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Lot 15
Solid fuel small combustion installations

Task 6: Technical analysis of BATs

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AEA Energy & Environment
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Bio Intelligence Service - Scaling sustainable development
Industrial Ecology - Nutritional Health

Bio Intelligence Service S.A.S - bio@biois.com
1 rue Berthelot - 94200 Ivry-sur-Seine - France
Tél. +33 (0)1 56 20 23 98 - Fax. +33 (0)1 58 46 09 95

Contact Bio Intelligence Service S.A.S.
Shailendra Mudgal – Anne Turbé
☏ + 33 (0) 1 53 90 11 80
shailendra.mudgal@biois.com
anne.turbe@biois.com

Project Team

- **Bio Intelligence Service**

  Mr. Shailendra Mudgal

  Dr. Anne Turbé

  Mr. Ian Kuwahara

- **AEA Technology Energy and Environment**

  Mr. Robert Stewart

  Mr. Mike Woodfield

- **Institute of Thermal Technology of the Silesian University of Technology**

  Dr. Krystyna Kubica

  Dr. Robert Kubica

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Task 6 – Technical analysis of BATs

This section presents the Task 6 of the Lot 15 EuP preparatory study on solid fuel small combustion installations (SCIs). Task 6 entails a description and technical analysis of Best Available Technologies (BAT) either at product or component[1] level.

BAT is a technology, leading to minimised environmental impacts, which is already available on the market (existing products inside and outside the EU market will be reviewed) or at least its technical feasibility has already been demonstrated (expected to be introduced at a product level within 2-3 years).

The assessment of the BAT provides input for the identification of the improvement potential in Task 7. Intellectual property, technical feasibility, and availability on the market in a strict sense are not judged here as the objective is to illustrate various technically available (or potentially available) options. However, Task 7 will take these issues into account when suggesting possible improvement options applicable to the Lot 15 products.

The description of technologies presented here is based on ongoing research. New cutting edge technologies are highly guarded secrets and detailed public information is limited. Thus, the information presented here should be seen as a general overview of technologies and potential improvement options rather than as a thorough technical analysis.

Note:

As all available SCIs are the assemblies of many components aiming at optimum energy and environmental performance, there is a wide range of best available technologies at the component level. The current document details and assesses the most relevant ones according to manufacturers and to other available studies.
All the registered Lot 15 stakeholders were invited to provide input to this task, and others were also welcome to contribute. Most of the technical data for this task has been provided directly by the manufacturers/designers or come from other published information. However, the efficiency or other performance levels claimed by them have not been verified independently.

Objective

The aim of the herein undertaken analysis is to identify and describe relevant BAT and BNAT design options and environmental benefits expected at both product and component level of SCIs.

[1] In this section « component » refers to the integral elements of Small Combustion Installations (i.e. firing grate, air supply system, control equipment etc.) and to the other/optional components of the product (e.g. draught fans, emission abatement devices etc.).

6.1 STATE-OF-THE-ART FOR THE PRODUCTS

All the products presented in the following sections are shown only for illustrative purposes. They are the examples of feasible technical solutions and by no means represent “role models”. As the SCIs market consists of a variety of appliances, depending on their functionality, and on the fuel types they support, they cannot be directly compared. Hence, no general BAT solution can be found, although at the component level many solutions e.g. control loops, will be relevant for all the categories of products under consideration. Also, it should be stressed that some features other than technical influence the purchase of a given product. Besides purchase costs and functionality, aesthetic reasons are also taken into consideration by the buyers.

Except for different functionality and fuels used, the appliances under consideration are being assessed on the basis of common parameters i.e. energy efficiency and environmental performance.

There are two general ways to decrease the energy consumption of SCIs:

- Improve the efficiency of the appliance, e.g. by optimising the performance of the combustion chamber and the heat exchange circuit (to air, water, or to hotplates and ovens for cooking). In the case of indirect heating appliances, namely boilers, the goal may also be to minimise heat losses through the chassis.
- Use a programmable control system, that maximises the efficiency of the heat produced not only based on the combustion process parameters but also according to the external environment, by reducing overheating phases, for instance.

All of the above primary options will also to some extent improve the environmental performance, by decreasing the emissions of pollutants. But where further improvement is desirable, secondary measures for emissions abatement can be undertaken. These can include dedusting, denitrification, desulphurisation, OGC reduction or catalytic afterburning (post-combustion). Of course, both the technical feasibility and the costs should meet the specific requirements of the market, which mostly covers the domestic and commercial sectors.

6.1.1 PRODUCTS ON THE MARKET

→ Closed fireplaces/fireplace inserts

As stated in Task 4, closed fireplaces/fireplace inserts can be built as cast iron or steel appliances, some of which have ceramic lining to enhance the performance of the combustion chamber. Closed fireplaces 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 is mainly transferred to the space by radiation and convection. Hence the state-of-the-art solutions include external (non-combustion) air ducts and a circulating fan to provide warm air into the room space. A catalytic afterburning of unburnt volatile matter can also be applied.

As in the case of all manually fuelled appliances operating under natural draught, a key issue to ensure optimum combustion conditions, is the provision of optimum and stable chimney draught. Some products also have a heat exchanger (e.g. water jacket, water coil) for indirect heating.

Typical options for BAT solutions for closed fireplaces and inserts are presented in Figure 6-1 and may include the following features and components:

- primary and secondary air distribution and control,
- natural draught control,
- fan assistance for indirect heat exchange,
- combustion chamber with ceramic lining,
- catalytic afterburning (only few products on the market),
- optional boiler for indirect heating (connected to a buffer tank),
- secondary abatement measure – e.g. electrostatic precipitator (ESP).

In the EU, a typical BAT closed fireplaces/fireplace insert is assumed to include the first four of these options: primary and secondary air control; ceramic lining of the combustion chamber; natural draught control; and, fan assistance for indirect heat exchange.

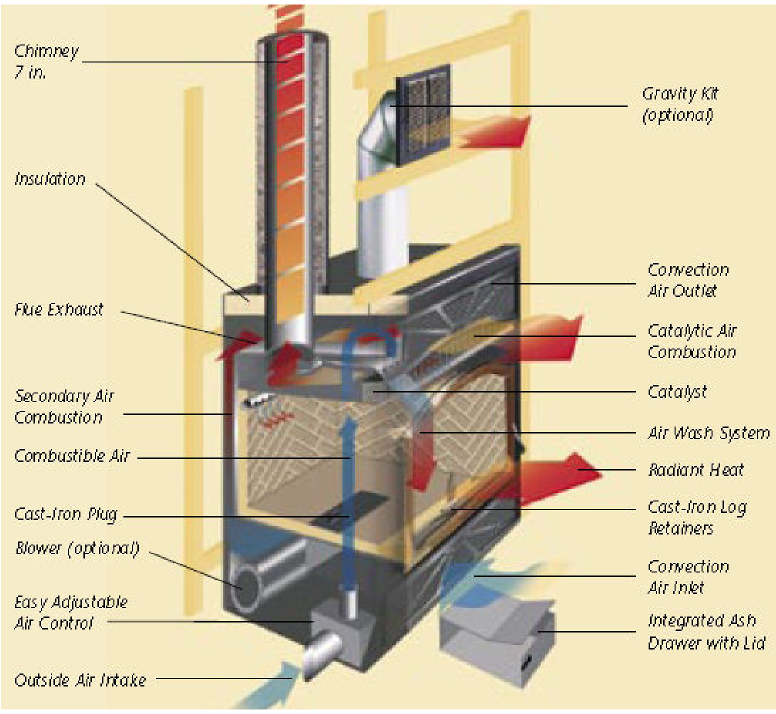


Figure 6-1: State-of-the-art solutions within the open fireplaces category[2]

[2] Lennox Industries Inc. 2005, http://www.lennox.com

This BAT product can reach the energy efficiency and environmental performance shown in Table 6-1.

Table 6-1: Energy efficiency and environmental performance of BAT solutions within the group of closed fireplaces/fireplace inserts, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC2 (**)
Energy efficiency, (NCV)	%	78	+11
Emission of CO*	mg/m^3	1500	-67
Emission of PM* (unabated)	mg/m^3	60	-70
Emission of NOx	mg/m^3	190	- (***)
Emission of OGC*	mg/m^3	100	-71

** when catalytic post-combustion is employed CO emissions can be significantly lower down to 350 mg/m^3. A slight improvement is also reached in the case of OGC emissions which may reach 80 mg/m^3. In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs – resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

(**) when compared to BC1 values, the following changes are considered (Efficiency +160; CO -88; PM -93; OGC -89)

(***) the best performance value given is related to the amount of nitrogen in the fuel, where values as low as 54 mg/Nm^3 were reported by questionnaire responses

➔ Advanced stoves, wood logs

These devices are usually freestanding appliances that provide direct heating, or when fitted with a boiler, they can also provide hot water and/or central heating. These stoves are less polluting and have higher thermal efficiencies than traditional and modern stoves (which have low energy efficiency and poor combustion control that causes significant pollutant emissions). The main innovations are the multiple air inlets. Secondary pre-heated air (heat exchange with hot flue gases) insures a more complete combustion. Moreover, thermal retention is increased by using special materials for the fireplace lining. Thermal efficiency is high at full charge, but energy efficiency may decrease at reduced charge.

A typical BAT solution for advanced stoves is presented in Figure 6-2 and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- natural draught control,
- fan assisted direct heat exchange
- advanced control loop (draught control according to temp. and flow rate of flue gases),
- catalytic afterburning,
- optional boiler for indirect heating (connected to a buffer tank),
- secondary abatement measure – e.g. ESP.

Figure 6-2: Typical advanced stove[3]

In the EU, a typical BAT advanced stove is assumed to include the first three of these options: primary and secondary air control; ceramic lining of the combustion chamber; and, draught control. This BAT product can reach the energy efficiency and environmental performance shown in Table 6-2.

Table 6-2: Energy efficiency and environmental performance of BAT solutions within the group of advanced stoves, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC3
Energy efficiency, (NCV)	%	79	+13
Emission of CO*	mg/m^3	1400	-69
Emission of PM* (unabated)	mg/m^3	50	-75
Emission of NOx	mg/m^3	190	- (**)
Emission of OGC*	mg/m^3	90	-74

** when catalytic post-combustion is employed CO emissions can be significantly lower down to 350 mg/m^3. A slight improvement can also be achieved in the case of OGC emissions which may reach 40 mg/m^3.*

In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs – resulting in 50-80% particulate removal efficiency in relation to unabated emissions.

(**) the best performance value given is related to the amount of nitrogen in the fuel, where values as low as 54 mg/Nm^3 were reported by questionnaire responses

[3] wwwstratfordboilerstoves.co.uk, www.ivicta.fr

➔ Advanced cookers

These wood-fuelled residential cooking appliances are usually made of cast iron or steel and the combustion chamber is often covered with fire bricks. Their efficiency can reach 70 % depending on the type and quality of the installation and also on the operation mode. They operate with natural draught, and are manually stoked. Advanced appliances employ automatic air control, in contrast to traditional cookers which have only manual control of combustion air. Their operating autonomy is up to a few hours. Pollutant emissions can be low for appliances employing all of the state-of–the-art-solutions, such as secondary or tertiary air control mechanisms which ensure a better combustion control.

A typical BAT solution for advanced cookers is presented in Figure 6-3 and may therefore include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- natural draught control,
- catalytic afterburning,
- optional boiler for indirect heating (connected to a buffer tank),
- secondary abatement measure – e.g. ESP.

Figure 6-3: State-of–the-art solutions within the advanced cookers category[4]

In the EU, a typical BAT advanced cooker is assumed to include the first three of these options: primary and secondary air control, ceramic lining of the combustion chamber, natural draught control. This BAT product can reach the energy efficiency and environmental performance shown in Table 6-3.

4 www.broseleyfires.com

Table 6-3: Energy efficiency and environmental performance of BAT solutions within the group of advanced cookers, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC5
Energy efficiency, (NCV)	%	78	+20
Emission of CO	mg/m³	2000	-60
Emission of PM* (unabated)	mg/m³	90	-60
Emission of NOx	mg/m³	190	- (**)
Emission of OGC	mg/m³	110	-76

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

(**) the best performance value given is related to the amount of nitrogen in the fuel

➔ Slow heat release stove – SHR stove

A heat retaining stove also called masonry stove, or masonry heater, is a heat storing fireplace. It works on the principle of burning a hot, relatively fast fire, and providing a means for the heat of the fire to be stored in the masonry mass. Instead of letting the hot gases of the fire go up the chimney and out of the house, the system of flue passages allows to heat to be recovered. The residence time of the exhaust within the mass of the fireplace allows the heat to be stored inside the masonry of the fireplace. Thus the exhaust that finally exits the stack is relatively cool and the heat is efficiently recovered. The stored heat then radiates gently but persistently for up to 12 to 24 hours after the fire goes out. A BAT within the group of SHR stoves is characterised by very good environmental and energy performance. With a properly used masonry heater, creosote is non-existent. The reason for this is the high combustion temperatures reached in the masonry core of the stove. Temperatures of 800°-1000°C are not uncommon within the secondary combustion chamber. Thick, black soot and creosote do not survive these temperatures. Typically SHR stove are very massive (1000- 3000 kg), fuel is burned only about 2 hours per day while energy is stored in the mass. Burning rate can be typically 20 to 30 kW. Heat is released slowly to the surrounding room (~2 to 4 kW). The SHR stoves can be both pre-fabricated and built on site. Soap stone is one of the most popular materials due to its high heat storing capacity (high weight) as well as easiness of processing.

A typical BAT solution for SHR stoves is presented in Figure 6-4 and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- catalytic afterburning,
- secondary abatement measure – e.g. ESP.

Figure 6-4: An example of a slow heat release stove[5]

In the EU, a typical BAT slow heat release stove is assumed to include the first three of these options: primary and secondary air control; ceramic lining of the combustion chamber; and, draught control. This BAT product can reach the energy efficiency and environmental performance shown in Figure 6-4.

Table 6-4: Energy efficiency and environmental performance of BAT solutions within the group of SHR stoves, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC6
Energy efficiency, (NCV)	%	82	+3
Emission of CO	mg/m^3	1000	-60
Emission of PM* (unabated)	mg/m^3	60	-60
Emission of NOx	mg/m^3	190	- (**)
Emission of OGC	mg/m^3	100	-50

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

(**) the best performance value given is related to the amount of nitrogen in the fuel

[5] www.tulikivi.com

➔ Pellet stoves

These devices can be freestanding appliances which may provide direct heating, or when fitted with a boiler, they can also provide hot water and/or central heating. These stoves 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 wood log combustion. Pellet stoves can be either natural draught, or equipped with fan and electronic control system for the supply of combustion air. The operational autonomy of pellet stoves is important (one to several days or more, when coupled with automatic fuel transportation from a storage facility).

A typical BAT solution for pellet stoves is presented in Figure 6-5and 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 heat exchange,
- advanced control system (with lambda probe),
- internal recirculation,
- catalytic afterburning,
- automatic fuel feed,
- automatic ash removal,
- optional boiler for indirect heating (connected to a buffer tank),
- secondary abatement measure – e.g. ESP.

Figure 6-5: Typical pellet stove[6]

[6] www.woodpelletstoves.net

In the EU, a typical BAT pellet stove is assumed to include the first four of these options: primary and secondary air control; ceramic lining of the combustion chamber; draught control; and, fan-assisted direct heat exchange. This BAT solution for pellet stoves, can reach the energy efficiency and environmental performance shown in Figure 6-5.

Table 6-5: Energy efficiency and environmental performance of BAT solutions within the group of pellet stoves, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC7
Energy efficiency, (NCV)	%	90	+5
Emission of CO	mg/m^3	300	-14
Emission of PM* (unabated)	mg/m^3	30	-60
Emission of NOx	mg/m^3	140	- (**)
Emission of OGC	mg/m^3	30	-40

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulates removal efficiency in relation to unabated emissions.*

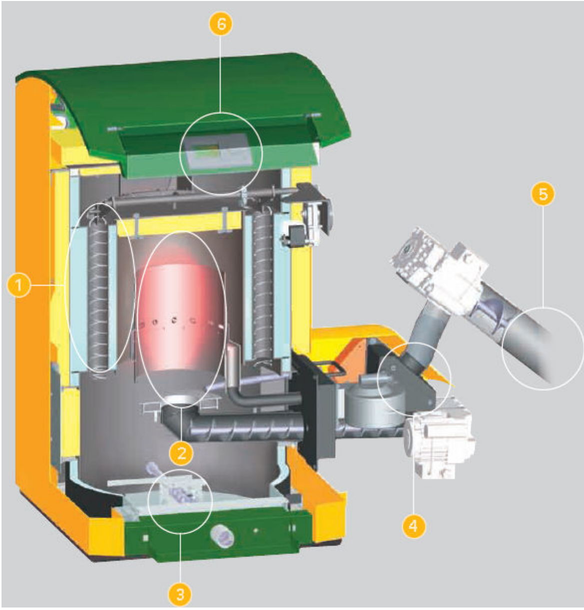
(**) the best performance value given is related to the amount of nitrogen in the fuel.

➔ Pellet boilers

Pellet boiler technology is similar to that employed for pellet stoves (see the section 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 the 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 BAT solution among pellet boilers is presented in Figure 6-6 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 (lambda probe, weather and room temp. control),
- doubled heat exchanger, boiler and system water- efficient operation at low load,
- internal recirculation,
- catalytic afterburning,
- automatic fuel feed,
- automatic ash removal,
- efficient boiler for indirect heating (with option for secondary heat exchanger enabling latent heat recovery – heat of condensation),
- low heat losses from outer surfaces - heat recovery by means of combustion air
- automatic boiler cleaning,
- secondary abatement measure – e.g. ESP.



