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Lot 15
Solid fuel small combustion installations

Task 4: Technical analysis of existing products

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4 Task 4 – Technical Analysis of Existing Products

This is the report for Task 4 of the Lot 15 preparatory study on eco-design of solid fuel small combustion installations (SCIs). The document incorporates stakeholder comments received following publication of the earlier Task 4 reports.

This task presents a technical analysis of solid fuel SCIs found on the EU-market as defined in Task 1. It includes general information on combustion technologies for small scale solid fuel combustion and information on the efficiency and pollutant emissions of SCIs. The information in Task 4 on product cases serves as input for identifying and defining Base cases in Task 5.

This task builds upon published information sources, the representative bodies of the SCI manufacturers and additional data collected on SCIs via a questionnaire to manufacturers and other stakeholders. It first describes the combustion process and combustion techniques, before presenting product-specific details on the design of solid fuel SCIs (Section §4.2), their distribution (Section 4.3) their emissions (Section 4.4) and their end-of-life (Section 4.6), to serve as input for the Life Cycle Assessment in Tasks 5.

4.1 COMBUSTION IN SOLID FUEL SCIs

Overview

Solid fuel SCIs can use a variety of fuels and combustion techniques, but in most cases the combustion process occurs on a fixed-bed (layer combustion). The combustion techniques vary a lot between small SCIs (<50kW) and larger ones (50-500kW), due both to technical and economic reasons. Accordingly, solid fuel SCIs can come in many shapes and sizes, ranging from older traditional SCIs that can be of very simple design to modern installations with significantly improved designs, perform a wide range of functions, and available in a wide capacity range.

The type and properties of the fuel affect the design and combustion techniques of an SCI. As explained in Task 1 (§ 1.1.5), solid fuels include a range of mineral fuels (e.g. hard coal, brown coal, manufactured solid fuels, coke), peat and wood fuels, which can come in raw form (e.g. wood logs) or be processed into briquettes or pellets, having different grain sizes and properties. Fuels size can vary significantly, e.g. wood logs are often 20-50 cm long, whereas wood pellets are typically 1 cm long. There are also different technical options to deal with the different fuel properties, since the fuel properties affect its combustibility. For instance, biomass fuels have a relatively high volatile matter content (twice that of hard coal), and a higher reactivity and velocity of combustion than solid mineral fuels. Therefore, advanced biomass combustion technologies use a separation of the combustion stages (two chamber combustion appliances) to optimise gas and char combustion.

The combustion techniques and the fuel properties also determine the emissions from solid fuel SCIs, along with operational practices (discussed in Task 3). Overall, solid fuel properties, particularly the physical characteristics and chemical composition, have a considerable influence not only on the combustion technology and the method of fuel stoking, but also on the emissions of pollutants[1].

4.1.1 COMBUSTION PROCESS

➔ Stages of combustion

Solid fuel combustion is a complex process in which fuel reacts with oxygen to produce heat energy. The combustion of fuel involves four main steps: drying (moisture evaporation), devolatilisation (with instantaneous pyrolysis inside the fuel grain, and gasification), char combustion, and gas phase oxidation (Figure 4-1).

The combustion process consists of consecutive homogeneous and heterogeneous reactions, that can occur simultaneously at different places in the SCI. The time used for each reaction depends on fuel size and properties, temperature, and combustion conditions. Usually the different reactions overlap, because their physical and thermal boundaries are not rigid. The main steps of solid fuel combustion are presented below.

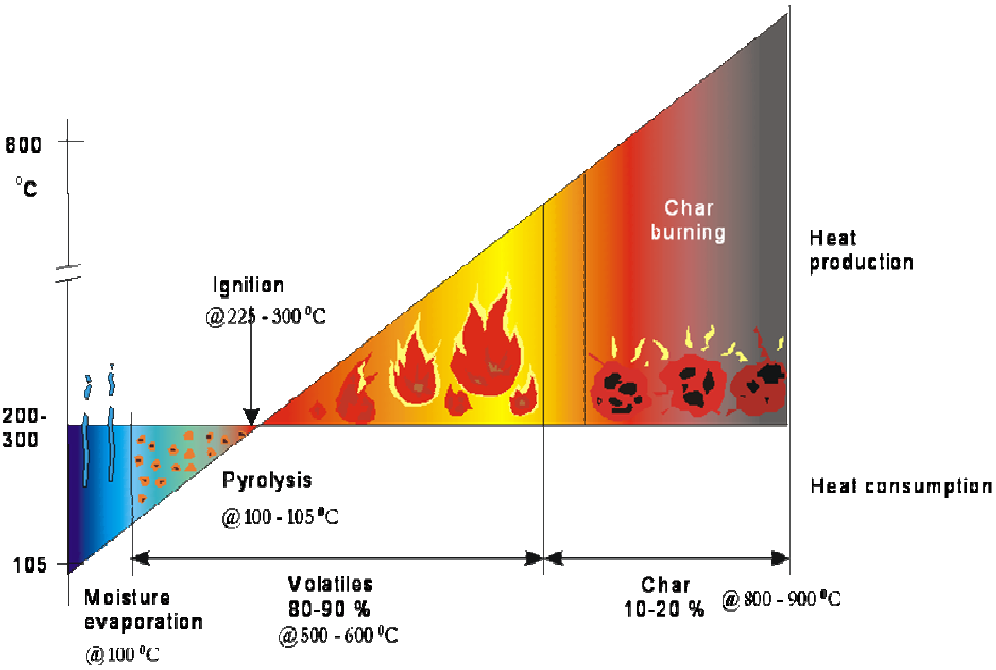

Figure 4-1: Phases of solid fuel (wood) combustion[2]

■ Drying

In the first phase, when the fuel approaches the combustion zone, it is heated up and moisture is driven off, with the water vapour passing to the exhaust gases. The drying of fuel depends on the fuel moisture content, with high moisture contents reducing

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[1] Van Loo S. and Koppejan J. (2002), Handbook of Biomass Combustion and Co-Firing; Twenty University Press, ISBN 9036517737. www.ieabioenergy.com (Task 32).

[2] Hall, A. (2007) Combustion Theory and Biomass Burner Technology, Biomass Energy Centre, www.bioenergygroup.org/uploads/documents/CleanHeatAndyHallPresentationI.ppt

heat absorption, and thus the temperature of the whole process. When the moisture level is too high, auto-thermal combustion, or combustion without any additional energy input, is not possible.

- Step 1: Fuel → dry fuel + water vapour

Devolatilisation (or pyrolysis)

Once the fuel has dried, carbonaceous fuel particles heat up. At high temperatures (up to 900°C) volatile matter begins to vaporise. The devolatilisation involves the release of carbon dioxide and chemically-bound water in the first place, followed by liquid then gaseous hydrocarbons and low volatile organic matter (or tar) at higher temperatures, and lastly by hydrogen and carbon monoxide (which will be burnt in the gasification phase). Char, consisting of carbon and ash (mineral matter), is produced from the solid residues of the pyrolysis. The composition of pyrolysis products depends on temperature and on the rate of the combustion process.

- Step 2: Fuel → char + volatiles (CH)

Combustion in gaseous phase (and gasification)

The volatile matter and some of the char react with oxygen to form carbon monoxide (CO), carbon dioxide (CO_2) and water (H_2O). The gasification occurs as the char reacts with carbon dioxide and water vapour to produce carbon monoxide and hydrogen. All burnable gaseous products from devolatilisation and char combustion take part in homogenous gaseous phase combustion reactions, which occur in the freeboard zone (above the fuel bed). In well-controlled combustion processes, these reactions can help reduce the emission of (hazardous) gaseous products arising from incomplete combustion.

- Step 3: Volatiles (CH) + O_2 → CO + H2O

  CO + ½ O2 = CO2

  C char)+ H2O → CO + H2

  C (char) + CO2 → 2CO

Char combustion

During the devolatilisation step, the ratio of C/H in the fuel increases, and the combustion of residual char starts. This is best described as the gradual oxidation of the reactive char (solid phase or heterogeneous reaction), and it takes place on the surface of char particles. The products of char combustion, besides heat, are slag, fly ash and gases (mainly CO and CO_2). The process depends on the rate of the chemical reaction and on the rate of diffusion of oxygen to the surface. As temperature increases, the rate of chemical reaction increases, and the reaction is limited by the oxygen diffusion process (the transfer of oxygen to the particle surface). In contrast, at lower temperatures, the process is limited by the chemical reaction, because the diffusion of oxygen to the particle surface is much higher than the oxygen consumption in chemical reactions.

- Step 4: $\phi C\ (char) + O_2 \rightarrow 2\ (\phi - 1)CO + (2 - \phi)CO_2$

➔ Requirements for complete combustion

As has been discussed in the Task 3 report (Section 3.2.1), three key conditions are necessary for achieving complete combustion (often referred to as the 'three Ts'): Temperature, Turbulence, and Time. Achieving the three conditions is dependent on the design of the appliance, as well as on appropriate fuel use and appropriate user behaviour. If the three Ts are not achieved, combustion is not optimal and the emissions of Products of Incomplete Combustion (PICs) increase. The PICs include pollutants such as carbon monoxide (CO), total suspended particulate matter (TSP), particulate matter of less than nominally 10 µm size (PM10), volatile organic compounds (VOC)), semivolatile organic compounds (SVOC) which contain polycyclic aromatic hydrocarbons (PAHs), and dioxins/furans (PCDD/Fs).

- **Temperature**: the combustion temperature affects primarily the degree of burn out of combustion compounds. At higher temperatures, oxidation reactions are faster and more complete than at lower ones. The combustion temperature is affected by the heat capacity, insulation and surface properties of the material used in the combustion chamber, as well as by the temperature of the combustion air (for example pre-heating the combustion air can considerably increase the temperature inside the combustion chamber). Moreover, for complete combustion, it is necessary to minimise the heat losses from the combustion chamber.

- **Turbulence**: good mixing of devolatisation and gasification products with air reduces the amount of air needed to achieve complete combustion (in other words, good mixing allows a lower excess air ratio) and also allows higher combustion temperatures. An adequate primary air supply, regulating the combustion rate, is very important for complete combustion. An overall lack of oxygen leads to smouldering combustion conditions. Although the combustion process may have an overall excess of air, in many cases there may be local air deficiency, due to poor fuel mixing. Overall or local air deficiency may also be caused by two common operational errors that reduce the gasification rate of the fuel: the restriction of the primary air supply, and fuel batches that are too large in relation to the size of the air supply. To provide good turbulence, air can be added in SCIs by forced or natural draught. In natural draught appliances, a chimney damper is used to control the flow conditions in the combustion chamber, but in practice too low and too high flow rates occur. A too low draught leads to insufficient air and the dying of the fire. A too high draught leads to a lower combustion temperature due to high excess air, or an increase in the gasification rate and an insufficiency of air, depending on the fuel surface area loaded. An excessive air flow through the combustion chamber can also agitate the fuel, char and ash leading to the entrainment of particles in the flue gas.

- **Time (residence time)**: due to often high volatile matter contents (e.g. for wood fuels), complete combustion of devolatilisation products is also important. Complete combustion requires a satisfactory residence time in oxidised zone of the product thermal decomposition solid fuel, and good mixing with secondary air. In double combustion chamber SCIs, introduction of heated secondary air on top of the primary combustion chamber enhances the ignition of the combustion gases in the secondary combustion chamber. In modern boilers, O2 sensors are increasingly used to monitor and adjust excess air levels to ensure good combustion conditions.

➔ Combustion management in solid fuel SCIs

As discussed in Task 3 (Section 3.2.1) and above, combustion conditions depend on the rule of the "3 Ts" and on the design of the appliance, and therefore indirectly on fuel properties (e.g. geometry of the combustion chamber, heat and mass transfer in the reaction zone). Combustion management may also depend directly on fuel properties (e.g. heating value, heat capacity, particle size, moisture content) and on operational practices (e.g. fuel seasoning, distribution of the fuel inside the combustion chamber, combustion rates, kindling approaches).

Regarding combustion conditions, the main role of the solid fuel SCI is to:

- organise the combustion process
- supply fuel and air to the combustion chamber, in the right proportions
- ensure an efficient transfer of the released heat (to the surroundings and/or for water circulation)
- ensure the safe removal of exhaust gases
- provide an ash collection mechanism

4.1.2 TECHNICAL SPECIFICATIONS OF SOLID FUEL SCIS

➔ Main components of solid fuel SCIs

A typical solid fuel SCI comprises a grate on which the fuel is loaded, a combustion chamber for burning the fuel, an air supply, various combustion controls, and an ash pit for collection of the solid fuel combustion residues. Automatic appliances may also include a fuel loading system.

- **Grate**: in solid fuel SCIs, fuel is generally loaded in a 'bed' on a cast-iron or steel grate. The grate is usually fixed inside the combustion chamber, but it can also be raked, agitated, or rotated to mix the fuel and remove ashes. Traditionally, solid fuel SCIs are equipped with a fixed grate, sometimes also referred to as a bottom grate. More recent appliances can include rocking and pusher grates that comprise a mixture of static and moving grate elements to move the fuel through the combustion chamber. Alternatively, in the largest appliances, the entire grate can move, transporting and agitating fuel through a combustion chamber and depositing ash (i.e. travelling-grate combustion). Fuel can be added to these bed arrangements from above (overfeed), or below (underfed), or from any intermediate position.
- **Combustion chamber**: the combustion chamber is the central part of the appliance, where fuel combustion occurs. In the simplest appliances, there may be no defined chamber (for example, fuel burning on a simple grate or firebasket or logs lying on a hearth), however, most SCIs include a separated combustion chamber. This chamber is made of a masonry, steel, or cast iron shell which is lined by refractory material. The design of the combustion chamber depends on the fuel type, fuel charging method, the desired

air/exhaust flow path, and the presence of a heat exchanger (in the case of boilers).

- **Primary air supply system**: primary air can be supplied either by natural or by forced draught. Many domestic SCIs operate under natural draught, i.e. the air is drawn through the appliance by the draught created by the chimney and the buoyancy of the hot exhaust gases passing up the chimney. Manual or automatic flaps and dampers are used to control the overall air flow and direct the combustion air to different parts of the combustion chamber. Active systems employing fans (forced-draught), powered dampers and lambda (oxygen) sensors may be used in domestic stand-alone boilers and pellet stoves, and in most larger SCIs (>50 kW)3. Automatic air controls can be bimetallic devices which are activated as temperature increases (or decreases). Most appliances draw combustion air from the room in which they are located but there are appliances which can draw air from outside the room and room-sealed appliances.

- **Control system**: fuel and combustion air can be controlled manually or via automatic control systems. Many domestic solid fuel SCIs are entirely manually operated, and the user loads the fuel and adjusts the air supply himself. However, automatic fuel and combustion air control systems are also available, with varying levels of sophistication. Basic automatic controls regulate air flow, depending on air or water temperature, and may be simple bimetallic devices. More elaborate systems provide an electronic control of fuel-feed and air distribution, which optimises the combustion and provides the heat output at defined times, so as to achieve user-defined room and/or water temperature.

- **Fuel charging system**: fuel can be added to the bed either manually, by gravity, or by some mechanical device. For most domestic SCIs, fuel loading is done manually by the user, either directly to the firebed or to an integral fuel hopper. Integral hoppers are usually designed to hold one or two days' fuel supply (three or five days for retort coal boilers), for users convenience. Such hoppers are common in pellet stoves and boilers with an output below 50 kW. In contrast, boilers with a capacity above 50 kW tend to have external fuel storage to provide longer term operation (several weeks). For larger boilers (>50 kW) a fuel transfer system, by auger or similar devices, is used to automate the charging of fuel to the appliance. The system typically includes a storage silo (a room, rigid silo, or flexible silo), an agitation system to direct the fuel to a screw feeder (auger) which transfers the fuel to the boiler's feed auger. The size of the fuel store and the length of the auger (and consequent electricity demand) depend on the needs of the user.

- **Ash pit**: the ash pit is an enclosed chamber for accumulating ash. It may include a small steel ash pan for the convenient retention and removal of the ashes. While the provision of an ash pit for ash collection is essential for solid mineral fuel SCIs, many smaller biomass SCIs intended only for intermittent use may not have an ash pit. In the latter, ash accumulates in the combustion chamber or hearth and needs to be removed periodically.

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[3] However, the EN Standards for residential cookers (EN 12815), inset appliances (EN 13229), room-heaters (EN 13240) and slow heat release appliances (EN 15250) do not cover appliances with fan-assisted combustion air.

- **Heat exchanger**: appliances which provide indirect heating incorporate a heat exchanger (boiler). In solid fuel SCIs, steel (or cast-iron) heat exchangers are located after the combustion chamber (downstream) and comprise an outer shell containing water through which tubes pass carrying the hot exhaust gases. Heat transfer to the water occurs through the tube wall.
- **Convection heating system**: a number of appliances incorporate ducting to allow a warm air, convection heating functionality. Some appliances also incorporate small air fans to aid air circulation. This can boost the effective heat output of the appliance.
- **Chimney**: while the chimney is generally not a part of the appliance itself, it is essential to guarantee the safe extraction of flue gases away from the appliance, without damaging the building or its occupants. Some SCIs have a leak-tight connection to the chimney, which for open fires, may be achieved through a hood or fireplace recess. Other SCIs include a flue spigot or socket and are connected to the chimney flue through a suitable connecting steel or cast iron duct. Masonry and metal chimneys are commonly used for SCIs.
- **Fireplace recess**: the fireplace recess is a space in the wall or chimney breast into which a heating appliance may be installed. It is constructed of non-combustible materials and provides access to the chimney flue.

➔ Combustion management techniques

Combustion techniques employed in solid fuel SCIs can be divided into three broad categories, according to the flow directions of the combustion air and of the fuel.

■ Counter-current flow (overfire, overfeed combustion)

In counter-current flow combustion, the fuel is manually fed onto the top of the burning fuel bed, while the primary combustion air passes through the fuel layer in the opposite direction to the fuel stream (Figure 4-2A). The flue gases then enter flue gas pipe (old design) or a second combustion chamber, where secondary air supply also arrives from the bottom, allowing the mixing of the combustion gases for a more complete combustion. This process, also known as ‘overfeed or overfire combustion’, is the most widely used in residential solid fuel SCIs (stoves, fireplaces, cookers and boilers), since it is the simplest and cheapest combustion technique.

In overfire (overfeed) combustion, the fuel is added to the top of the firebed and travels downward by gravity, going through the different steps of combustion (drying, devolatilisation, gasification and char combustion) as it passes through the firebed towards the grate (Figure 4-2B). In contrast, the primary air passes up through the firebed, carrying the products of gasification and devolatilisation up for combustion at the top or above the firebed (Figure 4-2B). This combustion arrangement is known as ‘overfire’ combustion because the combustion of devolatilisation products is occurring above the firebed. Overfire combustion is characterised by a brief and intense combustion of the entire fuel batch, with relatively low temperatures of the volatile matter in the oxidising zone (between 400°C to 900°C). Overfire combustion is also characterised by a local lack of oxygen, due to consumption of oxygen in the primary air and poor mixing with secondary air. These conditions cause incomplete combustion, creating high levels of pollutants such as TSP, CO, NMVOC and PAH. The efficiency of overfire appliances is usually in the range of 50% to 65%, depending on the design and the load capacity. Emissions of pollutants can increase due to the "cold wall effect" where the surrounding combustion chamber reduces temperature and hence makes complete combustion difficult. Emissions can also increase in overfire boilers operated at low load, since reduced loads necessitate a reduced air supply, leading to temperatures too low for complete combustion. In development design of overfire SCIs which use secondary air supply the efficiency increase above 80% and emission of pollutants decreases in high degrees that are achieving of a cross-flow flow combustion level.

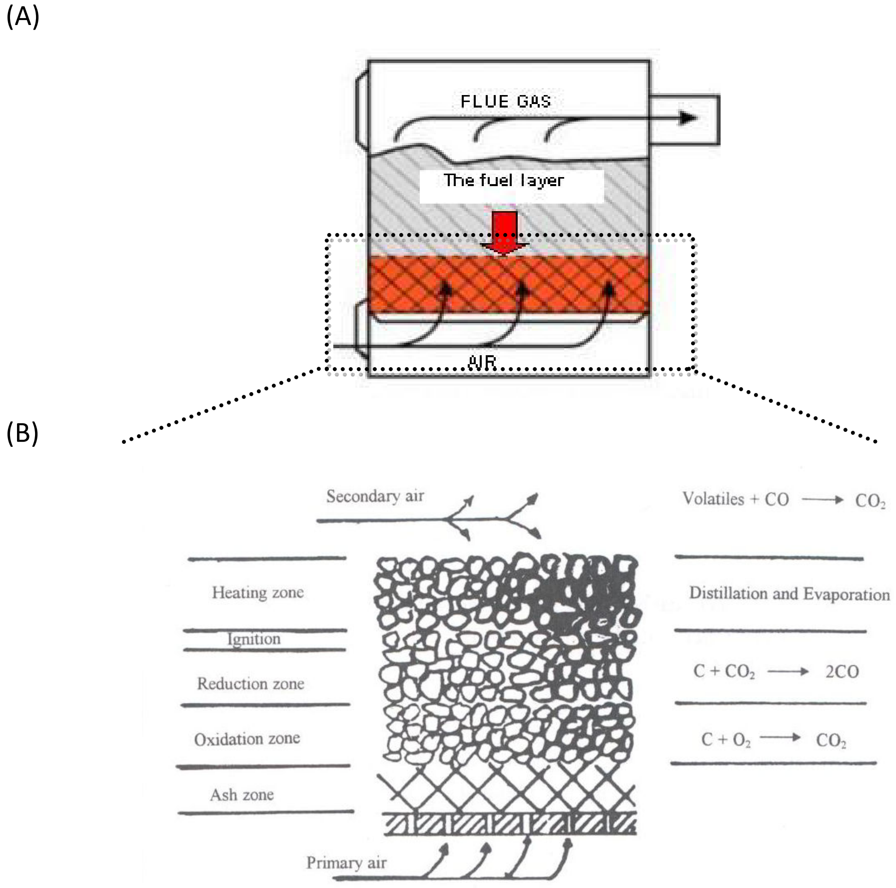

Figure 4-2: Overfire technique (A) and detail of the overfire combustion process (B)[4]

- **Co-current flow (upperfire overfeed combustion)**

This combustion technique, called sometimes the clean solid fuel (coal/biomass) combustion in SCIs. In co-current flow combustion, the combustion air and the fuel are guided in the same direction Figure 4-3. The raw fuel is fed from below the plane of fuel ignition. Before the fuel reaches the layer of ignition the moisture is evaporated and some of volatile matter is released. These gases then pass through the burning fuel bed where the temperature is about 1100°C. The organic matter formed within

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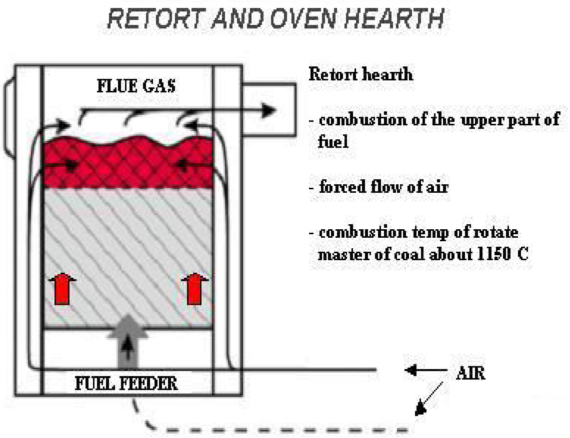
[4] [A] Kubica (2003) "Environment Pollutants from Thermal Processing of Fuels and Biomass", and "Thermochemical Transformation of Coal and Biomass" in Termochemical Processing of Coal and Biomass; pp 145-232, ISBN 83-913434-1-3, 2003, Zabrze-Kraków (Polish) and and detail of the overfeed combustion process [B] Williams A., Pourkashanian M., Jones J.M., Skorupska N. (2000) Combustion and Gasification of Coal; Copyright Taylor&Francis, New York, ISBN 1-56032-549-6, pp.125.

devolatilisation, pyrolysis and gasification processes is almost completely combusted in high temperature of combusted fuel char layer. A gasification process occurs in a major degree in comparison with counter-current flow combustion. This type of combustion process use of automatic supply fuel usually. The combustion air is divided in primary and secondary air and a control system for distribution is applied. A control of supply fuel to the combustion chamber is applied also. Co-current flow combustion achieves to supply fuel and air to the combustion chamber, in the right proportions. The three key conditions are necessary for achieving complete combustion are provided also, that are the combustion temperature, good mixing of devolatisation/pyrolysis and gasification products with combustion air and residence time of the product thermal decomposition solid fuel and combustion air mixture in oxidation zone. This combustion process organisation and the conditions ensure of high thermal efficiency (above 85%) and very low level emission of pollutants (PICs - CO, VOC, PAHs, PM and PCDD/Fs also). It all depends on the design of the appliance, as well as on appropriate fuel use and appropriate user behaviour. Co-current flow upperfire combustion can be achieved either by up-draught or down-draught techniques.

(A)



(B)

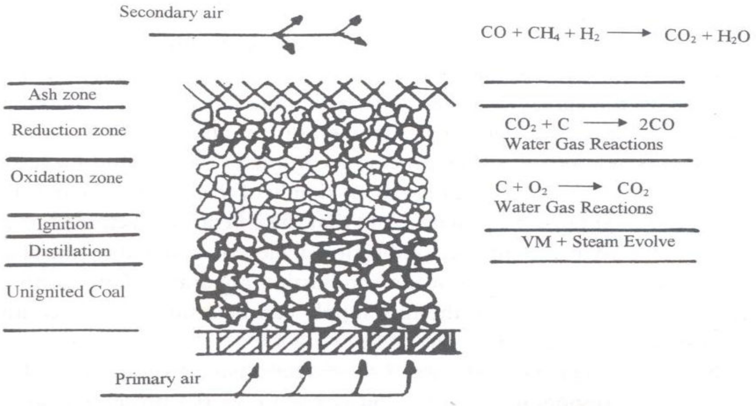


Figure 4-3: Upper-fire combustion technique (A) and detail of combustion zone (B)[5].

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[5] [A] Kubica (2003) "Environment Pollutants from Thermal Processing of Fuels and Biomass", and "Thermochemical Transformation of Coal and Biomass" in Termochemical Processing of Coal and Biomass; pp 145-232, ISBN 83-913434-1-3, 2003, Zabrze-Kraków (Polish) [B] Williams A.,

- **Down-draught, upperfire combustion**

In down-draught combustion, which is mainly applied in biomass (wood) combustion, the fuel and primary air are arranged to enter the top of the combustion chamber, while secondary air enters the combustion zone from the bottom (Figure 4-4). The solid fuel charge is loaded into the hopper, and slowly added to the fire from above the grate. The products of combustion are drawn down through the fuel bed into a separate combustion chamber. Accordingly, down-draught boilers have two chambers, a first chamber where the fuel is fed for drying, devolatilisation, gasification and layer combustion, and a second chamber which provides a region of high temperature, residence time and mixing with secondary air to facilitate complete combustion of the evolved combustable gases. The exhaust gases are typically drawn through the combustion chamber by a fan. Down-draught combustion is still an 'upperfire' technique, because the combustion occurs within and immediately beyond the firebed. The technique is particularly used in modern wood log boilers (gasifier boiler), but also in some stoves and fireplaces. Down-draught combustion achieves high combustion efficiencies (above 85%) and, as a result low PICs and particulate emissions.

