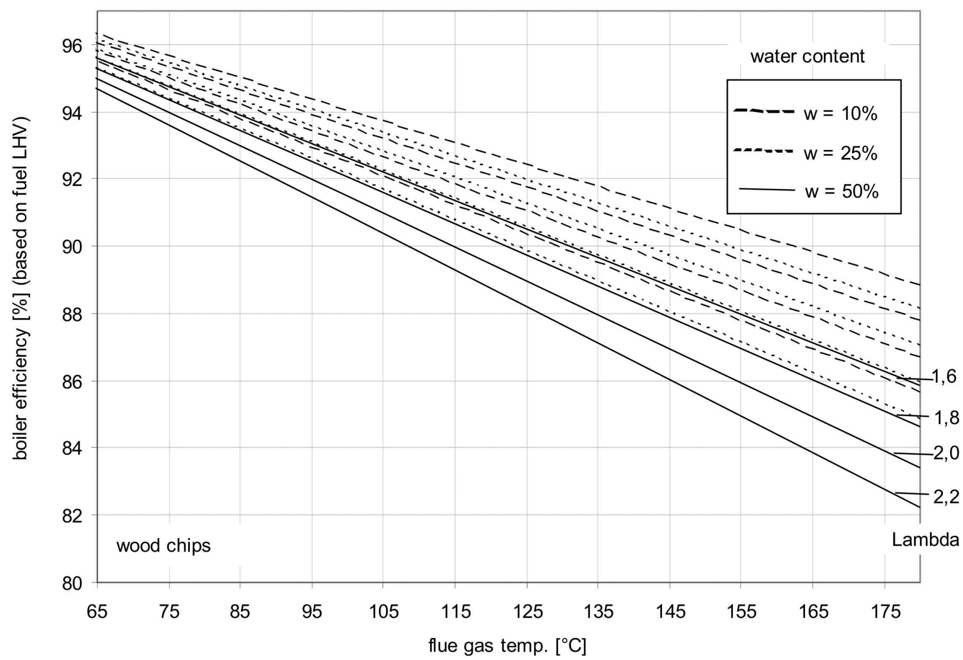


Figure 12: Boiler efficiency of wood combustor (without flue gas condensation) [10]
202x145mm (300 x 300 DPI)

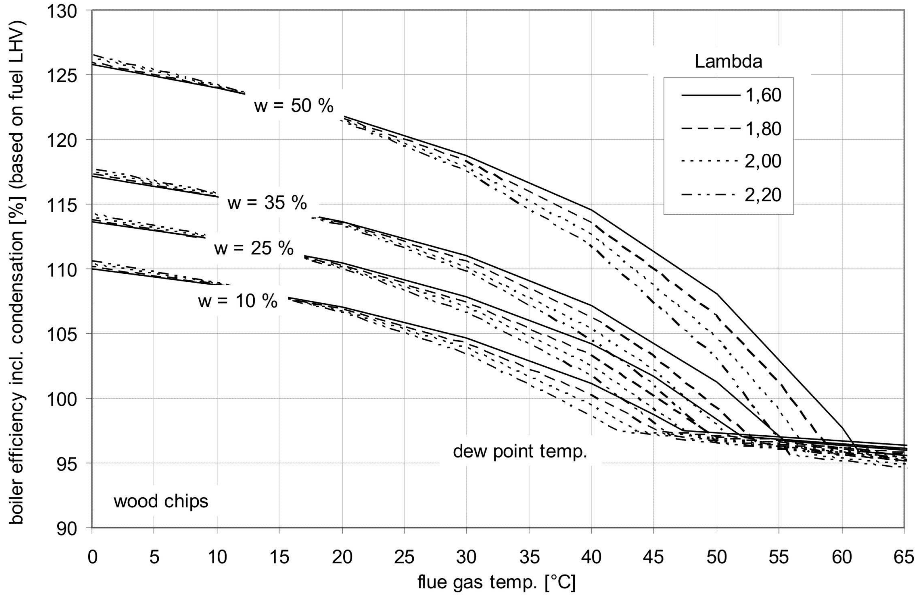


Figure 13: Boiler efficiency of wood combustor with flue gas condensation [10]
210x137mm (300 x 300 DPI)

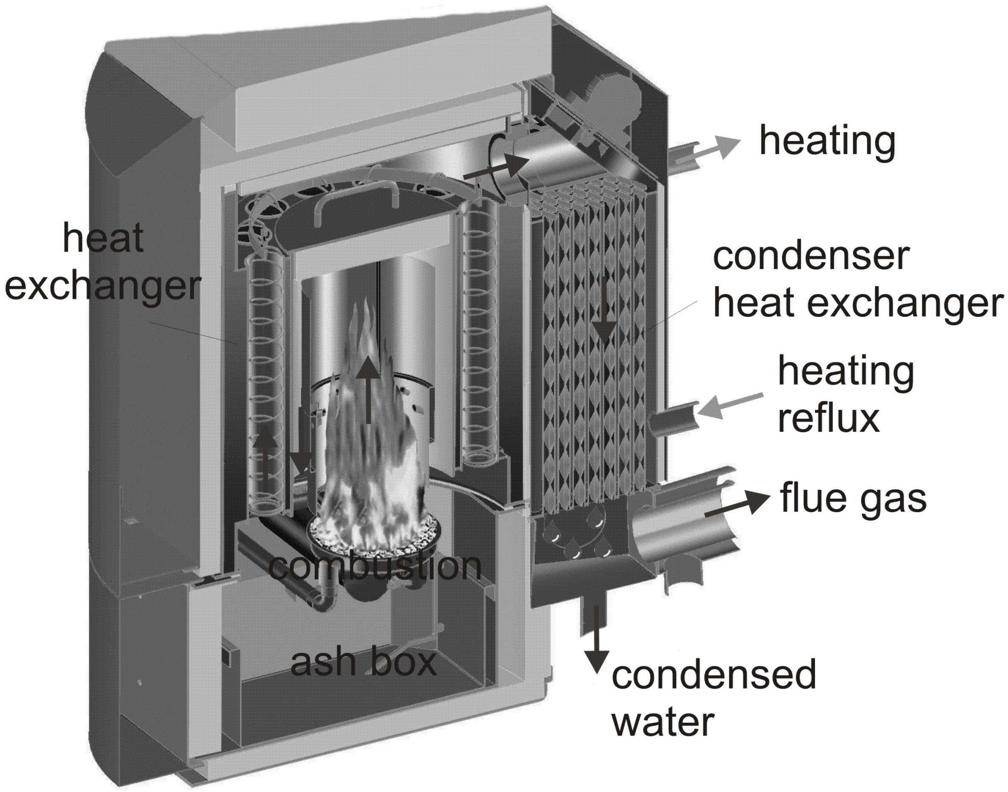
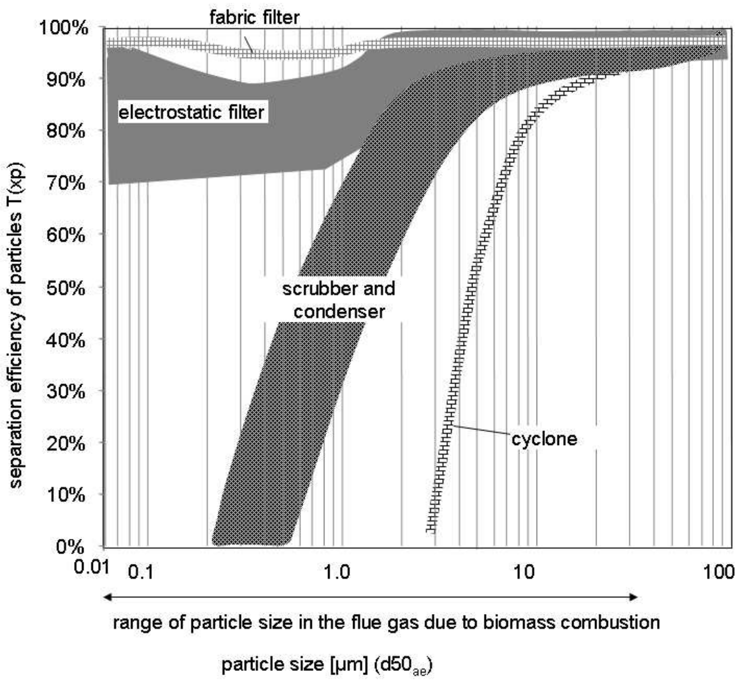