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 1 × 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: easy-to-use, fully automatic and unique.

Figure 6-6: Typical pellet boiler[7]

In the EU, a typical BAT pellet boiler is assumed to include the first four of these options: primary and secondary air control; ceramic lining of the combustion chamber; draught control; and, lambda probes. This pellet boiler can reach the energy efficiency and environmental performance shown in Figure 6-6.

Table 6-6: Energy efficiency and environmental performance of BAT solutions within the group of pellet boilers, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC11
Energy efficiency, (NCV)	%	92	+5
Emission of CO*	mg/m^3	150	-57
Emission of PM* (unabated)	mg/m^3	25	-50
Emission of NOx	mg/m^3	140	- (**)
Emission of OGC	mg/m^3	30	-40

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

*(***) the best performance value given is related to the amount of nitrogen in the fuel, where values as low as 70 mg/Nm^3 were reported by questionnaire responses*

[7] www.kwb.at

➔ Downdraught boilers

This type of boiler is the state-of-the-art in wood log combustion, but some can also use lignite/young hard, non-caking coal with a high content of volatile matter. Downdraught boilers are manually fuelled 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 while it moves slowly downward as the fuel beneath it 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 typical BAT solution for downdraught boilers (<50kW) is shown in Figure 6-7 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 probe, weather and room temp. control),
- internal recirculation, combustion intensification by enhanced turbulence in the combustion chamber
- combustion chamber with ceramic lining,
- catalytic afterburning,
- efficient boiler for indirect heating (with option for secondary heat exchanger enabling latent heat recovery – heat of condensation),
- automatic ash removal,
- low heat losses through the side outer surfaces - heat recovery by means of combustion air
- secondary abatement measure – e.g. ESP.

Figure 6-7: Typical downdraught boilers (<50 kW)[8]

In the EU, a typical BAT downdraught boiler (<50 kW) is assumed to include the first three of these options: primary and secondary air control; ceramic lining of the combustion chamber; and, draught control. This downdraught boiler can reach the energy efficiency and environmental performance shown in Table 6-7.

Table 6-7: Energy efficiency and environmental performance of BAT solutions within the group of downdraught boilers, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC9 (**)
Energy efficiency, (NCV)	%	90	+2
Emission of CO	mg/m^3	100	-50
Emission of PM* (unabated)	mg/m^3	40	-20
Emission of NOx	mg/m^3	190	- (***)
Emission of OGC	mg/m^3	10	0

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

(**) when compared to BC8 values, the following changes are considered (Efficiency +36; CO -98; PM -78; OGC -97)

(***) the best performance value given is related to the amount of nitrogen in the fuel.

➔ Coal stoker boiler

This type of automatic boiler is considered state-of-the-art in coal combustion. Retort boilers or stoker boilers, burn coal fuels by providing a very good combustion quality (a small amount of pollutants) and high efficiency that may reach about 89%. Retort boilers are equipped with a steel or cast iron retort burner, a screw to convey the fuel and a fuel storage box (usually of a capacity giving 4-6 days of autonomy). The boiler

[8] www.choiceheatingsolutions.com

regulator controls the operation of the feeder, the fan, as well as of the circulation pumps used both for central heating and warm water. Both slag and ash are automatically removed from the combustion chamber to the ash container. Hence the combustion chamber is automatically cleaned and the only maintenance operation is to periodically remove ash (once every 3-4 days). Both deashing and fuel refilling can be carried out while the boiler is in use. The combustion chamber is usually equipped with a ceramic deflector placed over the retort burner, enabling the afterburning of volatile matter carried with the flue. The retort boilers are also equipped with automatic cleaning of the heat exchanger surfaces of the boiler. Moreover, the energy efficiency of such boilers is almost constant, regardless of the operating loads (from 30% up to 100% of nominal power).

The BAT solutions found in retort boilers may therefore include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining, and ceramic catalyst deflectors
- fan assisted draught,
- advanced control system (with lambda probe, weather and room temp. control),
- secondary abatement measure – e.g. ESP.automatic ash removal,
- efficient boiler for indirect heating,
- low heat losses through the side outer surfaces - heat recovery by means of combustion air,

A typical solution is presented in Figure 6-8.

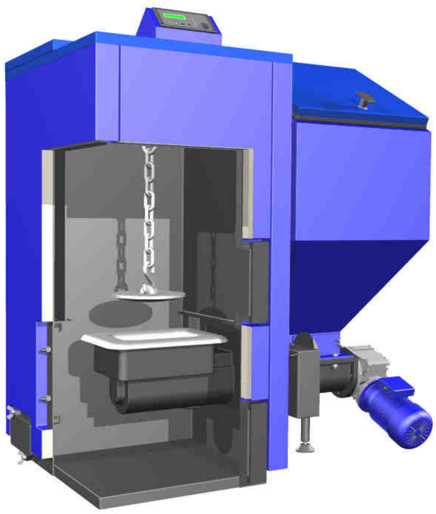


Figure 6-8: Typical coal stoker boiler[9]

[9] www.ogniwobiecz.com.pl

In the EU, a typical BAT retort boiler (>50 kW) is assumed to include the first five of these options: primary and secondary air control, ceramic lining of the combustion chamber, draught control, lambda probes, and secondary abatement measure (ESP or high efficiency cyclone). This retort boiler can reach the energy efficiency and environmental performance shown in Table 6-8.

Table 6-8: Energy efficiency and environmental performance of BAT solutions within the group of coal stoker boilers, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC10
Energy efficiency, (NCV)	%	88	+7
Emission of CO	mg/m^3	90	-55
Emission of PM* (unabated)	mg/m^3	40	-20
Emission of NOx	mg/m^3	210	- (**)
Emission of OGC	mg/m^3	10	0

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulates removal efficiency in relation to unabated emissions.*

(**) the best performance value given is related to the amount of nitrogen in the fuel.

➔ Chips boilers

These appliances closely resemble the pellet boilers described above. However the main difference is that they are equipped with a fuel stoking system and burners appropriate for both wood chips and pellets, e.g. retort burners or step burners.

A typical BAT solution among wood chips boilers is presented in Figure 6-9 and may include the following features and components:

- primary and secondary air distribution and control,
- combustion chamber with ceramic lining,
- fan assisted draught,
- advanced control system (with lambda probe, weather and room temp. control),
- internal recirculation,
- catalytic afterburning,
- automatic fuel feed,
- automatic ash removal,
- efficient boiler for indirect heating (with option for secondary heat exchanger enabling latent heat recovery – heat of condensation),
- doubled heat exchanger, with boiler water and system water- enabling efficient operation at low heat demand,

- low heat losses through surface - heat recovery by means of combustion air
- automatic boiler cleaning,
- secondary abatement measure – e.g. ESP.

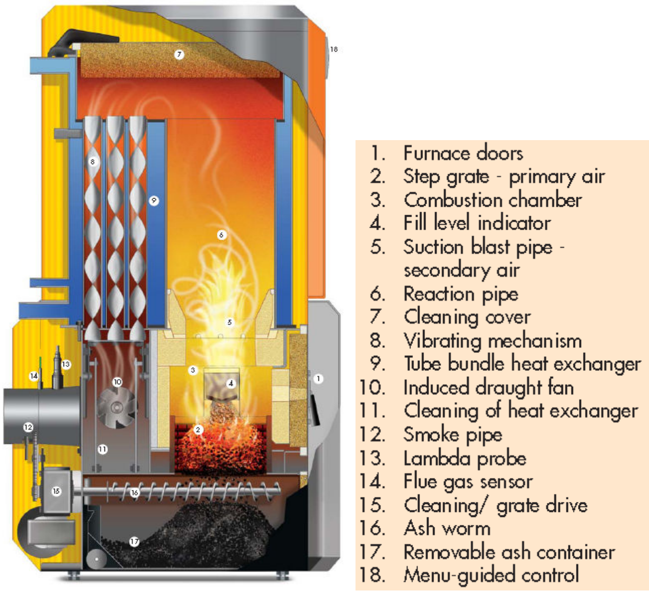


Figure 6-9: Typical wood chip/pellet boiler[10]

In the EU, a typical BAT wood chips/pellet boiler is assumed to have an output > 50kW and to include the first four of these options: primary and secondary air control; ceramic lining of the combustion chamber; draught control; and, lambda probes. This wood chips/pellet boiler can reach the energy efficiency and environmental performance shown in Table 6-9.

Table 6-9: Energy efficiency and environmental performance of BAT solutions within the group of chips/pellet boilers, at 13% of O_2.

Parameter	Unit	Best performance	% change to BC8
Energy efficiency, (NCV)	%	91	+3
Emission of CO	mg/m^3	170	-51
Emission of PM* (unabated)	mg/m^3	30	-40
Emission of NOx	mg/m^3	140	- (***)
Emission of OGC	mg/m^3	10	0

** In the case of PM further improvement can be achieved by means of secondary abatement measures like ESPs resulting in 50-80% particulate removal efficiency in relation to unabated emissions.*

(**) the best performance value given is related to the amount of nitrogen in the fuel, where values as low as 120 mg/Nm^3 were reported by questionnaire responses

[10] www.guntamatic.com

6.1.2 PRODUCTS DEVELOPMENTS, NEW EMERGING TECHNOLOGIES

Except for new emerging developments of SCIs discussed below, indirect heating appliances are quite often a part of the system incorporating a new useful heat sources such as solar panels. As these are broadly described and widely used the following discussion will be focused on new prototype level developments.

➔ Thermoelectric generators

Pellet burners and other automatic combustion appliances need auxiliary electrical power to provide heat in a comfortable and environmentally friendly way. The principle of thermoelectric generators is to produce the electricity needed (as well as additional electricity) within the furnace in order to save resources and to gain operation reliability and independence. Thermoelectric generators (TEGs) allow the direct conversion of heat to electrical power to a certain extent (see Figure 6-10). They have the advantages of a maintenance-free long life and soundless operation without moving parts or any working fluid. The basic system allows grid-independent operation of automatically running biomass furnaces including fuel delivery from a storage facility and the circulation of the cooling, respectively heating, water or air. The advanced system also supplies electricity to the network or other electrical devices as an additional benefit.

The TEG receives heat at a high temperature and delivers heat at a lower temperature when generating electricity. TEGs can be considered as intelligent heat exchangers which refine some of the exchanged heat into electricity.

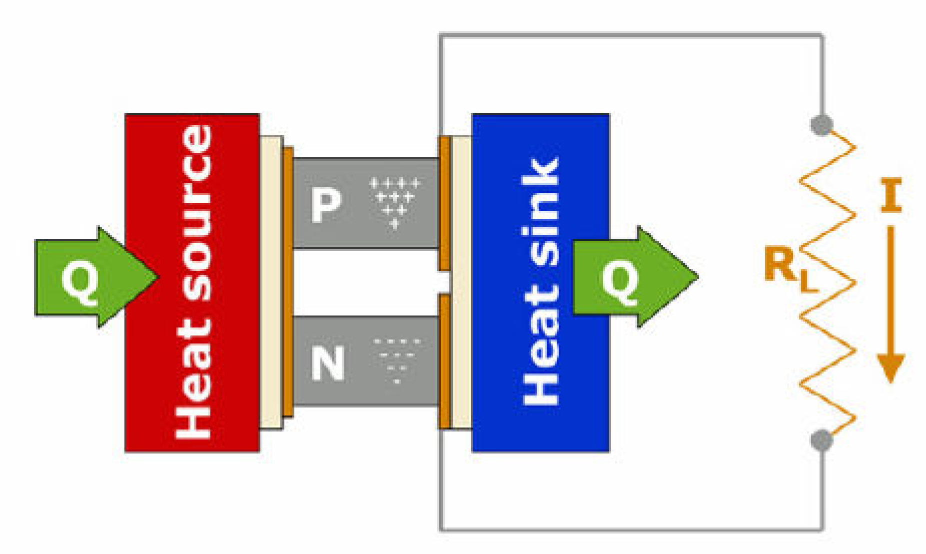


Figure 6-10: The principle of TEG operation[11]

[11] Wilhelm Moser, et al., Small-scale pellet boiler with thermoelectric generator, Thermoelectrics, 2006. pp.349-353, ISBN: 1-4244-0811-3

The higher the temperature difference between the heat source and the heat sink is, the higher is the efficiency and power output. But the TEG has to be carefully protected against overheating. Otherwise it will be damaged or even lead to a breakdown. So the challenge is to reach high (but not too high) and very constant temperatures on the hot side of the TEG for constant high electrical power output. State-of-the-art materials can convert a maximum of 5-6% of the useful heat into electricity, new materials promise 10% or more.

The electrical demand of pellet boilers can be reduced by modified control and new electrical equipment. One has to reconsider the technical demands of furnaces and meet these demands with as little electricity as possible. Various concepts with different electrical devices and working data for different purposes of the system are being developed, e.g. AC and DC solutions with different voltages, grid independent operation or network supply, systems for different power ranges (e.g. see Figure 6-11).

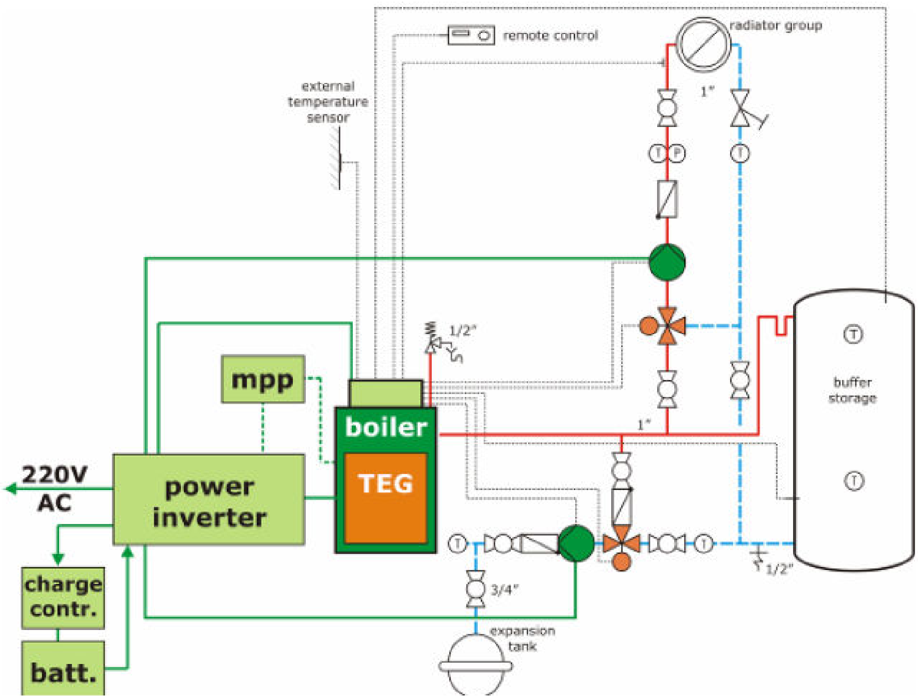


Figure 6-11: A diagram of TEG integration[12]

A novel kind of decentralised small-scale biomass based combined heat and power generation is emerging. The basic system allows grid-independent operation of automatically running biomass furnaces including fuel delivery from storage and circulation of the heating water. The advanced system will also provide electricity for network supply or other electrical devices as an additional benefit.

12 Wilhelm Moser, et al., Small-scale pellet boiler with thermoelectric generator, Thermoelectrics, 2006. pp.349-353, ISBN: 1-4244-0811-3

6.2 STATE-OF-THE-ART AT THE COMPONENT LEVEL

The analysis at the component level includes the integral elements of Small Combustion Installations (i.e. firing grate, air supply system, control equipment, etc.) and to the other/optional components of the product (e.g. draught fans, emission abatement devices, etc.). The following key components are discussed below:

- primary and secondary air distribution and control; natural draught control; fan assisted draught,
- advanced control system (with lambda and CO probes, weather and room temp. control),
- internal recirculation, combustion intensification by enhanced turbulence in the combustion chamber,
- combustion chamber lining,
- catalytic afterburning,
- efficient boiler for indirect heating (with option for secondary heat exchanger enabling latent heat recovery – heat of condensation),
- low heat losses through the side outer surfaces - heat recovery by means of combustion air,
- automatic boiler cleaning, ash removal,
- secondary abatement measure – e.g. ESP.

Chimneys play a key role in this respect. While they can be considered a key component in the heating system, it is very difficult to quantify the exact contribution of the chimney to energy efficiency and the reduction of emissions. However, it must be stressed that efficient SCIs for solid fuel can only be used with suitable chimneys and accessories like draft regulators or vents.

6.2.1 COMPONENTS ALREADY ON THE MARKET

➔ Draught control[13]

Flue systems or chimneys are dimensioned according to the capacity of SCIs. The efficiency of a draught system however is subject to natural fluctuations caused by temperature differences depending on the time of year and the weather. To guarantee reliable operation, the flue systems are designed for an assumed outside temperature of 15°C (according to EN 13384). However in cold months when the SCIs are mainly used, unfavourable temperature gradients can lead to a high under-pressure in the system. As a result the efficiency is reduced, making combustion less economic. This is valid in particular for all appliances operating under natural draught regimes, such as fireplaces, cookers, stoves, manual boilers, etc. To avoid these problems, several draught control solutions do exist.

[13] NOTE: Draught control options are all relevant for real operation, which can be influenced by conditions far from optimum – standard ones

NOTE:

All of the draught-control technologies (including the stove regulator) can be used with any solid fuel SCI operating under natural draught, such as direct heating appliances (fireplaces, cookers, stoves) and manual boilers.