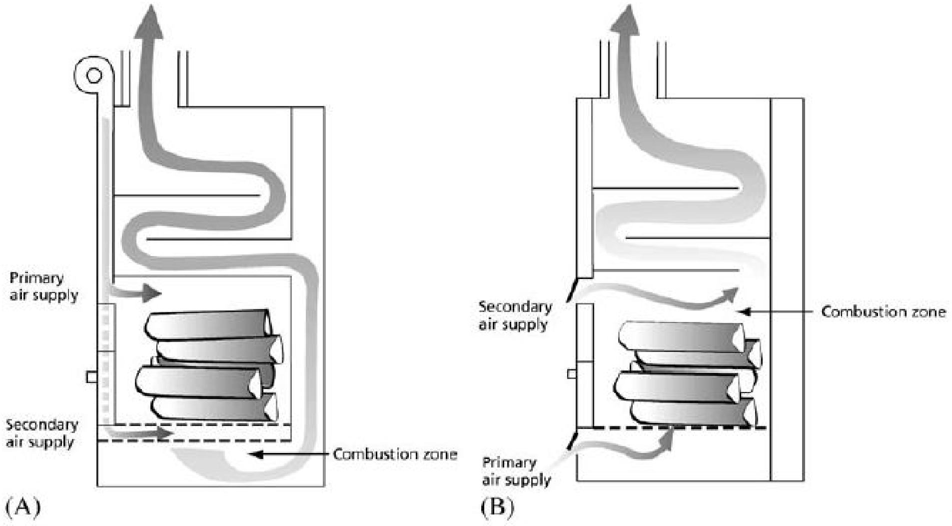

Figure 4-4: : Down-draught combustion (A) and up-draught combustion (B) [6]

- **Up-draught, upperfire (underfeed) combustion,**

In up-draught combustion, the fuel and primary air are arranged to enter the bottom of the combustion chamber. The raw fuel is therefore fed from below the plane of fuel ignition. The flue gases then enter a second part of combustion chamber, where secondary air supply also arrives from the bottom (Figure 4-4B), allowing the mixing of the combustion gases for a more complete combustion. A deflector plate is usually built within the second part of chamber to improve turbulence and mixing of the products of thermal decomposition, fuel and combustion air in oxidation zone. This combustion technique is used in stoker boiler with automatic fuel supply to the stoker or burner built in combustion chamber (Figure 4-5). The solid fuel with regular and

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Pourkashanian M., Jones J.M., Skorupska N. (2000) Combustion and Gasification of Coal; Copyright Taylor&Francis, New York, ISBN 1-56032-549-6, pp.125.

[6] [Johansson et al. (2004) Atmospheric Environment 38: 4183-4195]

small grain size, usually 5mm – 30 mm, is used. Distribution and control a system for the primary and secondary air as well as a control of fuel supply is applied. Stoker boiler is characterised by higher efficiency; usually above 80% (some of them can achieve more than 85%). This technology of combustion, results in decreased emissions resulting from incomplete combustion (PICs, PM and PCDD/Fs), however NOx emission increases due to the change of combustion process organisation that may be due to combustion temperature increase. But the mechanism for increase of NOx concentration in SCI flue gases is not well understood.

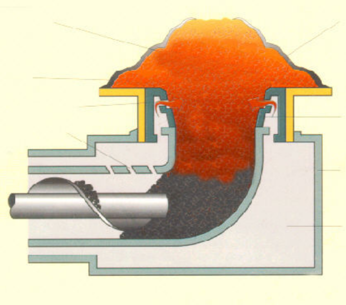

Figure 4-5: A design of coal stoker burner [7]

- **Cross-flow flow (underfire combustion)**

In cross-current flow, the combustion air passes across the fuel stream, generally parallel to the grate, whereas the removal of the flue gas occur towards the middle of the combustion chamber. The process bonds two above described combustion techniques organisation in a fixed-bed (layer combustion) and is also known as underfire combustion.It is essentially a variant of co-current flow but with a degree of counter-current flow also employed. In under-fire combustion appliances, the combustion chamber is a divided in two chamber (Figure 4-6). The first part is used for fuel storage and for partial devolatilisation and combustion of the fuel layer. The combustion gases are oxidised in the second part of the combustion chamber where secondary air supply also arrives from the bottom, allowing the mixing of the combustion gases for a more complete combustion. The combustion in under-fire boilers is more stable than in overfire boilers, due to the continuous gravitational feeding of the fuel into the fire bed. This results in higher energy efficiency (75-90%) and lower emissions of PICs in comparison to overfire combustion. However, pollutant emissions can still be high, due to a “cold wall effect” for instance or poor control of air distribution. Under-fire boilers (Figure 4-6) have manual fuel-feeding systems, semi-automatic or automatic fuel-feeding (stationary or sloping grates, stoker). Older-design boilers use natural draught, whereas advanced designs incorporate a fan-assisted control of flue gases and control systems for primary and secondary air supply and fuel supply, which ensures achieving conditions necessary for complete combustion – suitable amount of air, temperature, turbulence, and residence time.

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[7] Kubica (2003) “Environment Pollutants from Thermal Processing of Fuels and Biomass”, and “Thermochemical Transformation of Coal and Biomass” in Termochemical Processing of Coal and Biomass; pp 145-232, ISBN 83-913434-1-3, 2003, Zabrze-Kraków (Polish)

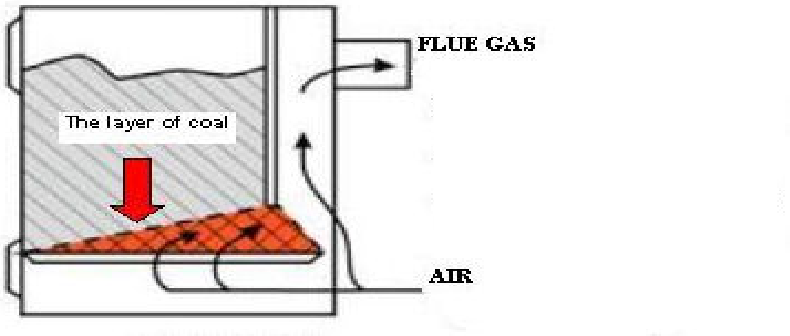

Figure 4-6: Underfire combustion technique [8]

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[8] Kubica (2003) “Environment Pollutants from Thermal Processing of Fuels and Biomass”, and “Thermochemical Transformation of Coal and Biomass” in Termochemical Processing of Coal and Biomass; pp 145-232, ISBN 83-913434-1-3, 2003, Zabrze-Kraków (Polish)

Table 4-1: Categorisation of residential direct heating solid fuel appliances

Appliance categories[1]	Appliance features						Typical output
	Combustion air	Fuel supply	Primary air control [2]	Secondary air design[3]	Main biomass Fuel	Main mineral Fuel [4]	kW
Open fireplace	Natural draught	Manual	No	No	Wood logs	MSF	5-15
Insert fireplace	Natural draught	Manual	No	No	Wood logs	MSF	5-10
Insert+ IIary air	Natural draught	Manual	No	Yes	Wood logs	MSF	5-10
Closed fireplace	Natural draught	Manual	No	No	Wood logs	MSF	5-15
Closed fireplace + IIary air	Natural draught	Manual	No	Yes	Wood logs	MSF	5-15
Traditional cooker	Natural draught	Manual	No	No	Wood logs	Coal	5-15
Advanced cooker	Natural draught	Manual	No	Yes	Wood logs	Coal	5-15
Slow heat release stove	Natural draught	Manual	No	Yes	Wood logs	-	2-7
Kachelofen	Natural draught	Manual	No	No	Wood logs	MSF	2-7
Traditional stove	Natural draught	Manual	No	No	Wood logs	Coal	6-10
Modern stove (intermittent)	Natural draught	Manual	No	Yes	Wood logs	Coal	6-10
Continuous burning stove	Natural draught	Manual	No	No	Wood logs	Coal	6-10
Advanced stove	Natural draught	Manual	Yes	Yes	Wood logs	Coal	6-10
Pellet stove	Forced draught	Forced	Yes	Yes	Wood pellets	-	5-15

Notes

1. Main function of appliance.
2. In some instances there is primary air control but this is considered to have minor significance with respect to environmental performance.
3. Secondary air design indicates whether appliances include provision for directed secondary air injection as opposed to incidental secondary air input.
4. MSF is manufactured solid mineral fuel, includes briquettes (patent fuels from hard/sub-bituminous coal and brown coal briquettes), coke,
5. Coal: refers to hard coal (anthracite, steam coal and sub-bituminous coal) and brown coal .

Table 4-2: Categorisation of indirect heating solid fuel appliances

Boiler categorisation [1]		Boiler features						Typical output
Size	Description	**Combustion air**	**Fuel supply**	**Primary air control [2]**	**Secondary air design[3]**	**Main biomass fuel**	**Main mineral Fuel**	**kW**
<50kW	Conventional, overfeed	Natural draught	Manual	No	No	Wood logs	Coal	10-50
	Conventional + Iary air	Natural draught	Manual	Yes	No	Wood logs	Coal	15-50
	Conventional + IIary air	Forced draught	Manual	Yes	Yes	Wood logs	Coal	15-50
	Conventional + IIary air	Forced draught	Manual	Yes	Yes	Wood chips	Coal	15-50
	Advanced, gravity feed	Natural draught	Manual	Yes	No	Wood logs	Coal	15-50
	Advanced, gravity feed	Forced draught	Manual	Yes	Yes	Wood logs	Coal	15-50
	Downdraught (gasifying)	Forced draught	Manual	Yes	Yes	Wood logs	Coal	15-50
	Stoker	Forced draught	Automatic	Yes	Yes	Wood chip	Coal	15-50
	Push-down	Forced draught	Automatic	Yes	Yes	Wood logs	Coal	15-50
	Pellet	Forced draught	Automatic	Yes	Yes	Wood pellets	-	15-50
50-500kW	Advanced, gravity feed	Natural draught	Manual	Yes	No	Wood logs	Coal	50-100
	Advanced, gravity feed	Forced draught	Manual	Yes	Yes	Wood logs	Coal	50-250
	Conventional + IIary air	Forced draught	Manual	Yes	Yes	Wood chips	Coal	50-300
	Downdraught (gasifying)	Forced draught	Manual	Yes	Yes	Wood logs	Coal	50-250
	Underfeed stoker	Forced draught	Automatic	Yes	Yes	Wood chips	Coal	50-500
	Pellet boiler	Forced draught	Automatic	Yes	Yes	Wood pellets	-	50-500
	Overfeed stoker moving grate	Forced draught	Automatic	Yes	Yes	Wood chips	-	300-500
	Underfeed rotating grate	Forced draught	Automatic	Yes	Yes	Wood chips	-	300-500

Notes

1. Direct heating appliances which incorporate a secondary indirect heating facility are considered to have the same general categorisation as direct appliances.
2. In some instances there is primary air control but this is considered to have minor significance with respect to environmental performance.
3. Secondary air design indicates whether appliances include provision for directed secondary air injection as opposed to incidental secondary air input
4. Coal: refers to hard coal (anthracite, steam coal and sub-bituminous coal) and brown coal

4.2 PRODUCTION PHASE

The Bill of Material (BoM) data presented in this section is derived from two sources:

- Questionnaire to manufacturers, sent in the context of this study
- National market data for direct heating appliances, BoM data from HKI[9] which is representative of both the current and the historical appliances sold on the German market, and BoM data from CIV[10] which is representative of the appliances sold by Belgian manufacturers. For indirect heating appliances, BoM data was obtained from ABC-energy, which is representative of 'state of the art' wood log and pellet boilers in the Austrian market.

The above two data are complementary: the questionnaire provides a picture of the appliances sold in Europe today. But, depending on the questionnaire response rate, these data may sometimes be limited. In addition, questionnaire data may be biased towards the better appliances available on the EU market, since the manufacturers contacted are typically among the bigger manufacturers of solid fuel SCIs in Europe. In contrast, national market data are representative of the entire range of appliances on the market, but they are characteristic of a specific Member State, rather than for the whole EU. Accordingly, the BoM data from questionnaires are systematically compared with BoM data from national sources.

4.2.1 OPEN FIREPLACES

➔ Description

Open fireplaces have a simple design and consist of a basic combustion chamber with large fixed openings in front of the firebed. The combustion chamber sits within a fireplace recess or hood, which is directly connected to the chimney. The fireplace recess consists of a non-combustible surround, comprising the hearth, fireback, sidewalls, and flue. When installed under a hood, open fireplaces can sit in a very large fireplace recess (Figure 4-4), or in the middle of a room (Figure 4-5). Some open fireplaces include a flue damper above the combustion area to limit the room air intake (and resulting heat losses) when the fire is not being used. Some fireplace surrounds also incorporate air ducts and a fan to provide warm air (convection) heating.

Open fireplaces are manually loaded with overfire overfeed combustion and their capacity ranges between 5-15 kW. Although often used only for decorative purposes, a number of open fireplaces sold on the market include hot water boilers providing a thermal output of up to about 12 kW, thus providing central-heating from a low cost living-room appliance. Open fireplaces exist in different shapes and forms:

- In its simplest form, an open fireplace consists of a cast-iron firebasket, which supports and retains the fuel bed. Such devices have no combustion controls (see Figure 4-4a and b).

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[9] HKI (Industrieverband Haus-, Heiz und Küchentechnik e.V.) is the German association of domestic heating and cooking appliances.

[10] CIV is the Belgian association for domestic heating (it comprises manufacturers and importers of stoves and fireplaces).

- The next tier of appliances are the grate and firefront, which are designed to be used in an existing masonry fireplace recess (e.g. a replacement grate and firefront in Figure 4-4c, or an installed grate and firefront in Figure 4-4d,e). The masonry fireplace recess forms the side and rear walls of the combustion area. Such devices have a very basic air control, primarily to control the primary air supply below the grate and towards the front of the firebed.
- Finally, there are appliances which include the entire combustion chamber (and boiler where fitted), and are designed to be fitted into an existing recess/enclosure (see Figure 4-4f). Such appliances include limited combustion air controls. There are also standalone open products on the market which are intended to be placed within a fireplace recess and include a basic grate as well as a fireplace surround (see Figure 4-5).

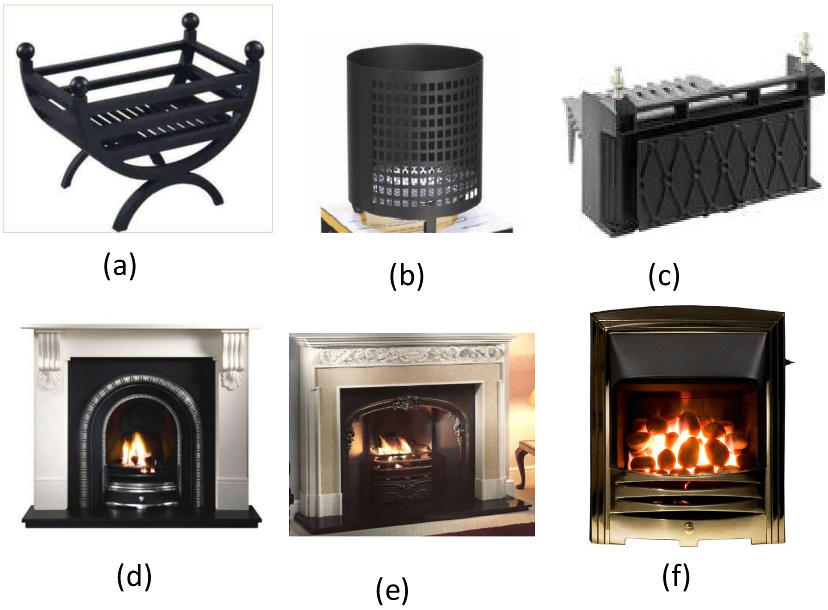

Figure 4-4: Examples of open fireplaces and firebaskets[11]

EN 13229 covers open fireplaces with or without boilers, but does not cover simple appliances such as firebaskets or grates and firefronts supplied for installation into an existing fireplace. Therefore, appliances covered by EN 13229 correspond only to the third-tier type, which incorporate the entire combustion chamber. **The definition of open fireplace products used in the rest of this study corresponds only to the third-tier type of open fireplaces covered by the EN 13229 standard.**

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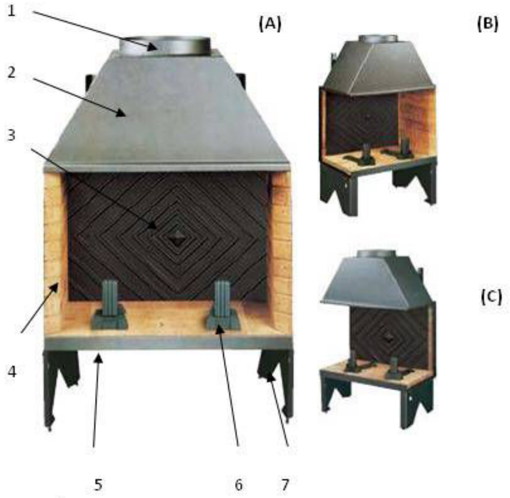
[11] From www.fireplacesareus.co.uk and www.percydoughty.co.uk



Legend:
(A) traditional open fireplace, (B) corner type open fireplace, (C) panoramic type open fireplace
- Flue_
- Steel roof
- Back wall
- Chamotte bricks

5. Steel coating
6. Wood holder
7. Leg

Figure 4-5: Example of a free-standing log-burning open fireplace[12]

➔ Bill of Materials

Bill of Materials (BoM) data from questionnaires were received for three EN 13229 open fireplaces and are presented in Table 4-3. The three fireplaces burn wood logs and exhibit a similar content of cast iron, steel, and stone/ceramics, which may reflect the fact that all data have come from a single manufacturer. Most of the weight of the appliance is due to stone/ceramics, which reflects the use of these materials for the fireplace surround.

The questionnaire data for the three EN13229 open fireplaces are compared with data on open fireplaces from HKI (for appliances in Germany), and with data on firebaskets and firefronts[13] in (Table 4-4). Firebaskets and firefronts consist only of cast-iron, and represent less than 10% of the weight of the EN13229 open fireplaces from the questionnaire. The HKI data for open fireplaces are very limited, providing only the stone/ceramics content, which is substantially lower than that observed in the questionnaire data. This difference is believed to reflect the fact that in the questionnaire EN13229 products, a large quantity of stone material is actually used for the fireplace surround.

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[12] Source: www.koperfam.pl

[13] Data collected by the Lot 15 team from inronmongers/DIY outlets

Table 4-3: BoM summary for fireplaces (from a single manufacturer)

3 Product cases			**Content**		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	12.2	12.0	10.5	14.0	1.8
Weight [kg]	313.3	300.0	270.0	370.0	51.3
			Content [%]		
Steel	2.0	2.0	2.0	2.0	0.0
Cast Iron	8.0	8.0	8.0	8.0	0.0
Stone/ceramics	86.7	90.0	80.0	90.0	5.8
Packaging			**Content [kg]**		
Plastic	1	1	1	1	0
Wood	12	12	12	12	0

Table 4-4: BoM summary for open fireplaces

Product	**Content**			
	Firebasket, firefront	**3 Open appliances**		**HKI**
		Mean	**Median**	
Output [kW]	5-15	12.2	12.0	10-30
Weight [kg]	5-25	313.3	300.0	-
	Content [%]			
Steel	0	2.0	2.0	-
Cast Iron	100	8.0	8.0	-
Coatings	0	0.0	0.0	<1
Electronics	0	0.0	0.0	-
Stone/ceramics	0 (0 kg)	86.7 (271 kg)	90.0 (270 kg)	- (10-30 kg)
Glass	0	0.0	0.0	-
Sealing compound	0	0.0	0.0	-
Packaging	**Content (kg)**			
Plastic	<1	1	1	<1
Cardboard	<1	0	0	-
Wood	0	12	12	10-12

Note: '-' denotes no data available

4.2.2 CLOSED FIREPLACES/ FIREPLACE INSERTS

➔ Description

Closed fireplaces and fireplace inserts are often used as supplementary heating appliances in residential dwellings, primarily for aesthetic reasons and usually have capacities between 5-15 kW. The appliance can either be a freestanding device (closed fireplace) or recessed into the building wall or into an enclosure (fireplace insert). The key difference compared to an open fireplace is that the combustion chamber is behind a firedoor, which provides greater control over the air supply in the combustion zone and reduces heat losses into the room. Depending on their design features, closed fireplaces with natural draught fall within the scope of EN 13229 or EN 13240 (see Table 4-5).

Table 4-5: Coverage of fireplace inset appliances by EN13229 and EN13240

Operating conditions recommended by the manufacturer	Standard applicable		
	Freestanding or inset appliances without functional modification[14]	**Freestanding or inset appliances which have functional modification**	**Inset appliances for fireplace recess and enclosure**
1 Appliances should be operated with firedoors closed	EN 13240	EN 13229	EN 13229
2 Appliances can be operated with firedoors closed or open	EN 13240	EN 13229	EN 13229

Closed fireplaces and fireplace inserts are manually-loaded with overfire overfeed combustion technique. They can incorporate air controls and, in particular, secondary air distribution features including an air 'wash' to keep the firedoor window clean. The heat produced in the appliance can be transferred to the space by radiation and also by convection if the appliance includes external (non-combustion) air ducts and a circulating fan to provide warm air into the room space. Some appliances also have a boiler for indirect heating (Figure 4-6).

Closed fireplace insert with boiler

Closed fireplace insert without boiler

Figure 4-6: Example of closed fireplace inserts, with and without boiler[15]

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[14] Without functional modification means a modification of the surround of an appliance, that only changes the transmission of heat, without effect on combustion.

[15] From http://Lechman.methane.pl and http://sobkowiak.prv.pl

➔ Bill of Materials

BoM data on closed fireplaces and fireplace inserts were received via 27 questionnaire responses, all using wood logs, but five of which could also burn solid mineral fuels. These closed fireplaces are typically made either of cast-iron or of steel appliances, although there are some appliances that comprise a mix of both steel and cast-iron.

■ BoM for fireplace inserts

Questionnaire data were received for 18 fireplace inserts, four without secondary air control, and 14 with secondary air control. The data indicate that fireplace inserts without secondary air controls are made predominantly of cast-iron (Table 4-6), whereas on average, fireplace inserts with secondary air controls have a large steel component (Table 4-7). However, a given open fireplace with secondary air control open fireplaces is actually made mainly either of cast iron or steel (as indicated by the maximum values for cast iron and steel). Fireplace inserts are very similar to closed fireplaces (see Table 4-10 and Table 4-11). However, fireplace inserts with secondary air control are on average 30% heavier than inserts without secondary air control, probably because they have more refractory materials. One of the secondary air control inserts also had electronic equipment due to the presence of convection fans.

Table 4-6: Summary of BoM for fireplace inserts (no secondary air provision)

4 Product cases			**Content**		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	11.0	10.0	10.0	14.0	2.0
Weight [kg]	136	131	112	170	24
			Content [%]		
Steel	5.6	5.9	0.8	10.0	4.6
Cast Iron	89.8	92.4	80.0	96.9	8.8
Other ferrous metals	0.0	0.0	0.0	0.0	0.0
Non ferrous metal	0.0	0.0	0.0	0.0	0.0
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.1	0.1	0.0	0.1	0.1
Total electronics	0.0	0.0	0.0	0.0	0.0
Stone/ceramics	4.2	1.5	1.2	10.0	5.0
Glass	0.1	0.1	0.0	0.1	0.1
Sealing compound	0.0	0.0	0.0	0.0	0.0
Packaging			**Content [kg]**		
Plastic	0.1	0.1	0.0	0.1	0.0
Cardboard	1.7	2.2	0.0	3.0	1.6
Wood	13.5	13.5	13.0	14.0	0.7

Table 4-7: Summary of BoM for fireplace inserts (with secondary air provision)

14 Product cases			Content		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	11.6	12.0	6.0	15.9	3.4
Weight [kg]	199	190	90	550	115
			Content [%]		
Steel	25.2	10.0	0.0	85.0	32.3
Cast Iron	47.6	67.8	0.0	95.3	40.1
Other ferrous metals	0.0	0.0	0.0	0.0	0.0
Non ferrous metal	0.0	0.0	0.0	0.0	0.0
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.3	0.2	0.0	0.9	0.2
Total electronics	0.1	0.0	0.0	0.8	0.2
Stone/ceramics	19.4	26.4	0.0	32.5	12.5
Glass	1.3	1.3	0.0	2.8	0.9
Sealing compound	0.2	0.2	0.0	0.8	0.2
Packaging			**Content [kg]**		
Plastic	0.4	0.1	0.0	2.0	0.7
Cardboard	2.5	1.8	0.0	9.5	3.0
Wood	10.2	8.5	5.0	17.0	4.0

- **BoM for closed fireplaces**

In the questionnaire data, a single BoM for a closed fireplaces with no secondary air provision was provided. This closed fireplace was made mostly of steel (Table 4-8). The summarised BoM data for eight closed fireplaces with secondary air are provided in (Table 4-9).

These data show that on average, a closed fireplace with secondary air provision is made mainly of cast iron. However, a given appliance is actually either a cast-iron or a steel appliance. One of these appliances had some electronic equipment, primarily related to the presence of a convection air fan.

Table 4-8: Summary of BoM for one closed fireplace without secondary air provision

1 Product case	Content
Output [kW]	14.7
Weight [kg]	205
	Content (%]
Steel	67
Cast Iron	32
Other Ferrous metals	0
Coatings	0
Stone/ceramics	0
Glass	1
Sealing compound	0
Packaging	**Content [kg]**
Plastic	1
Cardboard	2
Wood	12

- **Comparison with national market data**

The national market data from HKI and CIV did not distinguish closed fireplaces from fireplace inserts. Therefore, for comparison purposes, the questionnaire data was aggregated, and grouped simply according to whether the appliances were steel, cast-iron (Table 4-10), or fitted to a boiler (Table 4-11). The average BoM of closed fireplaces and inserts (without boilers) from questionnaire is broadly consistent with BoM data from HKI and CIV (Table 4-10). However, cast iron closed fireplaces have a higher share of steel in the HKI and CIV data than in current appliances. Less than 10% of a closed fireplace/insert weight is due to non-ferrous materials (non-ferrous metals, coatings, electronics etc). Moreover, the share of stone/ceramic materials (including refractory material) is approximately twice higher in current steel appliances than in the national market data. Similarly, the closed fireplace with boiler from questionnaire data is heavier and exhibits a higher ceramic/masonry content than HKI data (Table 4-11).