Figure 14: Pellet boiler with 12–32 kW thermal power with integrated flue gas condensation [17]
200x161mm (300 x 300 DPI)



254x190mm (96 x 96 DPI)

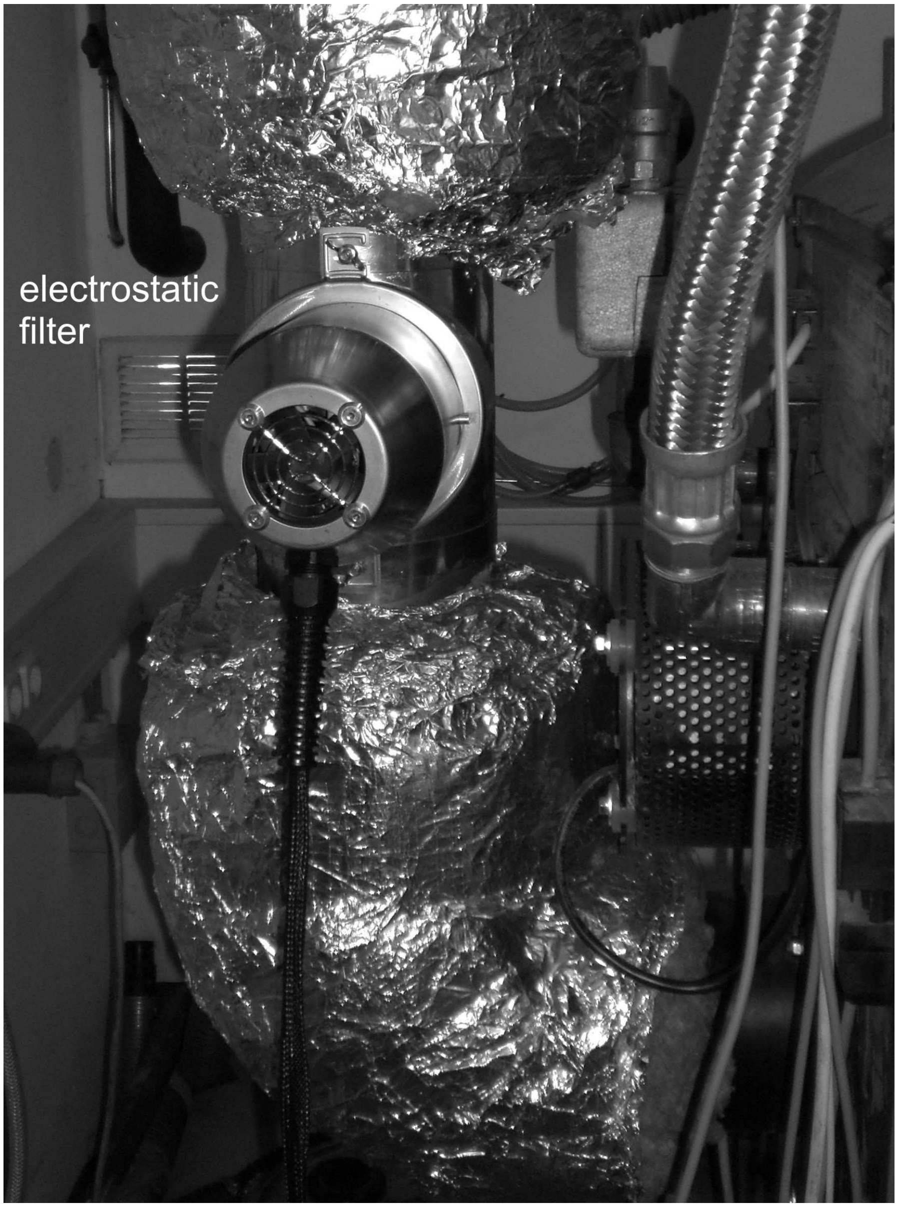


Figure 16: Small scale electrostatic filter for wood furnaces with 7 kW–100 kW thermal power [15], [16]
604x813mm (72 x 72 DPI)

897x812mm (72 x 72 DPI)

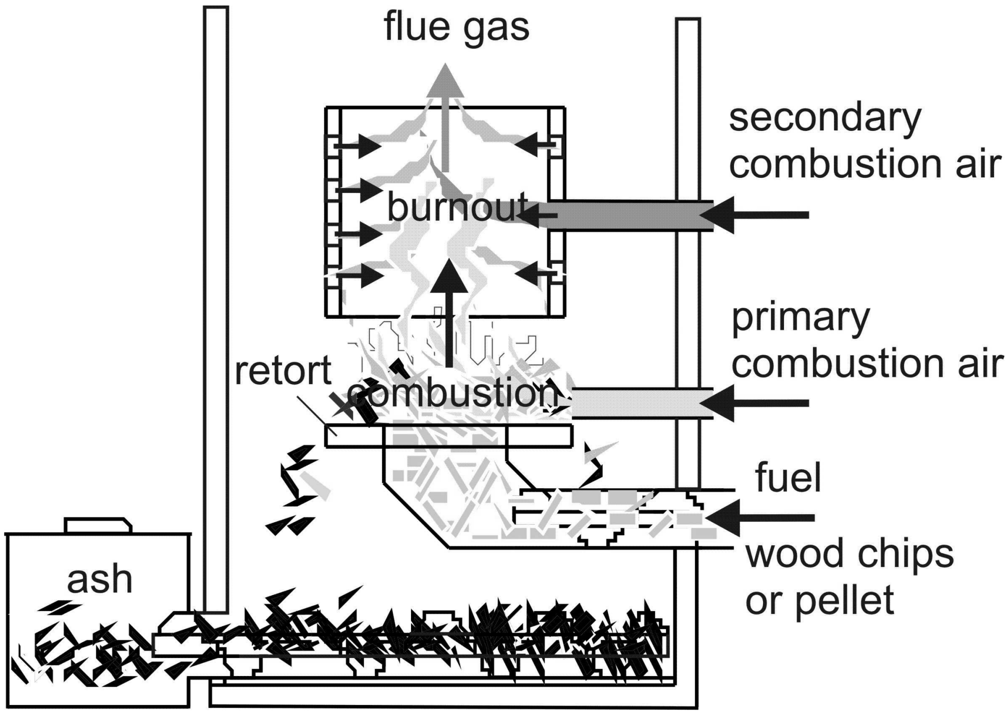


Figure 17: Principle of a underfeed furnace
201x142mm (300 x 300 DPI)