- **Draught limiter**

Draught limiters limit the under-pressure to the optimum value for the combustion heating appliance. Draught limiters (also referred to as secondary air devices in German Standards Institute DIN 4795) are mechanical or motorised components which produce uniform under-pressure conditions in a flue gas system (see Figure 6-12).

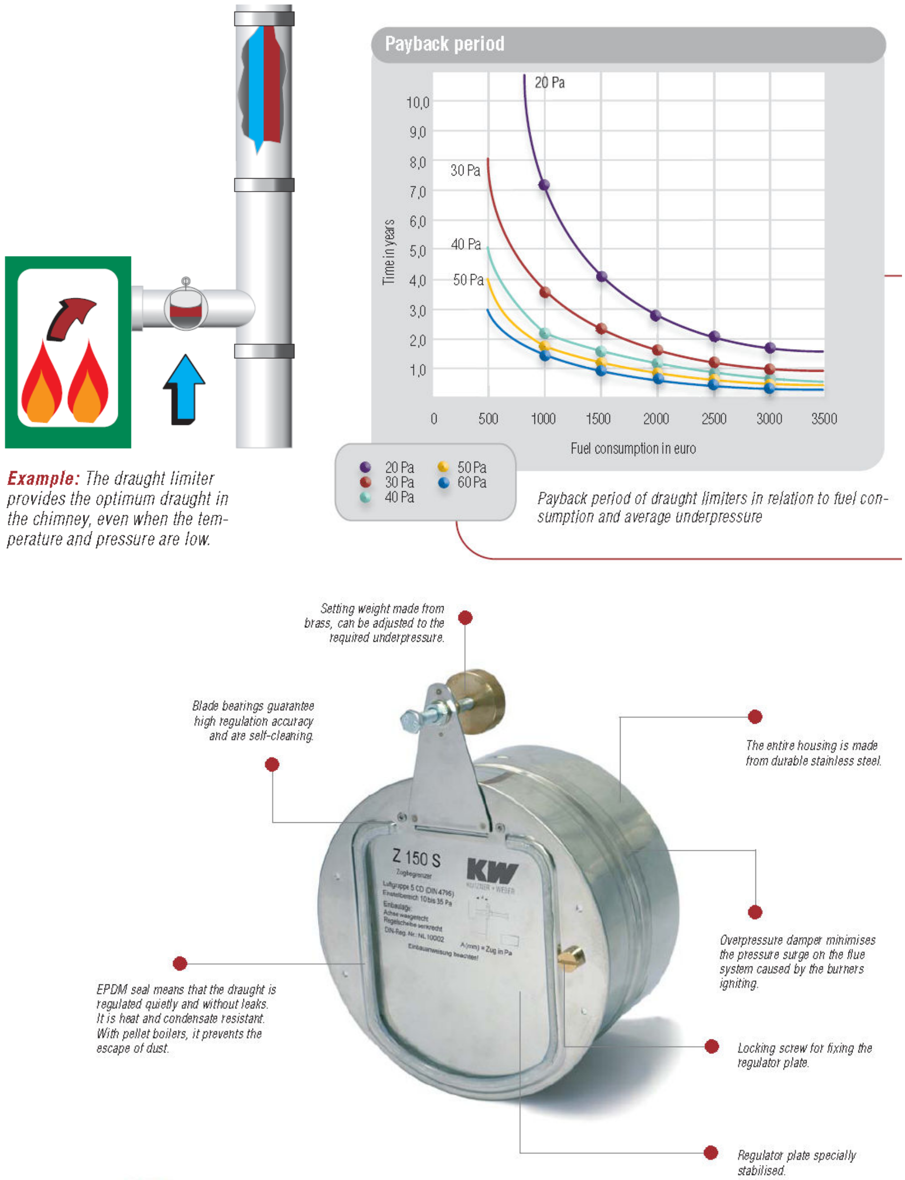


Figure 6-12: Mechanical draught limiter[14]

[14] www.kutzner-weber.de

As soon as the draught in the chimney exceeds the optimum value, the draught limiter damper opens and limits the under-pressure by supplementing the amount of air required. Upon reaching the optimum preset value, the damper closes again. This method, which is both simple and effective, facilitates uniform combustion and generates measurable energy savings. The money invested in draught limiters is usually recouped after a short time via the reduced fuel consumption. Accordingly, draught limiters are a simple way of reducing heating costs, both in the industrial and domestic sector.

- **Impact on LCA parameters**

Draught-limited are made of steel and non-ferrous material. When electrically driven, the BOM of draught limiters also consists of components typical for electrical motors. Moreover, draught limiters lead to reduction in emissions resulting from stabilised combustion. The use of draught limiters, leads to changes in operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-10.

Table 6-10: Draught limiters impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance[15]					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. consumpt.**
% change					**$Wh_{el.}/kWh_{th}$**
5	-(5-10)	-	-5	-(5-10)	
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
1,5	1,5				
Purchase costs, €					
130					

- **Chimney fans, draught fans**

A chimney fan system consists of a chimney fan connected to a manual or automatic control so that the chimney draught can be adjusted according to the needs (see Figure 6-13). The mechanical chimney draught system ensures a correct, constant, negative pressure, thereby enabling the chimney to work optimally under all conditions.

[15] NOTE: Improvement figures refer to real life conditions

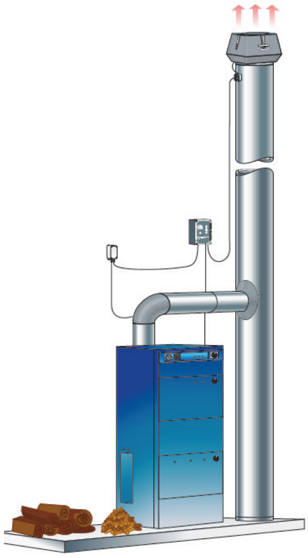


Figure 6-13: Chimney fan system[16]

◆ **Impact on LCA parameters**

As typical fans, draught fans are typically made mostly of steel and non-ferrous metals. Their BOM also consists of components typical for electrical motors. Draught fans can influence both efficiency and emissions of relevant SCIs, which results from stabilised combustion. The use of draught fans, leads to changes in operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-11.

Table 6-11: Draught fans impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance[17]					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. consumpt.**
% change					**$Wh_{el.}/kWh_{th}$**
5	-(5-10)	-	-5	-(5-10)	1
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
3	3				
Purchase costs, €					
960					

■ **Stove regulator**

A stove regulator consists of a microprocessor-controlled unit that receives, processes and sends information to regulator elements, such as the constantly operating supply-

16 www.kutzner-weber.de

17 NOTE: Improvement figures refer to real life conditions

air damper. The most important elements of the stove regulator are the sensors and switches, which tune combustion relevant parameters. These sensors and switches:

- measure the flue gas temperature
- measure the flue gas flow rate
- check the position of the window (open or closed) , where relevant
- check if the extractor hood is turned on, where relevant
- check if the stove door has just been opened to add wood, where relevant

The microprocessor-controlled regulator unit uses this input data to calculate the ideal parameters for an efficient and eco-friendly combustion (based on the known physical processes of combustion), and sends the corresponding commands to the regulator elements:

- supply-air damper, to regulate the supply of fresh air for the combustion
- draught regulator, that opens when the draught in the chimney becomes too strong
- optional chimney fan, to counteract a weak chimney draught and to operate in the heat-up phase if needed
- radio module, to control the extractor hood and turn it off, if necessary

The stove regulator optimises the combustion process leading to more efficient operation, less emissions (in particular CO and PM), and increases the ease of use of the appliance. Impressive results can be achieved when stove regulators are used in combination with modern fire places. A fire that is controlled by the stove regulator burns much longer than an unregulated combustion and radiates heat more evenly (Figure 6-14). In addition, since the temperature is kept below 600°C, no uncontrolled temperature peaks occur, which, in the worst case, could lead to a chimney fire.

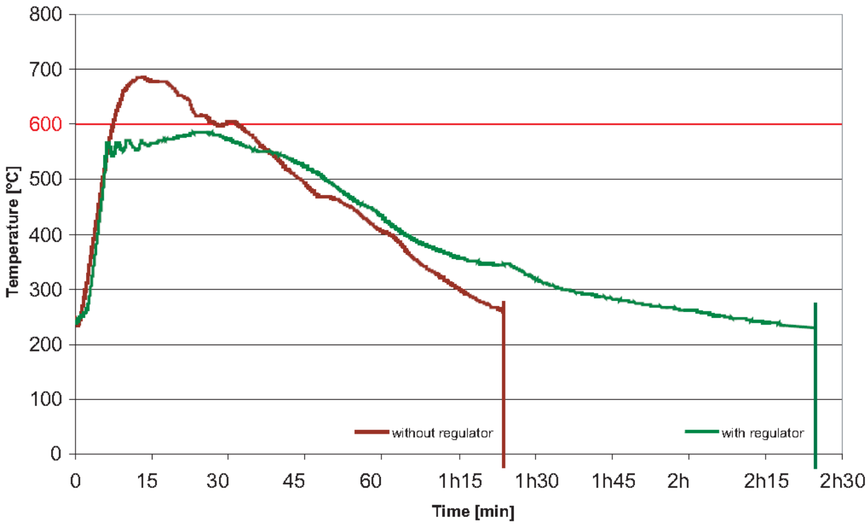


Figure 6-14: The effect of process control of the stove regulator on the combustion temperature and time[18]

- **Impact on LCA parameters**

Stove regulators can influence both efficiency and emissions of relevant SCIs, which results from stabilised combustion. The use of stove regulators, leads to changes in operating parameters and in the BOM of relevant SCIs. Estimates of these are presented in Table 6-12.

Table 6-12: Stove regulator impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance[19]					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. consumpt.**
% change					**$Wh_{el.}/kWh_{th}$**
5	-(5-10)	-	-5	-(5-10)	1
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
9	8				1
Purchase costs, €					
2380					

[18] www.kutzner-weber.de

[19] NOTE: Improvement figures refer to real life conditions

➔ Air distribution, clean burning

■ Afterburning - tertiary air

Tertiary air is brought into the rear of the stove and circulated via internal ducting to pre-heat the air. It is then, as it gains momentum, injected via a row of factory machined holes into the top of the combustion chamber (Figure 6-15). This action causes the un-burnt gases to be re-ignited and burnt down, producing extra heat and cleaner emissions.

Figure 6-15: A stove with tertiary air supply[20]

The stove or fireplace must be burning at its optimum temperature (350˚C) to achieve clean burning efficiency and to reduce emissions. Such solutions may also be used as retrofit options[21].

◆ Impact on LCA parameters

Such solutions may insignificantly increase the mass of ceramic parts in the appliance. Although the manufacturing process will require more sophisticated techniques as the design is more complicated. Hence clean combustion appliances may have slightly higher capital costs.

With clean burn technology, SCI appliances convert up to 90% of the gases and particles in smoke to heat. This results in decreased emissions of pollutants like CO, OGC and dust. Such solutions may increase the efficiency of the appliance by a magnitude of a couple of per cent when compared to an ordinary appliance (wood burning appliances). However, emission reduction can be found to have no major significance in this particular case.

[20] www.jotul.com

[21] www.ecoxy.no

➔ Heat exchange, heat recovery

■ Ceramic lining of the combustion chamber

The ceramic lining of the combustion chamber can be used in any solid fuel SCI. The ceramic lining of the combustion chamber can be made of various materials, which are reflected in the different effects they can achieve. There are two major groups:

- Heat storage materials: these provide heat capacity inside the combustion chamber lining. The heat stored in the lining can be released under the fuel batch. Hence the magnitude of changes in the combustion chamber temperatures is limited. Appropriate combustion parameters can therefore be preserved.
- Insulating materials: they help keep the heat in the volume of the combustion chamber. This prevents excessive radiation of heat from the combustion chamber. As a result, temperature can be maintained at the desired level, ensuring appropriate combustion parameters between the stoking operation.

As different effects are expected, good design requires a well-balanced use of the various types of linings. For instance, it is extremely important to insulate the combustion chamber of appliances which have a significant share of glass side walls, and where the key issue is radiation through the large glass surface.

◆ Example of heat storage lining

Chamotte is a refractory ceramic material used for combustion chamber lining. It has a high percentage of silica and alumina. It is made by firing different kinds of fire clay and tends to be porous and have low density. It is available as a powder, mortar, or in the form of fire bricks.

◆ Example of insulation lining

Vermiculite is a mineral consisting of aluminium-ferrous-magnesium-silicate. The vermiculite bricks used for lining the combustion chamber (see Figure 6-16) are mostly made of expanded vermiculite and have the following characteristics, which make them ideal for combustion chamber lining, where radiation should be prevented:

- good insulation value, against both heat and sound
- high mechanical strength
- high temperature resistance
- able to withstand direct flame impingement

Figure 6-16: Vermiculite brick [22]

Moreover the composition of vermiculate coupled with a precision-moulding technique allow the manufacturing of special shapes with various textures.

- **Impact on LCA parameters**

Ceramic lining of the combustion chamber will only affect the BOM of appliances slightly for direct heating appliances since the quantities of lining material for the combustion chamber remain small compared to the quantities of e.g. steel or cast iron. Moreover, ceramic components do not have a large environmental impact (far less than the impacts of steel for instance). Finally, the manufacturing phase has very minor impacts over the entire life cycle of appliances, compared to the use phase. As a result, the changes in the BOM of appliances with ceramic lining can be assumed to be insignificant.

Although the amounts of ceramics in the case of direct heating appliances may be found relatively small, the use of ceramic lining will increase the total price of the appliance itself. In the case of direct heating appliances, this may increase the material costs up to 10%. The significance of the ceramic lining in the case of boilers is far smaller, and can be therefore neglected.

Quantifying the efficiency and environmental performance changes produced solely by ceramic lining is difficult. However, it can assumed that insulation lining along with air staging ceramics produces the majority of the overall differences between BC parameters and BAT parameters in the case of direct heating appliances. In such cases the ceramic lining itself can contribute with a third of the overall changes. The influence of the ceramic lining on the efficiency and emissions of boilers is smaller as the key impact is the arrangement of the combustion process.

Condensation heat recovery

This BAT technology applies to biomass fuelled boilers. The idea is simply to recover the latent heat of condensation that would typically be released with the flue through the stack, as is done in gas boilers (Figure 6-17 and Figure 6-18). In a conventional non-condensing boiler, the hot combustion gases heat water contained in a heat exchanger. As a result, significant heat is lost to the atmosphere, both through the flue gases

[22] www.kutzner-weber.de

which are still quite hot (180°C - 200°C), and through the moisture (saturated steam) carried with the flue. However, the water produced by the combustion of the fuel (and in the case of solid fuels, moisture introduced with the fuel and subsequently evaporated) which leaves the boiler as a steam can instead be condensed. The heat of condensation (2260 kJ/kg) can be recovered through an additional heat exchanger. The use of such components seems to be limited to biomass boilers.

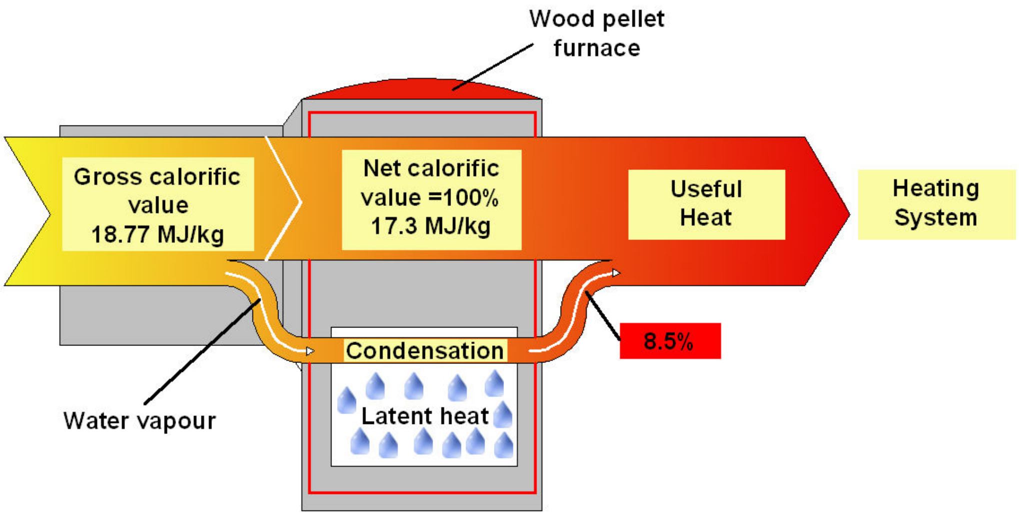


Figure 6-17: Scheme of condensation heat recovery[23]

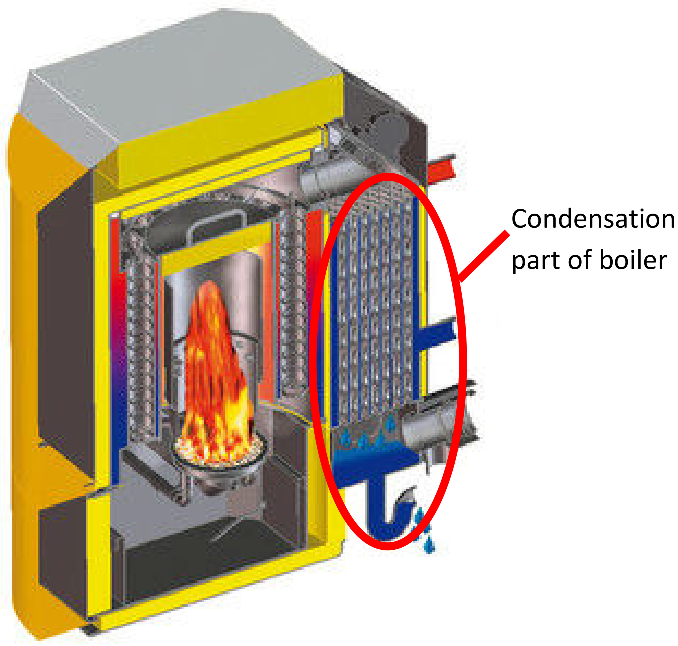


Figure 6-18: Additional heat exchanger for condensation heat recovery[24]

[23] www.oekofen.co.uk

[24] www.oekofen.co.uk

- **Impact on LCA parameters**

An additional heat exchanger will significantly increase the mass of steel parts in the appliance. Special material requirements need to be met (e.g. stainless steel), because of the acidic dew point that can be observed during the condensation of the flue gases. Therefore, such solutions may have a significant environmental impact on the manufacturing phase (slightly higher than the impacts of boiler steel for instance). In some cases such heat exchangers can be made of graphite instead of stainless steel. As a result, the changes in the BOM of appliances with additional heat exchangers can be significant – up to a 15% increase.