Table 4-9: Summary of BoM for closed fireplaces with secondary air provision

8 Product cases			**Content**		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	9.6	9.0	6.0	14.0	3.0
Weight [kg]	168	160	75	254	62
			Content [%]		
Steel	23.2	1.1	0.7	80.0	36.4
Cast Iron	66.5	89.4	0.0	97.8	45.5
Other ferrous metals	0.0	0.0	0.0	0.0	0.0
Non ferrous metal	0.2	0.0	0.0	0.8	0.3
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.1	0.1	0.0	0.4	0.2
Total electronics	0.0	0.0	0.0	0.1	0.0
Stone/ceramics	10.8	4.4	1.3	24.4	10.6
Glass	0.3	0.2	0.0	1.6	0.6
Sealing compound	0.0	0.0	0.0	0.1	0.0
Packaging			**Content [kg]**		
Plastic	0.1	0.1	0.0	0.5	0.2
Cardboard	1.5	1.5	0.5	2.2	0.7
Wood	10.9	10.3	9.0	14.0	2.3

Table 4-10: Comparison between closed fireplaces and inserts from questionnaire and national market data

Product	Content						
	Cast iron				Steel		
	Product cases (17)		HKI data	CIV data	Product cases (6)		CIV data
	Mean	Median	(30)		Mean	Median	
Output [kW]	10.6	10.0	5-15	5-15	11.5	12.5	5-15
Weight [kg]	174.1	170.0	200-350	100-250	161.5	152.5	90-250
	Content [%]						
Steel	4.2	2.1	>20	20	72.8	70.5	80-90
Cast Iron	84.4	89.4	>70	70	0.0	0.0	0-10
Non-ferrous metals	0.1	0.0	0	0	0.0	0.0	0
Coatings	0.1	0.1	<1	<0.5	0.4	0.4	<0.5
Electronics	0.1	0.0	-	0.1-0.2*	0.0	0.0	0.1-0.2*
Stone/ceramics	9.3	4.0	5-9	10-20	25.4	26.9	11-20
Glass	0.6	0.2	0.3-0.5	2-3	1.5	1.5	2-3
Sealing compound	0.1	0.0	<0.3	<0.3	0.3	0.2	0.2-0.5
Packaging	Content [kg]						
Plastic	0.3	0.1	<1	<1	0.7	0.5	<1
Cardboard	1.8	2.0	-	-	5.4	5.0	2-5
Wood	11.6	12.0	10-12	<10	7.5	8.0	<10

Notes: '-' denotes no data available

* Where present.

Table 4-11: Comparison between closed fireplaces with boilers from questionnaire and national market data

Product	Content	
	Product cases (1)	HKI data (10 appliances)
Output [kW]	14.5	5-15
Weight [kg]	533	150-400
	Content [%]	
Steel	77.5	>87
Cast Iron	0.0	-
Other Ferrous metals	1.1	0
Non-ferrous metals	0.8	<3
Coatings	0.1	<1
Electronics	0.0	-
Stone/ceramics	18.4	7-8
Glass	0.8	0.7
Sealing compound	0.1	<0.3
Packaging	Content [kg]	
Plastic	0	<1
Cardboard	8	-
Wood	12	10-12

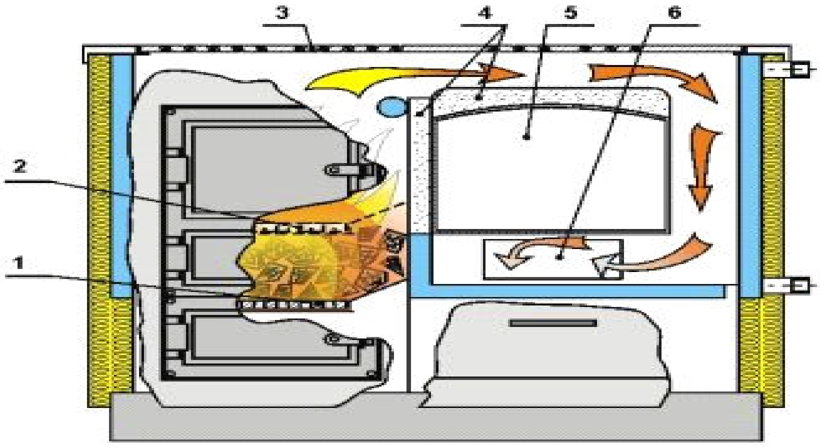
Note: '-' denotes no data available

4.2.3 COOKERS

➔ Description

Cookers are overfire combustion appliances with a 5-15 kW capacity. They typically consist of a cooking iron plate placed over the combustion chamber and a cooking oven (Figure 4-7). Some cookers can have a decorative design, while others are purely functional appliances (Figure 4-8). Older type cookers have a very simple air control, while modern cookers have both primary and secondary air controls, usually manual.

Cookers are used primarily for their cooking function, but they may also be used for space heating, either directly, or indirectly by being fitted with a boiler for hot water and/or central heating. Manually-fired appliances fall within the scope of EN 12815. Different kinds of solid fuels can be used in cookers, but wood logs and solid mineral fuels (in particular coke and other manufactured mineral fuels) are the most commonly used ones.



1. Lower position of grate (winter setup)
2. Upper position of grate (summer setup)
3. Cast iron cooking plate (with fire rings)
4. Chamotte plates
5. Cooking oven
6. Flue gases outlet

Figure 4-7: Diagram of a typical cooker [16]

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[16] www.sobkowiak.prv.pl

Figure 4-8: Examples of different types of cookers[17]

➔ Bill of Materials

■ BoM for cookers

Data on four cookers were received from questionnaires (see Table 4-12). Three cookers were without boiler, used wood logs as their primary fuel (one model could also use mineral fuel as a secondary fuel) and included secondary air controls (two appliances with manual controls and one with automatic control). One wood log manual control cooker was fitted with a boiler. None of the cookers had a significant cast iron component, which suggests the questionnaire data may not be representative of the market. Indeed, although a number of cookers available have a steel surround, many appliances on the market have a traditional cast-iron cladding.

Table 4-12: Bill of materials for cooking appliances (with secondary air provision)

3 Product cases			**Content**		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	5.7	5.0	5.0	7.0	1.2
Weight [kg]	157.8	160.0	131.0	182.5	25.8
			Content [%]		
Steel	85.6	90.0	76.7	90.0	7.7
Cast Iron	3.7	0.0	0.0	11.0	6.3
Coatings	0.3	0.3	0.3	0.4	0.1
Electronics	-	-	-	-	-
Stone/ceramics	13.8	13.8	11.0	16.8	2.9
Glass	0.4	0.0	0.0	1.1	0.6

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[17] www.sobkowiak.prv.pl

3 Product cases			Content		
	Mean	Median	Minimum	Maximum	Std Deviation
Sealing compound	0.2	0.3	0.0	0.4	0.2
Packaging	**Content [kg]**				
Plastic	1.0	1.0	1.0	1.0	0.0
Cardboard (1 appliance)	3.0	-	-	-	-
Wood	13.5	13.0	12.5	15.0	1.3

- **Comparison with national market data**

The questionnaire data and national data provided by HKI are broadly similar for cookers without boilers, although the steel content in the questionnaire data is slightly below the range indicated by HKI (Table 4-13). For the cooker with a boiler, the total weight of the appliance from the questionnaire data is below the range indicated by the HKI data. This may in part be explained by the absence of a stone/ceramic component in the appliance from questionnaire data.

Table 4-13: Comparison of cookers from questionnaire and national market data

Product	Content				
	Cooker			Cooker with boiler	
	Product cases (3)		HKI data	Product cases	HKI data
	Mean	Median	20 appliances	1 product	5 appliances
Output [kW]	5.7	5.0	5-10	22	10-25
Weight [kg]	157.8	160.0	110-220	164	170-260
	Content [%]				
Steel	85.6	90.0	>90	87	>87
Cast Iron	3.7	0.0	-	0	-
Non-ferrous metals	0.0	0.0	0	2	<3
Coatings	0.3	0.3	<1	0.3	<1
Electronics	-	-	-	-	-
Stone/ceramics	13.8	13.8	9-14	0	6-12
Glass	0.4	0.0	0.5-1	0	0.4-0.6
Sealing compound	0.2	0.3	<0.5	0.3	<0.3
Packaging	**Content [kg]**				
Plastic	1.0	1.0	<1	0.5	<1
Cardboard	3.0	-	-	-	-
Wood	13.5	13.0	10-12	13.5	10-12

Note: '-' denotes no data available

4.2.4 STOVES

➔ Description

Stoves are free-standing, enclosed residential space heaters of 2-10 kW, that display many similarities to closed fireplaces and fireplace inserts. Heat is transferred from the stove to the surroundings by radiation and convection. As with other direct heating appliances, stoves can incorporate a boiler for hot water and/or central heating. They fall within the scopes of EN 13240 or, depending on design features, EN 13229 (see

Table 4-5). In addition, slow heat release stoves are covered by the scope of EN 15250. **Stoves using wood pellets are covered in Section 4.2.5 .**

Fuel can be fed manually or supplied by a semi-automatic system (e.g. a gravity feed system). Different kinds of solid fuels can be used in stoves, including biomass, mineral raw and manufactured fuels. The most common biomass fuel used in stoves is wood logs, while mineral and manufactured fuels of various types and grain sizes are often used - usually 20-40mm, and above 40mm, or mixtures of both sizes. Peat or brown coal may also be used in some regions due to specific national circumstances.

Stoves can be either continuous or intermittent burning. Intermittent and continuous stoves are distinguished by their refuelling intervals and the ability to restore a fire from a dormant, slow combustion condition within a defined period (EN13240). Intermittent stoves have shorter minimum refuelling periods at nominal output than continuous stoves. In addition, intermittent stoves have no requirement to be able to be revived from a period of slow combustion operation whereas continuous stoves need to be able to be revived after ten or twelve hours of slow combustion (for wood and solid mineral fuel respectively). Continuous operation is not common for wood stoves but is more common in mineral fuel appliances.

While stoves can have very different designs, depending on their aesthetics and function[18], they are typically made either of cast iron or steel, and the combustion chamber is usually lined with refractory ceramics (chamotte or other types of fireproof materials). In many stoves a viewing window is provided in the front door which contributes to the aesthetics as well as gives the user the opportunity to adjust the stove for optimal combustion. The general combustion process used in stoves is overfire burning, whereby the fuel is added to the top or edge of the fuel bed. However, the burn rate of stoves is regulated by controlling the supply of primary and secondary combustion air. Stoves can therefore be classified on the basis of air flow paths through the combustion chamber, as described in Section 4.1.2 .

Four basic classifications are commonly used for stoves: up-draught, down-draught, cross-draught and S-draught (Figure 4-9), with numerous variants available. The simplest traditional stoves use overfire up-draught combustion, have very limited air control and may not have a grate or an ash box (Figure 4-10A – Traditional stoves).

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[18] Kubica K., Paradiž B., Dilara P. (2007) Small combustion installations: Techniques, emissions and measures for emission reduction; Scientific Reports of the Institute for Environment and Sustainability, EUR 23214 EN.

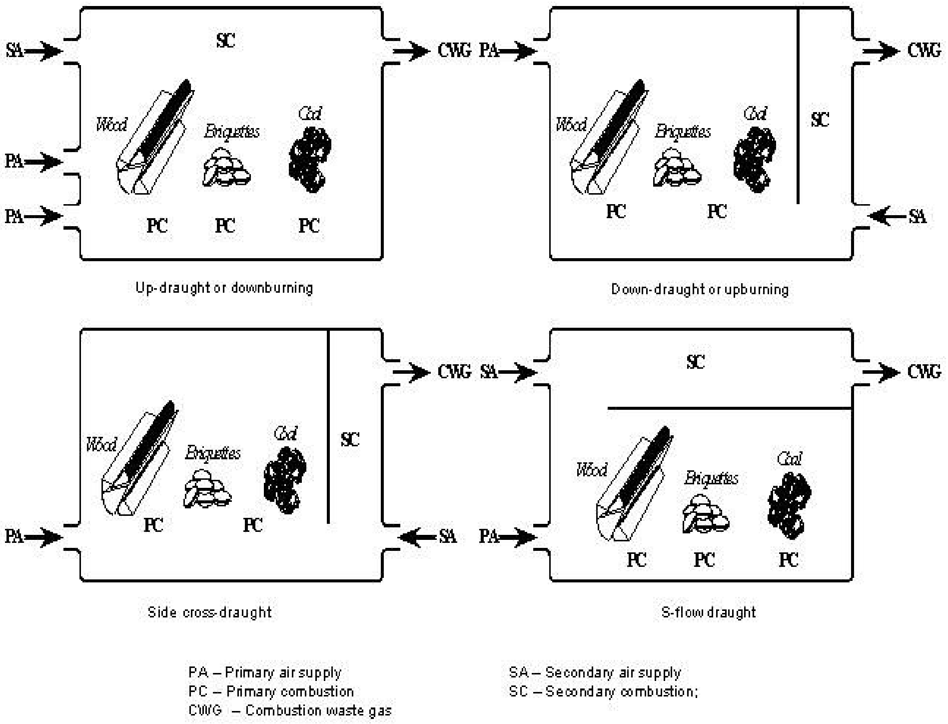

Figure 4-9: Classification of stoves depending of an airflow path through the fuel

More sophisticated modern and continuous burning stoves (Figure 4-10B) have a more elaborate combustion management (e.g. down-draught combustion configuration in Figure 4-9), characterised by the separation of the primary and secondary combustion chambers. These stoves are usually equipped with a removable grate and have both primary and secondary air controls, controlled by simple manual valves or bi-metallic elements. Modern and continuous burning stoves are more efficient than traditional stoves, because, as described in Section 4.1.2 , the combustible gases evolved from the fuel pass through the burning fuel bed to reach the secondary combustion chamber, and as a result, can be more completely oxidised.

Advanced cross-draught and S-flow stoves are even more efficient, since the cross and S-flow draught decrease the emissions of PICs further by providing a longer residence time of the flue gases in the reaction zone. The cross-draught arrangement is analogous to the cross-current flow described in Section 4.1.2 , and the S-flow stove is a variant of the cross-draught combustion which has a division of the combustion chamber above the fuel bed. **Advanced stoves will be discussed in Task 6, as Best Available Technologies.**

(A) Traditional stoves

(B) Modern stoves

(C) Slow heat release stoves

Figure 4-10: Typical stoves design; traditional, modern and slow heat release[19]

Slow heat release stoves can be distinguished from the classic radiating stoves (Figure 4-10c). Slow heat release stoves are typically masonry stoves available as a stand-alone products (assessed by EN 15250), with a capacity of 2-7 kW. They are made of bricks, stones, or a combination of both, together with refractory and fireproof materials. In contrast, the Kachelofen is a type of slow heat release stove which is constructed in situ and incorporates a type of insert as the heat source.

➔ Bill of Materials

BoM data on stoves were received from 44 questionnaires, including six for stoves with a boiler and six for slow heat release stoves. All of the questionnaire data were for stoves using wood logs as primary fuel, although some stoves could also use a mineral fuel as secondary fuel.

The BoM data from the questionnaires did not specify whether the stoves were intermittent or continuous burning. Although continuous burning stoves are available

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[19] www.visionstonestoves.com

on the market (particularly for mineral fuels), most wood-burning stoves are intermittent devices under the EN classification. Therefore the questionnaire data is assumed to represent intermittent burning stoves.

- **Traditional stoves**

BoM data (Table 4-14) were provided for three traditional stoves, that is overfeed appliances with up-draught overfire combustion and no primary or secondary air controls. These appliances were are almost entirely made of cast iron.

Table 4-14: BoM data for traditional stoves

3 Product cases			**Content**		
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	7.3	8.0	6.0	8.0	1.2
Weight [kg]	148	135	115	193	41
	Content [%]				
Steel	0.6	0.4	0.4	1.0	0.4
Cast Iron	96.7	97.8	93.9	98.3	2.4
Other ferrous metals	0.0	0.0	0.0	0.0	0.0
Non ferrous metal	0.0	0.0	0.0	0.0	0.0
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.1	0.1	0.1	0.2	0.0
Total electronics	0.0	0.0	0.0	0.0	0.0
Stone/ceramics	2.0	1.0	0.5	4.3	2.1
Glass	0.1	0.1	0.1	0.1	0.0
Sealing compound	0.0	0.0	0.0	0.0	0.0
Packaging	**Content [kg]**				
Plastic	0.1	0.1	0.1	0.1	0.0
Cardboard	1.4	1.1	1.1	2.0	0.5
Wood	6.7	4.0	4.0	12.0	4.6

- **Modern stoves**

BoM data was obtained for 33 modern stoves, 22 of which had a manual secondary air control, and 11 with automatic secondary air control.

On average, the stoves with manual controls are mainly made of steel and contain a significant amount of stone/refractory materials (Table 4-15), whilst the stoves with automatic secondary air controls are largely cast iron and have a smaller amount of stone/refractory materials (Table 4-16). However, stoves tend to be either cast-iron or steel, there are cast iron stoves with manual controls and steel stoves with automatic controls (as can be seen from the maximum values for steel and cast iron).

Table 4-15: BoM data for intermittent burning stoves (with manual secondary air control)

22 Product cases			Content		
	Mean	Median	Minimum	Maximum	Std Deviation
Output [kW]	9.2	8.0	5.0	15.0	2.9
Weight [kg]	195	183	90	360	67
			Content [%]		
Steel	66.4	76.1	5.0	91.1	24.3
Cast Iron	16.0	3.3	0.0	89.0	28.1
Other ferrous metals	0.7	0.3	0.0	3.0	1.0
Non ferrous metal	0.1	0.0	0.0	1.1	0.2
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.3	0.2	0.0	1.1	0.3
Total electronics	0.0	0.0	0.0	0.0	0.0
Stone/ceramics	15.6	10.9	0.0	43.3	13.5
Glass	0.9	0.7	0.0	2.5	0.8
Sealing compound	0.5	0.2	0.0	4.6	1.1
Packaging			Content [kg]		
Plastic	0.9	0.8	0.2	3.0	0.6
Cardboard	1.9	0.0	0.0	5.0	2.4
Wood	12.2	12.0	8.5	14.7	1.4

Table 4-16: BoM data for stoves with automatic secondary air control

11 Product cases			Content		
	Mean	Median	Minimum	Maximum	Std Deviation
Output [kW]	8.1	8.0	5.5	11.0	1.9
Weight [kg]	164	172	110	214	37
			Content [%]		
Steel	8.4	3.1	1.3	66.0	19.1
Cast Iron	85.1	93.9	0.0	95.3	28.3
Other ferrous metals	0.0	0.0	0.0	0.0	0.0
Non ferrous metal	0.0	0.0	0.0	0.0	0.0
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.1	0.1	0.0	0.3	0.1
Total electronics	0.0	0.0	0.0	0.0	0.0
Stone/ceramics	4.7	2.4	0.3	31.0	8.8
Glass	0.5	0.1	0.1	3.0	0.9
Sealing compound	0.0	0.0	0.0	0.0	0.0
Packaging			Content [kg]		
Plastic	0.1	0.1	0.0	0.1	0.0
Cardboard	2.3	2.5	0.0	3.0	0.8
Wood	11.6	12.0	9.0	15.0	2.1

Continuous burning stoves

It was not been possible to identify BoM data for continuous burning stoves from the questionnaire responses. Continuous burning stoves might be expected to be heavier than intermittent stoves since they may need to accommodate a deeper firebed and/or tighter air controls, which may require higher quantities of ferrous components (steel and cast iron) and refractory materials. However, while the overall weight may increase, the proportion of the different materials is likely to remain unchanged compared to that of modern stoves.

- **Comparison with national market data for stoves (other than slow heat release stoves)**

HKI and CIV provided some generic data on stoves sold in Germany and Belgium respectively. In these national datasets, the stoves are broadly categorised as steel or cast iron stoves, regardless of their combustion technique and air control mechanism. For comparison with HKI and CIV national data, the questionnaire data have therefore been re-classified in a similar way.

For steel stoves, the data in Table 4-17 suggest that BoM data from questionnaires are broadly consistent with the generic population data for steel stoves. However, the average steel content in the questionnaire data from manufacturers is slightly lower than the steel content reported in the HKI and CIV stoves.

Table 4-17: Comparison of BoM for steel stoves for direct heating only

Product	**Content**				
	Steel stove (direct heating)				
	Products (11)		**HKI**	**HKI**	**CIV**
	Mean	**Median**	**Simple[1] 40 appliances**	**Roomheater [2] 330 appliances**	**Steel stove**
Output [kW]	7.9	8.0	5-15	5-15	5-15
Weight [kg]	193.6	180.0	75-80	150-200	90-250
	Content [%]				
Steel	72.2	78.0	>90	>90	80-90
Cast Iron	6.0	1.1	-	-	0-10
Other Ferrous metals	0.4	0.0	0	0	0
Coatings	0.3	0.2	<1	<1	<0.5
Electronics	0.0	0.0	-	-	<0.2 kg*
Stone/ceramics	22.4	24.2	13-38	7-15	11-20
Glass	1.2	0.9	1	0.5-0.7	2-3
Sealing compound	0.6	0.2	<0.7	<0.3	0.2-0.6
Packaging	**Content [kg]**				
Plastic	0.6	0.7	<1	<1	<1
Cardboard	2.5	2.5	-	-	2-5
Wood	12.2	12.0	8	10-12	<10

Notes: '-' denotes no data available

* If present.

1. A simple stove will correspond to older, simpler traditional stoves in the categorisation adopted for task
2. Roomheaters will represent a mix of the traditional and other categories of stoves (excluding slow heat release stoves and kachelofen).

For steel stoves with boilers, the average data provided in questionnaires are generally within the range suggested by HKI (Table 4-18). The main exceptions are that in the questionnaire data the steel content is slightly lower than the HKI value (but this is minor if total ferrous metal content is considered) and the average total weight of the stoves is at the upper end of the HKI range.

Table 4-18: Comparison of BoM for steel stoves with boilers

Product	Content		
	Direct heaters		
	Products (6)		HKI
	Mean	Median	10 appliances
Output [kW]	10.6	10.0	5-15
Weight [kg]	233.6	224.0	180-230
	Content [%]		
Steel	81.1	80.0	>87
Cast Iron	5.1	0.0	-
Other Ferrous metals	1.2	0.0	0
Non-ferrous metals	0.2	0.0	<3
Coatings	0.4	0.2	<1
Electronics	0.0	0.0	<0.6
Stone/ceramics	8.9	10.5	6-13
Glass	0.3	0.4	0.4-0.6
Sealing compound	0.7	0.2	<0.3
Packaging	Content [kg]		
Plastic	0.8	1.0	<1
Cardboard			-
Wood	12.4	12.0	10-12

Note: '-' denotes no data available

For cast iron stoves, while the HKI and CIV total ferrous metal content is about 90% and similar to the average questionnaire data, the share of steel in the HKI and CIV appliances is much higher than in the questionnaire data (Table 4-19). The average weight of cast iron stoves from the questionnaires is lower than the range indicated by HKI, but within the range detailed by CIV.

- **Slow heat release stoves**

The key feature of the slow heat release stoves is their overall weight, due to the significance of masonry components in these appliances (Table 4-20). No national market BoM data were available for slow heat release stoves, but data for kachelofen stoves provided by HKI are provided in Table 4-21. However, the BoMs of the kachelofens include only the stove component and not the masonry materials, and therefore are not directly comparable to those of the slow heat release stoves.

Table 4-19: Comparison of BoM for cast iron stoves

Product	Content			
	Cast iron stove (direct heating)			
	Products (16)		HKI	CIV
	Mean	Median	30 appliances	
Output [kW]	8.5	8.0	5-15	5-15
Weight [kg]	162.0	165.0	180-250	100-250
	Content [%]			
Steel	4.6	2.5	>20	20
Cast Iron	91.4	93.9	>70	70
Other Ferrous metals	0.2	0.0	0	0
Coatings	0.1	0.1	<1	<0.5
Electronics	0.0	0.0	-	0.1-0.2*
Stone/ceramics	1.8	1.5	6-12	10-20
Glass	0.2	0.1	0.2-0.6	2-3
Sealing compound	0.0	0.0	<0.3	<0.5
Packaging	Content [kg]			
Plastic	0.4	0.1	<1	<1
Cardboard	2.5	2.5	-	-
Wood	10.6	12.0	10-12	<10

Notes: '-' denotes no data available
'*' where present

Table 4-20: BoM for slow heat release stoves

6 Product cases			Content		
	Mean	Median	Minimum	Maximum	Std Deviation
Output [kW]	2.3	2.3	2.0	3.0	0.4
Weight [kg]	1508	1533	1005	1925	380
	Content [%]				
Steel	0.6	0.0	0.0	2.1	0.9
Cast Iron	3.1	2.9	2.1	4.1	0.8
Other ferrous metals	0.0	0.1	0.0	0.1	0.0
Non ferrous metal	0.0	0.0	0.0	0.0	0.0
Plastic	0.0	0.0	0.0	0.0	0.0
Coating	0.0	0.0	0.0	0.0	0.0
Total electronics	0.0	0.0	0.0	0.0	0.0
Stone/ceramics	95.6	95.7	92.7	97.2	1.7
Glass	0.2	0.2	0.0	0.5	0.2
Sealing compound	0.3	0.3	0.2	0.4	0.1
Packaging	Content [kg]				
Plastic	1.0	1.0	0.7	1.2	0.3
Cardboard	9.8	4.0	4.0	21.7	8.3
Wood	37.7	40.0	30.0	40.0	4.1

Table 4-21: HKI data for inset tiled 'Kachelofen' appliances

Product	Content [kg]		
	Steel inset for tiled stove (5 appliances)	Cast iron inset for tiled stove (15 appliances)	Inset for tiled stove with boiler (4 appliances)
Output [kW]	5-15	5-15	5-15
Weight [kg]	120-180	150-200	150-350
		Content [%]	
Steel	>90	>20	>87
Cast Iron	-	>70	-
Non-ferrous metals	0	0	<3
Coatings	<1	<1	<1
Electronics	-	-	-
		Content [kg]	
Stone/ceramics	10-30 kg	10-30 kg	10-30 kg
Glass	1 kg	1 kg	1 kg
Sealing compound	<0.5 kg	<0.5 kg	<0.5 kg
Packaging			
Plastic	<1	<1	<1
Cardboard	-	-	-
Wood	10-12	10-12	10-12

Note: '-' denotes no data available

4.2.5 PELLET STOVES

➔ Description

These devices can be freestanding appliances which may provide direct heating, or when fitted with a boiler, can also provide hot water and/or central heating. These stoves (with or without boilers) fall within the scope of EN 14785 clearly differ from typical stoves by the type of fuel used and by the performances obtained. Pellet stoves reach high combustion efficiencies (80%-95%) and low emissions of pollutants by providing the proper air/fuel mixture ratio in the combustion chamber at all times. In non-ideal operating conditions, emissions from pellet stoves can be at least an order of magnitude lower when compared to log wood combustion. Pellet stoves can be either natural draught, or equipped with fan and electronic control system for supply of the combustion air. The autonomy of pellet stoves is important (one to several days and more, when assembled with automatic fuel transportation from storage facility). However, in comparison with a wood log appliance, some pellet appliances provide a more functional, less decorative appearance.

A typical solution for pellet stoves is presented in Figure 4-11 and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- fan assisted draught,
- fan assistance for indirect (convection) heat exchange,
- automatic fuel feed,
- automatic ash removal,
- boiler for indirect heating,

Figure 4-11 A typical pellet stove[20]

A summary of questionnaire responses for data on five direct heating pellet stove appliances is provided in Table 4-22.

The BoM data were collected for fewer products than in the case of fireplaces or other stoves but there is much less variation in total weight and component materials than for closed fireplaces.