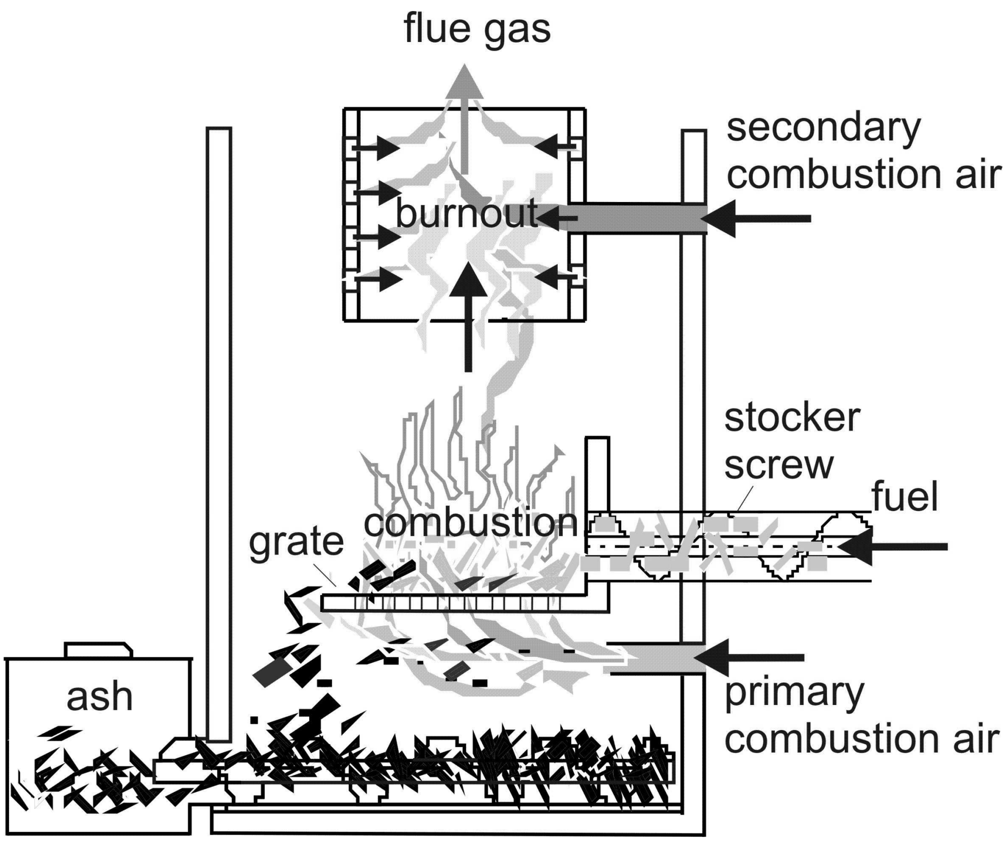


Figure 18: Principle of a stoker furnace
199x164mm (300 x 300 DPI)

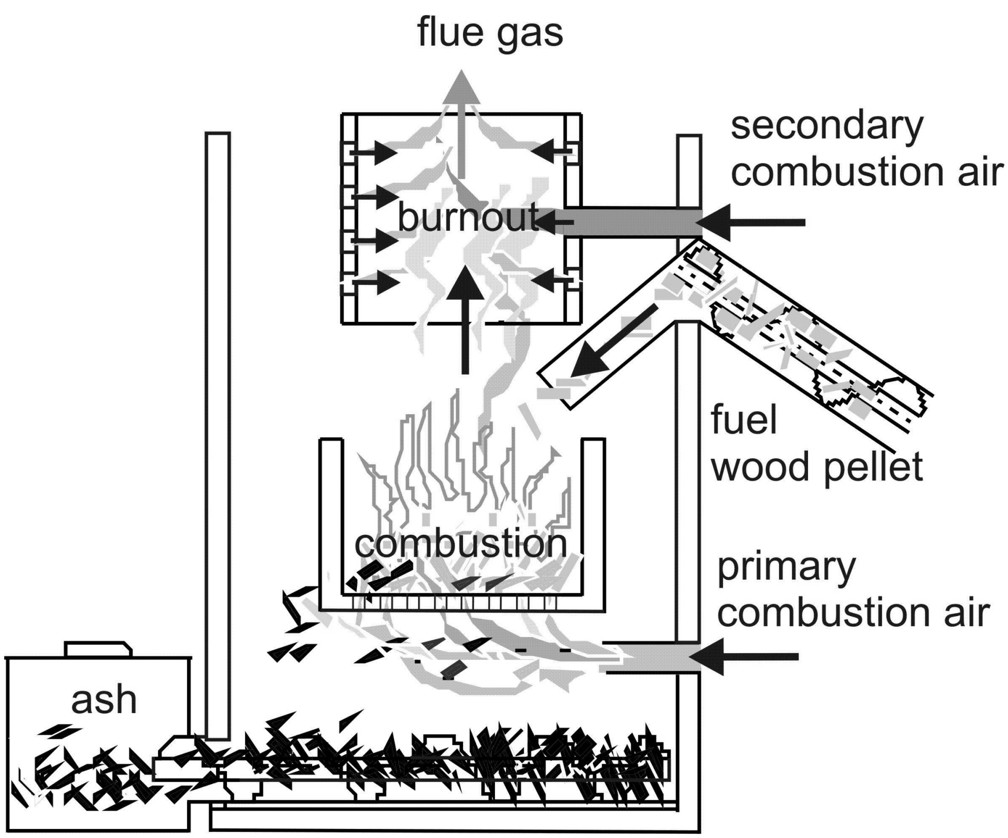


Figure 19: Drop-shaft furnace
201x165mm (300 x 300 DPI)