The use of an additional heat exchanger will also increase the total price of the appliance itself. It can be assumed that this may contribute to increasing the material costs by about 5%.

The purpose of an additional exchanger is to increase the efficiency of the appliance, by a magnitude of about 5-10% when compared to an ordinary appliance (wood burining appliances). Moreover, the OGC and hence dust emissions can be slightly reduced by the effect of condensation, although the magnitude of this reduction does not exceed more than a couple percent when compared to an ordinary appliance.

- **Economisers**

These components, which enable more effective recovery of heat carried by flue gases, can be either integral parts of appliances (see above) or add-ons, so-called economisers (Figure 6-19).

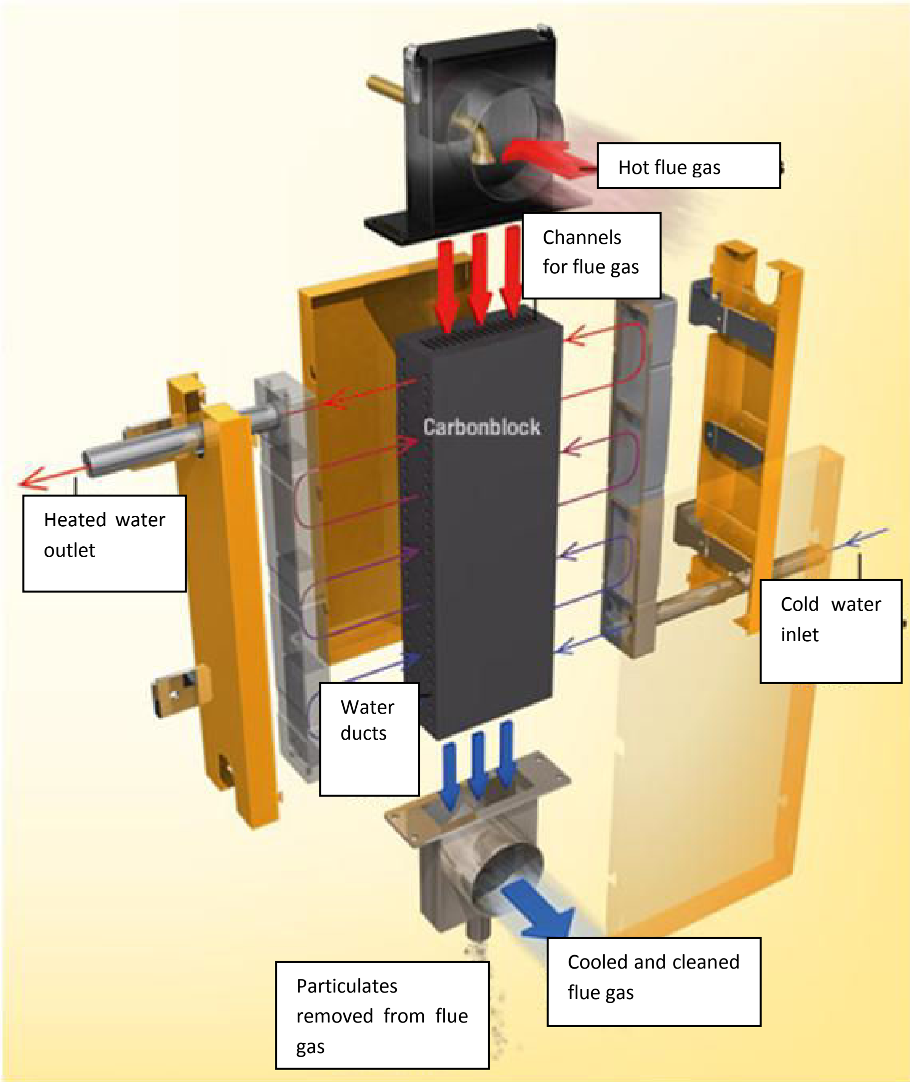


Figure 6-19: Economiser for condensation heat recovery[25]

The heat is retrieved from hot flue gas by means of cold water. A significant part of PM produced by biomass combustion is derived from condensable matter. Along with the heat recovery, a significant abatement effect can be reached by an additional heat exchanger made of special materials that cause condensation of volatiles, hence separating some particulates from the gases.

[25] http://www.oekofen.co.uk

Impact on LCA parameters

Under condensation conditions, an acidic dew point can be observed, hence corrosion proof solutions should be used, like graphite heat exchangers. The use of such heat-exchangers can result in additional heat recovery of 8 to 28% in the case of wood combustion. Volatiles condensation and successive particulates separation significantly decrease relevant emissions (Table 6-13).

Table 6-13: Economisers impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. consumpt.**
% change					**$Wh_{el.}/kWh_{th}$**
Up to 20	-	-	-50	-90	1
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
23	8		15		
Purchase costs, €					
-					

Balanced flue

A balanced flue consists of two ducts, one inside the other. The fresh air for the combustion is taken from the outer duct and the exhaust gases are removed by the central duct to the stack outlet (see Figure 6-20). Such an assembly allows for additional heat recovery, where combustion air is preheated by the flues. An additional safety feature is that combustion is independent of any air supply within the room, such appliances are often called room sealed. As the system is completely enclosed, there is no chance of exhaust gases escaping into the room. Another benefit is that the cooling effect (the effect observed when fresh, cold air is sucked into the compartment, where the appliance is installed) is avoided. The balanced flue assemblies can be use for both direct and indirect heating systems; however, currently they are most commonly applied for gas and oil appliances.

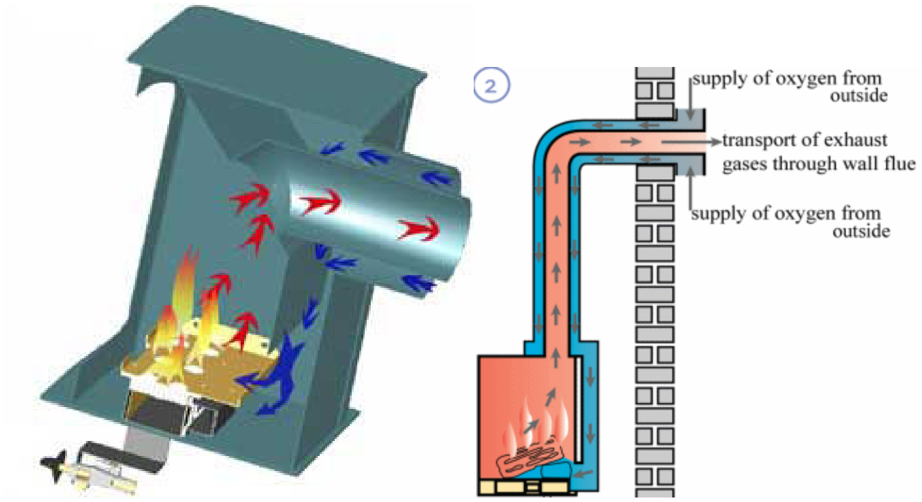


Figure 6-20: Balanced flue assembly[26]

- **Impact on LCA parameters**

Since gas-to-gas heat exchange is not as effective as gas-to-water heat exchange in boilers, the recovered heat by a balanced flue assembly is of smaller magnitude (Table 6-14). As in the case of condensing boilers, the conditions for condensation of volatiles can also be provided. Therefore some part of PM produced by biomass combustion can be removed. Under condensation conditions an acidic dew point can be observed, hence only corrosion proof solutions should be used, e.g. stainless steel components.

Table 6-14: Balanced flue assembly impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. $_{consumpt.}$**
% change					**$Wh_{el.}/kWh_{th}$**
+1	-	-	-10	-10	-
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
30	30				
Purchase costs, €					
200					

[26] www.muelaner.com; www.drugasar.co.uk

Three-layer heat exchanger

A three-layer heat exchanger exchanges heat between flue gas, boiler water and heating circuit water. It is controlled by thermostatic valves to prevent a direct heat exchange between cold return water and the flue gas. Thereby a dew-point safe operation of the boiler is ensured with variable heating circuit temperatures (30-85°C) and modulated power (30-100%). This solution (Figure 6-21) does not require an external return riser (pressure relief devise), even when the appliance is used with an under-floor heating system. This is achieved by an integrated flue/liquid/liquid heat exchanger[27]. The use of such components is limited to boilers.

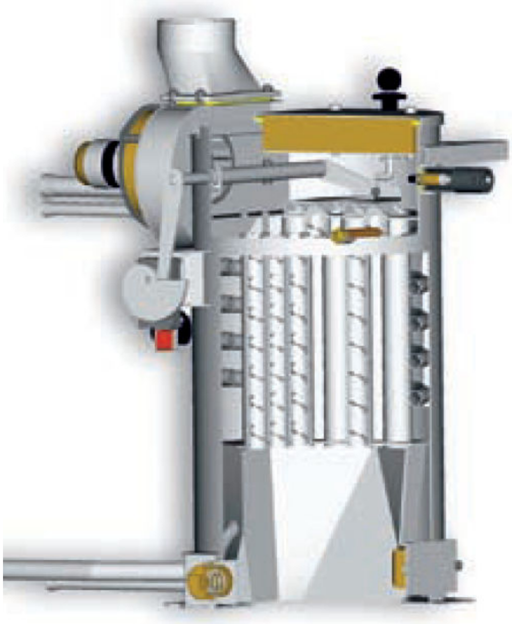


Figure 6-21: Three-layer heat exchanger[28]

Impact on LCA parameters

A three layer heat exchanger will increase the mass of steel parts of the BOM. Therefore such solutions may have a significant environmental impact (comparable to the impacts of boiler steel for instance). As a result, the changes in the BOM of appliances with additional heat exchangers are not significant – up to a 10% increase.

The use of an additional heat exchanger will increase the total price of the appliance itself. It can be assumed that this may increase the material costs by about 5%.

The purpose of three layer heat exchangers is to increase the flexibility of the appliances – to maintain a high efficiency at modulated power output - so higher efficiencies can be expected at decreased power outputs. Emissions of relevant pollutants will be maintained accordingly – at the decreased power outputs, they will be close to the parameters characteristic for nominal power output operation.

[27] patented by ETA, www.eta.co.at

[28] www.eta-heiztechnik.at

■ **Heat accumulator**

All heating appliances can be assembled with heat accumulators. A heat accumulator can be a buffer tank where heated water from the boiler is stored and gradually circulated in the heat distribution system, and after having emitted its heat then returned to the accumulator to be heated up again Such buffer tanks in the case of e.g. boilers may increase the energy efficiency of appliances by 1-5%, which depend on the insulation losses and how they can be recovered. But the main benefit of the accumulator tank in the case of boilers is that the boiler will more or less always work at the designed power output, which leads to significantly lower emissions than without a storage tank. Also, the comfort for the user increases significantly.

In general, every direct heating appliance can also be retrofitted or assembled with a conventional heat exchanger and connected to a heat accumulator (see Figure 6-22).

Alternatively, the heat from the flue gases can be stored in special stones (Figure 6-23) and/or granulate placed in a special container mounted at the flue outlet (Figure 6-24)[29], and released slowly afterwards. Heat storage stones are highly compressed, burnt elements containing magnesite and have a high apparent density of 2.9 kg/dm³, which gives them an enormous thermal conductivity and storage capacity. The stored heat is emitted via the outer skin with a constant and long storage time of up to five hours. The decrease in the exhaust gas temperature at the top exhaust connection is ca. 120 °C. Such a solution improves both the energy and the environmental performance of direct heating appliances. The space required for such solutions is not excessive.

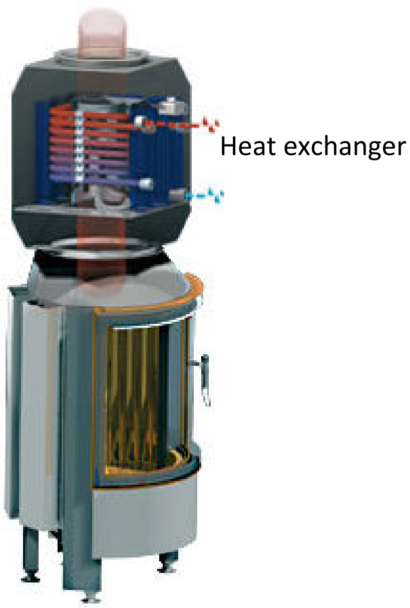


Figure 6-22: A fireplace insert assembled with a flue-water heat exchanger[30]

[29] www.spartherm.de
[30] www.spartherm.de

Energy efficiency is improved since the heat produced by combustion can be stored and hence used more efficiently.

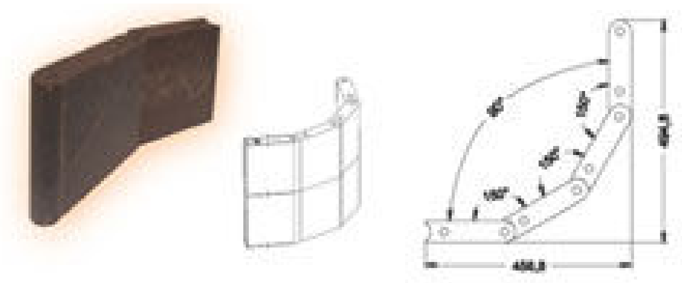


Figure 6-23: Heat storage stones[31]

Figure 6-24: Heat storage by means of bulk materials[32]

Heat accumulators can be used with direct heating appliances like fireplaces, cookers, stoves, etc.

- **Impact on LCA parameters**

Heat accumulators can influence the efficiency of relevant SCIs. The use of heat accumulators leads to changes in operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-15.

[31] www.spartherm.de

[32] www.spartherm.de

Table 6-15: Heat accumulators impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance (bulk ceramic accumulators/water accumulators)					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. $_{consumpt.}$**
% change					**$Wh_{el.}/kWh_{th}$**
1/2	-40*	-	-56*	-	1
BOM, kg (ceramic accumulators/water accumulators)					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
108/20	8/20		100/0		
Purchase costs, € (bulk ceramic accumulators/water accumulators)					
500/2500					

* - observed in the case of accumulator tanks installed with simple, manually fuelled appliances

➔ Self cleaning, ash removal

The necessity to clean surfaces within an appliance, whether this is in the combustion chamber or the heat exchanger, is a common requirement for both manually and automatically fuelled appliances. It may be observed that 1mm of soot or dust increases the flue gas temperature with about 50 °C[33] (depending of the construction of the appliance). This results in a decrease in the overall efficiency of approx. 3%. Therefore maintenance and cleaning seems to be the most cost-effective way to maintain the efficiency and the performance of the appliance at the high level expected of a newly installed appliance. The frequency of cleaning can be easily established by measuring the flue gas temperature at the appliance outlet, either in the appliance or in the connecting flue pipe at periodic intervals. The frequency is dependent on the type of fuel, type of appliance and the total heating installation (design and surrounding).

■ Self cleaning heat exchanger

The standard daily cleaning of the heat exchanger can be performed fully automatically. The cleaning is performed with special built-in springs that are periodically moved up and down to remove impurities from the heat exchange surfaces of the boiler. The springs not only clean the heat exchanger but also guarantee enhanced heat exchange, by being a type of turbuliser (Figure 6-25). The result is constant high efficiency and reduced fuel costs.

[33] ESCHFOE, informative brochure

Figure 6-25: Automatic heat exchanger cleaning[34]

◆ **Impact on LCA parameters**

This BAT can be used in any boiler and is made of steel. However, its BOM is negligible (< 5 kg) compared to the contents of other ferrous metals in solid fuel SCIs (such as steel and cast iron). As a result, the changes in the BOM of appliances with heat exchanger cleaning can be neglected.

Although the changes in BOM are found to be insignificant, the use of such solutions may slightly increase the total price of the appliance itself. It can be assumed that this may increase the overall costs by around 2%.

The purpose of automatic cleaning feature is to enhance the heat transfer and thereby increase the efficiency, by both cleaning the surface of heat exchanger and introducing turbulence in the flue ducts. Higher efficiencies can therefore be expected, although the magnitude of change seems to be relatively small, when compared to a properly operated appliance without an automatic cleaning feature. Thus the emissions of relevant pollutants will change accordingly, although when compared to well-maintained appliances, the changes may not be that significant.

■ **Ash removal**

Ash is a waste by-product of combustion. Accordingly, it needs to be removed first from the burners and then finally from the appliance itself. This can be done manually in the case of simple appliances, or automatically as in the case of boilers. After continual de-ashing of the burner plate, the ash is transported fully automatically from the firebox to an ash box built on the front of the boiler by a screw conveyor. There it is compressed by rotating screws (see Figure 6-26). The ash box is fitted with rollers and an extendable handle, so that it can easily be emptied by the customer, usually no more than twice per heating season.