Table 4-22: BoM for wood pellet stoves

Product	**Content**				
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	10.0	8.5	6.2	15.0	3.9
Weight [kg]	145.6	138.0	130.0	180.0	20.9
	Content [%]				
Steel	81.9	88.4	68.0	90.0	10.6
Cast Iron	9.7	9.4	0.0	25.0	10.5
Non-ferrous metals	0.8	0.0	0.0	2.0	1.1
Coatings	0.2	0.3	0.0	0.4	0.2
Electronics	0.6	0.7	0.0	0.8	0.3
Stone/ceramics	7.2	0.0	0.0	20.0	10.0
Glass	0.7	0.7	0.6	0.8	0.1
Sealing compound	0.2	0.2	0.0	0.4	0.2
Packaging	**Content [kg]**				
Plastic	0.7	0.5	0.5	1.0	0.3
Cardboard	6.8	8.0	3.5	9.0	2.9
Wood	11.0	12.0	9.0	12.0	1.4

- **Comparison with national market data for stoves**

HKI has provided some generic data on pellet stoves sold in Germany. These are compared with manufacturers' data for pellet stoves in Table 4-23 which suggests that product data for pellet stove room heaters are broadly consistent with the generic population data. The steel content of current products from manufacturers tends to be a little lower than the HKI data, although there is slightly more cast iron in the data from manufacturers than indicated by HKI.

The product information for the pellet stove with an indirect heating function is generally within the range of composition provided by HKI,

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[20] www.woodpelletstoves.net

Table 4-23: Comparison of manufacturer and HKI BoM data for pellet stoves

Product	**Content**				
	Direct heaters			**Heaters with boiler**	
	Products (5)		**HKI**	**Products**	**HKI**
	Mean	**Median**	**20 appliances**	**1 product**	**5 appliances**
Output [kW]	10.0	8.5	5-15	10	5-15
Weight [kg]	145.6	138.0	180-200	190	100-300
	Content [%]				
Steel	81.9	88.4	>90	81	>87
Cast Iron	9.7	9.4	0	0	-
Non-ferrous metals	0.8	0.0	0	1	<3
Coatings	0.2	0.3	<1	0.3	<1
Electronics	0.6	0.7	<0.5	0.5	<1
Stone/ceramics	7.2	0.0	~10	16	10
Glass	0.7	0.7	<0.5	0.5	<1
Sealing compound	0.2	0.2	<0.3	0.3	<0.5)
Packaging	**Content [kg]**				
Plastic	0.7	0.5	<1	1	<1
Cardboard	6.8	8.0	-	-	<3
Wood	11.0	12.0	10-12	11	8

4.2.6 Boilers <50 kW

➔ Description

This group of appliances includes manual and automatically-fuelled solid fuel appliances whose primary duty is to provide hot water for central heating and domestic hot water. This type of appliance covers stand-alone boilers, but does not include boilers that are fitted to stoves or other direct heating appliances[21]. Residential independent boilers <50 kW whose primary function is to provide hot water for central heating and/or domestic hot water fall within the scope of EN 303-5. Similar boilers which have a secondary space heating function on the other hand are within the scope of EN 12809.

Small boilers for central heating for individual households are commonly found in temperate regions and usually have a nominal capacity between 10 kW to 50 kW. They can use different types of solid fuels, depending on regional availability, but the most frequently used fuels are wood logs and mineral fuels. Small boilers can be categorised according to a number of technical characteristics, including fuelling method (overfeed, gravity-feed, or underfeed), fuel type (wood logs, chips, pellets, mineral briquettes, mineral coals) and combustion process (see categorisation in Section 4.1.2).

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[21] For the purposes of the study, appliances which incorporate boilers but whose primary function is to provide direct heating are categorised in accordance with the categorisation developed for direct heating appliance.

➔ Manually fuelled boilers < 50 kW

■ Conventional overfeed overfire boilers

Conventional overfeed boilers usually use natural draught and have efficiencies of 55-65%. The combustion process is of up-draught type, whereby the fuel is manually fed onto the top of the burning fuel bed and the hot combustion gases heat the new fuel charge, which rapidly devolatilises (Figure 4-12). Some modern solutions employ fan assistance for control of primary and secondary air supply (Figure 4-13), resulting in improved efficiencies (70-85%). Overfire boilers have high emissions of pollutants.

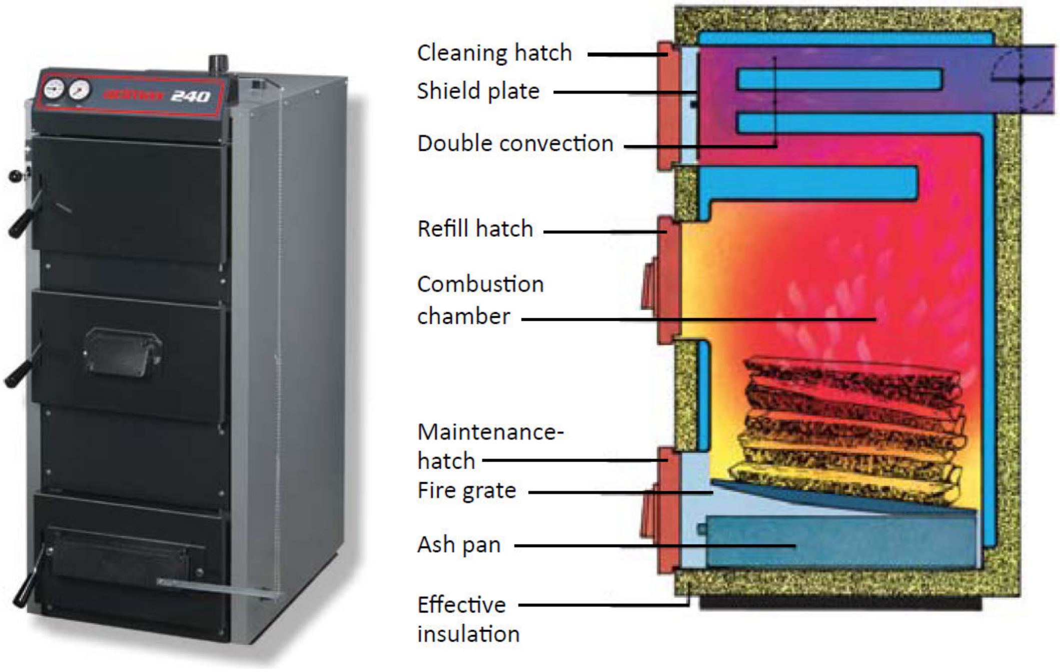

Figure 4-12: Conventional overfire manually fuelled boiler[22]

■ Conventional overfeed up-draught upperfire boilers, with counter-current flow

This type of boilers can only be fuelled with non-caking fine (small) coal, which is manually fed into the combustion chamber of the boiler. The combustion cycles occur successively until the fuel is consumed and then the user needs to clean the combustion chamber, before filling it with a new charge of fuel. This combustion technique uses fan-assistance for improved management of primary and secondary combustion air. Conventional up-draught boilers (Figure 4-14) have the main disadvantage of requiring periodical operation and refuelling.

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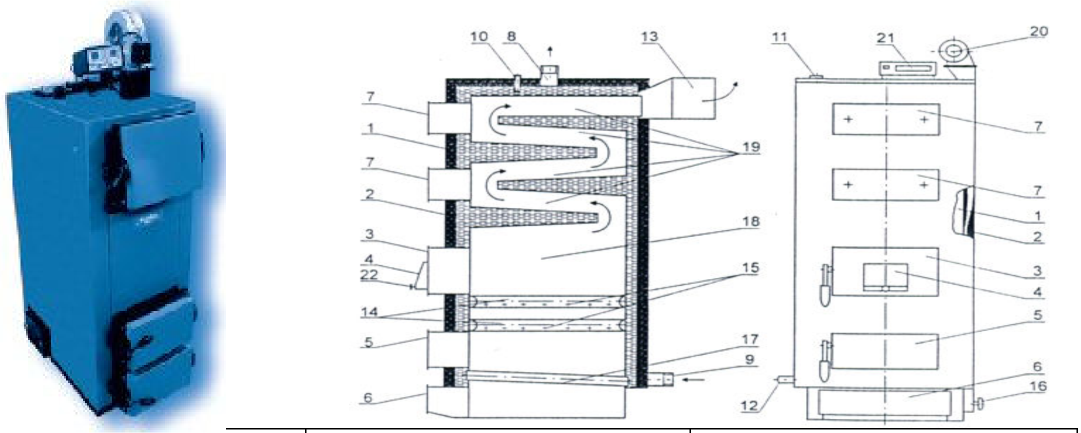
[22] http://www.swebo.com/fileadmin/pdf_productsheets_en/prodsheet_arimax240_en.pdf



1. Boiler construction	9. Water outlet nozzle	16. Air entrance adjustment
2. Insulation	10. Thermometer connection	17. Water grate
3. Charging (batch) door	11. Thermo-manometer nozzle	18. Combustion chamber
4. Secondary air damper	12. Drain water nozzle	19. Convection channels
5. Chamber door	13. Flue	20. Fan blower
6. Ash pit door	14. Air-duct	21. Microprocessor controller
7. Cleaning door	15. Air entrance nozzles	22. Secondary air adjustment
8. Water inlet nozzle		

Figure 4-13: Conventional overfire manually fuelled boiler, with fan-assisted air control[23]

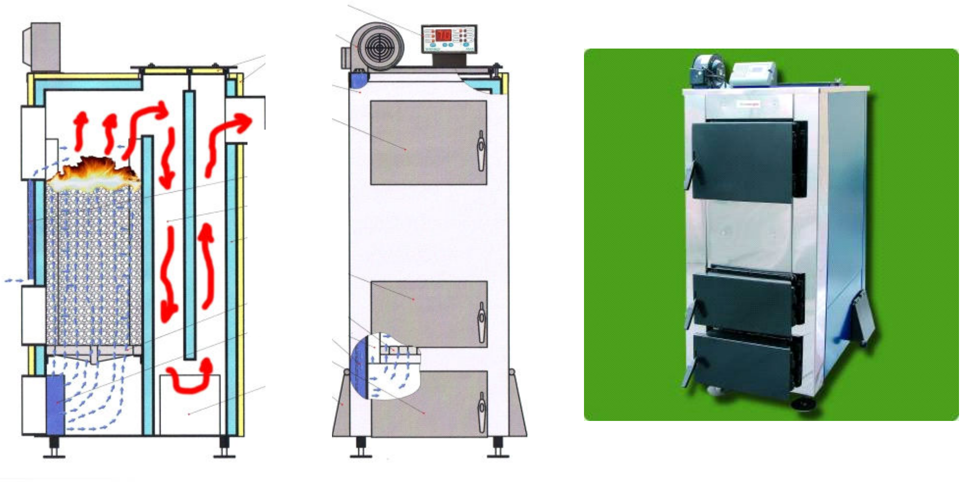


Figure 4-14: Conventional up-draught upperfire, manually-fuelled boiler[24]

- **Advanced gravity-feed underfire boilers and downdraught boilers.**

This type of boiler is state-of-the-art in wood log combustion, but some can also use lignite/young hard, non-caking coal with high content of volatile matter. Downdraught log boilers are manually fuelled with wood logs and can be considered semi-automatically-fuelled appliances. They have two chambers. In the first (upper) chamber the fuel is stored and undergoes drying, devolatilisation and char combustion

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[23] http://www.kotlarstwopleszew.pl/

[24] www.ekoenergia.eu

while it moves slowly downward as the fuel beneath is consumed. The products of partial devolatilisation/pyrolysis and gasification of the bottom fuel layer are transferred to the secondary chamber, where the burning of released combustible gases occurs. Due to the partial gasification taking place in this boiler, it is also known as a gasifying boiler. Downdraught wood boilers use a combustion air fan or flue gas fan. The secondary combustion air is partly introduced in the grate and partly in the secondary chamber. Some of these boilers incorporate lambda control probes to measure flue gas oxygen concentration and provide automatic combustion air control as well as staged-air combustion.

A downdraught boilers (<50kW) is shown in and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- fan assisted draught,
- advanced combustion management (with lambda and CO probes, weather and room temp. control),

Figure 4-15 Typical downdraught wood log boilers[25]

➔ Automatically fuelled boilers < 50 kW

The main advantage of automatically-fuelled appliances over manually-fuelled ones, is that automatic fuel delivery gives greater control over the combustion process, since both the air and the fuel supply can be controlled. The advantages of this type of SCIs is that they are highly efficient and have low pollutant emissions. However, they do have specific fuel quality requirements, concerning for example the grain size, the caking behaviour (in the case of coal fuels) and the ash melting point. Wood pellets are the predominant biomass fuel for automatically fuelled SCIs below 50 kW, whereas wood chips are the predominant biomass fuel for larger SCIs (50kW – 500 kW). Some coal boilers can burn pellets as well as chips (pellet and chip boiler).

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[25] www.choiceheatingsolutions.com

Stoker boilers

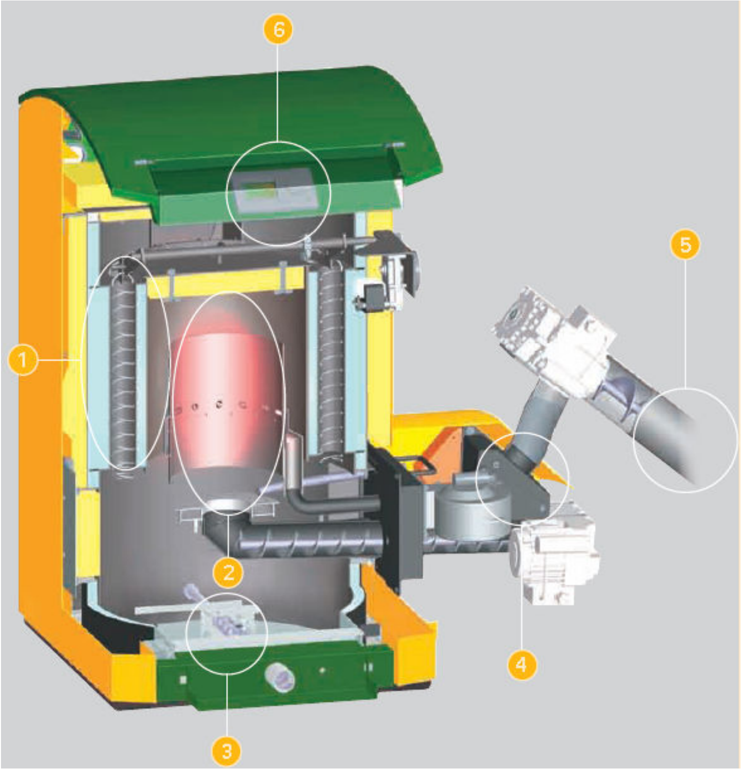
Such boilers can use a range of automatic fuel feed mechanisms and techniques of combustion (upperfire, overfire and underfire) as well as many different kinds of construction (Figure 4-17). The main types of technologies found in the EU are described below.

Pellet boiler

Pellet boiler technology is similar to that employed for pellet stoves (see section 4.2.5 above). Fuel is metered into the combustion chamber, and a fan provides primary and secondary air. The user fills the storage hopper and empties the ash container at appropriate intervals but other operations are largely automatic. Pellet boilers are characterised by high efficiency as well as very low pollutant emissions. This type of boilers can be treated as a state-of-the-art solution in solid biomass combustion.

A typical pellet boiler is presented in Figure 4-16 and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- fan assisted draught, advanced combustion management (with lambda and CO probes, weather and room temp. control),
- automatic fuel feed,
- automatic ash removal,
- efficient boiler for indirect heating (with option for secondary heat exchanger enabling latent heat recovery – heat of condensation),



1. Heat exchanger: upright, auto-cleaning, tubular heat exchanger.
2. Firing system: auger-fed gasifier, afterburning ring as turbulent high-temperature burnout zone and integrated partial-flow recirculation.
3. Ash removal: high ease of use — ash container emptied only once per heating season (up to 20 kW).
4. Fire shutter: gas-tight, flashback-proof and tested.
5. Fuel extractor: reliable, maintenance-free conveying technology for high individual requirements.
6. Control panel

Figure 4-16 Typical pellet boiler[26]

◆ Underfeed upperfire stoker boilers

In underfeed stoker boilers (e.g. Figure 4-18), the fuel is introduced into the combustion chamber from below the plane of fuel ignition, which means that before the fuel reaches the plane of ignition, the moisture is evaporated and some volatile matter is evolved. These gases then pass through the burning fuel bed where the temperature is about 1100°C. Therefore, the organic matter formed within the devolatilisation process is almost completely combusted. The fuel, which ideally has a low ash content and a grain size between 4 mm and 30 mm, is fed into the hearth (retort) by a screw conveyor. Stoker boilers are available for mineral fuels such as bituminous coal and anthracite, and for wood chips and pellets. They have a forced-air supply which provides primary and secondary air management. This technology of combustion results in decreased emissions compared to manually-fuelled appliances and provides high efficiency (80-90%) and low emissions of PICs. The main advantage of stoker boilers is their ability to operate at high efficiency with load ranges starting from 30% up to nominal capacity. Figure 4-17 provides common examples of automatic fuel delivery and grate/furnace configurations. Wood chips are fed with augers, from a container or other storage, to the combustion section. In stoker boilers <50 kW, the

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[26] www.kwb.at

combustion section normally only consists of a small grate or, for bowl burners (see Figure 4-17), a cast iron or high temperature resistant steel combustion cup.

Wood chips stoker installations (Figure 4-19) exist both as over- or underfeed burners. The ignition of the chips can be made via hot air. Wood chips stoker boilers use forced-draught air supply and can have a completely automatic control of the combustion process. Their efficiency exceeds 80%.

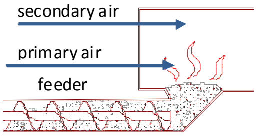
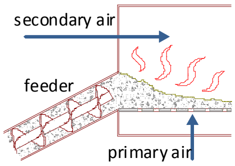
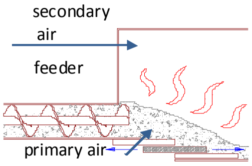
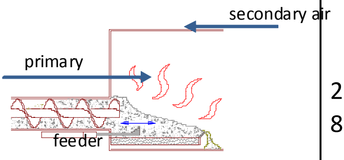
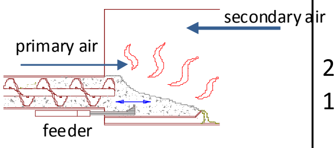
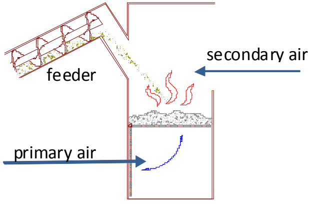
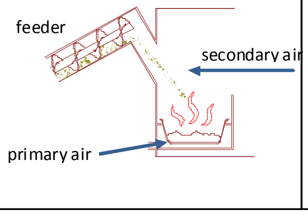
Operation principle	Grate	Type	Organisation	Output	Fuel
1	2	3	4	5	6
Retort-uplifting fuel				10 kW to 2,5 MW	Pellets Wood chips
Side-feed boiler	Grate	Stationary grate		> 35 kW	Pellets, Wood chips
		Underfeed stoker		100 kW to 20MW	Pellets, Wood chips
	No grate	Water-cooled		25 kW to 800kW	Pellets, Wood chips
		No cooling		25 kW to 180kW	Pellets, Wood chips
Spreader boiler	Grate	Lift grate		15 kW to 30kW	Pellets, Wood chips
	No grate	Bowl burner		6 kW to 30kW	Pellets, Wood chips

Figure 4-17 : Example of fuel supply systems and combustion technologies used in biomass stoker boilers27

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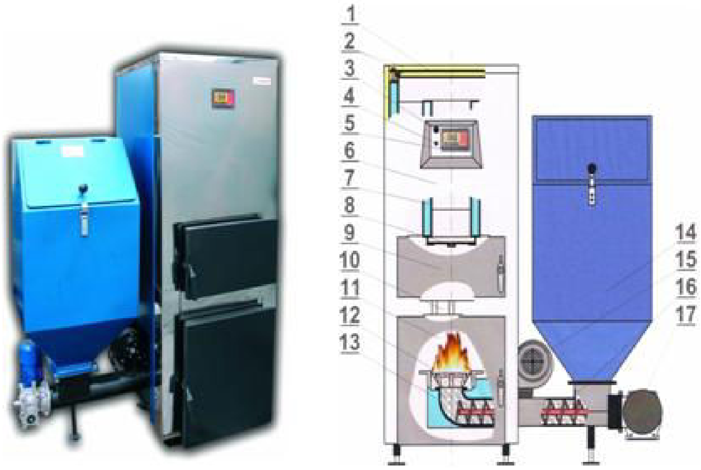
[27] Pilarski S.; The Proceeding of Conference „Efficient Utilisation of Renewable Energy RE in HVAC”, The Mazowiecki Agricultural Advisory Centre, Plonsk, 6 -7 December 2007



1- Boiler coating
2 - Insulation
3 - STB - Water overheating sensor
4 –Safety fuse
5 - Microprocessor controller
6 - Boiler body
7 - Heat-exchanger
8 - Cleaning hole
9 - Second furnace (emergency)
10 - Ceramic catalyst deflector
11 - Door
12 - Retort furnace
13 - Air duct
14 - Ceramic combustion chamber
15 - Fuel box
16 - Fan
17 - Feeding screw
18 - Motor reducer

Figure 4-18 : Automatic upper-fire, stoker retort boiler[28]

Figure 4-19: Automatic wood chips stoker boiler[29]

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[28] www.ekoenergia.eu

[29] www.hdg-bavaria.com

◆ Push-down underfire stoker boiler

In push-down stoker boilers, the combustion process is organised according to the underfire technique, whereby the raw fuel is automatically fed to the furnace by a push-piece or ram (see Figure 4-20). These types of boilers have fan-assisted air controls and are mainly fuelled with fine or bean coal.

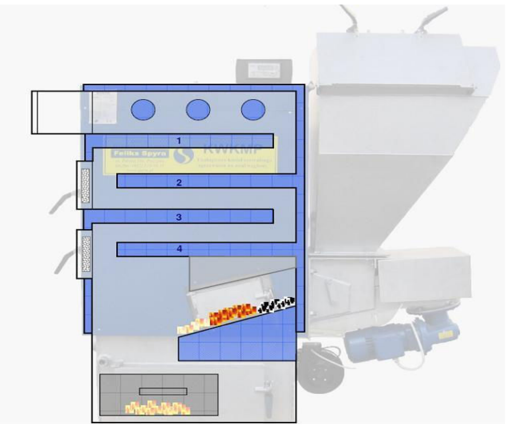

Figure 4-20 : Automatic underfire push-down stoker boiler[30]

➔ Bill of Materials

Data was received by manufacturers on seven manually-fuelled wood log boilers < 50 kW (Table 4-24), twelve pellet boilers (Table 4-25)and five solid mineral fuel boilers < 50 kW (three coal-fired boilers, a coke-fired boiler and, a brown coal-fired boiler; Table 4-26). No manufacturers indicated a secondary fuel, but two appliances incorporated electrical heater elements as a secondary or alternative source of heat.

Based on a review of manufacturers literature, the wood log boilers appear to be mainly downdraught devices rather than conventional ones. Similarly, mineral fuel boilers are understood to be manually-fuelled devices belonging to either of the advanced under-fire categories. However, the BOMs of these technologies are assumed to be not significantly different from those of conventional manual fuelled boilers or automatically fuelled stoker boilers.

Manual fuel boilers weigh between 300-500 kg on average (Table 4-24). The main components by weight are steel or cast iron (appliances are typically either steel or cast iron appliances) and ceramic or refractory elements. Most appliances are made exclusively of steel (>90% of the weight of the appliance), but some can have up to 20% cast-iron, or even be fully made of cast-iron . Manual boilers usually have some electronic components, for controls and fans.

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[30] www.spyra.com

Table 4-24: BoM for boilers <50kW burning wood logs

7 Product cases	**Content**				
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	30.7	35.0	16.0	36.0	7.7
Weight [kg]	385.7	310.0	270.0	795.1	205.1
	Content [%]				
Steel	86.3	87.2	75.0	97.0	8.2
Cast Iron	4.6	0.5	0.0	20.0	8.5
Non-ferrous metals	0.1	0.1	0.0	0.3	0.2
Plastics	0.0	0.0	0.0	0.2	0.0
Coatings	0.1	0.0	0.0	0.6	0.0
Electronics	0.8	0.4	0.0	3.2	1.4
Stone/ceramics	6.6	5.3	0.0	13.5	5.0
Glass	0.5	0.5	0.0	1.0	0.6
Packaging:	**Content [kg]**				
Plastic	0.6	0.4	0.0	2.0	0.9
Cardboard	2.9	0.8	0.0	10.0	5.6
Wood	31.4	15.0	13.5	80.0	32.8

Table 4-25: BoM for <50kwW pellet boilers

12 Product cases	**Content**				
	Mean	**Median**	**Minimum**	**Maximum**	**Std Deviation**
Output [kW]	20.3	20.0	10.0	35.0	6.2
Weight [kg]	294.6	277.5	195.0	430.0	84.0
	Content [%]				
Steel	91.6	92.5	84.5	95.1	3.1
Cast Iron	0.4	0.0	0.0	2.0	0.7
Other Ferrous metals	0.2	0.0	0.0	2.3	0.7
Non-ferrous metals	2.0	0.4	0.0	10.0	3.2
Plastics	0.6	0.0	0.0	3.8	1.3
Coatings	0.3	0.1	0.0	1.0	0.3
Electronics	0.8	0.3	0.1	3.8	1.1
Stone/ceramics	1.5	0.2	0.0	7.5	2.6
Glass	1.1	1.5	0.0	1.8	0.8
Sealing compound	-	-	-	-	-
Packaging	**Content [kg]**				
Plastic	0.5	0.5	0.1	0.8	0.2
Cardboard	0.3	0.2	0.0	0.6	0.3
Wood	15.7	16.5	7.0	23.5	6.1

Note: '-' denotes no data

Table 4-26: BoM for <50kW solid mineral fuel-fired boilers

	Content		
	1 product	**1 product**	**3 products**
Fuel	Coke	Brown coal	Coal
Output [kW]	32	24	25
Weight [kg]	280	215	473
	Content [%]		
Steel	9.0	90.0	95
Cast Iron	90.0	7.0	3
Other Ferrous metals	0	0	-
Non-ferrous metals	0.2	1.0	0.3
Plastics	0.3	1.0	0.8
Coatings	0.5	1.0	-
Electronics	0	0	0.1
Stone/ceramics	-	-	0.8
Glass	-	-	-
Sealing compound	-	-	-
Packaging	**Content [kg]**		
Plastic	0.45	0.36	-
Cardboard	1.35	1.44	-
Wood	42.8	16.2	30

Note: ‘-’ denotes no data available

➔ Comparison with national market data for boilers <50 kW

The Austrian Biomass Centre (ABC) provided some generic data for a ‘state-of-the-art’ pellet boiler and wood log boiler (the latter applying advanced under-fire combustion). These are compared with the questionnaire data for pellet and wood log boilers in Table 4-27 and Table 4-28 respectively.

The questionnaire product data are broadly consistent with the data for a state-of-the-art pellet boiler. However, the questionnaire data displays a higher steel content and lower ceramic content than the Austrian data.