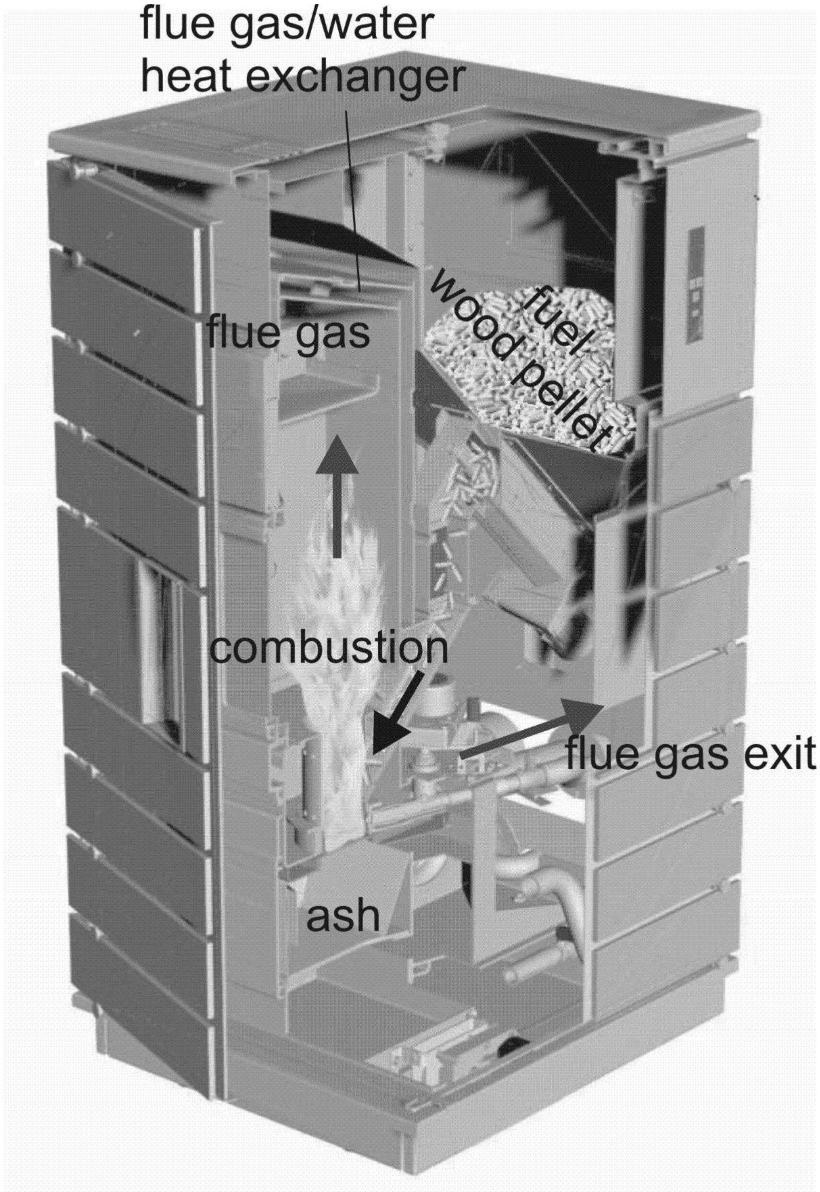


Figure 20: Pellet chimney stove for central heating with 3–11 kW thermal power, energy 5 % radiation and up to 95 % warm water, room-air independent systems [20]
101x149mm (300 x 300 DPI)

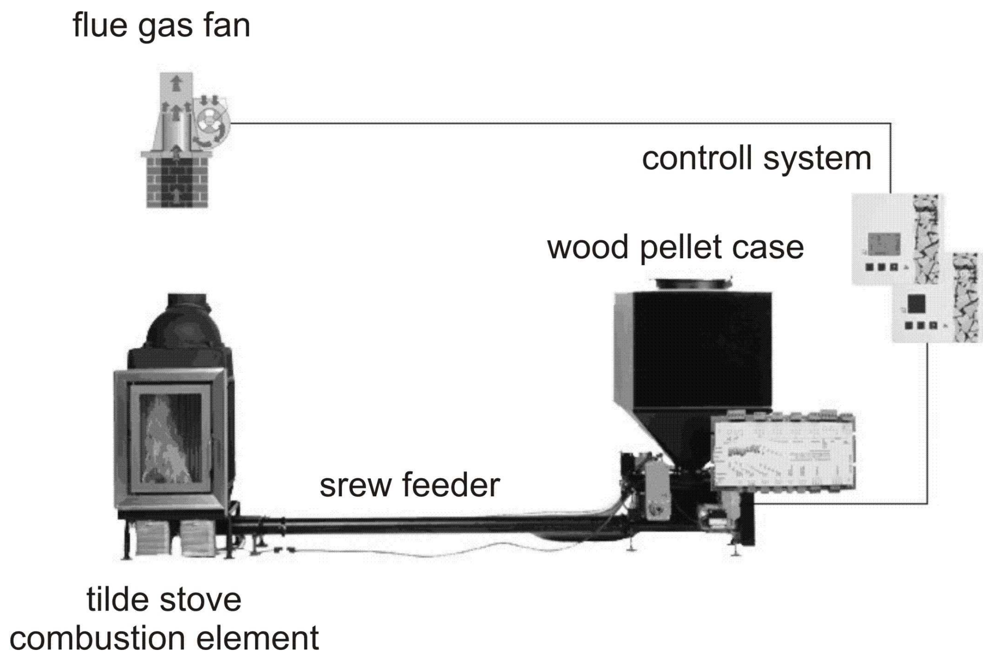


Figure 21: Tiled stove heating element with screw feeder, fired with wood pellet. In addition a big bag for wood pellet is possible [21]
183x117mm (300 x 300 DPI)

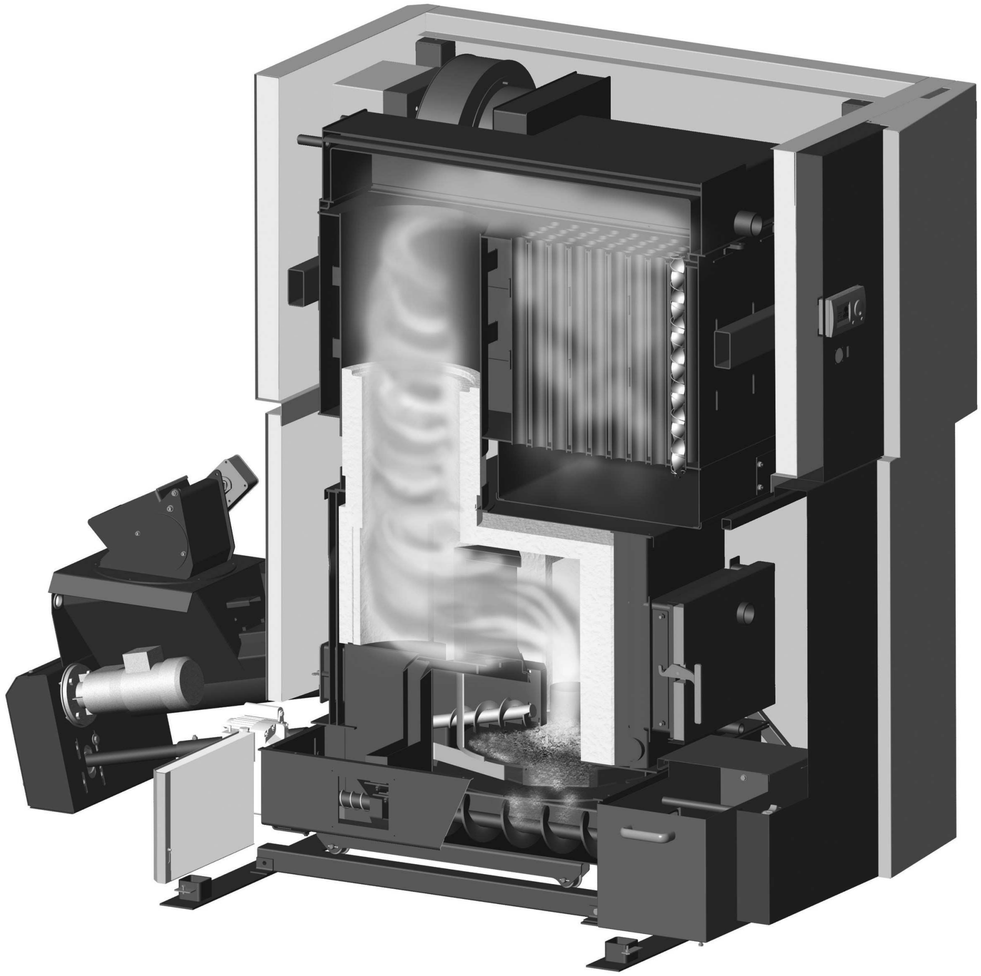


Figure 22: Wood chip and pellet boiler with a rotating circular designed grate with 150 up to approx. 300 kW thermal power [22]
200x202mm (305 x 305 DPI)