[34] www.kwb.at

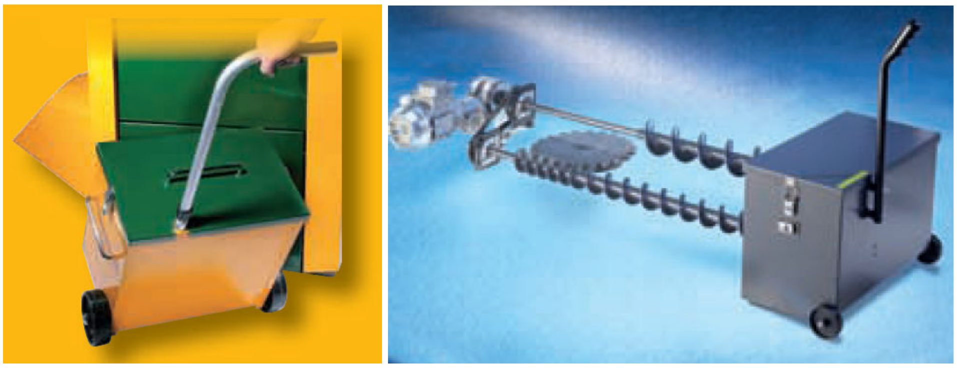


Figure 6-26: Automatic ash removal system[35]

- **Impact on LCA parameters**

Ash removal devices can be used in any boiler, and are typically made of metal. They will slightly increase the mass of steel parts of the BOM, but the magnitude of change should not be higher than 2% of the total steel in the BOM.

Although the changes in the BOM are found to be insignificant the use of such solutions may increase the total price of the appliance itself. It can be assumed that this may increase the overall costs by around 3%.

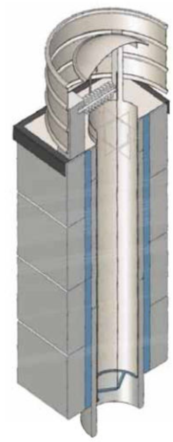
The main purpose of automatic ash removal feature is to increase the ease of use. So the influence on both efficiency and emissions can be neglected.

→ After-treatments

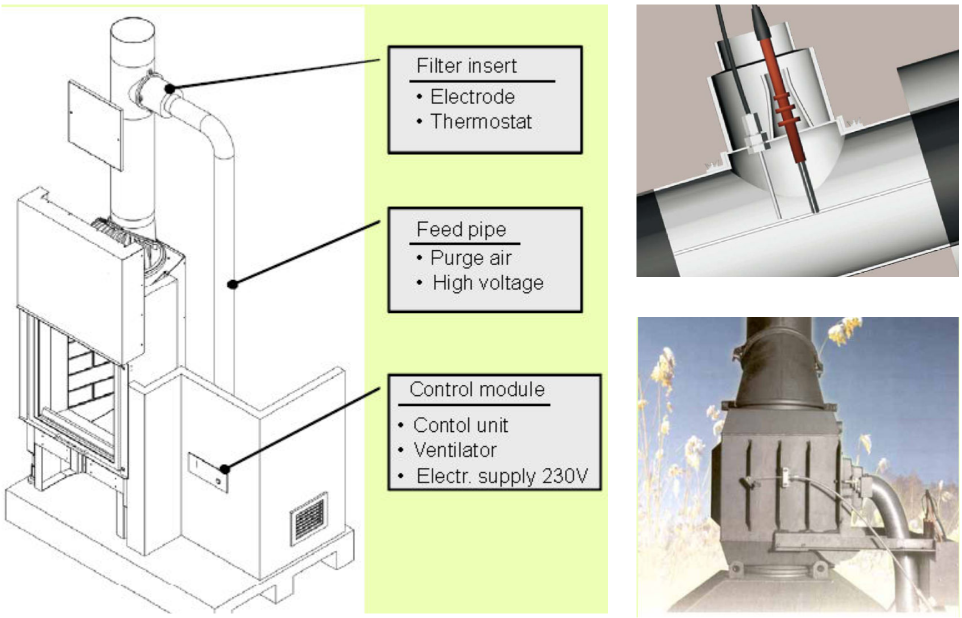
- **Electrostatic precipitators (ESPs)**

An electrostatic precipitator (ESP) is a device that removes particulates from the flue gases using an electrostatic force field (produced by a high-voltage corona discharge). ESPs are highly efficient PM abatement devices producing insignificant pressure drop (low resistance of flow), and they can easily remove fine particulate matter such as submicron particles. They can have high dedusting efficiency, up to 99%. However, when used for the abatement of PM emissions from biomass combustion, up to 90% removal efficiency has been observed. ESPs apply energy only to the particulate matter being collected and therefore are very efficient in their consumption of energy (in the form of electricity). ESP solutions are available, either as “end of pipe” devices or as in-stack devices, which are assembled directly at the flue outlet of the SCIs (see Figure 6-27).

35 www.kwb.at



ESPs - End of pipe solutions



a) [36]

b) [37]

ESPs- in-stack assemblies, mounted at flue outlet of SCIs;

Figure 6-27: Different types of ESPs

ESPs can be used with any heating appliance, such as fireplaces, cookers, stoves, boilers, etc.

- **Impact on LCA parameters**

ESPs influence only emissions of PM of SCIs. The use of ESPs, leads to changes in operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-16.

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[36] www.kwb.at

[37] www.spartherm.de

Table 6-16: ESPs impact on operating parameters of relevant SCIs with BOM data and investment costs

Energy & Environmental performance					
Efficiency	E_{CO}	E_{NOx}	E_{PM}	E_{OGC}	El. consumpt.
% change					$Wh_{el.}/kWh_{th}$
-	-	-	-(50-80)	-	2
BOM, kg					
Total	Steel	Cast iron	Ceramics	Glass	Electronics
5	4				1-2
Purchase costs, €					
1500					

- **Fabric filters**

Fabric filters, along with ESPs, are the most common PM abatement solution used in the energy sector. With fabric filters, PM emission abatement can reach 95-99% filtration efficiency (see Figure 6-28). However, the filters produce a significant pressure drop, around 1000 Pa. As a result, more electricity is required to overcome this flow resistance, and a significant increase in the operating costs of solid fuel SCIs is therefore observed. This explains why fabric filters are not used today together with small scale equipment.

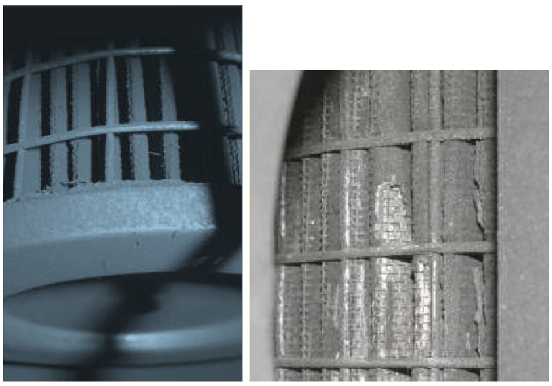


Figure 6-28: Fabric filter in steel housing

Fabric filters can be used with any heating appliance like fireplaces, cookers, stoves, boilers, etc.

Impact on LCA parameters

Fabric filters influence only the PM emissions of solid fuel SCIs. The use of fabric filters, leads to changes in the operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-17.

Table 6-17: Fabric filters impact on operating parameters of SCIs

Energy & Environmental performance					
Efficiency	E_{CO}	E_{NOx}	E_{PM}	E_{OGC}	El. consumpt.
% change					$Wh_{el.}/kWh_{th}$
-	-	-	-(90-95)	-	5
BOM, kg					
Total	Steel	Cast iron	Ceramics	Glass	Electronics
4	4				
Purchase costs, €					
1000					

High efficiency cyclones

High efficiency cyclones seem to be the most cost-effective solution for separating dry particulate material from gas streams. In this system, the separation of particulates from the flue gases is based on a centrifugal mechanism. A helical flow is produced by the tangential inlets of the flue gas, so that dust particles are separated from the gas stream, and settle over the side walls of the apparatus. The cleaned gas is then released through the upper nozzle, while the dust is collected in the bottom part of the apparatus (see Figure 6-29).

Figure 6-29: Cyclone type deduster[38]

[38] www.mikropul.de

The dedusting efficiency of cyclone type dedusters is relatively low when compared to ESPs and fabric filters, although it can reach 100% for particulates of sizes above 10 µm. Although cyclones produce a lower pressure drop than fabric filters, the pressure drop is still much higher than in the case of ESPs. However in practice, the cut diameter limits their application to SCIs fuelled with solid coal fuels. In this particular case they offer benefits, such as:

- low investment and operating costs
- no moving parts
- low space requirement

Cyclones, which are typically made of steel, can be used with any heating appliance like fireplaces, cookers, stoves, boilers, etc, although due to low cut diameters their application is rather limited to coal fuelled SCIs.

- **Impact on LCA parameters**

Cyclones influence only the PM emissions of solid fuel SCIs. The use of cyclonic dedusters leads to changes in operating parameters and the BOM of relevant SCIs. Estimates of these are presented in Table 6-18.

Table 6-18: High efficient cyclones impact on operating parameters of relevant SCIs (coal) with BOM data and investment costs

Energy & Environmental performance					
Efficiency	**E_{CO}**	**E_{NOx}**	**E_{PM}**	**E_{OGC}**	**El. consumpt.**
% change					**$Wh_{el.}/kWh_{th}$**
-	-	-	-80	-	1
BOM, kg					
Total	**Steel**	**Cast iron**	**Ceramics**	**Glass**	**Electronics**
4	4				
Purchase costs, €					
700					

- **Oxidation catalyst, afterburning**

Oxidation catalysts can be used to reduce emissions of organic pollutants – components of flue gases. An oxidation catalyst is effective for the control of carbon monoxide (CO), non-methane hydrocarbons (NMHC) and volatile organic compounds (VOC). For effective post-combustion of organic compounds, the flue gas must be lean (excess oxygen) for the following reactions to occur:

Carbon Monoxide $CO + \frac{1}{2} O_2 \rightarrow CO_2$

Hydrocarbons $C_mH_n + (m + {}^n/_4) O_2 \rightarrow m\, CO_2 + {}^n/_2\, H_2O$

Hydrogen $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

The operating temperature window of oxidation catalysts is between 240°C – 520C°. There are several catalysts available to reduce emissions of CO and VOC.

The catalyst usually consists of a support covered with thin layers of precious metals, usually platinum or palladium, which interacts with CO and other organic components of flue and oxidises them.

- **Impact on LCA parameters**

Oxidation catalyst only insignificantly increases the mass of metal parts in the BOM. As a result, the changes in the BOM of appliances with such a solution can be neglected.

Although the changes in the BOM are found to be insignificant, the use of such solutions due to its sophisticated design and valuable materials used may increase the total price of the appliance itself. It can be assumed that this may increase the overall costs by around 5%. However it must be stressed that operating costs may increase significantly as the lifetime of such currently available solutions seems to be much shorter than the lifetime of the appliance itself. There are cases reported where catalyst efficiency was lost after only a couple of months, when used in simple, direct heating appliances.

The only purpose of catalysts is to abate emissions of CO and other organic compounds. Therefore higher efficiencies cannot be expected, but the emissions of relevant pollutants can change significantly. The following conversion rates can be achieved by means of oxidation catalyst, see Table 6-19.

Table 6-19: Exemplary conversion rates of oxidation catalyst

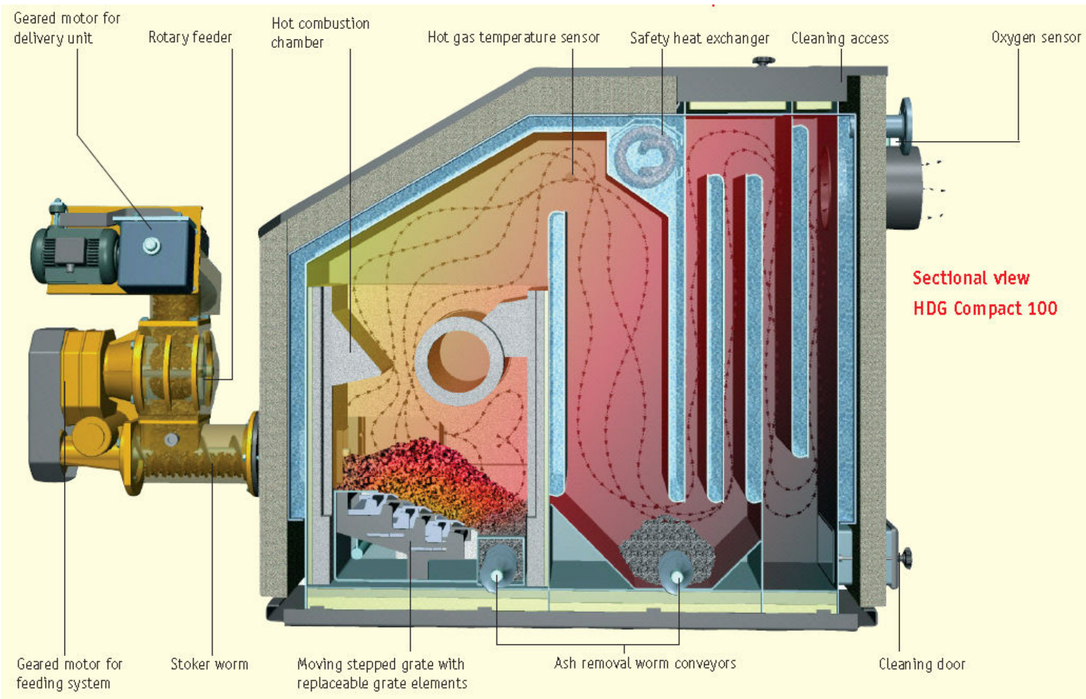
NOx	CO	NMVOC	VOC	PAHs
-	70-99%	40-90%	60-99%	60-99%

→ Burners/grates

Since improvements to burners and grates are motor driven, they apply mainly to the automatic solid fuel boilers regardless of whether they are fuelled with biomass or mineral fuels.

- **Stepped grate**

Stepped grate technology (see Figure 6-30) ensures that the optimum performance of the SCIs is maintained, even when the proportion of non-combustible material is increased. The fuel moves on the grate through different temperature zones, and is thereby dried, degassed and finally burnt thoroughly. Boilers equipped with stepped grates are capable to adapt to different types of fuels.



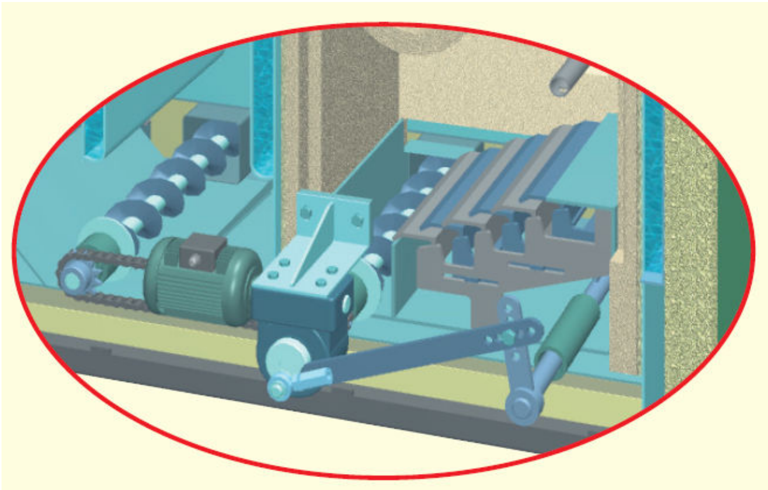


Figure 6-30: Stepped grate solution[39]

- **Impact on LCA parameters**

Stepped grates only insignificantly increase the mass of steel parts in the BOM. As a result, the changes in the BOM of appliances with such solutions can be neglected.

Although the changes in BOM are found to be insignificant the use of such solutions, due to its complex mechanics may increase the total price of appliance itself. It can be assumed that this may increase the overall costs by around 2%.

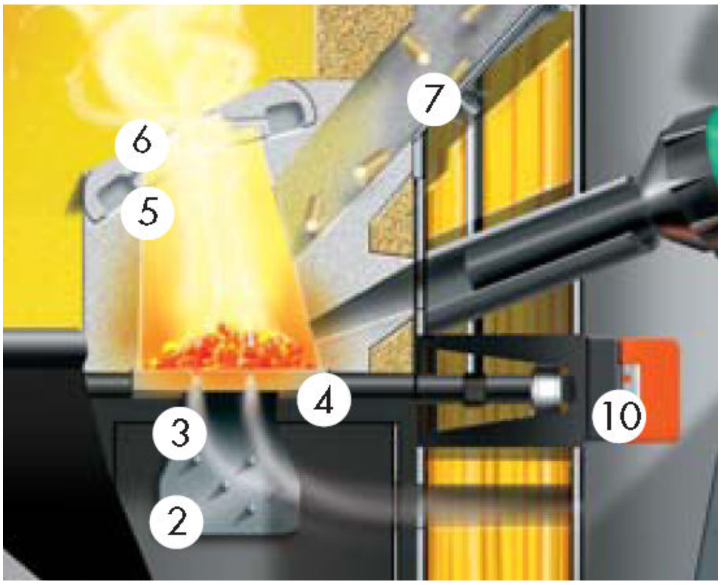
The purpose of stepped grate is to provide more flexibility to changes of fuel parameters. Higher efficiencies can be expected only when compared to a typical appliance fuelled with a fuel of inappropriate type/quality. The emissions of relevant

[39] www.hdg-bavaria.de

pollutants will change accordingly, but when compared to appliances fuelled with appropriate quality fuel, the changes may be negligible.