The state-of-the-art wood log boiler is substantially heavier than the average wood log boiler from the questionnaire, and contains less steel but more ceramics than the questionnaire appliances. Most of the steel used in ABC boilers is sheet steel (about 90% as sheet steel for a wood log boiler).

Table 4-27: Comparison of <50kW pellet boiler BoM

Product	Content		
	Products (12)		ABC
	Mean	Median	State of the art
Output [kW]	20.3	20.0	15
Weight [kg]	294.6	277.5	300-350
	Content [%]		
Steel	91.6	92.5	75
Cast Iron	0.4	0.0	5
Other Ferrous metals	0.2	0.0	-
Non-ferrous metals	2.0	0.4	2
Plastics	0.6	0.0	<1
Coatings	0.3	0.1	<1
Electronics	0.8	0.3	<1
Stone/ceramics	1.5	0.2	16
Glass	1.1	1.5	-
Sealing compound	-	-	-
Packaging	Content [kg]		
Plastic	0.5	0.5	1
Cardboard	0.3	0.2	2.3
Wood	15.7	16.5	20

Note: ‘-’ denotes no data.

Table 4-28: Comparison of <50kW wood log boiler BoM

Product	Content		
	Products (7)		ABC
	Mean	Median	State of the art
Output [kW]	30.7	35.0	25
Weight [kg]	385.7	310.0	550-600
	Content [%]		
Steel	86.3	87.2	78
Cast Iron	4.6	0.5	1-2
Other Ferrous metals	0.0	0.0	-
Non-ferrous metals	0.1	0.1	1
Plastics	0.0	0.0	<1
Coatings	0.1	0.0	<1
Electronics	0.8	0.4	-
Stone/ceramics	6.6	5.3	20
Glass	0.5	0.5	-
Sealing compound	0.0	0.0	-
Packaging	Content [kg]		
Plastic	0.6	0.4	1
Cardboard	2.9	0.8	1.3
Wood	31.4	15.0	15-20

Note: ‘-’ denotes no data available

4.2.7 BOILERS >50 KW

These boilers include manual and automatically-fuelled solid fuel appliances which provide hot water for indirect heating to larger buildings, these may include multi-dwelling residential apartments but also schools, offices and other commercial/institutional buildings. While these boilers can be manually fuelled, most boilers over 250 kW output have an automatic fuel feeding mechanism. The boilers with a capacity below 300 kW fall within the scope of EN 303-5 (see the Task 1 report for details of this non-harmonised Standard).

Boilers with a capacity above 50 kW tend to employ similar combustion technologies as residential boilers (see Section 0). However, as capacity increases, moving grates replace fixed grate systems. Wood chips are the predominant biomass fuel at the upper end of the Lot 15 range although wood logs and pellets are also used.

➔ Manually-fuelled boilers > 50 kW

Four main categories of manually-fuelled boiler are manufactured in this size range:

1. Conventional overfeed boiler with upper–fire combustion
2. Advanced gravity-feed boiler with natural draught (and fan-assisted secondary air control)
3. Downdraught (gasifying) boiler

These use essentially the same technologies as those described for the boilers fuelled by solid biofuels and mineral fuels <50 kW (Section 4.2.6).

➔ Automatically-fuelled boilers > 50 kW

■ Underfeed stoker boilers

The technologies applied are essentially the same as described for <50kW boilers. Wood chips boilers of capacity 50-100kW are very similar to smaller appliances as described in Section 4.2.6 . But in large installations (greater than about 100 kW) the chips are burnt using a variety of feed and grate combinations (Figure 4-17) such as underfeed rotating grate or moving stepped grate. Stepped grate technology ensures that optimum performance is maintained even when the proportion of non-combustible material in the fuel is increased. The fuel moves through different temperature zones on the grate where it passes through the drying, devolatilisation, gasification and char combustion stages. The geometric design of the combustion chamber facilitates an above average retention time and mixing of the combustion gases at high temperatures. The control system for combustion and output enables the system to adapt to different types of fuel or variations in fuel quality. Primary air, secondary air and fuel quantity are automatically optimised. This makes it possible to regulate the system's nominal thermal output between 30% and 100%. Modern wood chip boilers achieve efficiencies of over 80% through the use of lambda sensors, which detect the amount of oxygen in the flue gas. Optimum combustion levels are maintained by controlling the combustion air through one or more of the following: inlet air fans, flue damping, flue extractor fans and flue return fans (Figure 4-21).

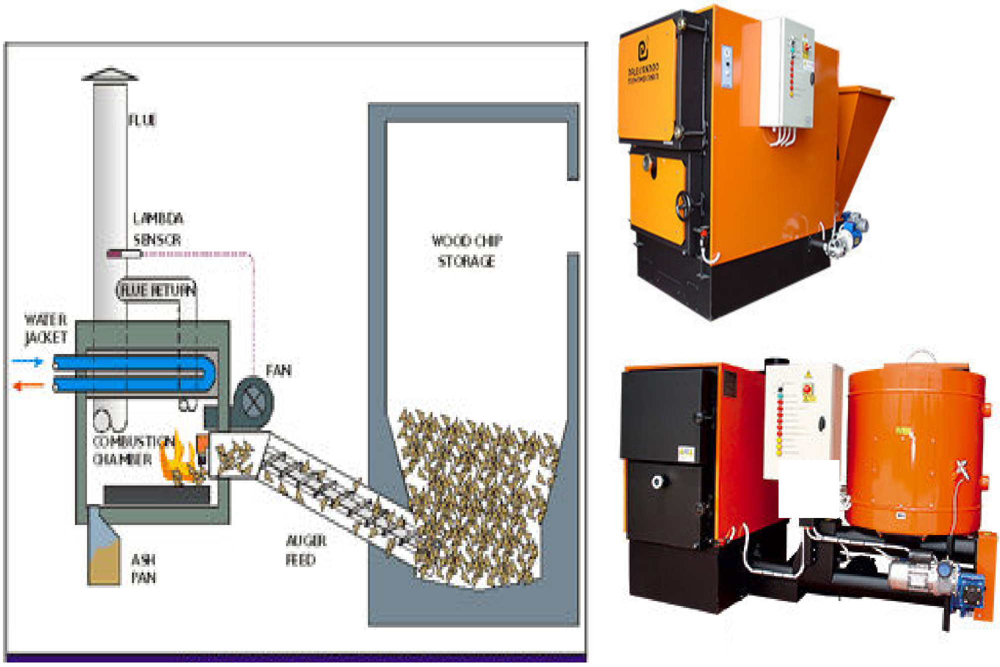
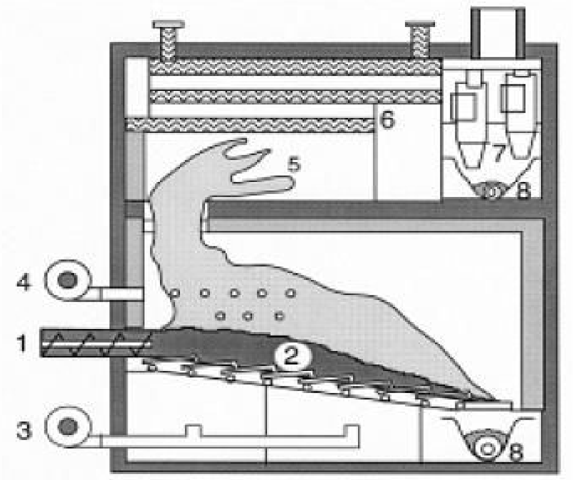


Figure 4-21: Automatic wood chips stoker underfeed boiler >50 kW[31]

- **Moving grate overfeed stoker boilers**

Fuel such as wood chips is fed from above onto one end of a sloping or stepped grate comprising moving and fixed grate elements (Figure 4-22). The grate elements provide air distribution, agitate and mix the fuel to ensure combustion as the fuel passes down the grate.



1 - Fuel loading 3 - Primary air 5 - Combustion chamber 7 - Cyclone	2 - Grate 4 - Secondary air 6 - Thermo-conductor 8- Ash pit

Figure 4-22 – Moving grate overfeed boiler >50kW

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[31] http://web.itsligo.ie/woodfuel/Boilers.htm, www.gizex.com

- **Underfeed rotating grate**

This technology is employed in boilers burning wood chips or pellets. The fuel is fed with an underfeed screw onto a rotating grate where combustion takes place (Figure 4-17). Ash forms on the outer edge of the fuel pile and where it falls into the ash collection area.

➔ **Bill of Materials**

No BoM data were provided by manufacturers for boilers with a capacity above 50 kW. Sales literature and technical data for 23 wood chip and pellet-fired appliances from five manufacturers were used to provide data on appliance weight, volume and output. In the absence of any product-specific BoM data, the BoM for pellet boilers may provide a reasonable approximation for boilers >50 kW (Table 4-27).

4.3 DISTRIBUTION PHASE

SCIs are typically packed in a cardboard and/or wooden boxes to ensure maximum protection of the product. The product sits on a wood base (pallet) to enable use of a fork lift for easy loading and unloading.

Depending of the type and model of the SCI (<50 kW), the weight of the packaged product is between 75 and 1000 kg. The heavier appliances are the boilers and slow heat release stoves. Typically the volume of a packaged residential product is a little larger than 1 m^3 with cookers and the slow heat release stove having the largest volume of residential appliances – this is not unexpected as cookers need to incorporate oven space(s) and a large hotplate surface. The data obtained from manufacturers are summarised in Table 4-29.

No packaging data have been received from manufacturers for boilers larger than 50 kW but data from selected manufacturers' product specifications indicate volumes around 1 m^3but up to 20 m^3. For the boilers with a capacity above 50 kW, there is a reasonable but weak linear correlation, between appliance output and weight (R^2=0.7629) but a poor correlation between output and volume (R^2=0.289).

Table 4-29: Summary of distribution data (volume and weight of packaged product)

Appliance type		Dimension	Mean	Minimum	Maximum
Open fireplace	Direct	Volume (m^3)	1.0	0.5	2.0
		Weight (kg)	166	75.0	265
Closed fireplace/ fireplace inset	Direct	Volume (m^3)	1.0	0.5	2.0
		Weight (kg)	166	75.0	265
	With boiler	Volume (m^3)	1.65	-	-
		Weight (kg)	533	-	-
Stoves	All steel/cast iron	Volume (m^3)	1.4	0.9	2.0
	Steel direct	Weight (kg)	184	108	300
	Steel with boiler	Weight (kg)	244	90	360
	Cast iron direct	Weight (kg)	162	110	214
	Slow heat release	Volume (m^3)	1.7	0.9	2.0

Appliance type		Dimension	Mean	Minimum	Maximum
		Weight (kg)	1508	1005	1925
	Pellet stove (direct)	Volume (m^3)	0.9	0.5	2.0
		Weight (kg)	155	130	200
	Pellet stove with boiler	Volume (m^3)	2	-	-
		Weight (kg)	200	-	-
Cooker	All	Volume (m^3)	2.0	1.0	3.0
		Weight (kg)	158	131	183
Boiler <50 kW	Pellets	Volume (m^3)	1.2	0.7	1.4
		Weight (kg)	295	195	430
	Wood logs	Volume (m^3)	1.2	0.8	1.3
		Weight (kg)	386	270	795
	Mineral fuel	Volume (m^3)	0.8	-	-
		Weight (kg)	248	-	-
Boiler >50 kW	All	Volume (m^3)	6.6	1.4	20
		Weight (kg)	2389	505	6575

4.4 USE PHASE (PRODUCT)

4.4.1 FUEL AND ELECTRICITY CONSUMPTION

➔ Consumption of fuel

The fuel consumption of a solid fuel SCI is determined by two factors:

- **Heat demand** is determined by the consumer, the weather and the infrastructure surrounding the SCI. The consumer demands heat and will modify the fuel supply to the SCI to match the desired demand either directly through supplying fuel or indirectly through a thermostat mechanism. Weather determines the heat demand by modifying the rate at which heat is lost from the heated space to the environment. Cold days, would naturally require more fuel to maintain the same temperature inside a heated space. The infrastructure surrounding the heated space also influences the rate at which heat is lost from the heated space to environment. For example, insulated walls or weather-proof windows can help to reduce the heat loss to the environment.
- **System efficiency** (appliance and system), both the SCI itself and any associated system (hydronic system, etc.) determine the amount of useful heat which can be extracted from the fuel and hence the amount of fuel consumed to serve the demand. Product and system efficiency are described further in Sections 4.5.1 and Section 4.4.2 .

  The overall heat demand, accounting for appliance efficiency was estimated in Task 3 at the Eu-level.

➔ Consumption of electricity

An SCI may use electricity to power various different systems :

- the control system
- flue gases extraction fan
- automatic fuel transfer (and ash removal on larger appliances)
- fan-assisted air supply
- ignition heat
- fan-assisted convection air circulation

Electricity consumption is mainly related to the appliance type, i.e. simple, manually fuelled and controlled appliances have no electricity requirement, whereas modern, automatic SCIs require electrical power for both fuel supply and air control features. In general, the consumption of electricity increases with increasing appliance output, due for instance to an increase in fuel feeding frequency and/or air supply.

In appliances below 500kW, only a relatively small part of the electricity consumption is required for the automation of the combustion process control. Therefore, the electricity consumption of combustion control elements may be treated as constant.

The electricity consumption in on-mode, with all electrical devices operating at their nominal power (which is far from normal operating conditions), is equal to the instantaneous power of the appliance (power installed), which is closely related to the power output of the appliance. Selected data on the relationship between instantaneous power and output are given in Table 4-30 by automatically-fuelled coal boilers. However, due to production process optimisation, the electrical power installed in SCIs can be similar for appliances of different nominal output, resulting in a stepped curve between nominal output and power installed, as illustrated in Figure 4-23 for a coal fuelled stoker boiler. The relationship between appliance output and the electrical consumption of fans used to provide convection heating (installed fan power) and combustion air is also shown in Table 4-31.

The ratio between instantaneous power and boiler nominal output decreases (see Figure 4-24), indicating that the relative consumption of electricity decreases with increasing boiler power output.

However, in reality, the actual electricity consumption (expressed in Wh) is far from the values that would be observed at the nominal power consumption of all appliance components. In fact, electricity use is mostly related to the thermal power output (fuel supply and air movement). Some example data on electricity consumption for various wood pellet, wood chips and wood log boilers are given in Figure 4-24 and Figure 4-26.

Pellet boilers and wood chip boilers data can be extrapolated over other groups of appliances like coal automatic boilers. Wood log boilers data on electricity consumption is relevant for all fan-assisted appliances with manual stoking like stoves, manual coal boilers.

Table 4-30: Examples of instantaneous power of coal boilers series

No.	Parameter	unit.	Power output of EKR coal boiler											
			EKR 15	EKR 25	EKR 38	EKR 50	EKR 75	EKR 100	EKR 150	EKR 200	EKR 250	EKR 300	EKR 350	EKR 500
1	Nominal power output	kW	15	25	38	50	75	100	150	200	250	300	350	500
2	Boiler wieght (without water)	kg	315	360	412	470	730	845	940	1210	2580	3090	3960	4750
3	Electrical power installed	W	170	170	170	170	440	440	800	800	1320	1320	1320	2280
4	(Weight/power) ratio	kg/kW	21	14,4	10,8	9,4	9,7	8,4	6,3	6	10,3	10,3	11,3	9,5
5	(El. power isntalled/Boiler output) ratio	W/kW	32,2	25,8	18,4	14,3	12,1	10,3	5,4	4,2	3,1	3,6	2,6	1,8

Table 4-31: Examples of installed fan power on SCIs

Appliance type	Appliance output, kW	Fan use	Installed power, W	Comment
Automatic pellet stove	11	Convection air	15	
Closed wood log inserts	5-10	Convection air	20 or 40	1 or 2 fans
Closed wood log inserts	7-11	Convection air	30	
Closed wood log insert	12	Convection air	27	
Closed wood log insert	16	Convection air	45	
Closed wood log fireplace/inserts	Up to 30	Convection air	Up to 80	Capacity for several rooms
Automatic Pellet boiler	18-50	Combustion air	120	

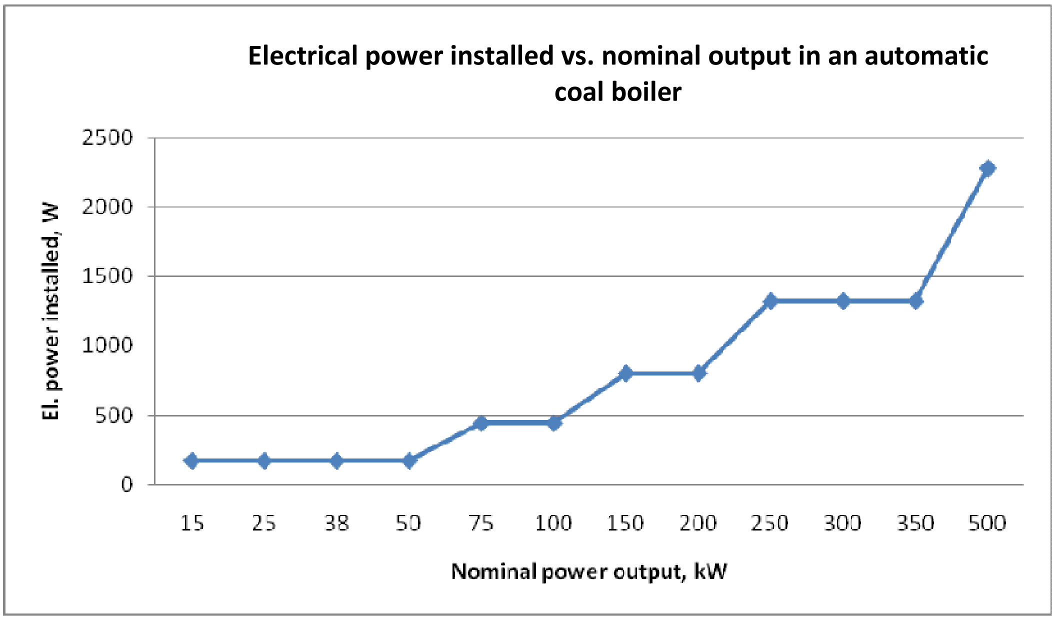

Figure 4-23 : Electrical power installed and boiler output in family of appliances from same manufacturer

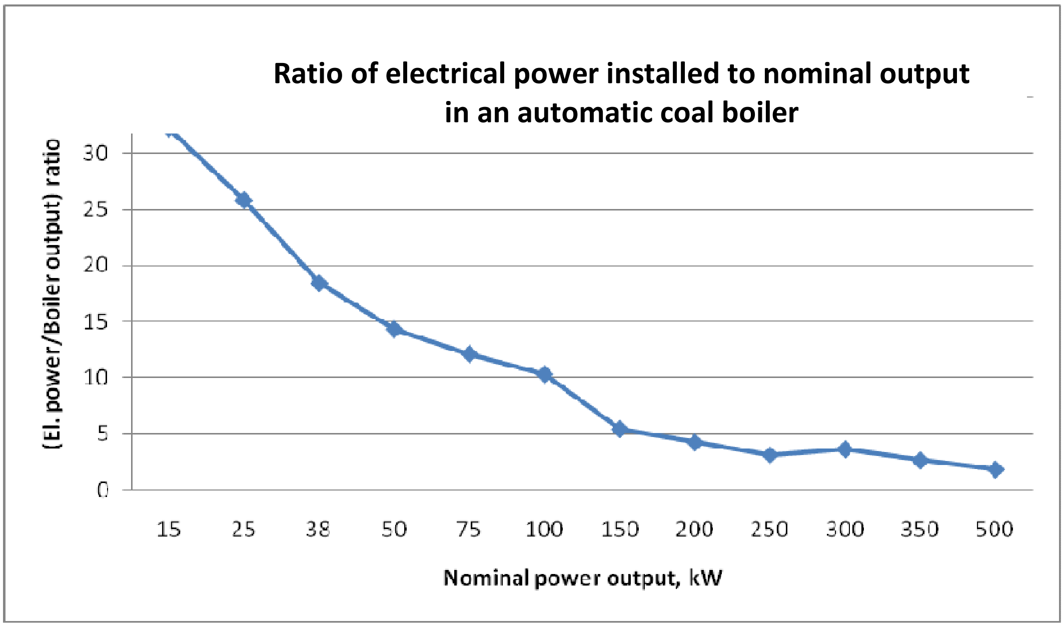

Figure 4-24 : Ratio of electrical power to appliance output

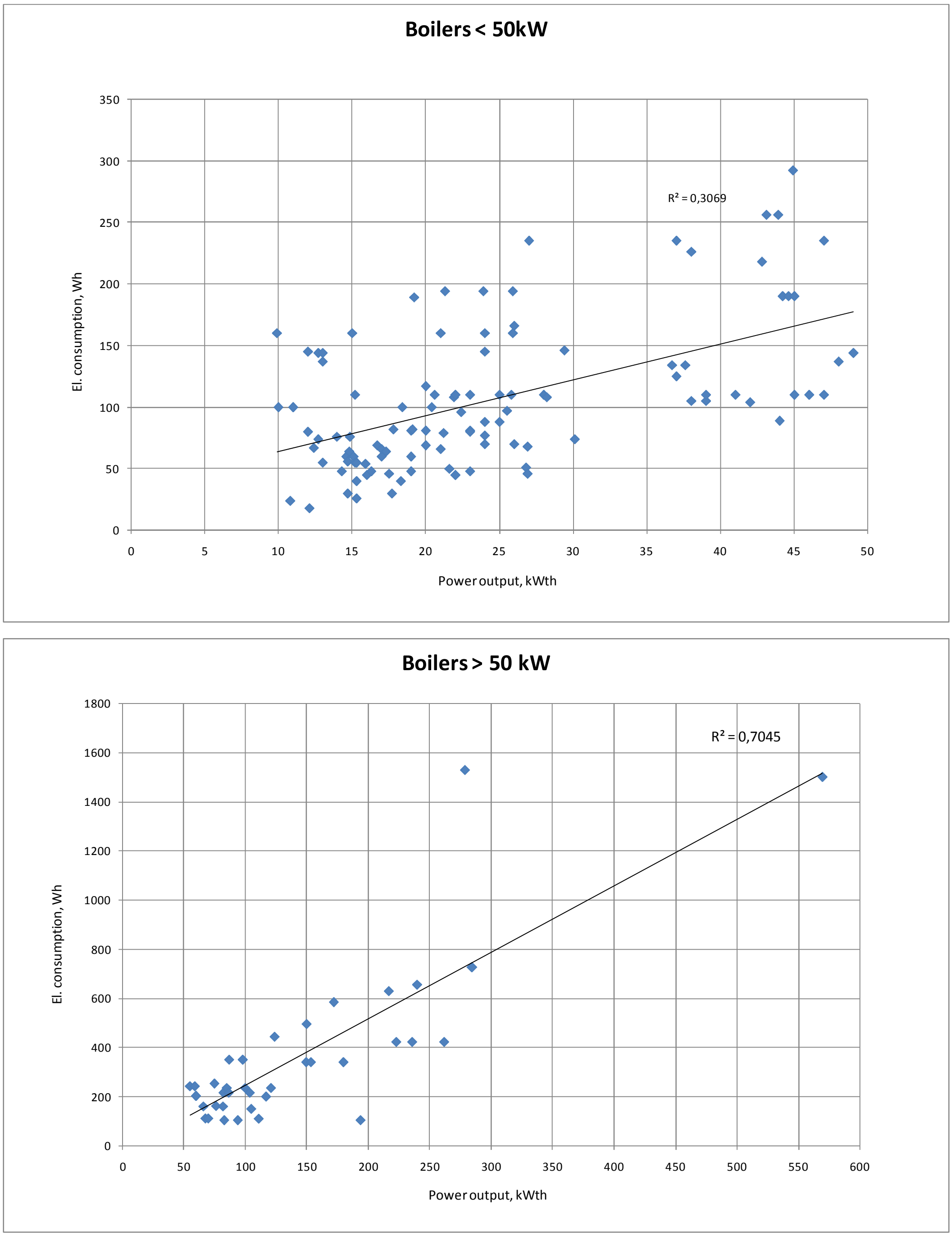

Figure 4-25: Electricity consumption of different pellet boilers[32]

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[32] Danish Technical Institute, Type testing, data provided by appliance manufacturers

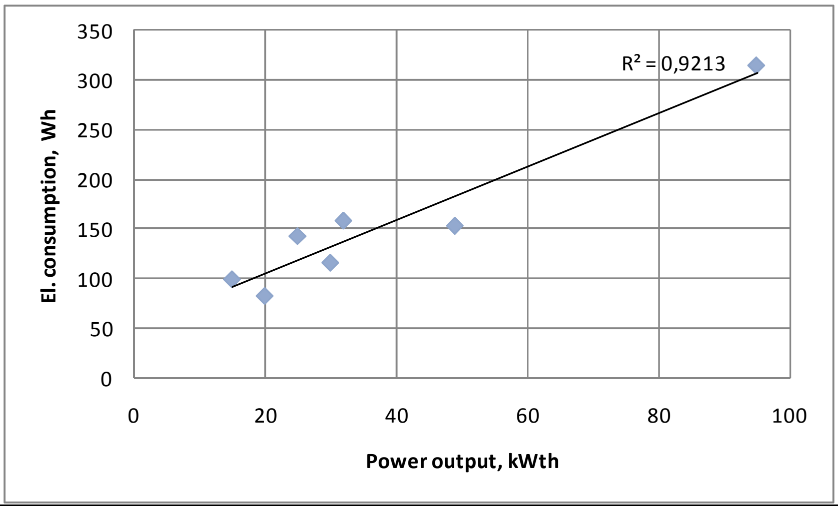
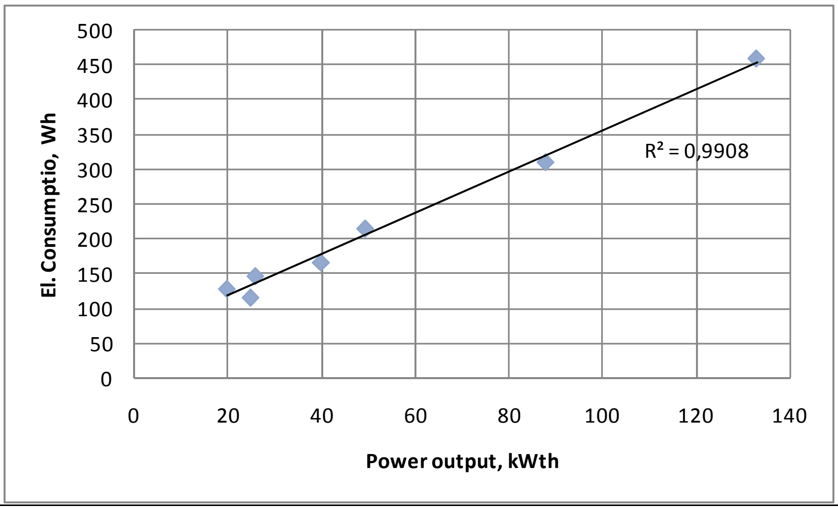
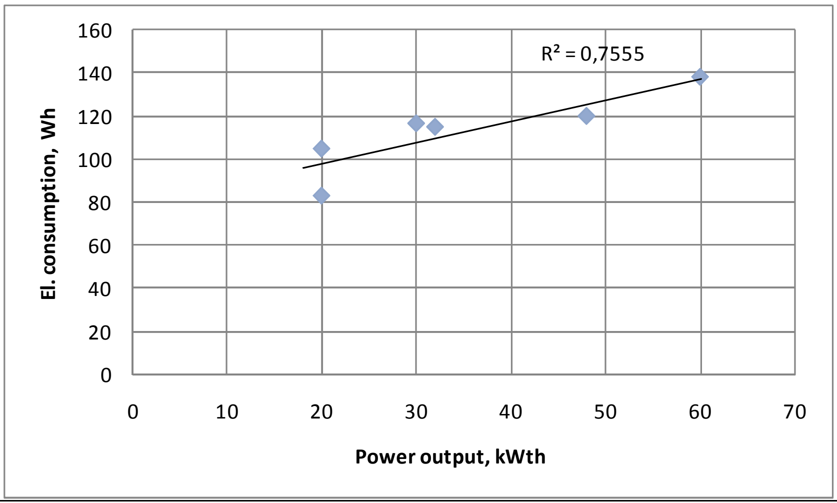
Pellet boilers	
Wood chip boilers	
Wood logs boilers	

Figure 4-26: Electricity consumption of different appliances[33]

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[33] Josephinum, data for Buderus appliances,

4.4.2 EFFICIENCY LOSSES IN SCIs

In the case of a solid fuel combustion process, there are four main types of energy losses: chemical and thermal losses in exhaust gas and chemical and thermal losses in ash.