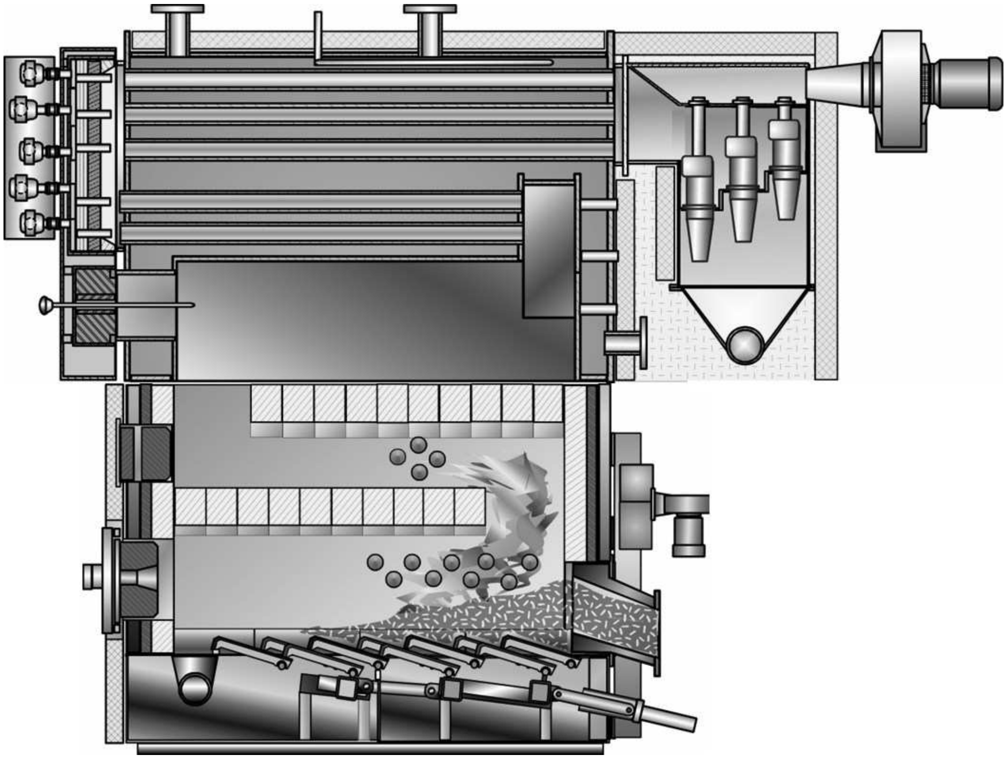


Figure 23: Wood chip boiler with moving grate in flat level construction suitable for fuels with a water content w from 30–60 % w.b. and high ash content, thermal power from several 100 kW up to approx. 5.000 kW, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]
177x133mm (150 x 150 DPI)

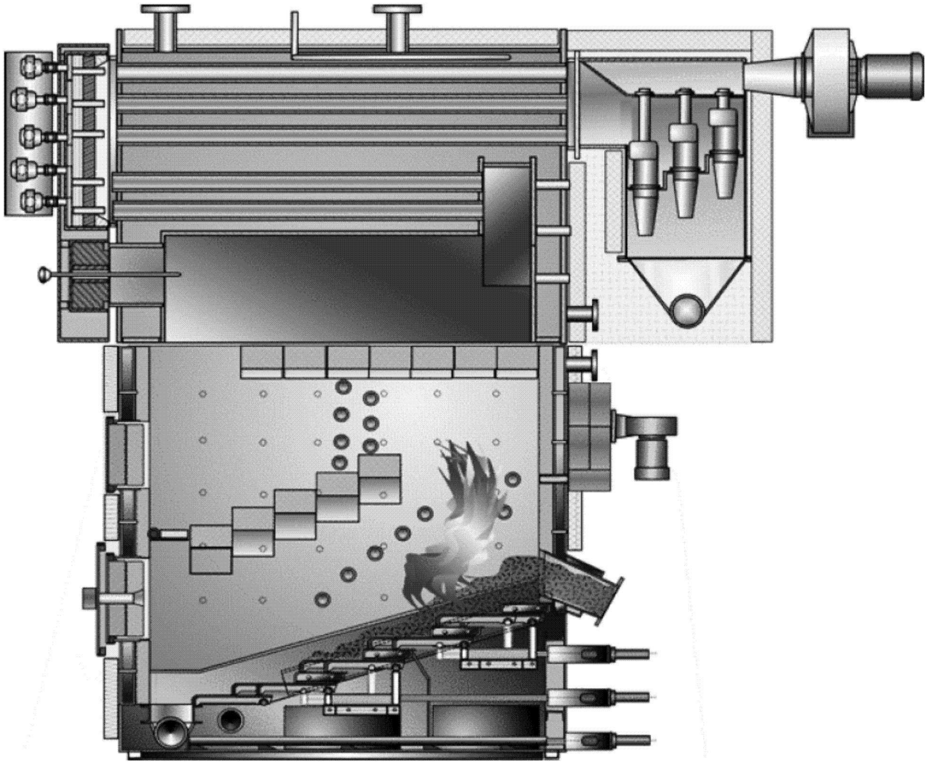


Figure 24: Wood chip boiler with moving grate in stair construction suitable for fuels with a water content w from 15–45 % w.b. and high ash content, thermal power from several 300 kW up to 5.000 kW or more, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]
176x137mm (300 x 300 DPI)

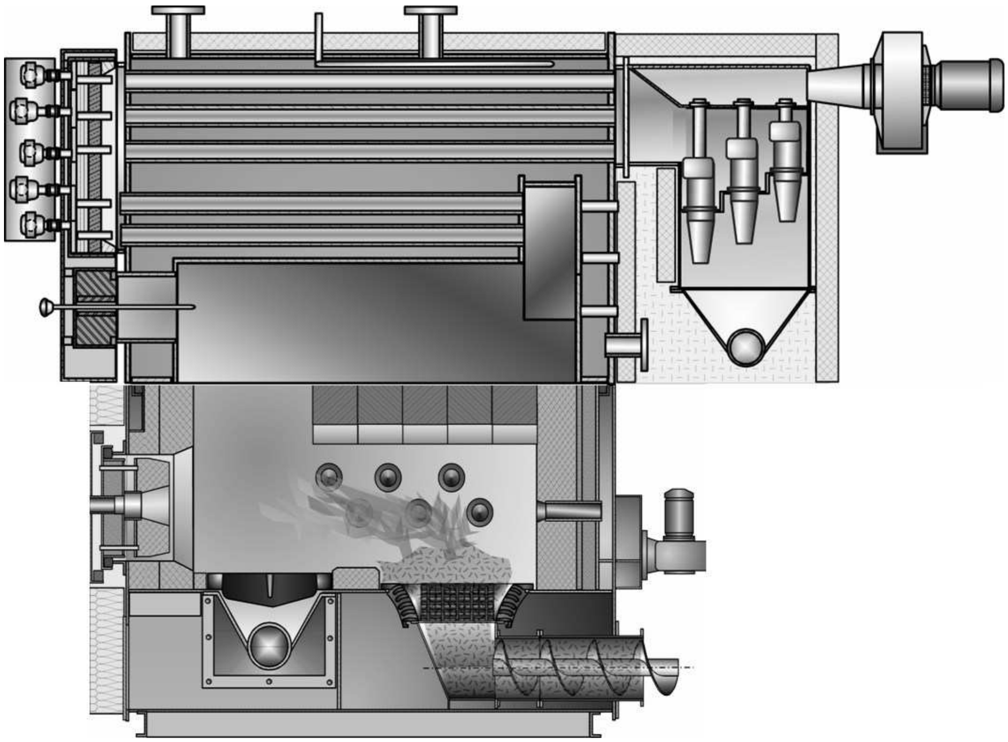


Figure 25: Wood chip boiler with underfeed furnace for fuels with a water content w from 10 %–50 % w.b., thermal power from 180 kW up to approx. 2.000 kW, primary and secondary combustion air, three pass boiler flue with pneumatic pressed air cleaning of boiler tubes, multi cyclone and flue gas fan [23]
180x131mm (150 x 150 DPI)