- **Self-cleaning bowl burner**

To introduce a self-cleaning feature to a new advanced appliance, a different burner design is usually required. One such design is a burner with a tipping plate (see Figure 6-31). In this case, the bottom of the burner is perforated, which allows the supply of primary combustion air. The burner is periodically cleaned by a tipping plate, which is a plate with rods to clean the perforated openings.



2. Grate cleaning plate, 3. Primary air, 4. Self-cleaning grate, 5. Secondary air, 6. Twisting plate 7. Backburn-proof drop shaft, 10. Cleaning motor

Figure 6-31: Self cleaning burner

- **Impact on LCA parameters**

Self-cleaning bowl burners are essentially metallic, and do not substantially differ in their BOMs from conventional burners, and the metallic plate represents a negligible addition (< 5kg) in comparison to the contents of steel already in the appliance.

The cost of such a solution should not significantly vary when compared to typical solutions; hence they will not be taken into account.

The presence of a self-cleaning bowl burner reduces the maintenance requirements for the appliance. Therefore, it is more of a convenience solution than a solution which substantially improves the efficiency or reduces the emissions of the appliance under normal operating conditions.

■ Rotary grate[40]

This solution (see Figure 6-32) allows the continuous de-ashing of the grate during combustion. A cleaning system cleans the grate outside of the firing area. The movement of grate ensures the fire bed is constantly riddled, resulting in high burnout with little ash.

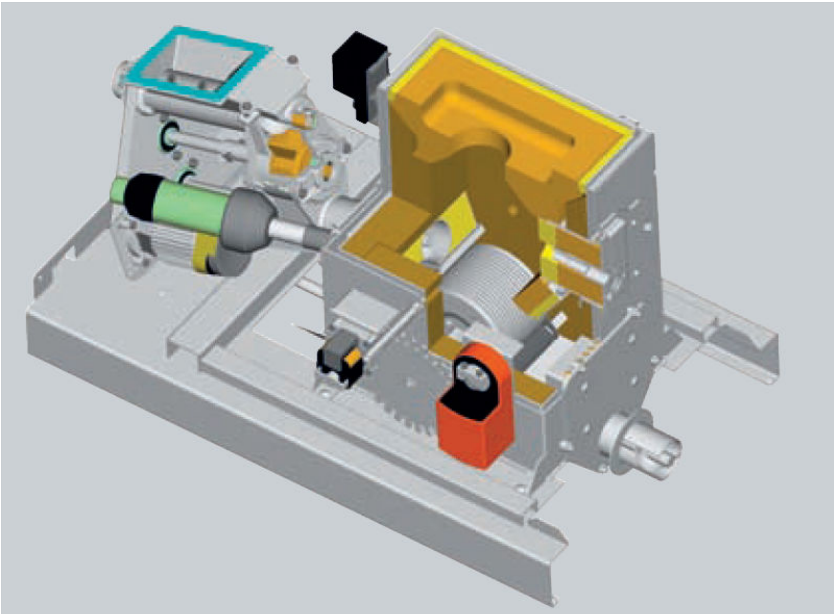


Figure 6-32: Rotary grate

◆ Impact on LCA parameters

Rotary grates are made of steel, and their contribution to the overall BOM of boilers remains negligible (< 50 kg) in comparison to the contents of steel already in the appliance.

[40] www.eta.co.at

The presence of a rotary grate allows both high burnout and de-ashing. The de-ashing is mostly a convenience function, which reduces the operational and maintenance requirements for the appliance. Although, the high burnout enabled by the rotary grate modifies the efficiency and emissions the magnitude of changes can be insignificant, when compared to well operated, different burners.

- **Pellet burners, retrofit option**[41]

As the advantages of pellet burners are well recognised these efficient solutions are used as a retrofit option for boilers fuelled with other types of fuel, both liquid and solid (Figure 6-33).

Figure 6-33: Pellet burner

The pellet burners can be equipped with warm air ignition and thermostatic control for comfortable, safe operation. The flame is directed forward which provides the best appropriate combustion conditions and simplifies the installation. The electronic control panel is separated from the burner for increased safety. The compact design with few moving parts provides long life-time and minimal maintenance.

The pellet burners are suitable for most central heating boilers currently on the market.

- **Impact on LCA parameters**

Having typically heat output within the range of 10-25 kW and 30-40 kW, pellet burners offer approx. 90% efficiency. Power consumption of approx. 40 W is comparable with typical automatic burners fuelled with solid fuels. Pellet burners, being a switch option, will insignificantly influence the overall BOM of boilers. Changes in relevant emissions will depend on the former fuel used (before pellet burner retrofitting).

[41] Retrofit options are not further considered within the study, according the Ecodesign Directive, however they are included and described to give a complete overview of options available

➔ Advanced combustion controls

■ Weather conditions, room temperature control

Room temperature controls and weather condition controls are used to adjust the flux of heat produced to the actual heat demand (Figure 6-34). The system assesses the room and weather temperature, then adjusts the first heat delivery via the heating water circuit and if necessary adjusts the output of SCIs. In addition to a fully automatic heat control, this solution offers a high ease of use for the consumer. Such solutions are mainly applicable to automatic boilers and automatic pellet stoves.

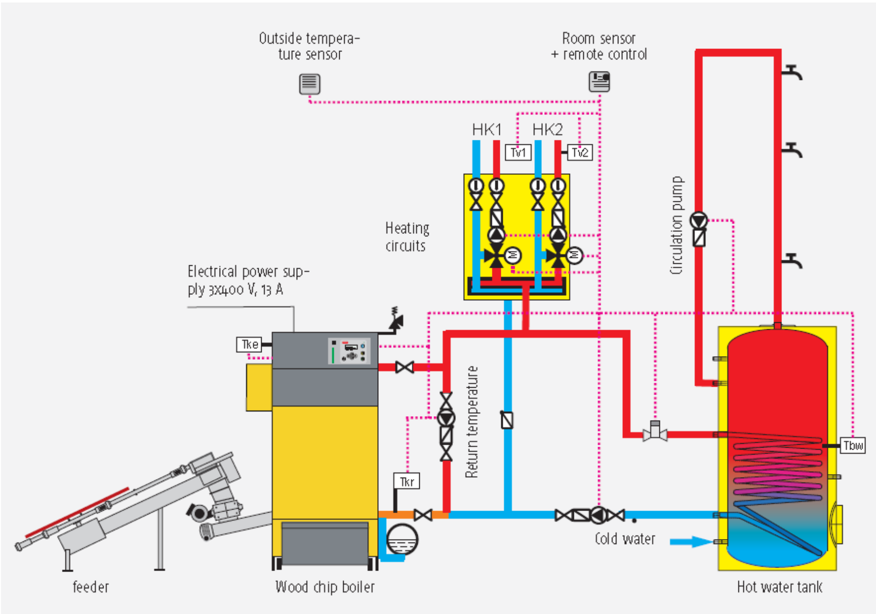


Figure 6-34: External control loops for room temperature and weather conditions[42]

◆ Impact on LCA parameters

Advanced control loops may significantly increase the mass of electronics in the BOM by over 100%.

Along with the changes in BOM, due to its advanced and sophisticated operation, weather/room control will increase the total price of the appliance itself (although it may be seen as element of the system). It can be assumed that this may increase the overall costs by around 10%.

The purpose of such solutions is to adjust the flux of heat produced to the actual heat. So the higher efficiencies and better environmental performance of the appliance itself should not be expected. It is more a convenience solution than a solution which substantially improves the efficiency or reduces the emissions of the appliance under normal operating conditions.

[42] www.eta.co.at

Lambda sensors

A lambda probe (Figure 6-35) continuously monitors the O_2 content of the exhaust. Based on this, the air induction can be adjusted automatically to ensure optimal burning conditions at all times. The combined action of lambda sensors permits to understand the nature of the fuel. As a result, changes of the fuel will be automatically recognised and the combustion parameters automatically adjusted. Except for a steel casing support, lambda probes contain a sensing element made of zirconia ceramic, coated on both the exhaust and reference sides with a thin layer of platinum. High efficiency and low emissions can be therefore achieved in the daily use of SCIs.

Figure 6-35: Lambda probe[43]

Impact on LCA parameters

Lambda probes insignificantly increase the mass of metal parts in the BOM, but it requires additional electronics. As a result, the changes in the BOM of appliances with such solutions can be neglected, except for the amount of electronics which can be increased by 20%.

Although the changes in BOM are found to be insignificant, the use of such solutions due to its sophisticated design will increase the total price of appliance itself. It can be assumed that this may increase the overall costs by around 10%.

The purpose of using lambda probes is to optimise the combustion parameters, hence provide more flexibility to changes of fuel parameters. Higher efficiencies can therefore be expected only when compared to typical appliances fuelled with inappropriate fuel. Emissions of relevant pollutants will change accordingly. When compared to appliances fuelled with fuel of appropriate quality the changes may be negligible.

Modulating controllers

Modulating controllers are designed for the control of small biomass boilers with or without oxygen control (lambda probe). The controller measures the outlet temperature of the boiler water and controls both the blower and the feeder motor to ensure that the temperature required is kept in the system. The blower is regulated

[43] www.biotech.or.at

without using a frequency converter and the pulse and pause period of the feeder motor is used to regulate the amount of fuel fed into the boiler. The temperature probe makes it possible to control the boiler output from less than 20% up to 100% continuously. When equipped with an oxygen probe, the controller will constantly measure the level of oxygen in the exhaust gas. Then the controller regulates the blower and the feeder motor in order to reach the best possible combination of oxygen and fuel for the actual boiler performance. Controllers can be typically equipped with:

- Direct output to feeder motor (3x400VAC) with solid state relays or alternatively: 1x230V feeder motor and option between a 1x230V refill or a 1x230VAC exhaust fan
- Direct output to blower (230VAC) with solid state relay
- Direct output to automatic ignition (1x230VAC)
- Alarm output (max. 1A.230VAC.24VDC)
- Input from hot boiler safety switch, which cuts the power to feeder motor and blower (double relay for safe operation)
- Inputs for security switches (lid open, connection, feeder motor overheat)
- Input for external start/stop
- Input for flame control or exhaust temperature
- Input for feeding pipe temperature (to minimize the risk of a backburning) or for photo cell (for fuel level, for refill)
- Controls the outlet temperature of the boiler water, which can be set by the user
- Can be extended to controlling the oxygen level in the exhaust gas
- Controls start-up procedure with or without automatic ignition
- Controls pause mode or restart with or without automatic ignition
- Menu based display, which shows the actual temperature, the oxygen level, the controller status, and the performance etc.
- Prepared for serial communication with PC or GSM phone

◆ **Impact on LCA parameters**

The controller is mounted in a plastic cabinet with a front foil containing the control buttons and the display (Figure 6-36).

Figure 6-36: Modulating controller[44]

The controller is an alternative to typical controllers assembled with boilers. As a result, the changes in the BOM of appliances with such solutions can be neglected. The use of such solutions may only insignificantly increase the total price of the appliance.

The purpose of using modulating controllers is to assure high efficiency at decreased power outputs. Higher efficiencies can be expected only when compared to typical appliances operated manually or with old, outdated controllers without modulation. Emissions of relevant pollutants may change accordingly. The effect can be observed at decreased power outputs.

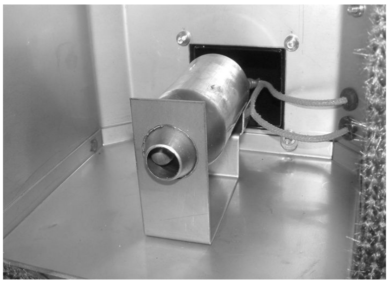
➔ Automatic ignition

This feature is most commonly seen in pellet appliances. There are two main solutions commonly used to start the fire, hot air and glow igniters.

- **Hot air igniters**

The pellets are ignited using a hot air blower (see Figure 6-37). Air is heated by being blown over the element and onto the pellets in the combustion chamber which ignite within a couple of minutes. The system is simple and reliable.

[44] Techno-Matic A/S, Denmark, www.techno-matic.dk



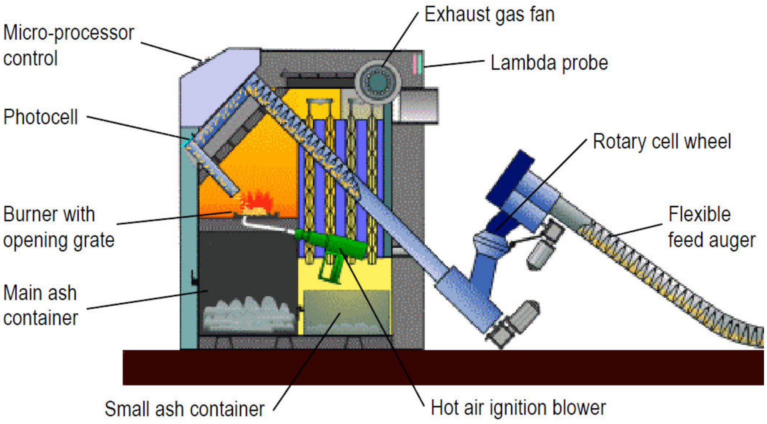


Figure 6-37: Hot air igniters[45]

- **Impact on LCA parameters**

The influence of hot air igniters on the BOM can be neglected, as the electricity consumption is the main parameter that should be considered. Hot air blowers may consume between 1500 and 1800 W[46].

- **Glow igniters**

The pellets are automatically ignited by a glow pencil (Figure 6-38) which is a high temperature resistant fully ceramic heating element. The glow pencil requires less electricity when compared to hot air blowers. The glow pencil operates quietly and is maintenance-free.

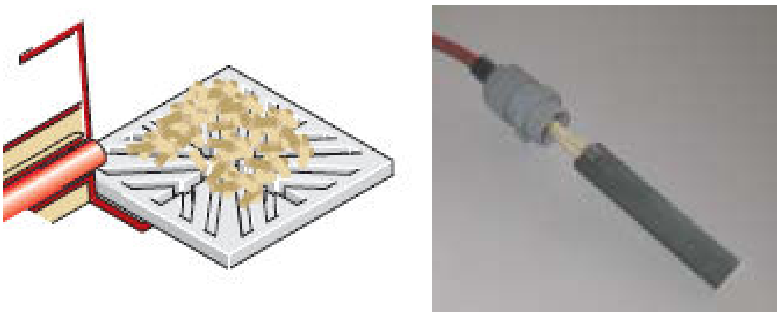


Figure 6-38: Glow igniters[47]

[45] www.hi-res-ltd.com, www.ariterm.se

[46] www.solarfocus.at

[47] www.hi-res-ltd.com, www.ariterm.se

Impact on LCA parameters

The influence of glow igniters on the BOM can be neglected, as the electricity consumption is the main parameter that should be considered. Glow igniters may consume around 260 W[48].

Flue system

Chimneys

Together with the developments of heating technology in the past decades,

the requirements for chimneys have also changed and became more stringent. The main challenges coming from efficient solid fuel SCIs are related to

- low flue gas temperatures. With that, the risk of condensation of water and acids on the chimney wall is high. New material and production technology ensures that no vapour diffuses through the walls of the chimney into the building. Chimneys need to be resistance to vapour diffusion and corrosion.
- unintentional sootfires. Due to the combustion process the flue gas contains ash and soot particles that are transported up the chimney. Parts of them deposit on the chimney wall, which over time and without proper cleaning will lead to unintentional burning. To ensure safety and health, chimneys have to withstand such an incident. Chimneys are required to be resistant to sootfire.

Today, two generic types of chimneys can be found on the market:

- Single-wall chimneys: Made of concrete, ceramic (including traditional bricks) or steel, these products consist of only a liner or monoblocks. Without insulation and additional outer casing, this type of chimney does not allow for modern solid fuel SCIs to be connected.
- Multi-wall chimney systems: Made of ceramic and steel, they consist of usually three layers: an inner liner; insulation; and, an outer casing. The components are tested together according to EN standards to ensure the performance. Suitable chimneys for efficient solid fuel SCIs fall under this category.

Without using a multi-wall chimney system, it is impossible to install efficient solid-fuel SCIs. In addition to the basic requirements stated above, modern products also feature integrated combustion air-shafts. They improve the efficiency by providing a stable supply of pre-heated (depending upon the design) combustion air and make SCIs usable for room sealed application.

Impact on LCA parameters

Several tests have shown that multi-wall chimney systems positively impact the performance of modern solid fuel SCIs, and therefore bring energy savings, when compared to single wall chimneys.

[48] www.solarfocus.at

6.2.2 COMPONENTS DEVELOPMENTS

➔ Combustion control, unburnt sensors, fuzzy logic controllers

■ CO probes

A CO probe continuously monitors the CO content of the exhaust for unburnt hydrocarbons, allowing automatic air adjustments (lambda probe optimisation). CO probes are still in the implementation phase, but the use of these novel sensors for unburnt elements (e.g. CO and hydrocarbons) in combination with oxygen sensors can provide efficient control to ensure optimal performance with respect to emissions and efficiency, independently of variations in heat demand and in fuel quality[49]. A control scheme including both lambda and CO sensors is described in Figure 6-39.