- **Chemical loss in exhaust gas**: As a result of incomplete combustion, the exhaust gas contains combustible substances, like CO and hydrocarbons. These substances contain energy in chemical bonds which can be released in a combustion process and are a cause of energy loss. The methods for minimising this loss are to design the combustion chamber so as to maximise the combustion efficiency of the intended fuel.
- **Thermal or physical loss in exhaust gas**: Exhaust gases from combustion contain energy since they are at a higher temperature than the ambient temperature. Thermal losses are increased as the temperature of the exhaust gas from chimney increases or if additional 'tramp' air is passed through the chimney. Such losses can be minimised by design measures that improve heat recovery in the heat exchanger (where fitted), or measures that increase the emission of heat into the room and that control the air supply. Thermal losses are typically the largest contributor to the overall losses.
- **Chemical loss in ash**: solid residues from the combustion process (ash including fly ash) may contain carbon which was not burnt in the combustion chamber. Insufficient combustion time of fuel particles, fuel dimension and fuel composition are reasons for chemical loss in ash.
- **Physical loss in ash**: the ash, which is removed from the lower part of the appliance, also has a temperature above the ambient one. This means, that some part of released energy during combustion process was not passed to the other medium, thus this energy may also be lost (if material is removed while hot).

Other relevant losses can include losses from the appliance surfaces but this depends on the type of appliance, its function and location. For example, a cooker will lose heat to the surrounding environment through its external surfaces, but this energy contributes to the heat input to a kitchen/house and hence is not considered lost.

4.4.3 EMISSION FROM SMALL COMBUSTION INSTALLATIONS

➔ Pollutants

In any type of combustion process, a set type of pollutants is usually formed, but their amount differs depending on fuel and appliance type, and on operational mode. These pollutants and their formation process[34] have been defined in the following way[35]:

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[34] From the UNECE Task Force on Emission Inventories and Projections (TFEIP) Emission Inventory Guidebook chapter on small combustion emissions. Available at:reports.eea.europa.eu /EMEPCORINAIR5/en/B216v2.pdf

[35] Source: CORINAIR, Emission Inventory Guidebook, December 2006, p.15 to 18.

- **CO**

Carbon monoxide is found in the gaseous combustion products of all carbonaceous fuels, as an intermediate product of the combustion process and in particular in sub-stoichiometric conditions. CO is the most important intermediate product of fuel conversion to CO_2; it is oxidised to CO_2 under appropriate temperature and oxygen availability. Thus CO can be considered as a good indicator of the combustion quality. The mechanisms of CO formation, thermal-NO, VOCs and PAH (see sections below) are in general similarly influenced by the combustion conditions. The emissions level is also a function of the excess air ratio as well as of the combustion temperature and residence time of the combustion products in the reaction zone.

- **PM, PM_{10}, $PM_{2.5}$**

Particulate Matter (PM also referred to as TSP) in flue gases from combustion of fuels (in particular of solid fuels and biomass) might be described as carbon, smoke, soot, stack solid or fly ash. Particulate matter can be split between three groups of fuel combustion products.

The first group of particulate matter is formed via gaseous phase combustion or pyrolysis because of the incomplete combustion of fuels (Products of Incomplete Combustion or PICs). Soot and organic carbon particles (OC) are formed during combustion as well as from gaseous precursors through nucleation and condensation processes (secondary organic carbon). These precursors occur as a product of chemical radicals' reactions in the presence of hydrogen and oxygenated species within a flame. Condensed heavy hydrocarbons (tar substances) are an important, and in some cases, the main contributor to the total level of particles emission, in small-scale solid fuels combustion appliances such as fireplaces, stoves and old design boilers.

The second and third groups of particulate may contain ash particles or cenospheres that are largely produced from mineral matter in the fuel, they contain oxides and salts (S and Cl) of Ca, Mg, Si, Fe, K, Na, P, and heavy metals, and unburned carbon form from incomplete combustion of carbonaceous material (black carbon or elemental carbon – BC; this is called carbon-in-ash (or loss on ignition)[36].

Particulate matter emission from SCIs is typically combined with PICs associated and/or adsorbed onto particulate. Size distribution depends on combustion conditions. Optimisation of the solid fuel combustion process (for example by introduction of continuously controlled conditions such as automatic fuel feeding and distribution of combustion air) leads to a decrease of TSP emission and to a change of PM distribution[11]. Several studies have shown that the particulate emissions from modern and 'low-emitting' residential biomass combustion technologies are dominated by submicron particles (< 1µm) and the proportion[37] of the mass concentration of particles larger than 10 µm is normally < 10 % for SCIs.

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[36] Kupiainen, K., Klimont, Z., (2004); "Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control"; IIASA IR 04-079, http://www.iiasa.ac.at/rains/reports.html

[37] Boman Ch., Nordin A., Boström D., and Öhman M. (2004); "Characterisation of Inorganic Particulate Matter from Residential Combustion of Pelletized Biomass Fuels"; Energy&Fuels 18, pp. 338-348, 2004

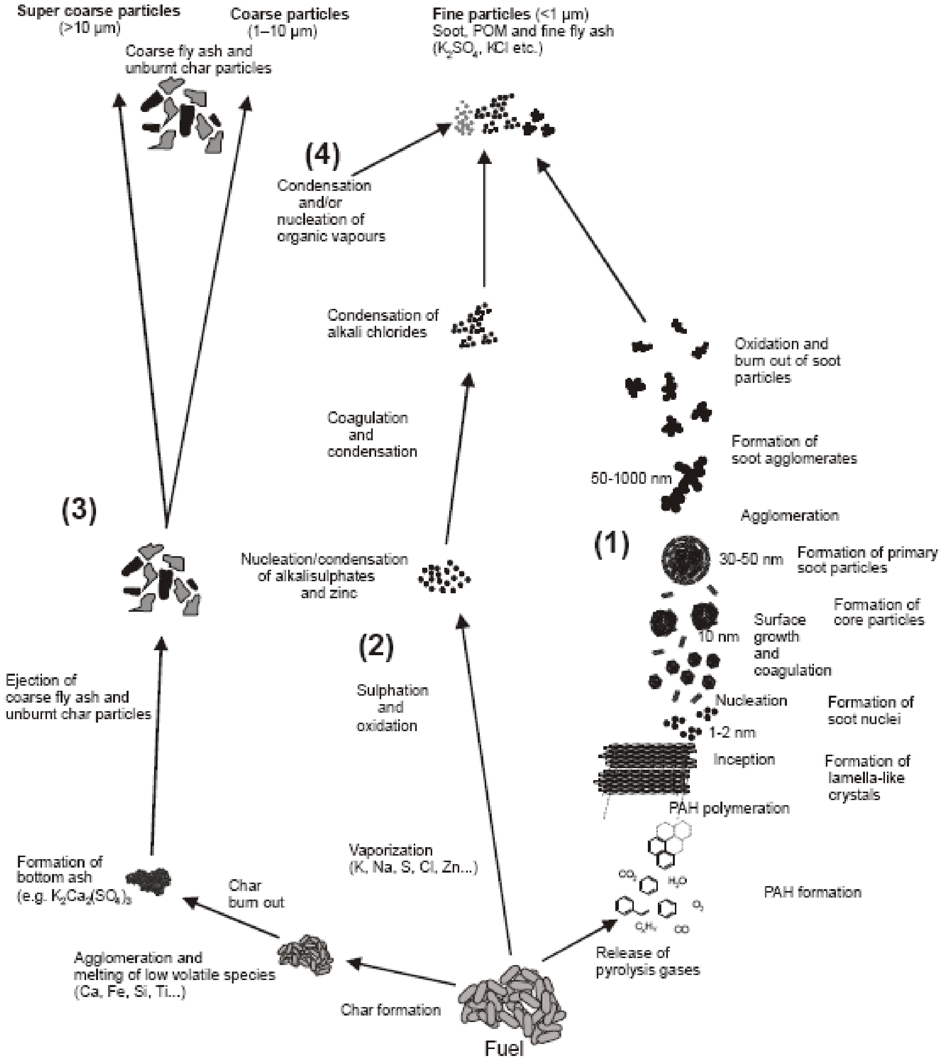

Figure 4-27: Illustration of the soot formation process (1), fine ash (2), coarse particles (3), particle organic matter (4), during residential wood combustion[38]

It must be stressed again that TSP values arising from solid fuel combustion differ significantly according to the measurement method used. As mentioned in Task 1, commonly used methods are:

- gravimetric method, in stack (VDI)
- gravimetric method with dilution tunnel (Norwegian)

While less frequently methods deemed to have significant potential are:

- electrostatic precipitation
- particles count

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[38] Tissari J., 2008, Fine particle emissions from residential wood combustion, PhD Thesis University of Kuopio (FI)

Currently, research is being carried out (see Figure 4-28) to compare the PM measurements obtained with different test methods. Intense work is also ongoing to develop an new unified measurement method across the Europe[39].

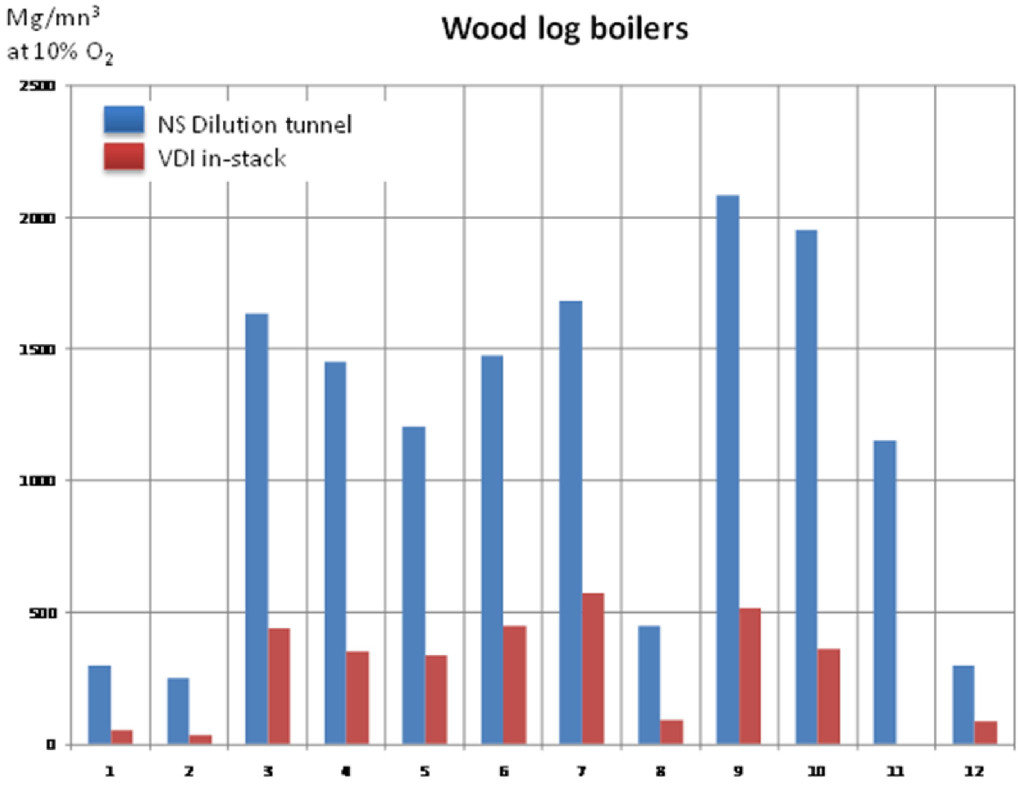

Figure 4-28: Comparison of different TSP measurement methods[40]

As shown in Figure 4-28, the dilution tunnel method results in significantly higher observed TSP values than the direct gravimetric method. This may be caused by the presence of secondary aerosols under dilution conditions (produced during the condensation of gaseous precursors). This may also be caused by the less convenient measurement conditions in the direct measurement method – lower linear velocities of flue gases, cause non-uniform concentration distribution in the stack, and greater losses of particles.

NO$_x$

'Oxides of nitrogen', expressed as NO$_2$ (general convention for reporting NO$_x$ emissions) are the sum of nitric oxide (NO) emissions (>90% of the NO$_x$ emission) and nitrogen dioxide (NO$_2$, typically <10% of the NO$_x$) emissions. Nitrogen emissions are the result of the partial oxidation of fuel nitrogen ("fuel NO"). The emissions of NO$_x$ increase with increasing nitrogen contents in the fuel, as well as with increasing excess air ratio, and higher combustion temperature. Nitrogen content in fuels vary both among and within fuel types: coals contain nitrogen mainly in N-organic form (0.5% to 2.9% daf, average about 1.4%). Biomass fuels contain N in N-organic form (0.05% to 0.8% daf) for coke the N-contents is

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[39] HKI Position paper on new measurement method for dust emission

[40] Courtesy of a stakeholder Kim Winter, the Danish Technological Institute

between 0.6 to 1.55% (daf), for peat between 0.7 and 4.4 % (daf). NO_x emissions may be reduced by both primary and secondary measures aiming at emission reduction, but secondary measures are not applied in small installations due to economic factors.

Additional NOx may be formed from nitrogen in the air under certain conditions, as "thermal NO" and as "prompt-NO". Thermal and prompt-NO are generated by the flames surrounding individual particles, through free radical reactions. Nitrogen in the air starts to react with O-radicals and forms NO at temperatures above approximately 1300°C, its amount depending on O_2 concentration and residence time. However, the combustion temperatures in SCIs, in general, are lower than 1300°C and hence thermal NOx formation is not usually important (especially for fireplaces and insert appliances). However, most of the thermal NO_x is formed in the post-flame gases (after the main combustion process), and due to development of small boilers design, the significance of such emissions may be increasing.

NMVOC

It is a generic term for a large variety of chemically different compounds, like for example, benzene, ethanol, formaldehyde, cyclohexane, 1,1,1-trichloroethane or acetone. Essentially, NMVOCs are identical to VOCs, but with methane excluded. They are intermediates in the thermal conversion of fuel to CO_2 and H_2O. As for CO, emission of NMVOC is a result of too low temperature, too short residence time in oxidation zone, and/or insufficient oxygen availability. The NMVOC/CH_4 emissions from combustion processes are often reported together as VOC. Emission of VOC has tendency to decrease as the capacity of the combustion installation increases, due to application of advanced or controlled combustion techniques.

OGC

This is defined as organic gaseous carbon in EN303-5 and is essentially equivalent to a VOC emission.

PCDD/F

The emissions of dioxins and furans are highly dependent on the conditions under which cooling of the combustion and exhaust gases is carried out. Carbon, chlorine, a catalyst and oxygen excess are necessary for the formation of PCDD/F. Coal fired stoves in particular have been reported to release very high levels of PCDD/F when using certain kinds of coal[41]. The emission of PCDD/F is significantly increased when plastic waste is co-combusted in residential appliances or when contaminated/treated wood is used. The emissions of PCDD/F can be reduced by introduction of advanced combustion techniques of solid fuels[42].

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[41] Quass U., Fermann M., Bröker G.; (2000);"The European Dioxin Emission Inventory - Stage II" Desktop studies and case studies"; Final Report 31.21. 2000; Volume 2, pp. 115-120, North Rhine Westphalia State Environment Agency

[42] Kubica K. (2004) "Threats caused by persistent pollutants, particularly by dioxine and phuranes from residential heating and the directions of protection actions aiming at their emission reduction"; Project: GF/POL/01/004 - Enabling activities to facilitate early action on the implementation of the Stockholm

PAH

Emissions of polycyclic aromatic hydrocarbons result from incomplete (intermediate) conversion of fuels. As for CO and VOCs, emissions of PAH depend on the organisation of the combustion process, particularly on the temperature (too low temperature favourably increases their emission), the residence time in the reaction zone and the availability of oxygen[43]. It has been reported[44] that coal stoves and old type boilers (hand-fuelled) emit several times higher amounts of PAH in comparison to new design boilers (capacity below 50 kW), such as boilers with semi-automatic feeding. Technologies of co-combustion of coal and biomass that can be applied in commercial/institutional and in industrial SCIs lead to reduction of PAHs as well as TSP, VOCs and CO emissions[45].

NH_3

Small amounts of ammonia may be emitted because of the incomplete combustion of solid fuels containing nitrogen. This occurs at very low combustion temperatures (e.g. in fireplaces, stoves, old-design boilers). NH_3 emissions generally can be reduced by primary measures aiming to reduce products of incomplete combustion and increase energy efficiency.

SO_2

The emission of sulphur dioxide depends on the fuel sulphur content. For coal, sulphur content normally varies between 0.1 and 1.5% (daf) (up to an extreme value of 10%) and for biomass, it varies between 0.01 and 0.9%. Both the coal and biomass sulphur content may vary significantly depending on their origin. Sulphur content of biomass also depends on the type of biomass. In biomass fuels, sulphur appears mainly as organic and salts sulphur. In coal, sulphur can be found in three forms:

(i) inorganic – mainly pyritic sulphur (FeS2), and sulphur salts;

(ii) organic – as sulphides, disulfides; and cyclic compounds mainly tiophene compounds;

Convention on Persistent Organic Pollutants (POPs Convention); Warszawa, (Polish); http://ks.ios.edu.pl/gef/doc/gf-pol-nip-r1.pdf; Kubica K. (2008) “Domestic Sector Measures to Reduce Dioxin Emissions in Poland”, Expert Workshop Dioxin Emissions from Domestic Sources, Brussels, http://www.bipro.de/dioxin-domestic/sub/meetings.htm

[43] Kubica K. (1997) “Distribution of PAH generated in domestic fuels boilers”; Proc. of 9th International Conference on Coal Science; Essen, Niemcy, 7

[44] Kubica K., (2002)“Emission of Pollutants during Combustion of Solid Fuels and Biomass in Small Appliances”; UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: ”Emissions from Small and Medium Combustion Plants”, Ispra, Procc. No.I.02.87; Kubica (2003): see footnote 11. Kubica at al. (2004) Kubica K., Paradiz B., Dilara, “Toxic emissions from Solid Fuel Combustion in Small Residential Appliances”; Procc. 6th International Conference on Emission Monitoring CEM-2004, Milano Italy; www.cem2004.it; Gullett B.K., 2003

[45] Kubica et al. (1997), Kubica, K., Raińczak, J., Rzepa, S., Ściążko, M., “Influence of biofuel addition on emission of pollutants from fine coal combustion”, Proc. 4th Polish-Danish Workshop on Biofuels, Starbieniewo, 12-14 czerwca; Kubica K. (2004); “Combustion and co-combustion of solid fuels” chapter in “Management of energy in the town”; ISBN 83-86492-26-0; Polska Akademia Nauk Oddział w Łodzi, Łódź 2004 s. 102-140.

(iii) elemental sulphur. Pyritic and organic sulphur are a major part of the sulphur in coal; both types are responsible for SOx formation (SO2-usual >95%, and SO3 - <5% is formed at lower temperatures).

Moreover, for coals the content of calcium carbonate is also relevant, due to its capacity to absorb the SO_2 generated. The following equation can be used for calculating the SO_2 emission factor for solid fuels:

$$EF_{SO_2,k} = 2 \cdot \overline{Cs_k} \cdot \left(1 - \overline{\alpha_{S,k}}\right) \cdot \frac{1}{H_k} \cdot 10^6 ,$$

Where :

$EF_{SO2,k}$	emission factor for SO_2 for fuel type k [g/GJ]
$\overline{Cs_k}$	average sulphur content of fuel type k (mass S/mass fuel [kg/kg])
H_k	average lover heating value for fuel type k [MJ/kg]
$\overline{\alpha_{s,k}}$	average sulphur retention in ash

For biomass fuels, the average sulphur retention in ash can be taken as zero. For the coal fuels, the default value of 0.1 can be taken in the absence of real data. Pre-cleaning, pre-treatment processes of raw coals and improvement of their quality can achieve reduction of SO2 emissions[46].

- **Heavy metals:**

Most heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn) are usually released as compounds associated and/or adsorbed with particles (e.g. sulphides, chlorides or organic compounds). During the combustion of coal and biomass, particles undergo complex changes, which lead to vaporisation of volatile elements. Some metals (Hg, Se, As and Pb) are at least partially present in the vapour phase. The rate of volatilisation of heavy metal compounds depends on technology characteristics (type of boilers; combustion temperature) and on fuel characteristics (their contents of metals, fraction of inorganic species, such as chlorine, calcium, etc.). Less volatile elements tend to condensate onto the surface of smaller particles in the exhaust gases. Higher emission of Cd and Zn has been observed in biomass in comparison to coal.

The chemical form of the mercury emitted may depend in particular on the presence of chlorine compounds. The nature of the combustion appliance used and any associated abatement equipment will also have an effect[47]. Mercury emitted from SCIs occurs in elementary form (elemental Mercury vapour Hg^0),

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[46] Kubica K. (2002) "Emission of Pollutants during Combustion of Solid Fuels and Biomass in Small Appliances"; UN-ECE TFEIP Combustion and Industry Expert Panel Workshop on: "Emissions from Small and Medium Combustion Plants", Ispra, Procc. No.I.02.87. see also footnote 11.

[47] Pye S., Jones G., Stewart R., Woodfield M., Kubica K., Kubica R., Pacyna J. (2005/1); "Costs and environmental effectiveness of options for reducing mercury emissions to air from small-scale combustion installations"; AEAT/ED48706/Final report v2, December 2005

reactive gaseous form (Reactive Gaseous Mercury, RGM) and total particulate form (Total Particulate Mercury, TPM)[48]. The distribution of particular species of emitted mercury from SCIs is different to the distribution observed in large-scale combustion.

Contamination of biomass fuels, such as treated or painted wood, may cause significantly higher amounts of heavy metals emitted (e.g. Cr, As). Heavy metals emissions can be reduced by secondary emission reduction measures, with the exception of Hg, As, Cd and Pb that have a significant gaseous phase component.

➔ Emission factors

An emission factor relates the rate of release of a pollutant to the rate of an activity. For solid fuel combustion, emission factors are typically expressed as a mass of pollutant emitted per mass of fuel burned (for example g/kg) or, as used in this report, per unit of energy input (for example g/GJ). In this study, emission factors have been derived from concentration data provided by manufacturers to enable a comparison with published and experimentally derived values.

4.4.4 MEASURED EMISSIONS FROM SOLID FUEL SCIS

While emissions results can be found from literature and test laboratories, these results often cannot be compared to each other due to variations in the measurement conditions and methods. In this study, the focus is chosen to be on emissions measured in standard test conditions, since standardised conditions provide the only solid basis for comparison, although they may not be representative of real-life emissions. Nevertheless, for information purposes, real-life emissions are presented separately.

Among the data measured in test standard conditions, different measurement techniques may be used, in particular for PM emissions. These data are therefore not comparable. Accordingly, in this study the DIN+ standard method is chosen as the representative method since most of the emissions data relevant to the Lot 15 study were measured in these conditions. Results for other test methods are also presented separately, for information purposes. The choice of the DIN+ standard over others does not mean that this standard is considered better than the others (see discussion in Section 4.4.3 , it merely suits the needs of this study.

Many stakeholders throughout the duration of the study have commented on different reasons why one method should be better than others. It is not the intent of this study to recommend or determine which measurement method should be used industry wide. As such, as soon as a measurement method is accepted industry wide, it is imperative that all testing standards, labelling criteria and ELVs be updated to accommodate this.

➔ Historical improvements

Aside from user behaviour, emissions levels from solid fuel combustion depend on the performance of the SCIs. The performance of solid fuel SCIs is constantly improving,

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[48] Pacyna J.M., Munthe J. (2004), "Summary of research of projects on mercury funded by EC DG Research"; Workshop on Mercury Needs for further International Environmental Agreements, Brussels, March 29-30, 2004

due to their recognised heavy environmental impact. Accordingly appliances sold today have an improved environmental performance compared to appliances sold in the past. For instance, it can be seen that for CO and dust emissions the improvements were fast at first, but are relatively small today, reflecting that the scope for evolutionary improvement in emissions is perhaps limited. (Figure 4-29). Indeed, industry associations have commented that for direct heating biomass appliances, 80% (NCV) represents an upper limit to efficiency for many solid fuel appliance users because beyond this efficiency, condensation problems and backdraught (safety) issues in the chimney are technically or economically constraining.

Given that the lifetime of SCIs can reach up to 50 years, the stock of installed appliances is in fact a mixture of appliances from the last 50 years. Therefore, emissions from the stock of installed appliances needs to be estimated from historical data.

Table 4-32 presents such emissions data for 20-30 year old biomass direct heating SCIs, obtained from long-term testing in test standard conditions (with the DIN+ method).