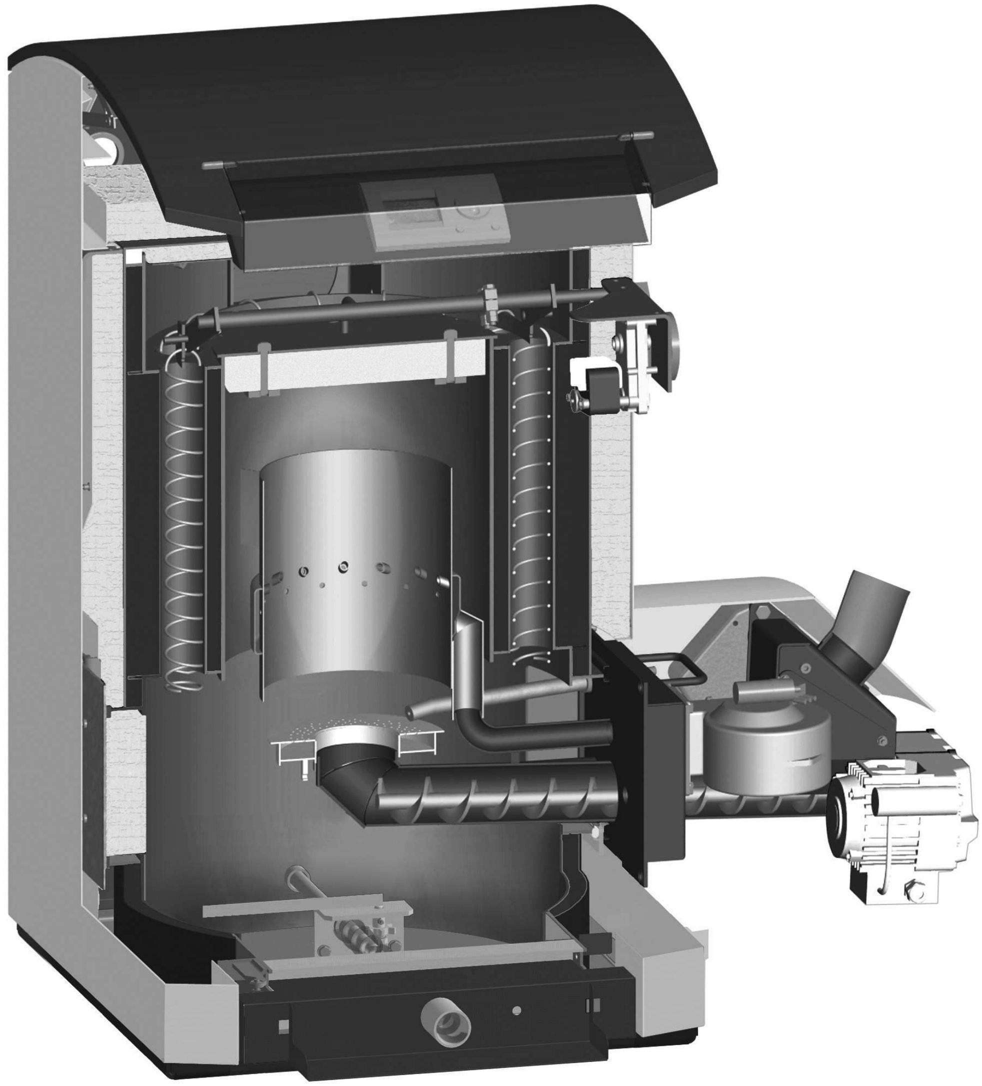
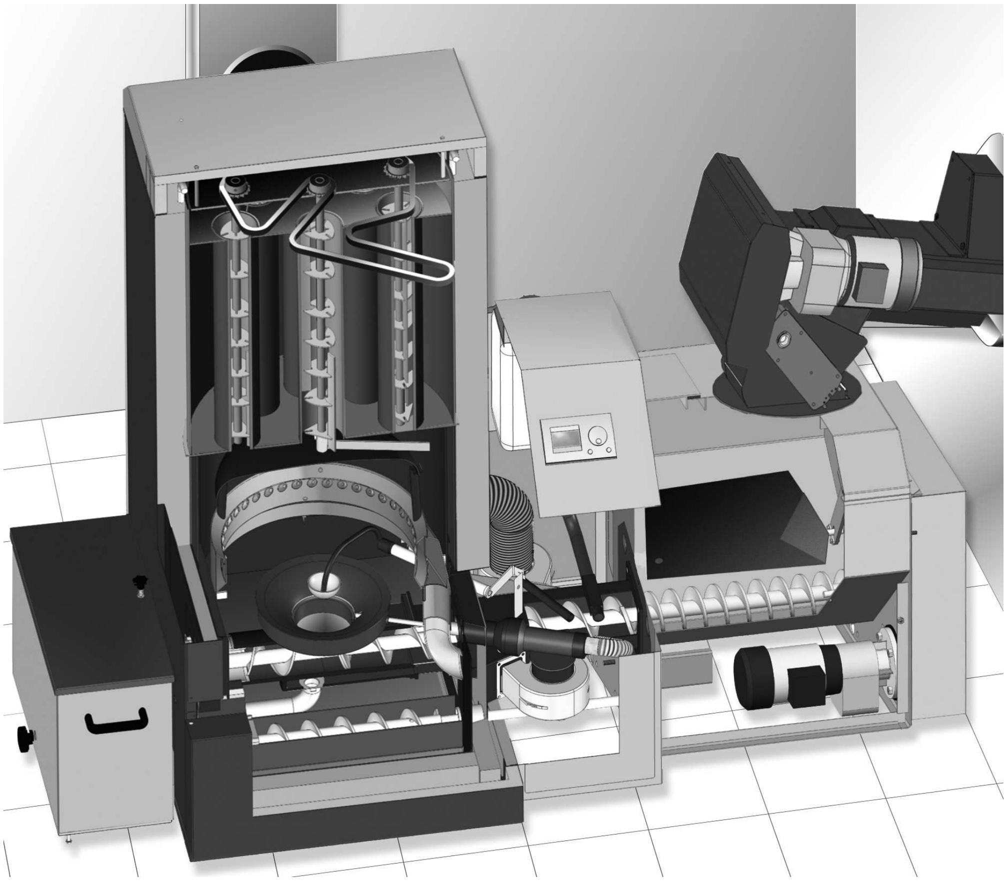


Figure 26: Left: pellet boiler with underfeed furnace, 10–30 kW thermal power, primary and secondary combustion air, two pass boiler flue, combustion air and flue gas fan. Right: wood chip boiler with underfeed furnace, up to 100 kW thermal power, one pass boiler flue, combustion air and flue gas fan [22]
309x345mm (150 x 150 DPI)



315x274mm (150 x 150 DPI)