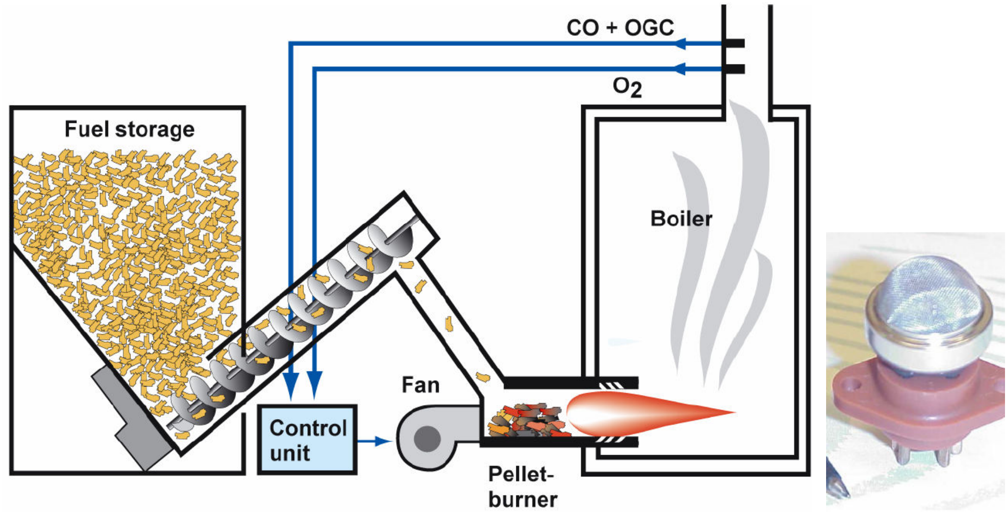


Figure 6-39: Unburnt sensor use for combustion process control optimisation[50]

[49] D. Eskilsson et al. / Biomass and Bioenergy 27 (2004) 541–546

[50] Reinhard Padinger, Small scale combustion control, International workshop Combustion control of small scale wood fired appliances, 2005 VTT Processes, Jyvaskyla, Finland

Figure 6-40: Combustion control scheme including lambda and CO sensors

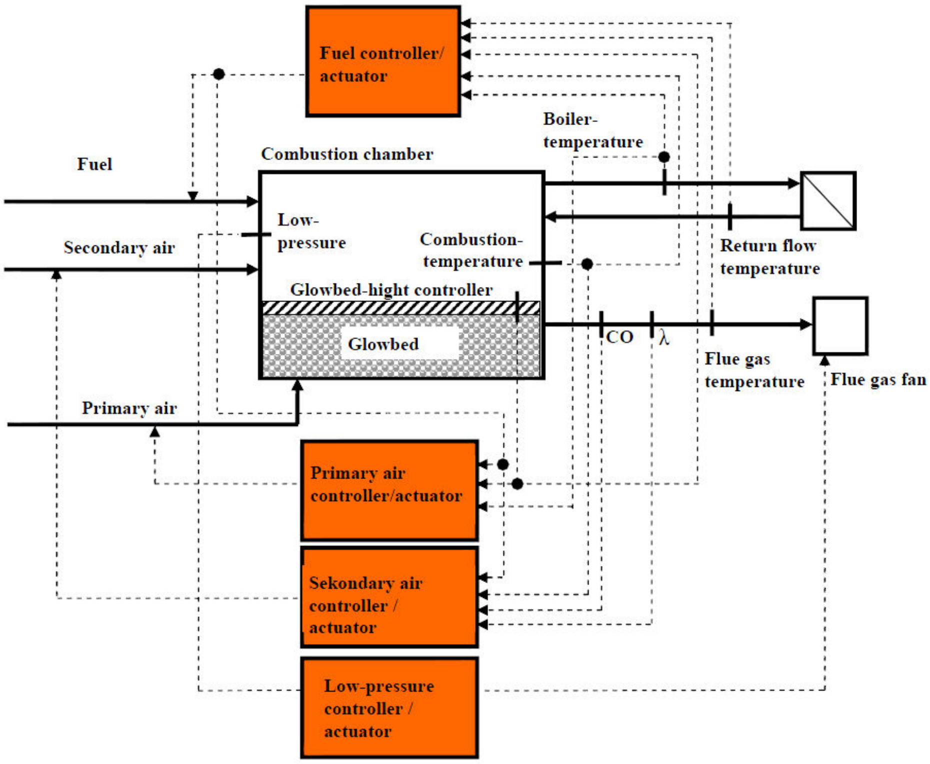


Figure 6-40: Combustion control scheme including lambda and CO sensors

A typical control scheme (Figure 6-40) may operate according to any of the following control strategies:

- Control the air using the CO-concentration as a set point
- Using the sensor for CO contents to optimise the set point of oxygen (lambda probe operation)[51]
- Optimise the split of primary and secondary air (automatic air staging optimisation)

Therefore CO probes can help minimise the emissions of CO and hydrocarbons as well as decrease the excess air ratio, resulting in higher efficiency.

The second strategy can result in the following benefits:

- Higher efficiency – lower fuel costs
- Higher fuel flexibility – probably lower fuel costs
- Higher availability - "compensate" ash slagging
- Warning system – bad combustion

[51] Good J, Nussbaumer Th; "Efficiency improvement and emission reduction by advanced combustion control (ACCT) with CO/Lambda control and setpoint optimization" European Conference and Technology exhibition: Biomass for energy and industry, 1998, Wurtzburg

■ **Fuzzy logic**[52]

Neuro-fuzzy systems combine the theory of artificial neural networks and fuzzy systems. Artificial neural networks provide effective learning methods and increase the speed of computations, whereas fuzzy set theory allows ill-defined data to be analysed in an effective manner, in addition to presenting the learnt information in more understandable form.

Fuzzy Logic Controllers (FLC) have played an important role in the design and enhancement of a vast number of applications. The proper selection of the number, the type and the parameter of the fuzzy membership functions and rules is crucial for achieving the desired performance, and in most situations, this is challenging. Adaptive Neuro-Fuzzy Inference Systems are fuzzy Sugeno models put in the framework of adaptive systems to facilitate learning and adaptation. Such a framework makes FLC more systematic and less dependent on expert knowledge. The combustion model, utilising the ANFIS structure (Figure 6-41), calculates the combustion power (P_{comb}) and flue gas components (C_f) including the oxygen content, from the fuel screw Q_{Hz}, signal primary airflow F_p and secondary airflow F_s.

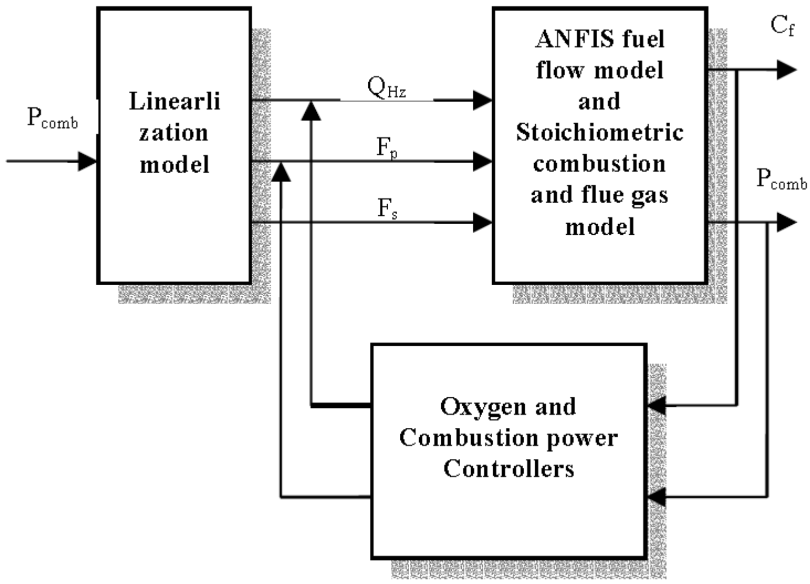


Figure 6-41: Scheme for combustion process control by means of Adaptive Neuro-Fuzzy Inference Systems

[52] Zoltán Hímer, et. al. CONTROL OF COMBUSTION BASE ON NEURO- FUZZY MODEL, Proceeding (443) Applied Simulation and Modelling - 2004

➔ Burners

■ Variable geometry pellet burner[53]

A new type of pellet burner/boiler unit has been developed in order to improve efficiency and lower emissions in the range of 0-30% of nominal output. The basic principle is an enhanced combustion controlled by the variable geometry of the burner (Figure 6-42).

Figure 6-42: Variable geometry burner

The results were compared to a standard pellet boiler. The stand-by heat loss of the unit was reduced by 20%. The heat loss at continuous minimum load was reduced by 30%, raising the boiler efficiency to a 79% (best result) at only 1.35 kW output. The prototypes were tested for up to 66 hours at continuous minimum output showing no signs of instability or raising emissions. Measured CO at continuous minimum load (best result) were 327 mg/Nm^3 at 10% O_2. Measured OGC at continuous minimum load (best result) were 3 mg/Nm^3 at 10% O_2. The efficiency and emissions at nominal output remained unchanged. The condensation of flue gasses was prevented by a combination of raised air number and flue gas by-pass.

[53] Kim Winther, Danish Technological Institute, 2003

➔ Abatement techniques – secondary measures

■ Wet ESPs

Wet ESP scrubbers (Figure 6-43) are another option for particulate abatement. They efficiently combine the wet scrubbing mechanism with the electrostatic force field. Flue leaving the boiler encounters a dispersed (sprayed) water stream which is beforehand charged with an electrostatic load (a high voltage discharge) in counter-current flow. However, the use of a support media, which can be water, produces some inconvenience, as successive separation of dust sludge from circulating water is then necessary. This can significantly complicate the use of such solutions, also increasing the operating costs. The reported efficiency of ESP wet scrubber is around 50%.

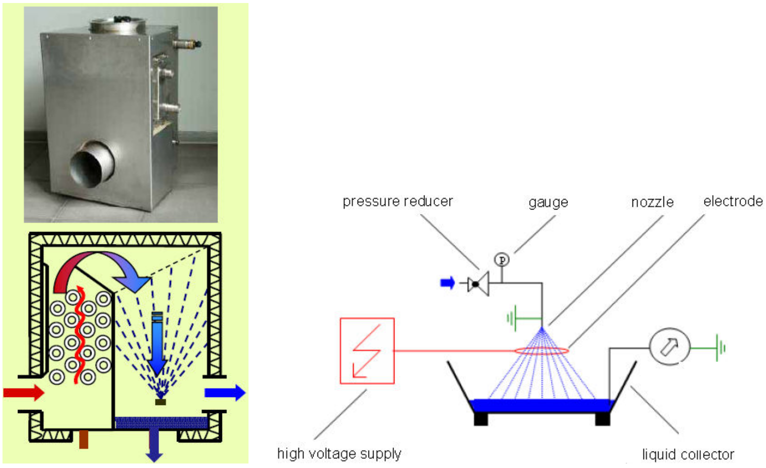


Figure 6-43: Wet electrostatic precipitator – wet scrubber

6.3 STATE-OF-THE-ART OF BEST EXISTING PRODUCT TECHNOLOGY OUSTSIDE THE EU

As the production of useful heat is a worldwide issue, and so are the techniques applied, there are seldom any additional BAT technologies available outside the EU that are not already covered by the above analysis.

6.3.1 NORWAY AND SWITZERLAND

There has been considerable research into biomass/wood-burning in solid fuel SCIs in Norway and Switzerland. SCIs available in these countries are also available in the EU and although there are differences in national regulation, BATs in these countries are considered to be equivalent to BATs in the EU.

6.3.2 NORTH AMERICA

➔ Certification schemes

The US Environmental Protection Agency (USEPA) introduced standards of performance for residential wood heaters in 1988. These exclude masonry fireplaces, boilers and cooking stoves. Since 1992, all new wood heaters subject to the performance standards have to be certified and there are different requirements for particulate emission from wood heaters with catalyst and those without catalysts. About 750 (as of February 2009) are certified, of which about 5% are pellet burners, about 35% fitted with catalysts, and the remainder do not incorporate catalysts.

The USEPA certification scheme is also recognised in Canada which has developed a similar standard (CSA B415.1) but fewer appliances have been certified to the this standard. About 40% of Canadian stoves are stated to be advanced types but the use of catalytic appliances has decreased in recent years.

In addition to the USEPA national certification there are more stringent regional certification requirements in a number of states.

➔ BATs

Information on BATs is difficult to obtain. The performance standards have not been revised since their introduction, but today many appliances achieve certification with emissions substantially below the particulate emission criteria.

- Advanced stoves

Published US and Canadian guidance generally refers to all certified appliances as advanced stoves which could be considered analogous to BATs, but they cover a wide range of technologies. The Canadian guidance considers advanced combustion stoves to have:

- an insulated firebox, to maintain high temperature
- a secondary preheating introduced above and behind the fuel bed
- good residence time (provided by internal baffles)

- Catalytic appliances/catalysts

A catalytic appliance incorporates a catalyst (see Figure 6-44) in the flue gas exit to reduce products of incomplete combustion.

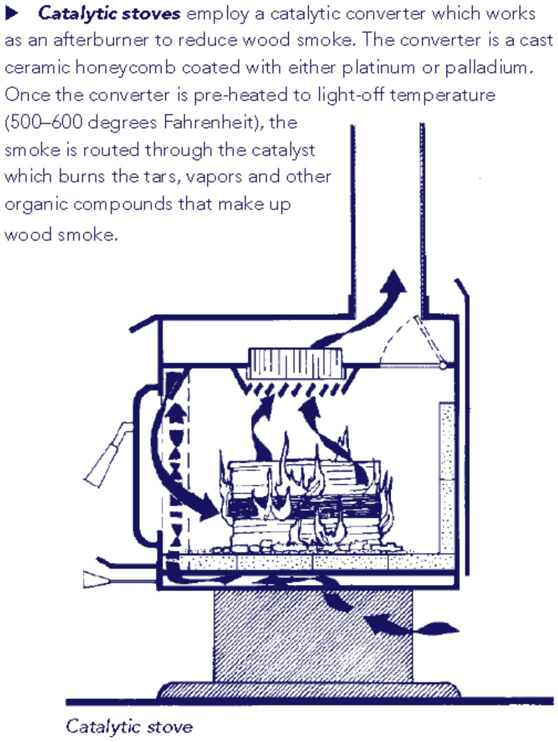


Figure 6-44: The scheme of advanced stove with catalyst

About 35% of current certified stoves in USA have catalysts, but catalyst performance can degrade and can also become blocked and thereby affect draught. Stoves with a catalyst have a more stringent emission target than stoves without a catalyst (Figure 6-45).

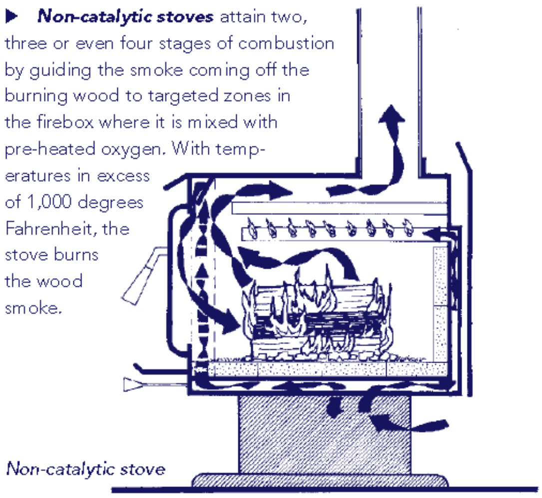


Figure 6-45: The scheme of advanced stove without catalyst

➔ BAT developments

A 2008 review of certification results comparing emissions from non-pellet appliances submitted in the early and more recent stages of the USEPA certification scheme indicates that average emission rates have fallen but does not identify changes in technologies.

A 2000 review of certification tests for pellet heaters indicates that despite a relatively recent entrance to the market, improvement in efficiency and PM emission performance was evident from early models. Although 23 pellet stoves have been certified since 1988 only one was listed in 1999 (there were about 40 in February 2009), but it was noted that some stoves were exempt from USEPA certification.

A 1998 review of residential heating appliances for the USEPA considered 'state-of-the-art' wood-fired appliances in several categories, but characterised broad appliance types (stoves, fireplaces, pellet stoves, masonry heaters) for PM emissions; generic efficiency data are also provided but little detail is provided of BATs. The report comments that there has been little incentive to increase the thermal efficiency of stoves and efficiency determination is not required under the USEPA certification process. Pellet stoves were highlighted as having higher efficiencies and lower PM emissions than log stoves. Notably, fewer than 20 models of residential wood-fired central heating furnace were available in 1999 and they (together with fireplaces) are exempt from USEPA certification.

A recent (2008) press release by the New York State Energy Research and Development Authority (NYSERDA) suggests that the USA is looking at European developments for boiler technology for biomass; that is, the US boilers are not considered BATs. Despite this comment at least one of the NYSERDA project partners includes a manufacturer of log-burning downdraught boilers.

6.3.3 Australia and New Zealand

➔ Certification schemes

There are solid fuel heating appliance certification schemes in both Australia and New Zealand. Australia applies a voluntary national particulate emission limit on stoves and inserts, which has become mandatory in most states. New Zealand also applies the voluntary particulate limit but has a lower particulate emission limit and a 65% minimum efficiency in urban areas. The standards AS NZ 4013 and 4012 define the procedures used for measuring particulate emissions and efficiency respectively. However, the efficiency determination is different from those in EN Standards (the gross heat input is used and the heat rate into a room is measured in AS NZ 4012 as opposed to the indirect efficiency determination use in EN appliance Standards).

➔ BATs

The efficiencies of certified appliances in Australia in 2004 are illustrated in Figure 6-46, however no details of appliance types are provided and it is not possible to identify appliances which may represent BAT in the region. In New Zealand, the Ministry of Environment publishes details of wood burning appliances which meet the design standard for new wood burners in urban areas[54]; there is also a list for pellet burners which are exempt from the design standard. However, little additional detail is provided. Published efficiencies (gross basis) for appliances certified by April 2009 include wood log stoves and inserts (ranging from 65% to 77%) and pellet stoves (71-92%).