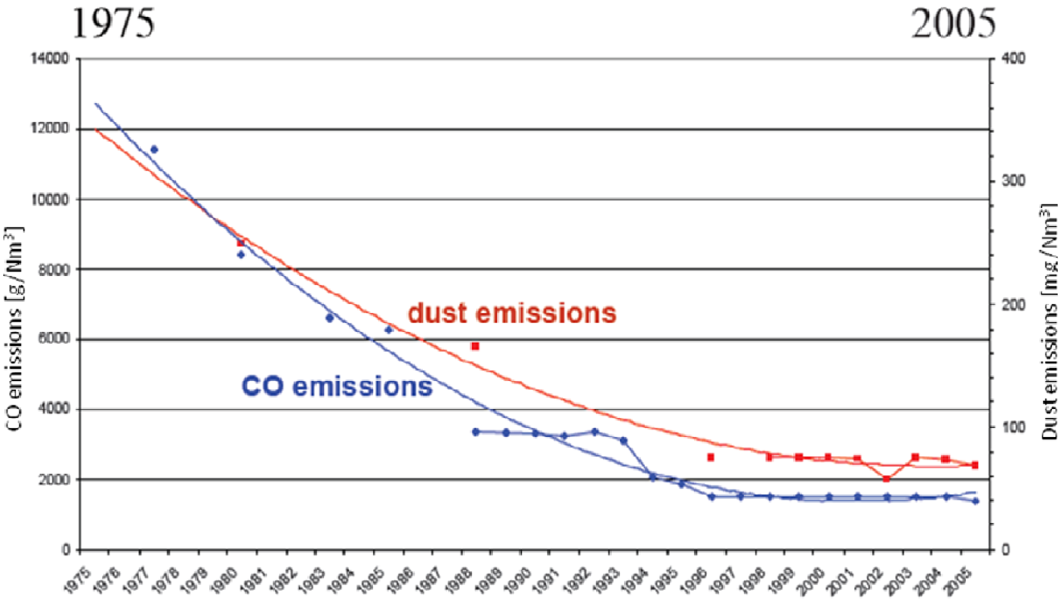

Figure 4-29: Historical improvement of CO and dust emissions from biomass SCIs[49]

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[49] Data courtesy of “Industrieverband Haus-, Heiz- und Küchentechnik e.V.” (HKI), industry representatives of manufacturers and of the producers of domestic heating and cooking appliances, Germany

Table 4-32: Historical efficiency and emission data, 20-30 year old combustion installations, with the DIN+ measurement method[49]

	Efficiency %	Particulate mg/m³	CO mg/m³	OGC mg/m³	NOx mg/m³
Open fireplaces	5-40	150-5000	6 000-37 500	300-1 500	< 200
Inset fireplaces	40-60	90-120 (5 000)	6 000-17 500 (37 500)	200-500 (1 500)	< 200
Closed fireplace	40-60	90-120 (5 000)	6 000-17 500 (37 500)	200-500 (1 500)	< 200
Slow heat release stove	60-75	90-150 (5 000)	10 000-17 500 (37 500)	250-750 (1 500)	< 200
Kachelofen	60-75	90-150 (5 000)	10 000-17 500 (37 500)	250-750 (1 500)	< 200
Traditional cookers	50–60	100-200 (5 000)	8 000-20 000 (37 500)	300-900 (1 500)	< 200
Cookers with water components	50-65	100-200 (5 000)	10 000-20 000 (37 500)	300-900 (1 500)	< 200
Continuous burning stoves	50-70	90-150 (5 000)	10 000-17 500 (37 500)	250-750 (1 500)	< 200
Traditional stoves	50-70	90-120 (5 000)	4 000-15 000 (37 500)	200-500 (1 500)	< 200
Modern = Trad + 2nd air (intermittent) stove	50-70	90-120 (5 000)	4 000-15 000 (37 500)	200-500 (1 500)	< 200
Notes:					
- Values up to the parenthesis-values were observed sporadically					
- For open fireplaces data is only estimated, there is no certified data available for all the parameters					
- CO above 3% is undeterminable due to measuring range					
- German requirements state 0,3/0,4 % vol. CO since the beginning of the 80s. In the rest of Europe, a PM-range of 100-1000 might be more realistic.					

Table 4-33 shows historical efficiency and emission data for indirect heating appliances, specifically biomass boilers <300 kW. Since no measurement standard exists, these data have been compiled based on Austrian type testing of appliances and can be considered comparable because they were compiled in a similar fashion to each other. They also can be assumed to be comparable to the emissions of direct heating appliances listed in Table 4-32 for the purposes of this historical data review because the measurement methods are similar (type testing by accredited laboratories, while not guaranteed, even for particulate matter the Austrian Boiler Association and HKI Germany are expected to maintain similar testing methods).

Table 4-33: Historical efficiency and emission data, 10 year old biomass solid fuel combustion boiler installations[50]

	Efficiency [%]	Particulate [mg/m³]	CO [mg/m³]	OGC [mg/m³]	NO$_x$ [mg/m³]
Log wood boilers	89,8	18	123	2,5	109
Wood chip boilers	90,4	25	46	1	124,5

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[50] Statistical evaluation of emission data of type-tests at FJ-BLT, BIOENERGY 2020+ GmbH and ABC Boilers, 2005, Austria

For mineral fuel boilers <50 kW, polish historical data on efficiency and emissions is presented in Table 4-36. The emissions were measured in Polish labs since 1998 in the same conditions, and with methods considered comparable to the Austrian type testing ones. Therefore the data can be compared with that of biomass appliances.

➔ Standard emission limits for direct heating SCIs

According to the currently used EN Standards for SCI testing, emission of pollutants is expressed in mg/m^3 of given species in the flue gases under reference conditions. The reference conditions consist of measurements of dry flue gases at Standard Temperature and Pressure (STP, 0 °C, 101.3 kPa) standardised to 13% 0_2 (10% O_2 for EN303-5 boilers). The EN standardised limits for biomass fuelled direct heating appliances are presented in Table 4-35.

Table 4-34: Historical efficiency and emission data for boilers <50kW fuelled by bituminuous coal over the last 10 years (13% O_2)[51]

Installation	Period, year	Efficiency, %		Emissions factor of pollutants (net calorific value), mg/m^3					
				CO		TSP		NOX	
		range	mean	range	mean	range	mean	range	mean
Manually fuelled	<1996	50 – 67	65	8730-5090	4360	800-510	655	35-90	75
	1996-1999	67 - 78	70	5090-1820	3640	510-110	290	35-180	110
	2000-2005	70 - 80	77	3640-870	2180	180-90	145	75-220	145
	2005-2008	75 - 83	80	1020-580	870	110-45	90	90-255	145
Retort (automatic fuelled)	1998 - 1999	75 – 80	78	1090-1820	1090	145-95	110	230-365	290
	2000-2005	75 – 84	80	870-580	435	110-65	90	230-330	290
	2005-2008	78 - 89	84	870-95	365	90-20	50	220-330	220

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[51] Courtesy of ITT (2009)

Table 4-35: Standard emission and efficiency limits for various biomass fuelled direct heating appliances with relevant standard

Appliance	Standard	Efficiency	CO
		%	g/GJ
Open fireplace	**EN 13229**	>30	<8594
Closed fireplace with natural draught	**EN 13240**	>50	<8594
Cooker	**EN 12815**	>60	<8594
Slow heat release stove	**EN 13229**	>75	<1719
Stove	**EN 13240**	>50	<8594
Pellet stove (nominal output)	**EN 14785**	>75	344
(reduced heat output)	**EN 14785**	>70	516

Table 4-36: Standard emission and efficiency data for various heating appliances using the DIN+ testing method[52]

Appliance	Configuration	Number of responses	Standard	Effi-ciency	CO	PM	NOx as NO_2	VOC/ OGC
				%	g/GJ	g/GJ	g/GJ	g/GJ
Closed Fireplaces	No secondary air	2	EN 13229 DIN+	76	859	18	23	n.d.
	With secondary air	15	EN 13229 DIN+	75.9	1000	41	123	77
	Manual primary and secondary air	16	EN 13229 DIN+	75.8	963	36	116	70
	Automatic primary and secondary air	2	EN 13229 DIN+	80	1031	n.d.	138	83
Cookers	Manual primary air	4	EN 12815 DIN+	72	1186	65	129	76
	Automatic primary air	2	EN 12815 DIN+	71.5	1933	69	138	69
Stoves	No secondary air	4	EN 13240 DIN+	76	859	16	80	42
	With secondary air	25	EN 13240 DIN+	76.8	952	25	125	73
	Manual primary air	27	EN 13240 DIN+	77	936	42	120	69
	Automatic primary air	1	EN 13240 DIN+	76.8	952	25	125	73
Pellet stove	Data for rated output	6	EN 14785 DIN+	88.7	138	26	103	10
	Data for reduced output			88.7	361	n.d	n.d.	n.d

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[52] Based on survey responses from stakeholders for Lot 15 study

➔ Direct heating SCIs emissions, measured with the DIN+ method

A summary of the emission factors measured according to the DIN+ method and obtained from questionnaire data is provided in Table 4-36 for biomass fuelled direct heating appliances. Mineral fuel efficiency and emissions data for direct heating appliances was not provided in the questionnaires.

Overall, the questionnaire data show that direct heating appliances have similar emission levels and that as appliances have more controls, efficiency tends to increase. Emissions should correspondingly be expected to decrease, however, this is not apparent from the data presented here. This may be a result of the limited sample of appliances, and even more limited number of manufacturers represented in each sample. These data are thus presented here for indicative purposes, but will not be used further in the study.

National market data from HKI, also measured with the DIN+ method, shows that closed fireplaces and traditional stoves have very similar efficiency and emissions, whereas traditional cookers tend to be slightly less efficient and more polluting (Table 4-37). The emission levels are comparable to the ones provided from the questionnaire data.

Table 4-37: Standard emission and efficiency data for various heating appliances provided by HKI[49]

Appliance	Standard	Efficiency	CO	PM	NOx as NO_2	VOC/ OGC
		%	g/GJ	g/GJ	g/GJ	g/GJ
Closed fireplaces	**EN 13229 HKI**	75-80	859-1031	47-52	<138	69-83
Cookers	**EN 12815 HKI**	65-75	1238-2406	62-69	<138	76-83
Modern stoves	**EN 13240 HKI**	75-80	859-1031	38-52	<138	76-83
Pellet stoves (rated output)	**EN 14785 HKI**	85-90	110-138	17-24	<103	6-7

Further data was obtained from questionnaires, that was measured according to the relevant EN standard, but not with the DIN+ testing method. As a result, PM emissions from these data cannot be compared (see Section 4.4.3). However the different methods used for CO, VOCs and NOx measurements are assumed not to differ substantially, and these data are presented in Appendix, Table 4-49. Overall, the average efficiency of each type of direct heating appliance is above the relevant required EN efficiency for that appliance (Table 4-35 and Table 4-49 -). Open fireplaces have efficiencies ranging from 30-64% (30% higher than the EN requirement on average), closed fireplaces and stoves have similar and better efficiencies ranging from 40-80%, and slow heat release stoves or kachelofens have efficiencies above 75%. Stoves with automatic air control have efficiencies between 75% and 80%, while closed fireplaces or inserts with automatic air control have slightly higher efficiencies (75%-85%). CO emissions are usually 2-3 times lower than the respective EN requirements. CO emissions are lowest in stoves with automatic primary air and secondary air and highest in open fireplaces or simple closed fireplaces or inserts with no secondary air.

No product-specific data were obtained for mineral fuel appliances.

➔ Standard efficiency and emission classes for indirect heating SCIs

Standalone boilers that do not have a direct heating function are covered by EN 303 Part 5. Similarly to direct heating appliances, the reference conditions consist of measurements of dry flue gases at Standard Temperature and Pressure (STP, 0°C, 101.3 kPa) standardised to a reference oxygen content 10% O_2 for EN303-5 boilers. In the case of Austrian data for biomass boilers, the data are recalculated to 13% of oxygen, according to country regulations. The scope of EN 303-5 specifies three classes of emission limits. The boiler class efficiency is determinate by the following equations:

- for class 1, $\eta_k = 67 + 6 * \log Q_N$,
- for class 2, $\eta_k = 57 + 6 * \log Q_N$,
- for class 3, $\eta_k = 47 + 6 * \log Q_N$,

where η_k = boiler efficiency in %, Q_N = nominal heat output in kW.

The emission requirement shall be satisfied if the limits specified in Table 4-38 are not exceeded. Boilers < 300kWare tested in accordance with EN-305-5, but this standard is also frequently used to test larger boilers, including those up to the nominal threshold of 500 kW applied in the Lot15.

Appliances that include boilers to provide a secondary indirect heating function are included in the direct heating section, relating to the appliances primary direct heating function. Standalone residential boilers that also fulfil a direct heating function are covered by EN 12809.

Table 4-38: Emission limits and classes definitions according to EN 303-5

Stoking	Fuel	Nominal heat output [kW]	Emission limits								
			at 10% O_2* [mg/m^3]								
			CO			OGC			Dust		
			class 1	class 2	class 3	class 1	class 2	class 3	class 1	class 2	class 3
Manual	Biomass	≤ 50	25000	8000	5000	2000	300	150	200	180	150
		> 50 to 150	12500	5000	2500	1500	200	100	200	180	150
		> 150 to 300	12500	2000	1200	1500	200	100	200	180	150
	Mineral	≤ 50	25000	8000	5000	2000	300	150	180	150	125
		> 50 to 150	12500	5000	2500	1500	200	100	180	150	125
		> 150 to 300	12500	2000	1200	1500	200	100	180	150	125
Auto-matic	Biomass	≤ 50	15000	5000	3000	1750	200	100	200	180	150
		> 50 to 150	12500	4500	2500	1250	150	80	200	180	150
		> 150 to 300	12500	2000	1200	1250	150	80	200	180	150
	Mineral	≤ 50	15000	5000	3000	1750	200	100	180	150	125
		> 50 to 150	12500	4500	2500	1250	150	80	180	150	125
		> 150 to 300	12500	2000	1200	1250	150	80	180	150	125

* referred to dry exit flue gas, 0^{o}C, 1013 mbar

Once converted to g/GJ (assumptions: 8m^3 of flue gas per kg of biomass fuel and NCV of fuel equal to 16 MJ/kg, and 15m^3 of flue gas per kg of coal fuel and NCV of fuel equal to 25 MJ/kg), the standardised emission limits for the indirect heating appliances considered in the Lot15 study are shown in Table 4-39 for biomass appliances and in Table 4-40 for mineral fuel appliances.

Table 4-39: Standard emissions data for various biomass fuelled indirect heating appliances with relevant standard (for class 3)

Appliance	Standard	CO	PM	VOC/ OGC
		g/GJ	g/GJ	g/GJ
Manual boiler <50kW	**EN 303-5**	2500	75	75
Automatic boiler < 50kW	**EN 303-5**	1500	75	50
Manual boiler 50kW – 150 kW	**EN 303-5**	1250	75	50
Automatic boiler 50kW – 150 kW	**EN 303-5**	1250	75	40

Table 4-40: Standard emissions data for various mineral fuelled indirect heating appliances with relevant standard (for class 3)

Appliance	Standard	CO	PM	VOC/ OGC
		g/GJ	g/GJ	g/GJ
Manual boiler < 50kW	**EN 303-5**	3000	75	90
Automatic boiler < 50kW	**EN 303-5**	1800	75	60
Manual boiler 50kW – 150 kW	**EN 303-5**	1500	75	60
Automatic boiler 50kW – 150 kW	**EN 303-5**	1500	75	48

➔ Indirect heating SCIs emissions, measured according to EN 305-5

A summary of the emission factors for indirect heating appliances relevant to the Lot 15 study measured according to EN 305-5 standard in the same conditions is shown below. Data on biomass boilers efficiency and emissions is shown in Table 4-41 and Table 4-42, based on Austrian and laboratory tests data respectively. Efficiency and emissions data on mineral fuelled boilers from laboratory tests are also shown in Table 4-43.

These data show that biomass boilers have reported efficiencies ranging between 82-99%, with little difference among the different categories of boilers, although boilers >50kW tend to have slightly better efficiencies (> 90%). CO emissions range from 2-1548 g/GJ and are on average two times below the EN emission limits. The Austrian data suggests that boilers < 50kW have CO emissions 2-3 times higher than larger boilers (>50 kW), although this trend is not confirmed in the public data. Biomass boilers have similar PM emissions, ranging between 4-60 g/GJ, and generally lying between 15-20 g/GJ on average, which is 4-5 times below the EN-305-5 limits. The Austrian data suggests that PM emission are higher in automatic appliances than in manually fuelled ones.

When compared to emissions from biomass appliances (Table 4-42), emissions from mineral fuel appliances (Table 4-43) measured in the same conditions tend to be higher. CO emissions range between 86-1338 g/GJ on average, while PM emissions range between 30-70 g/GJ on average. The main differences are among conventional manually fuelled mineral and biomass boilers, where mineral boilers have CO and PM emissions approximately twice as high as those of biomass boilers.

Table 4-41: Standard emissions data for Austrian biomass boilers measured according to EN-305-5 standard[53]

Appliance	Standard	Num-ber	Efficiency		CO		PM		Nox		VOC/OGC	
			Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
			%	%	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Downdraught boiler <50kW	EN-303-5	34	90.9	82.3 - 99.6	324.9	46 - 1548	17	4 - 52	101.5	76 - 163	24.1	(<1) - 80
Automatic boiler < 50kW	EN-303-5	120	89.1	84.3 - 93.8	409	10 - 807	15	7 - 23	91.5	52 - 131	23	(<1) - 46
Automatic wood chips boiler < 50kW	EN-303-5	120	82.2	86.6 - 95.3	177.9	11 - 1077	27.5	9 - 60	146.7	103 - 188	20.7	(<1) - 14
Manual boiler >50kW	EN-303-5		91.7	90.6 - 93.6	80.3	31 - 191	19	10 - 31	114	99 - 141	1.5	(<1) - 4
Automatic wood chips boiler > 50kW	EN-303-5		91.8	87.6 - 95	117	6 - 235	29	5 - 44	153.5	95 - 234	5	(<1) - 9

n.d.: no data

ITT Data[54]												
Wood pellet boilers >50 kW	EN 303-5	22	91.9	90.6-93.2	72.5	6-139	55.5	5-106	66	21-111	1	<1-1

Table 4-42: Standard emissions data for biomass boilers measured according to EN-305-5 standard

Appliance	Standard	Num-ber	Efficiency		CO		PM		Nox		VOC/OGC	
			Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
			%	%	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Downdraught boiler <50kW	EN-303-5	4	88.6	86.4 - 90.1	76.8	72 - 82	16	14 - 17	101.3	94 - 115	5	40089
Automatic wood chips boiler < 50kW	EN-303-5	4	90.4	87.3 - 91.8	43.5	2 - 66	17.3	9 - 25	96.3	69 - 123	<1	<1
Manual boiler >50kW	EN-303-5	2	91.0	90.6 - 91.3	74.5	29 - 120	15.5	10 - 21	90.5	88 - 93	<1	n.d.
Automatic wood chips boiler > 50kW	EN-303-5	4	91.4	90.5 - 91.8	38.3	8 - 75	21.5	15 - 29	103.5	95 - 113	<1	n.d.

n.d.: no data

ITT DATA[54]												
Wood pellet boilers <50kW	EN 303-5	7	88.9	88.1-93.7	108	23-221	19	8-53	73	61-90	1.6	0.7-2.8
Wood pellet boilers >50 kW	EN 303-5	3	91.4	90.6-91.8	15	8-20	16	14-18	84	64-102	1	<1-1
Manual boiler, Downdraught <50kW	EN 303-5	8	89.5	86.4-91.8	62	2-99	15	10-17	87	70-107	2.5	0.7-9.6
Manual boiler, Downdraught >50kW	EN 303-5	3	91.9	90.6-93.2	20	10-35	30	3-73	46	14-76	1	<1-1

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[53] Courtesy of ABC Boilers, Austria

[54] Appliances in the second table are provided by ITT Partners

Table 4-43: Standard emissions data for coal-fired boilers measured according to EN-305-5 standard

Appliance	Standard	Number	Efficiency		CO		PM		Nox		VOC/OGC	
			Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
			%	%	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Conventional manual boiler <50kW	EN-303-5	8	81.2	n.d.	1338	n.d.	70.2	n.d.	127.2	n.d.	73.2	n.d.
Automatic boiler < 50kW	EN-303-5	10	85.3	n.d.	257.1	n.d.	48.2	n.d.	214.3	n.d.	23.3	n.d.
Manual recirpocal feed boiler >50kW	EN-303-5	1	86.1		88.4		30.0		190.2		15.0	
Automatic retort boiler > 50kW	EN-303-5		84.2	81.2 -86.5	152.1	85.7 - 225	34.8	21.4 - 56.3	187.5	68.8 - 214.	18.8	15 - 27.9

n.d.: no data

Further data was obtained from questionnaires, that was measured in accordance with EN 305-5, but with different testing method. As a result, PM emissions from these data cannot be compared (see Section 4.4.3). However the different methods used for CO, VOCs and NOx measurements are assumed not to differ substantially, and these data are presented in Appendix, in Table 4-50 for biomass boilers and in Table 4-51 for mineral fuel boilers. These results are broadly consistent with the Austrian and public data. However, for manual mineral fuel boilers, requirement on CO and VOC emissions are only met by the more advanced appliances, with forced draft.

In addition, efficiency and CO emission data from Denmark for several appliance types are provided in Table 4-52; these show a low efficiencies and high CO emissions for updraught appliances, particularly for older design appliances. The downdraught appliances indicate better efficiencies.

4.4.5 OTHER SOURCES OF EMISSION FACTORS

To further understand the emissions of solid fuel heating appliances, other sources of data are presented in the following sections. While useful for understanding the relative differences between appliances as interpreted by other experts in the industry, these separate data sets are not compatible with each other due to difference measurement standards, and hence should not be compared to each other.

➔ Corinair default emission factors

The UNECE Task Force on Emission Inventories and Projections (TFEIP) has published default emission factors[55] for various activities including residential combustion. These factors are intended to aid consistent emission reporting by the countries that are signatories to the Convention on Long-range Transboundary Air Pollution (CLRTAP). The emission factors are published within the Corinair Emission Inventory Guidebook.

Default emission factors for SCIs represent a wide range of fuels, combustion appliance technology and user behaviour. Emission factors provided by Emission Inventory Guidebook can be treated as relevant for emission of pollutants from SCIs under real life conditions. They were developed based on laboratory tests and field conditions, with best practices assumed. The guidebook provides guidance on uncertainties associated with the default emission factors and these are summarised in Table 4-44. But these uncertainty figures should be viewed qualitatively, and may not be appropriate to a particular appliance.

A summary of the default Corinair emission factors applicable to the appliances in the Lot 15 study is presented in Table 4-45.

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[55] Emission Inventory Guidebook reports.eea.europa.eu/EMEPCORINAIR5/en/page002.html

Table 4-44: Uncertainty ranges of Corinair default emission factors for solid fuel[56]

Pollutants	**Uncertainty range [%]**
NOx	20-60
SO_2	20-60
NH_3	50-150
PM	50-150
Heavy metals	50-150
PAH	50-150
PCDD/F	100-300
CO	20-60
NMVOC	50-150

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[56] Small combustion chapter: reports.eea.europa.eu/EMEPCORINAIR5/en/B216v2.pdf

Table 4-45: Default Corinair emission factors applicable to direct heating appliances of solid fuel combustion[56]

		Fireplace		Stove			Advanced stove	Boilers <50 kW				Boilers >50 kW					
Fuel Type		Wood	Coal	Wood	Coal	Mineral briquettes	Wood	Coal	Mineral briquettes	Advanced boiler coal (man)	Advanced boiler coal (auto)	Wood	Advanced boiler wood (man)	Advanced boiler wood (auto)	Mineral fuels	Advanced boiler coal (man)	Advanced boiler coal (auto)
CO	g/GJ	6000	5000	6000	5000	4000	3000	4000	3000	1500	400	3000	3000	300	100	100	20
PM	g/GJ	900	350	850	500	200	250	400	120	150	80	250	80	70	100	150	80
NO_x (NO_2)	g/GJ	50	60	50	100	100	90	130	200	200	200	150	150	150	150	200	200
VOC/OGC[3]	g/GJ	1300	600	1200	600	300	250	300	200	100	20	250	250	20	100	100	20
SO_2	g/GJ	10	500	10	900	500	20	900	500	450	450	50	20	20	500	450	450
PM_{10}	g/GJ	860	330	810	450	100	240	380	100	140	76	240	76	66	80	140	76
$PM_{2.5}$	g/GJ	850	330	810	450	100	240	360	100	130	72	240	76	66	80	130	72
Hg	mg/GJ	0.4	3	0.4	5	3	0.4	6	3	6	8	0.6	0.5	0.6	3.5	6	8
PCDD/F	ng iTEQ/GJ	800	500	800	1000	300	300	500	200	200	40	500	300	30	100	200	40
PAH[4]	mg/GJ	600	450	820	920	220	290	710	150	290	50	280	150	40	90	290	50
BaP	mg/GJ	180	100	250	250	50	100	270	50	90	17	80	50	12	30	90	17

➔ IEA particulates emission data

Table 4-46 provides a summary of PM emissions data gathered by the IEA[57]. Particulates emissions are of particular interest because of the wide variation in results generated by differing test methods. For example, although the range of emission factors determined by the IEA for PM was between 23 and 265 g/GJ for open fireplaces determined by gravimetric method without dilution tunnel, the selected national emission factors for PM from residential fireplaces range from 160 g/GJ (Germany) to 450 g/GJ (Norway and UK). In contrast, dilution tunnel based measurement is higher by 2-5 times and equals to 910 g/GJ (Norway and Finland). The highest national emission factors derived from dilution tunnel measurement data illustrate the measurement issue concerning measurement of PM. This issue is discussed further in section 4.4.3 and Figure 4-28.

Table 4-46: IEA Particulate emission factors for appliances applicable to solid fuel SCIs

Open fireplace	Closed fireplace	Closed fireplace	Boiler >50kW Under stoker	Boiler >50 kW Grate
Wood	Wood	Pellet	Wood	Wood
23-265	47-83	10-50	70-100	20-100

➔ National emission factors: Canada

Presented below are the national emission factors established by Canada.

Table 4-47: National emission factors for wood fired appliances[58]

Parameter		Conventional open fireplace	Conventional insert	Conventional closed fireplace	Advanced technology
CO	g/GJ	4856	7213	6163	4400
PM	g/GJ	1206	900	844	319
NOx (NO_2)	g/GJ	87.5	87.5	87.5	87.5
VOC/OGC	g/GJ	406	1331	1313	438
SO_2	g/GJ	12.5	12.5	12.5	12.5
PM_{10}	g/GJ				300
$PM_{2.5}$	g/GJ				300

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[57] Nussbaumer T., Czasch C., Klippel N., Johansson L., Tallin C., Particulate Emissions from Biomass Combustion in IEA Countries, Survey on Measurements and Emission Factors; http://verenum.ch/Publikationen/IEAReportPM10Jan08.pdf

[58] Original factors in kg/tonne of fuels, for recalculation Hu of 16 GJ/t for wood was assumed, source: Gulland J. (2003); "Residential Wood Combustion, Overview of Appliance Categories", June 2003, Updated September 2003; (http://www.bcbudget.gov.bc.ca/sp2004/wlap/wlap.pdf)

4.5 USE PHASE (SYSTEM)

4.5.1 OVERVIEW

There are many factors affecting the relationship between a SCI and its emissions, the design and operation of the appliance are key factors but there are wider influences including the system in which the appliance is installed. The appliance Standards are based on a defined system boundary which is essentially the appliance itself however, appliances are generally part of a wider 'system'. This system can include an indirect heating circuit attached to a boiler but, in a wider sense, the operating environment can also be considered part of the system. Specifically, the built and wider environment form part of the system.

➔ Efficiency and Thermodynamics

The function of small combustion installations is to generate and efficiently deliver heat to where it is needed. The operating efficiency is a combination of several factors, those determined by the design of the SCI and those determined by the operation of the SCI. Understanding the efficiency of the SCI requires the definition of an SCI by placing it within a thermodynamic boundary and performing an energy balance.

Thermodynamically the process that occurs is the heat transfer between two systems. An energy balance analysis of the SCI shows various energy streams. Heat input comes from the oxidation of the solid fuel, while the heat outputs are the heated exhaust gas, heat transferred to hot water in a boiler and heat transferred to the surroundings by radiation and conduction (Figure 4-30).