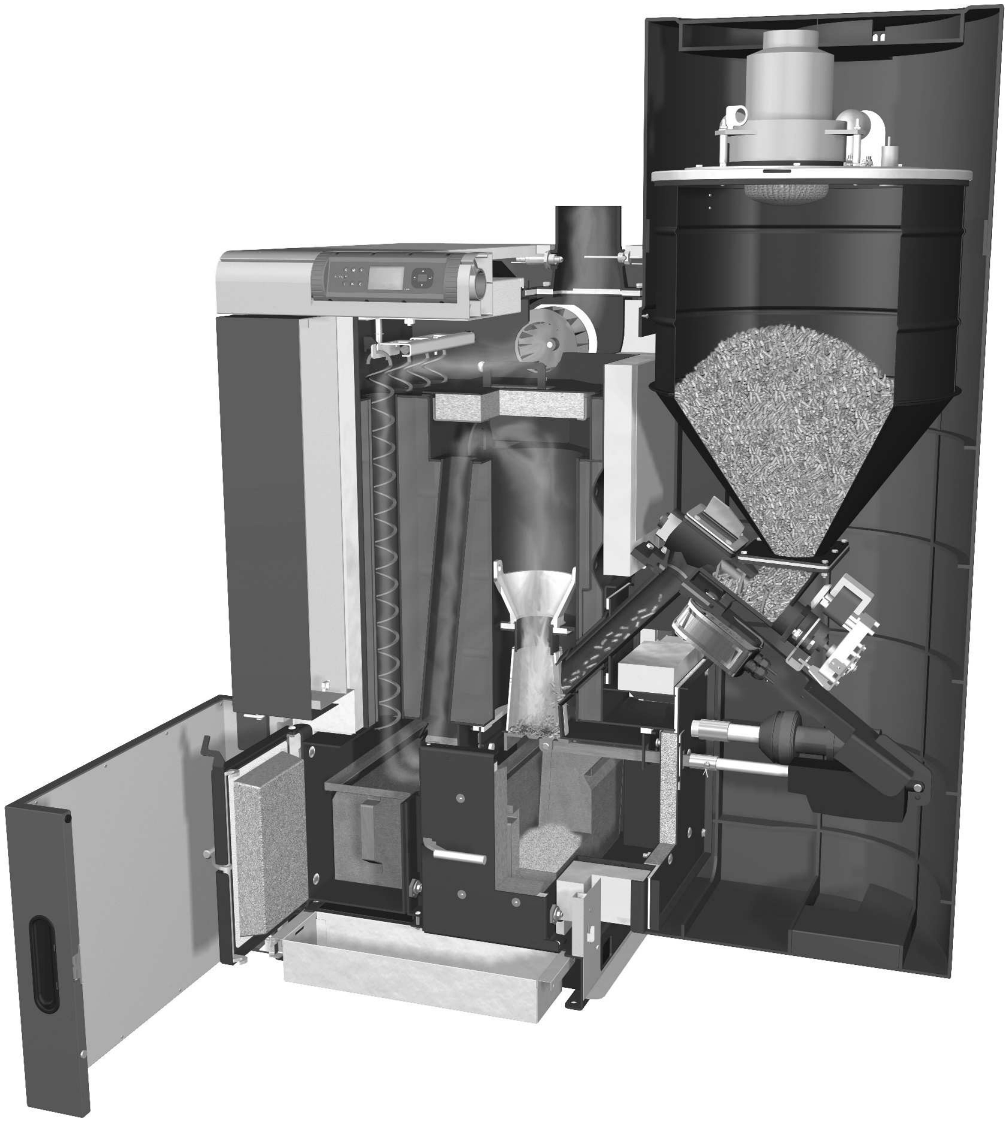


Figure 27: Pellet boiler with drop-shaft furnace, 8 to 60 kW [8]
282x314mm (300 x 300 DPI)

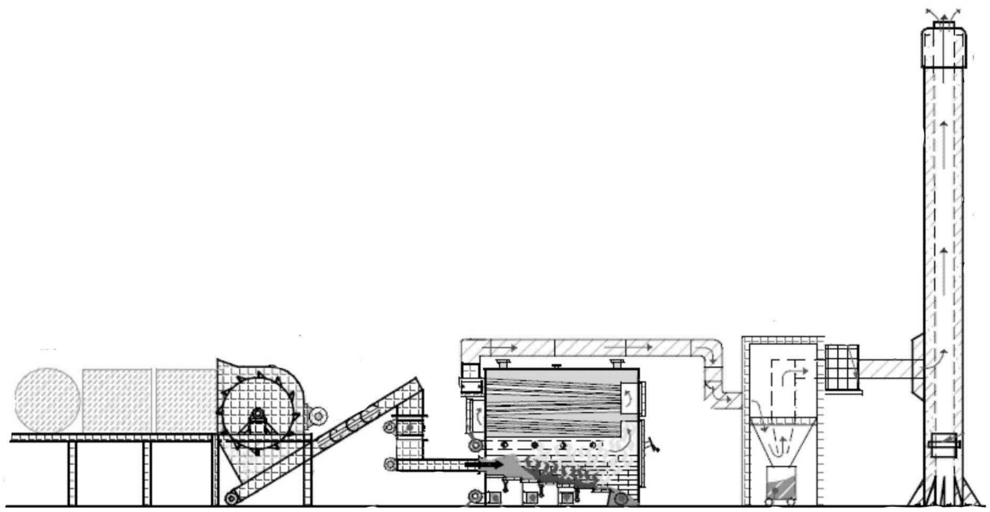


Figure 29: Straw bale firing unit with a moving grate furnace and a cyclone, thermal power 100 kW up to several 1.000 kW [24]
160x82mm (300 x 300 DPI)

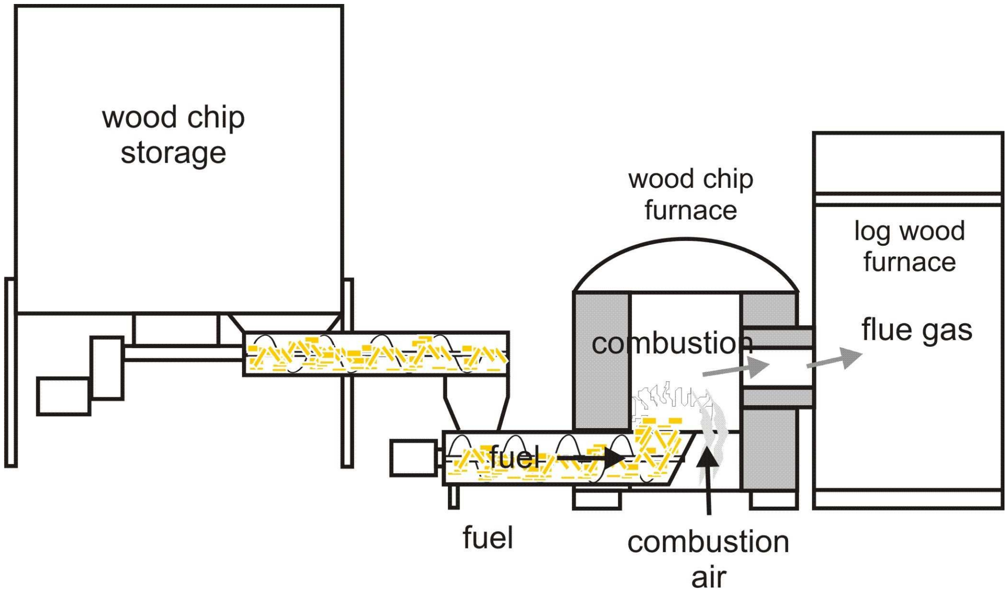


Figure 28: Wood chip-dual-chamber furnace with pre-oven [8]
176x103mm (300 x 300 DPI)

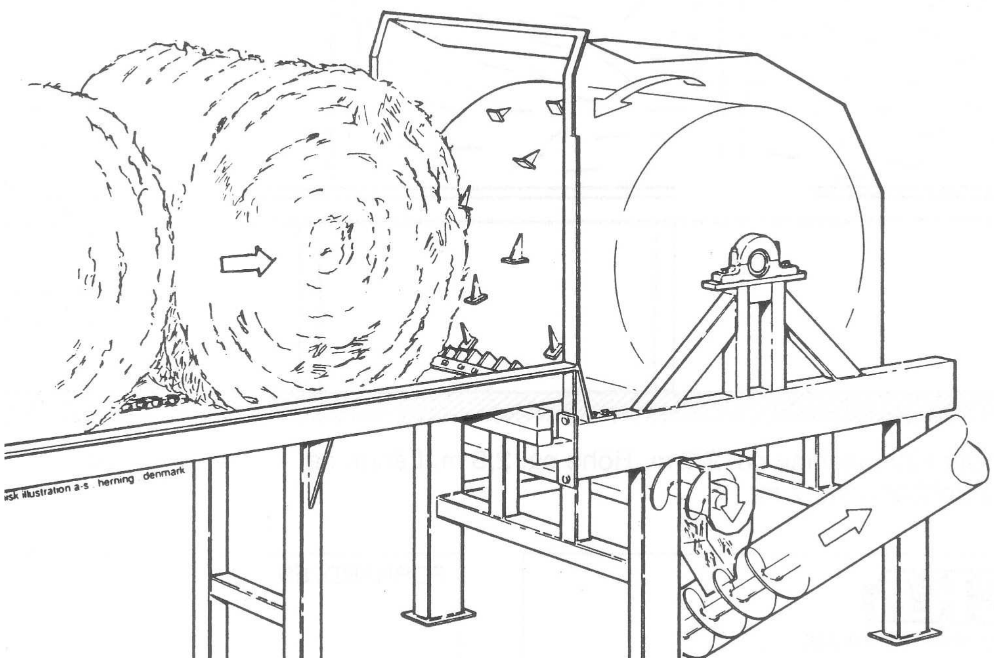


Figure 30: Straw bale cutting device [24]
402x266mm (96 x 96 DPI)

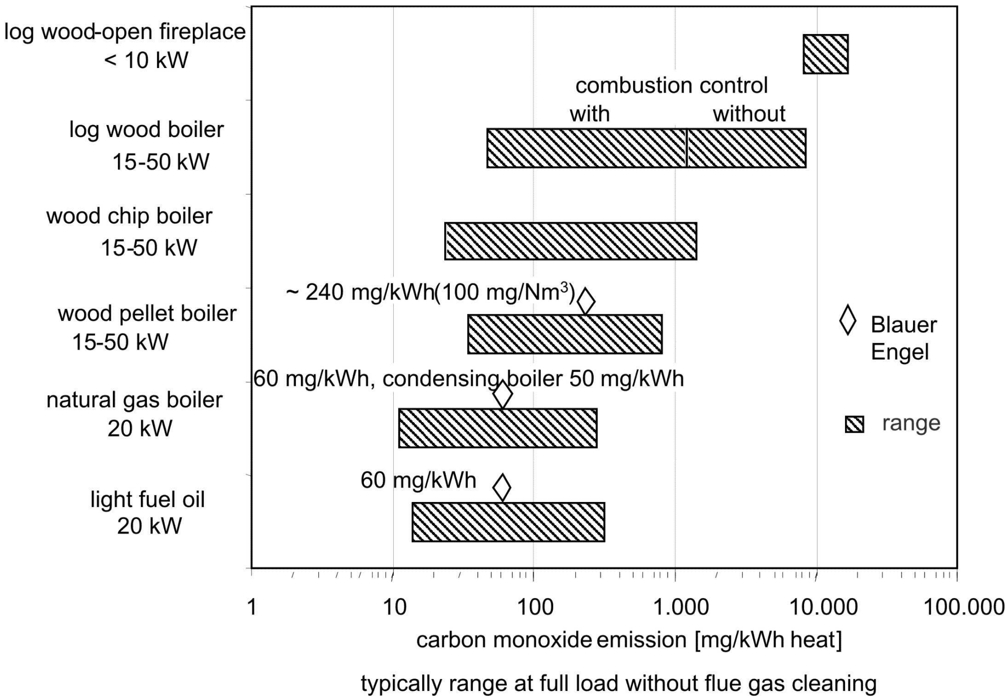


Figure 31: Carbon monoxide emissions of different combustors [10]
184x127mm (300 x 300 DPI)

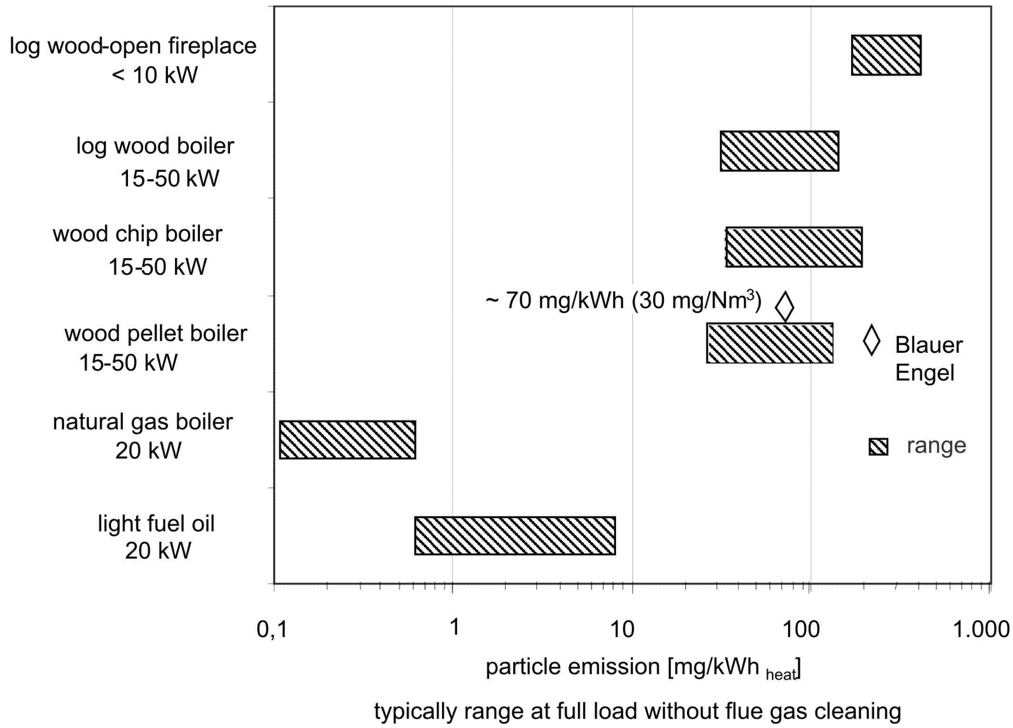


Figure 32: Particle emissions of different combustors [10]
Blauer Engel (blue angel) … Germans ecolabel for pellet stoves and pellet boilers, www.blauer-engel.de (2009)

180x129mm (300 x 300 DPI)