Prior to performing the energy balance, the system boundaries must be defined to allow the measurement of the energy streams crossing these boundaries. In the EN Standards, the boundary has been set around the SCI itself and does not include electricity consumption. In general, it has been assumed that the exhaust flue does not transfer heat to the room. In reality heat transfer into the building will occur, with the flue transferring up to 11% of the available heat[59]. However, setting the boundary around the SCI allows analysis of the performance of the SCI itself and enables the comparison of different designs under defined and repeatable conditions.

It is worth noting that the efficiency of the heat transfer between two systems increases the greater the temperature difference between the systems in accordance with the second law of thermodynamics. Therefore, variation in the ambient temperature has a small influence on the efficiency of the SCI. However the variation in the operating temperatures through an operating cycle and the steady state operating temperature variation between designs will influence the efficiency of each design with an increase in the operating temperature increasing the efficiency of the SCI.

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[59] Based on information provided by Schiedel from "Gutachten uber warmetechnische Berechnungen, DI Wolfgang Kahrer, 2007"

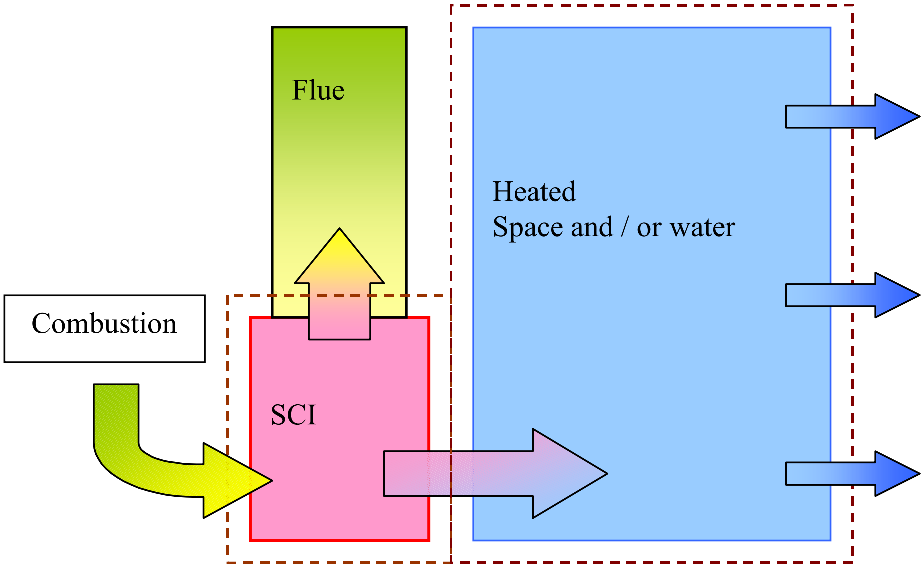

Figure 4-30 : SCI System losses

➔ Heat transfer

Heat transfer is the mechanism by which energy is transferred from the SCI to the surroundings. The heat transfer can occur in three ways :

- Radiation – transfer of energy by emission of radiation significant at high temperatures and where the reaction chamber of the SCI is not completely enclosed,
- Convection – transfer of energy through fluid flow and fluid mixing, much of the heat in the flue gases is transferred using this mechanism and,
- Conduction – transfer of heat through solids or still fluids

At normal operating temperatures it is expected most heat transfer in an SCI occurs via conduction and convection. Heat is also transferred by radiation particularly for open fireplaces and also within appliances where the oxidation of fuel is occurring at much higher temperatures than at the outer surface of the appliance.

➔ Direct space heating

This is the transfer of heat from the SCI directly to the surroundings. This process is influenced by the overall heat transfer coefficient of the SCI, the temperature difference between the SCI and it surroundings and the heat transfer area.

The overall heat transfer co-efficient and the heat transfer area are determined by the design and construction of the SCI and are approximately constant throughout an operating cycle. .

A direct heating SCI can respond rapidly to changes in the heat requirements, however its efficiency is limited by the outer wall temperature, it will have a relatively small heat transfer area and will only heat the immediate surroundings. Some appliances incorporate air ducts and air circulating fans to facilitate heat transfer to the room by convection.

➔ Indirect heating

This is the transfer of heat to a working fluid (usually water). The working fluid carries the heat to the areas where it is required. This process has two stages; heating the working fluid within the boiler and then transfer of heat from the working fluid to the surroundings. The heat transfer to the working fluid occurs at high temperature and the boiler has a relatively large transfer area, making this stage relatively efficient. Heat transfer from the working fluid to the surroundings occurs at lower wall temperatures however large transfer areas can be achieved (and fan-assisted ventilation may be used) making this stage relatively efficient.

An indirect heating SCI has a time-lagged response to changes in the heat requirements, however it can achieve greater efficiency than direct heating and, will heat several areas matching each of their requirements. The highest efficiencies are achieved by use of large heat transfer areas and a high temperature difference when transferring heat from the combustion gases to the working fluid.

➔ Losses

In all heat transfer systems some heat will not be delivered where it is needed. In SCIs a significant portion of the heat generated is lost in the escaping flue gases through direct loss of heat and, from inefficient combustion (as products of incomplete combustion). For direct heating systems this is perhaps the only significant heat loss. In indirect heating systems, heat lost in the flue gases is the most significant loss however, heat lost in the distribution and storage of the heat working fluid can also be significant.

4.5.2 SYSTEM FACTORS INFLUENCING SCI EFFICIENCY

➔ Built environment

The building in which an SCI is installed has an impact on the operation of the SCI. A key component is the chimney or discharge flue and, for appliances which are not room-sealed (most solid fuel appliances at present), ventilation in the room. The chimney manufacturer Schiedel suggests that for SCIs “chimneys with an air-intake shaft allow for an adequate stable supply of combustion air, which is a pre-requisite for efficient room independent appliances”.

In the case of a direct heating SCI the design of the building can have a significant effect on the efficiency and emissions of the SCI. The air necessary for combustion is taken from the room and must be replenished from the atmosphere outside. For simple open fireplaces there will be additional loss of air through the chimney and this can result in a net loss of energy from the building[60]. In any event, movement of air into the building will increase heat losses but, if the ventilation is inadequate it can result in a build up of toxic gases such carbon monoxide.

The specific energy demand of heating space in an older building is greater than that of newer buildings due to heat losses associated with the movement of warm air. Modern building design is more exactly specified and results in better-sealed rooms that minimise heat loss through the loss of warm air but also prevent air ingress. This implies that room-sealed appliances may be necessary to ensure adequate air supply

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[60] IEA Biomass combustion handbook 2nd edition.

and safe removal of combustion products. However, solid fuel appliances have a number of practical challenges to become room-sealed.

➔ Operational loading

The difference in efficiency between nominal and part load from EN Standard tests for modern boilers is small – the data in Section 4.3 suggest that the average change in efficiency is rarely more than about 5% in absolute terms under Standard test conditions and is frequently much lower. This is perhaps counter-intuitive but indicates that the operational loading should have relatively little influence on their performance.

➔ System Fouling and aging

All combustion equipment becomes coated in combustion residues (soot) due to the incomplete combustion and contamination of the fuel or air steams and to non ideal reaction conditions. The batch insertion of solid fuel into a SCI makes it more likely for these non ideal conditions and contaminants to be encountered and therefore SCIs foul more rapidly. The fouling that occurs provides resistance to heat transfer and, in chimney flue, restricts the extraction of flue gases. As a result, it is expected that the SCI efficiency drop over time will be greater than that of equivalent oil or gas based heating equipment.

Repeated operating cycles create mechanical stresses within an SCI. These stresses eventually cause the deformation or failure of mechanical parts and pipe work reducing the efficiency of the SCI. Proper maintenance is an effective measure to prolonging the operating life of the equipment however it is not possible to completely recover the efficiency lost through maintenance.

➔ Control systems

Control of combustion with an SCI is fundamentally more challenging than oil or gas fuelled heating equipment because of the physical characteristics of the fuel and the batch or intermittent fuel addition. This causes mixing dead spots in the reaction chamber. It also means that the air supply is the only one that can be instantaneously controlled. This in turn has an efficiency penalty since the instantaneous combustion rate and mixing are unlikely to be ideal. Incomplete combustion of pyrolysis products reactions may occur when non ideal conditions are present increasing the emissions of PICs.

A large variety of control systems can be found with various SCIs, varying from automatic systems controlling the supply of solid fuel and the air supply to match an oxygen level and/or temperature set point, to open fireplaces where a user adds fuel or adjusts a damper (where available) as they feel is necessary.

4.5.3 FLUE GAS EXTRACTION

The extraction of the flue gases to atmosphere has two effects on the overall heating performance of heating equipment. It provides a heat transfer area where flue gases transfer heat to the surround areas, this effect is excluded from standard expression of the performance of the SCI appliance as the heat transferred from a flue varies with the design of the flue. The design of the flue depends on the design of the house and is deliberately outside the system boundary of a SCI. Second, the weather conditions at the flue exit affect the flue gas extraction rate and correspondingly the flow rate of air into the reaction chamber and the operating temperature. For example, a breeze across the flue would reduce the pressure at the flue exit improving draught. This factor is controlled during Standard appliance tests by setting a fixed (within limits) chimney draught.

Building or Construction Regulations in many Member States have requirements for heat producing appliances and chimneys:

- That there is an adequate supply of air.
- That the products of combustion are safely discharged to the outside air.
- That the building is protected from catching fire.

Technical properties of chimneys in a building[61]:

- Dimensioning - The diameter of the cross section influences the behaviour and real life efficiency of an appliance. This complex calculation is laid down in the European standards EN 13384-1 and –2
- Fire, water and, corrosion resistance - Pre-requisite for using high-efficiency, solid fuel appliances.
- Secondary air intake - Chimneys with an air-intake shaft allow for a stable supply of combustion air, which is a pre-requisite for efficient room independent appliances
- Insulation - Proper insulation chimneys with air-intake shaft increase the efficiency of appliances as combustion air for the appliance is pre-heated

➔ Electricity consumption

SCI may use electricity to power various different systems :

- The control system,
- Warm air convection systems,
- Automatic fuel transfer (and ash removal on larger appliances),
- To provide fan-assisted air supply and,
- To provide ignition heat.

Clearly an appliance may not use any of these but they become more relevant as the appliance size increases and whether it is intended to operate automatically. While this use of electrical energy may detract from the overall efficiency, there are efficiency gains from maintaining ideal conditions in the combustion chamber. In addition these systems result in a more controllable combustion and heat transfer process. However. It should be noted that the electricity used in SCIs is not accounted for in the overall determination of ‘Standard’ efficiency.

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[61] Source: Schiedel

4.5.4 EMPIRICAL ANNUAL OPERATIONAL EFFICIENCIES

These may be considered as real-life efficiencies but they incorporate system elements in the sense of wider environment (climate) impacts and control system impacts on Standard efficiency.

➔ SEDBUK – Seasonal Efficiency of Domestic Boilers in the UK

SEDBUK is the average annual efficiency achieved in typical domestic conditions. making assumptions about pattern of use, climate, control and other influences. It is a public database which is used to allow assessment of the energy demands of buildings. It is mainly developed for gas-fired appliances and is calculated from the results of Standard efficiency tests (at nominal output and at low output) together with empirical factors derived from other sources information such as boiler type, ignition arrangement, internal store size, fuel used, and knowledge of the UK climate and typical domestic usage patterns. In effect, the database modifies the Standard efficiency by converting to a gross heat input basis and applying an empirical efficiency penalty (K-factor) for UK climate and typical domestic usage patterns. At present, there are no adjusted SEDBUK factors published for solid fuel appliances and energy assessments are based solely on the Standard efficiency of appliances.

The SAVE II programme modelled EU energy demand by applying the K-factor approach to EU-15 countries for gas appliances[62]. Significant simplifying assumptions were made to develop the seasonal efficiencies and a number are irrelevant to solid fuel appliances :

- The average number of heating hours/day is the same in all EU countries,
- The internal design temperature is the same in all EU countries,
- The effect of a permanent pilot flame is ignored,
- All regular boilers are assumed to be on/off (non-modulating),
- All combination boilers are assumed to be modulating,
- The load factor for each country has been determined from the number of degree days, design temperature difference, and number of heating hours; this implies that the boiler sizing method is the same throughout Europe,
- The boilers are assumed to provide hot water service all year in addition to heating.

Nevertheless, the k-factors (Table 4-48) do provide an indication of the annual efficiency penalty associated with different patterns of use. Although these factors are for gas appliances, they indicate the impact of annual heat demand (degree days) on appliance efficiency; fewer degree days means a larger impact on fuel efficiency.

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[62] Save II action, Labelling and other measures for heating systems in dwelling – Final report January 2002.

Table 4-48: SAVE II K - value for different space and hot water heating loads across Europe

	Space heating and hot water heating all year		Space heating only (no hot water heating)		Space heating and hot water heating in the winter only	
	k for regular boilers % gross	k for combi boilers % gross	k for regular boilers % gross	k for combi boilers % gross	k for regular boilers % gross	k for combi boilers % gross
Portugal	-3.4	-2.8	-3.6	-3.3	-2.5	-2.4
Greece	-3.5	-2.9	-3.8	-3.4	-2.6	-2.5
Spain	-3.4	-2.8	-3.6	-3.2	-2.5	-2.4
Italy	-3.1	-2.6	-3.2	-2.9	-2.2	-2.1
Ireland	-2.6	-2.2	-2.5	-2.4	-1.7	-1.7
France	-2.7	-2.3	-2.6	-2.5	-1.7	-1.8
Belgium	-2.8	-2.3	-2.7	-2.6	-1.8	-1.9
UK	-2.5	-2.1	-2.2	-2.2	-1.5	-1.6
Netherlands	-2.6	-2.2	-2.4	-2.3	-1.6	-1.7
Germany	-2.8	-2.3	-2.7	-2.6	-1.8	-1.9
Luxemburg	-2.5	-2.1	-2.3	-2.3	-1.5	-1.7
Denmark	-2.5	-2.1	-2.2	-2.2	-1.5	-1.6
Austria	-2.7	-2.2	-2.5	-2.4	-1.7	-1.8
Sweden	-2.6	-2.2	-2.4	-2.3	-1.6	-1.7
Finland	-2.3	-1.9	-1.9	-2.0	-1.3	-1.4

➔ AFUE – Annual fuel utilisation efficiency

The Annual Fuel Utilisation Efficiency (AFUE) is a US measure of efficiency for combustion equipment like boilers and heaters. The AFUE takes account of operational fluctuations in performance by empirically deriving the actual, season-long, average efficiency of an SCI. The method for determining the AFUE for residential SCIs is the subject of ASHRAE Standard 103. The difference between the design peak efficiency and the AFUE can be significant.

4.5.5 OPERATING TIME

The heat demand placed on a particular SCI will depend on both the requirement for heated water and space heating. Heated water demand ('tapping pattern') varies throughout the day. However, the daily demand for heated water is consistent as are the times during the day that heated water is required. The space heating requirements depend on the local climatic conditions. Current practice is to use the measure of annual degree days to quantify the local climate and therefore the heating requirement for space heating when the local temperature falls below a stated set point (15.5 °C). The energy required to meet the space heating requirements would be delivered by the central heating system or the SCI can be calculated from multiplying the required heat output with the period of time the heat was required. This requirement will vary across Europe where the climate varies from northern Scandinavia to the Mediterranean.

4.5.6 HARMONISING HEATING DEVICE WITH HEAT DISTRIBUTION SYSTEM.

➔ Defining heating requirements

The initial sizing of an SCI is dependent on the maximum continuous heat demand. However, periodically there may be a requirement for heating at a greater rate than can be met by the idealised sizing of the SCI. In order to resolve this, the SCI must either be oversized, which is wasteful of construction materials and fuel, or use a buffer (accumulator) that can meet the instantaneous heat demand.

➔ Systems Control

The selection of appropriate controls is important in minimising energy use in a heating or hot water system. The UK Energy Savings Trust guidance identifies the following control options as best practise:

- Programmable room thermostat
- Cylinder thermostat
- Pipe thermostat – to prevent overheating in system and can be used to prevent low temperature
- Thermostatic radiator valves – allowing lower temperatures in low occupancy rooms
- Boiler interlock – avoids boiler firing if no demand, reduces heat loss by unnecessary circulation of heating fluid.
- Zone controls – different time and/or temperatures in two or more zones
- Optimised/delayed start – adjusts programme start time automatically to reflect heating needs for actual internal and/or external temperature.

The Energy Savings Trust guidance comments that: “Installing a minimum standard of controls on a system which previously had none can reduce fuel consumption by 18 per cent. Reducing higher than necessary room temperatures will cut energy use. Turning down the room thermostat by 1°C will reduce space heating consumption by 6-10 per cent. An easy to use programmer that is adjusted to match the householder’s occupancy pattern helps reduce wasteful heating when no one is at home.”

➔ Control lag

The combustion of solid fuel occurs at much lower rates than combustion in oil and gas fuelled heating equipment due to the lower specific surface area for combustion. As a result there can be a significant lag between heat demand and supply. To overcome this problem two strategies can be employed, anticipating the heat demand using a timer and appropriate temperature set points to meet predictable water and space heating requirements and, using a heat reservoir (accumulator) to supply the required heat in the interim.

➔ Fuel

The timing of fuel input is dependent on the anticipated heat demand and an understanding of the time lag between the demand and supply of heat. It is difficult to quantify the time lag between demand and supply with solid fuels which are heterogeneous by nature. In order to reduce the time lag between supply and demand and make it more consistent the fuel can be processed (for example wood pellets, wood chips and mineral fuel briquettes). The processing may include reducing the particle size and therefore increasing the specific surface area and the responsiveness of the fuel. However processing the fuel increases the operating cost. Automatic fuel handling and control of the combustion conditions can help to provide a more continuous process and the ability to increase the air flow rate will provide some head room for sudden increases in the heat demand. The consequence of this approach is that the SCI will be oversized for the required duty or operate inefficiently at peak outputs.

➔ Buffer (Accumulator) Tanks.

A buffer tank is a heat store, when integrated into an indirect heating system it decouples heat generation from heat demand. The benefits of this approach are that hot water can be supplied from various sources and that demand can be met instantaneously while the working fluid is heated in the most energy efficient manner. Using a buffer tank also allows the supply of both space heating and hot water. The impact of use of an accumulator tank on particulate emissions is provided in.

➔ Appliance environment - Built environment and appliance configuration

A very important point is the good dimensioning of the appliance in function of the heat demand of the dwelling. Modern houses tend to have much lower heating needs than older ones due to higher levels of insulation, fewer draughts and, more energy-efficient windows. Minimum requirements for new buildings defined by the Energy Performance of Buildings Directive (2002/91/EC) are expected to reinforce this trend. As a consequence, appliances installed in new houses often have better efficiency and tend to be of a lower capacity, thus burning less fuel. From efficiency point of view , problems may arise if the better energy performance of a new building is not taken into account while choosing the heating appliance. Oversized heating appliances are often a problem, especially in old buildings where the insulation may be improved over years but where the old heating appliance is maintained despite the lower heating needs of the building. In such cases, where the appliance is too large for the system, its efficiency can be reduced

For example, experience from Denmark shows that many installed stoves are too large for the rooms they are supposed to heat up. A typical stove burning 1 kg of wood per hour at an efficiency of 75% currently yields 3 kW which is considered to correspond to the heating requirement of a 60 m^2 living room at an outdoor temperature of minus 12°C. However, these are not typical conditions (seldom do people have a 60 m^2 living room, insulation standards vary and minus 12°C is unusual in some countries)[63]. Therefore, it is often observed that the rooms with such stoves get too hot. In most

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[63] A stakeholder has noted that “a room with a area of 60 m^2 corresponds with a volume of approx. 150 m^3. According to calculations performed by German notified bodies for testing solid fuel appliances a capacity of 7 kW heat output is necessary to heat a room with this size. Therefore a heat output of 3 kW for heating a room of 60 m^2 is rather small.” This may reflect differences in the average insulation of the building stock between Denmark and Germany.

cases, the heat reduction is achieved through turning the air supply down but this results in a reduction in the efficiency of the stove, under-exploitation of fuel and significant increase in emissions. If the stove is set at half of the output it was designed for, pollution levels can triple[64].

4.6 END-OF-LIFE PHASE

Residential appliances and larger boilers are not considered to be likely candidates for significant re-use although 'antique' residential units with a high decorative value may have some second life through architectural salvage. In general, industry reports that where a new appliance is installed, the installer will recover the old appliances for scrap.

Stakeholders comment[65] that 99% or more of metals content in SCIs is recycled. Stakeholders have also commented that glass (where used) can be recycled. There is negligible material within the BoM for recovery by burning and the remaining metal and all other material will be disposed of to landfill.

4.7 CONCLUSIONS FOR TASK 4

The real life products identified for the purpose of Task 4 will be used to define Lot 15 base cases in Task 5. This task presented the diversity of existing products that can fall into the scope of Lot 15 and also provides the input database for the environmental analysis to be conducted in Task 5. It also analysed the products in a system context and illustrated how the external factors can affect their environmental and energy efficiency.

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[64] Skøtt, T. Danish stoves - a cosy and eco-friendly heat source www.videncenter.dk/exportcat/stoves_and_small_boilers.pdf

[65] CEFACD stakeholder meeting on 4 November 2008

4.8 ANNEX – TASK 4

Table 4-49 - Direct heating appliances efficiency and emissions data measured under test standard conditions

Appliance			Efficiency [%]		Test standard	CO [g/GJ]		NOx [g/GJ]		VOC/OGC [g/GJ]	
			Average	Range		Average	Range	Average	Range	Average	Range
Open fireplace and open firplace insert	Public data (5 appliances)*		55	40.2 ÷ 63.6	EN 13229	2033	1750 ÷ 2333	-	-	-	-
	Questionnaire responses		40	30 ÷ 53		2766	1631 ÷ 4163	-	-	-	-
Closed fireplace and closed fireplace insert	Public data (23 appliances)*		75.4	66.9 ÷ 80.3		1859.8	41.8 ÷ 5411	59.6	36.0 ÷ 74.0	-	-
	Questionnaire responses (41 appliances)	No secondary air (4 appliances)	72.8	71 ÷ 74.5		2400	1547 ÷ 3091	n.d.	n.d.	n.d.	n.d.
		With secondary air (17 appliances)	74	67.5 ÷ 82.7		2445	789 ÷ 4293	107	103 ÷ 111	68	52 ÷ 85
		Manual primary and secondary air (19 appliances)	73.2	67.5 ÷ 82.1		2580	1374 ÷ 4293	103	103 ÷ 103	85	85 ÷ 85
		Automatic primary and secondary air (1 appliance)	75.1	75.1 ÷ 75.1		1889	1889 ÷ 1889	n.d.	n.d.	83	83 ÷ 83
Traditional Stove	Public data (17 appliances)*		75.7	72 ÷ 78.7	EN 13240	1705	56.5 ÷ 2846	-	-	-	-
	Questionnaire responses (26 appliances)	No secondary air	n.d.	n.d.		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
		With secondary air	68.4	38 ÷ 80		1515	773 ÷ 3091	77	18 ÷ 138	44	30 ÷ 75
		Manual primary air (traditional + continuous burning, 9 appliances)	66	38 ÷ 80		1685	851 ÷ 3091	74	18 ÷ 138	47	30 ÷ 75
		Automatic primary air (advanced + modern, 3 appliances)	77	75 ÷ 80		801	773 ÷ 1031	100	80 ÷ 138	41	39 ÷ 83
Slow heat release stove	Public data*		-	>75	-	-	<1031	-	<137	-	<83
Kachelofen, insert for kachelofen	Public data*		-	>80	-	-	<1031	-	<137	-	<83
Cookers	Questionnaire responses (2)	Manual primary air (traditional)	84	78 ÷ 90	EN 12815	1306	1238 ÷ 1375	138	138 ÷ 138	69	69 ÷ 69
		Automatic primary air (advanced)	n.d.	n.d.		n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

* Public data from web sites, accredited laboratory measurements, or manufacturers

Table 4-50: Biomass fuelled indirect biomass heating appliances efficiency and emissions data from questionnaires, measured in accordance with EN-305-5.

Appliance		Num-ber	Efficiency		CO		NOx		VOC/OGC	
			Average	Range	Average	Range	Average	Range	Average	Range
			%	%	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Conventional manual boiler <50kW	Overfire, manual air control	1	86	n.d.	2567	n.d.	71	n.d.	n.d.	n.d.
	Overfire, automatic air control	3	85.8	85.6 - 86	569	448 - 644	124	94 - 153	34	22 - 47
Automatic woodchips boiler < 50kW		4	90.4	87.3 - 91.8	47	2 - 69	79	63 - 94	0.7	n.d.
Manual boiler > 50kW	Downfire gravity-feed	3	91.1	90.5 - 91.4	72	54 - 83	87	61 - 101	2	1 - 4
Automatic woodchips boiler > 50kW		4	91.4	90.5 - 91.8	40	8 - 78	97	85 - 102	1.4	0.7 - 4.1

n.d.: no data

Table 4-51: Mineral fuelled indirect heating appliances efficiency and emissions data from questionnaires, measured in accordance with EN-305-5.

Appliance		Num-ber	Efficiency		CO		NOx		VOC/OGC	
			Average	Range	Average	Range	Average	Range	Average	Range
			%	%	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ	g/GJ
Conventional manual boiler <50kW	Overfire, natural draft, manual primary air control	5	79	77 - 84	1684	984 - 2442	161	126 - 207	54	33 - 78
	Overfire, forced draft, manual primary air control	1	84	82.8 - 85.4	1275	900 - 1650	141	114 - 168	33	24 - 42
	Overfire, forced draft, automatic primary air control	3	83	81 - 84	867	683 - 1023	109	64 - 188	43	18 - 78
	Upperfire, forced draft, manual air control	1	77.7	75.4 - 80	905	n.d.	101	n.d.	60	n.d.
Automatic boiler < 50kW		10	85.7	82 - 91.6	262	62 - 538	217	145 - 279	24	9 - 38
Manual boiler > 50kW	Overfire, forced draft, manual air control	1	80	78.6 - 81.3	2430	n.d.	111	n.d.	39	n.d.
	Downfire, gravity feed, forced draft, manual air control	2	77.8	75.4 - 80	885	756 - 1014	146	113 - 180	46	24 - 67
	Upperfire, forced draft, manual air control	1	80	78.4 - 81.3	1698	n.d.	168	n.d.	54	n.d.
	Upperfire, forced draft, automatic air control	3	81	78.9 - 83	460	222 - 858	164	102 - 222	26	18 - 42
Automatic boiler < 50kW		6	82.9	78.4 - 86.1	124	44 - 225	175	145 - 214	44	42 - 46

n.d.: no data

Table 4-52 Danish EPA boiler performance testing

Boiler type	Fuel	mg/m^3 CO at 10% O_2	Efficiency, %
Up draught	Wood logs	4761	65,7
		3129	65,9
		3316	66,0
		9375	52,5
		9298	55,7
		20 718	45,7
		22 697	49,2
		9129	58,1
Up draught	Coke	956	75,0
		846	75,3
		791	76,1
Up draught (old type)	Wood logs	7920	58,8
		17 533	52,7
		10 627	50,4
		26 988	41,7
		27 068	45,2
		14 483	57,2
Up draught (old type)	Coke	5245	76,7
		6311	75,7
		5778	76,2
Down draught	Wood logs	400	90,0
		1288	89,0
		658	86,0
		2678	91,0
Cross draught	Wood logs	4438	74,0