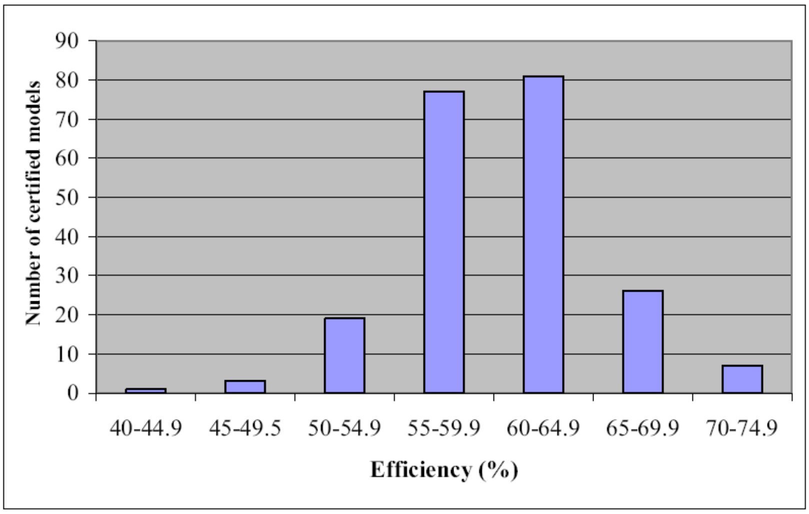


Figure 6-46: The efficiency of Australian certified heater models (2004)[55]

6.3.4 JAPAN

In Japan, about 28% of the total energy consumed is utilised for domestic usage, of which about 50% is used for hot water supply and space heating. A variety of SCIs is recognised and used in Japan. Pellets stoves in particular, are found to be advanced appliances offering high energy and environmental performance. But although these benefits are appreciated, it is thought that there is still a potential for improvement in the biomass thermal processing.

One of the most recent developments is a biomass charcoal combustion heater for household utilisation. The combustion system can be operated in continuous mode, with low fuel demands. It ensures a good contact between fuel and air for fast start-up and extinction, as well as for complete oxidation to have low CO in the flue gases. This solid fuel combustion technology is called “thin bed cross-flow” (TBCF). A TBCF prototype solution is shown in Figure 6-47.

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[54] Available at http://www.mfe.govt.nz/laws/standards/woodburners/authorised-woodburners.html

[55] Wood heater particle emissions and operating efficiency standards, 2006, report prepared for the Department of the Environment and Heritage (Australia)

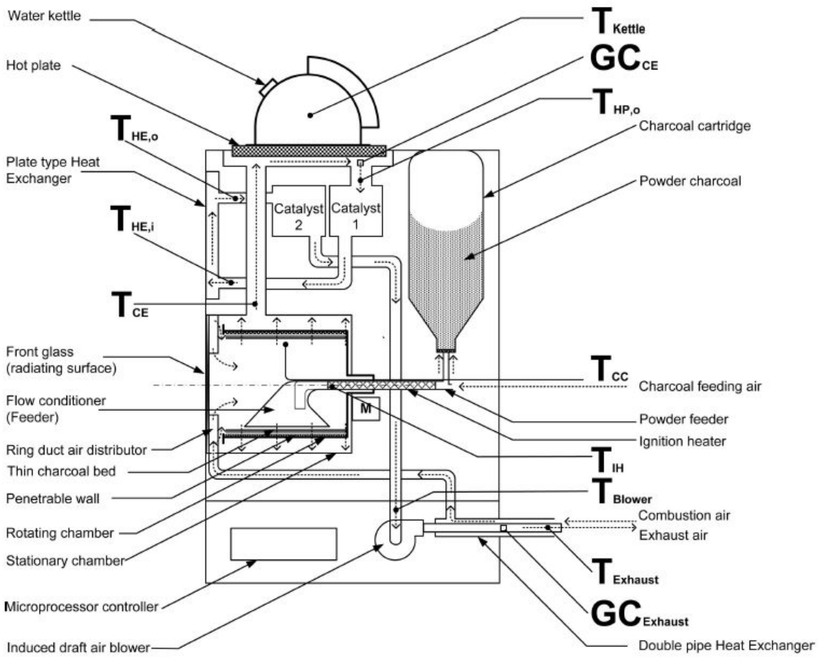


Figure 6-47: The biomass charcoal combustion heater[56]

The charcoal combustion heater consists of a TBCF combustion chamber. The combustion chamber was fabricated from a punched 1 mm thick steel plate to form a horizontal cylinder (of 200 mm inner diameter and 100 mm long). The combustion chamber is coupled to a gear assembly and rotated by a 15 W single phase induction motor. The inner curved surface of the TBCF combustion chamber is covered with a ceramic fibre mesh to form the penetrable wall. The combustion air is injected in the combustion chamber through the ring duct air distributor by an induced draft, with the aid of a 50 W radial fan type air blower of 250 L/min design capacity. The gases from the combustion chamber flow through the annular gap between the rotating and the stationary parts of the cylindrical combustion chamber into a 40 mm outlet pipe which is connected radially to the stationary cylinder. From the outlet pipe the exhaust gases passed through a plate type heat exchanger placed on top of the combustion heater, which can be used as a hot plate for heating a water kettle or a small pan. The exhaust gases, after leaving the plate type heat exchanger, flow through an alumina-based CO oxidation catalyst (Almite). The catalyst is prepared by spray coating the catalyst material on a ribbon heating element (35 W) for quick response to the demand. The exhaust gases then flow through another plate type heat exchanger for space heating and then into the second-stage CO oxidation catalyst to oxidize any residual CO in the combustion heater exhaust. A double pipe heat exchanger is connected in the combustion heater exhaust to preheat the inlet combustion air to recover flue gas losses. Testing found out that the thermal efficiency is highest (86%) when the charcoal combustion heater is operated near the design conditions - nominal heat output (and

[56] Masayuki Horio, et al. Ind. Eng. Chem. Res., Vol. 48, No. 1, 2009, pp. 361-372

fuelled with wood charcoal). The thermal efficiency of the combustion heater for waste biomass charcoal combustion is in the range of 60-81%, which is slightly lower than what is obtained for wood charcoal.

6.4 CONCLUSIONS AND SUMMARY OF TASK 6

6.4.1 MAINTENANCE

In addition to above mentioned technical means aiming at the improvement of SCI performance, it must be stressed that maintenance and cleaning is the most cost-effective way to maintain the efficiency and the performance of the appliance at the same high level expected of a newly installed appliance. The frequency of cleaning can be easily established by measuring the flue gas temperature at the appliance outlet, either in the appliance or in the connecting flue pipe at periodic intervals. Cleaning frequency is dependent on the type of fuel, type of appliance and the heating installation in total (design and surrounding). It is reported that 1 mm of soot or dust may increase the flue gas temperature by 50°C (depending of the construction of the appliance) which can results in a decrease in the overall efficiency by approximately 3 %.

6.4.2 POTENTIAL SHORT TERM IMPROVEMENTS

➔ **BAT at product level**

Based on the carried out analysis as well as taking into account the questionnaire query responses, the following BAT solutions with relevant parameters denoting short term improvements can be listed (see Table 6-20).

Table 6-20: Energy efficiency and environmental performance of BAT solutions within the different categories at product level, (emissions at 13% of O_2).

Code BAT_PL			1	2	3	4	5	6	7	8	9
Product			Closed fireplace, fireplace insert	Advanced stove	Advanced cooker	Slow heat release stove	Pellet stove	Pellet boiler	Downdraught gasifying boiler	Stoker boiler, coal	Chips boiler
Energy & Environmental performance	Power output	kW	7	7	8	15	7	25	20	25	160
	Efficiency	%	78 (82)	79 (84)	78 (79)	82 (84)	90 (94)	92 (94)	90 (92)	88 (89)	91 (92)
	Seasonal efficiency	%	75	76	75	79	87	75	74	72	75
	E_{CO}	mg/m^3	1500	1400	2000	1000	300	150	100	90	170
	E_{PM}		60	50	90	60	30	25	40	40	30
	E_{OGC}		100	90	110	100	30	30	10	10	10
	El. Consumpt.	$Wh_{el.}/kWh_{th}$	-	-	-	-	4	4	4	2	2
BOM	Total	kg	126	135	170	1450	120	350	360	399	1170
	Steel		98	104	153	170	102	335	330	385	950
	Cast iron		-	-	-	-	-	-	-	-	-
	Ceramics		28	31	16	1279	17	14	30	14	220
	Glass		-	-	1	1	1	1	-	-	-
	Electronics		-	-	-	-	-	1	1	1	1
Costs	Capital costs	€	1935	2300	2995	1938	2652	6816	6305	4000	35000

Note:

- *in the case of efficiency, numbers given in brackets denote maximum announced value, however they will not be taken into account for further analysis (due to the fact that e.g. relevant CO values are not reported for which efficiency),*
- *power output is equal to the relevant base case output,*
- *n.d.a. – no data available, however data is necessary for the analysis.*

➔ BAT at component level

BAT solutions at component level are either:

- those which can be found as separate elements assembled with SCI as options,
- as well as those which are the integral elements of appliances having influence on key performance parameters.

However, the further analysis is focused only on the first group: separate elements that are options for the product itself. Therefore excluded in this study are:

- options which improve only the ease of use like automatic de-ashing,
- retrofit only options, like tertiary air device “ecooxy”,
- options with improvement potential relevant to real life conditions, like draught regulators,
- options that are integral elements of BAT at the product level, like internal circulation in the combustion chamber.

BATs at component level with relevant parameters are given below in Table 6-21. Where energy and environmental performance is given as a percentage change related to the basis, which is a BAT solution at product level. No simple addition effects of several component options is considered.

Table 6-21: Energy efficiency and environmental performance of BAT solutions within the group of closed fireplaces/fireplace inserts, at 13% of O_2.

		Code BAT_PL	1	2	3	4
		Product	Boiler/heat storage	Lambda probe control	ESP	Condensation heat recovery
Energy & Environmental performance	Efficiency	% change	+(1-2)	+1	-	+(8-20)
	E_{CO}		-40(**)	-10	-	-
	E_{PM}		-56(**)	-5(*)	-(50-80)	-40(*)
	E_{OGC}		n.d.a.	n.d.a.	-	-90(*)
	El. consumpt.	$Wh_{el.}/kWh_{th}$	-	-	2	-
BOM	Total	Kg	160	-	5	28
	Steel		160	-	4	8
	Cast iron		-	-	-	-
	Ceramics		-	-	-	15
	Glass		-	-	-	-
	Electronics		-	<<1	1	-
Costs	Capital costs	€	2500	1000(*)	1500	1000(*)

Note:

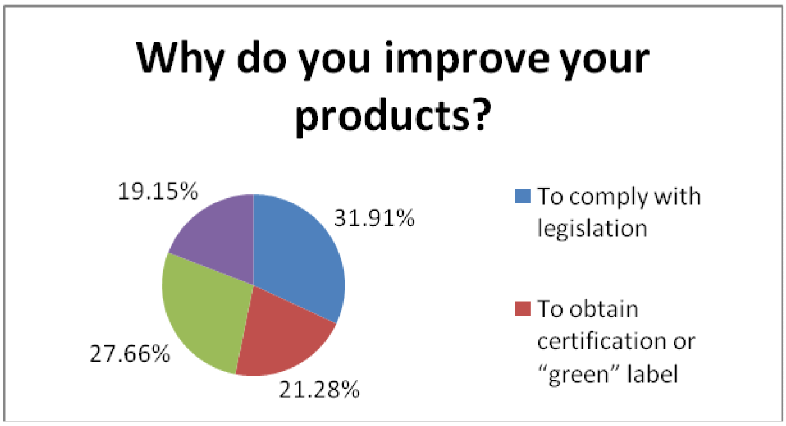
n.d.a. – no data available, however data is necessary for the analysis,

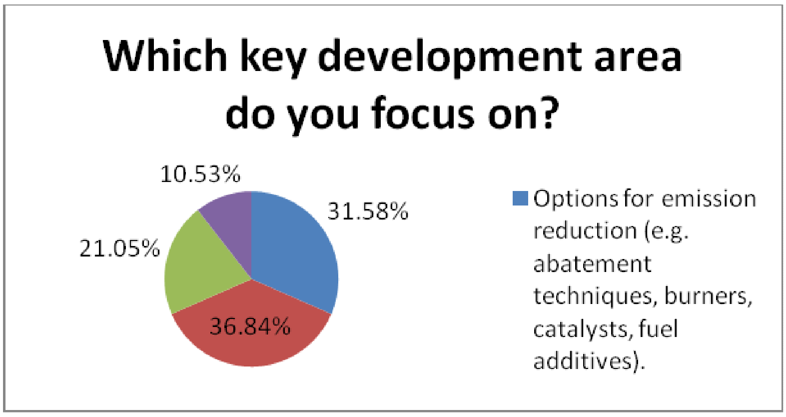
** – estimate,*

*** – for manually fuelled appliances, whereas for automatic appliance there is a slight or negligible increase*

6.4.3 LONG TERM IMPROVEMENTS, EFFECTS

There are constant technology developments, which have the potential to contribute to the improvement of both energy efficiency and environmental performance of SCIs within different categories subjected to analysis. Being asked about the potential of certain measures, technology experts from industry indicated the following concerning the improvements they seek for.





As indicated in the responses, long term improvements at product level would most probably include advance stoves, wood gasification appliances as well as pellet boilers. They can also include prototype level solutions as described in the previous sections.

On a component level the major improvement is predicted to be within two general categories:

- process control,
- abatement techniques.

It must be noted that due to the relatively high energy efficiency of BAT being currently provided by manufacturers, the improvement is foreseen to be limited, down to 1-2%.

Based on the same inquiry market trends have been estimated, indicating that in general market shares the majority of appliances subjected to analysis will not change significantly (Figure 6-48).

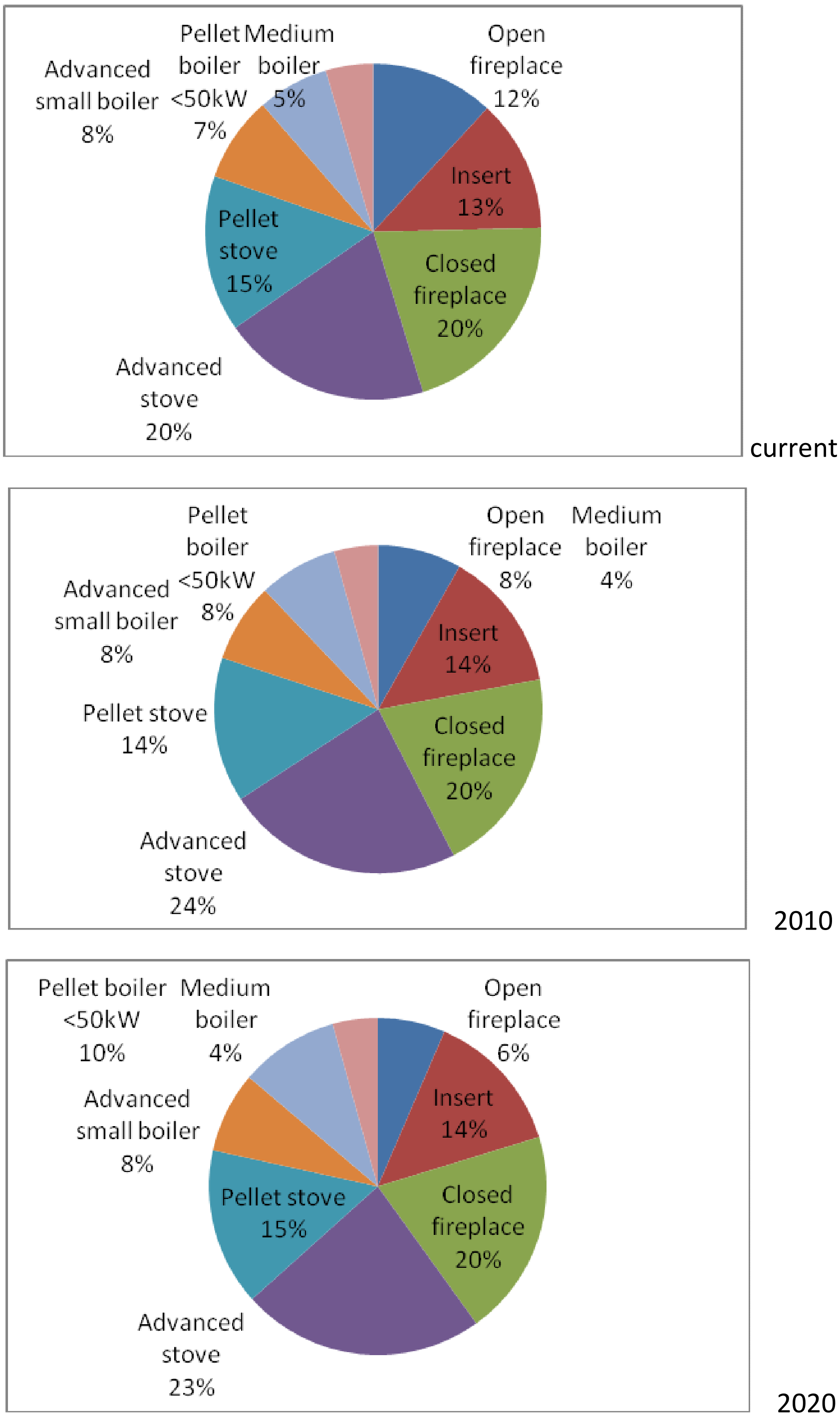


Figure 6-48: Future market shares

Although selected categories will encounter significant changes, like fireplaces of which the market is expected to shrink to 50% (see Figure 6-49).

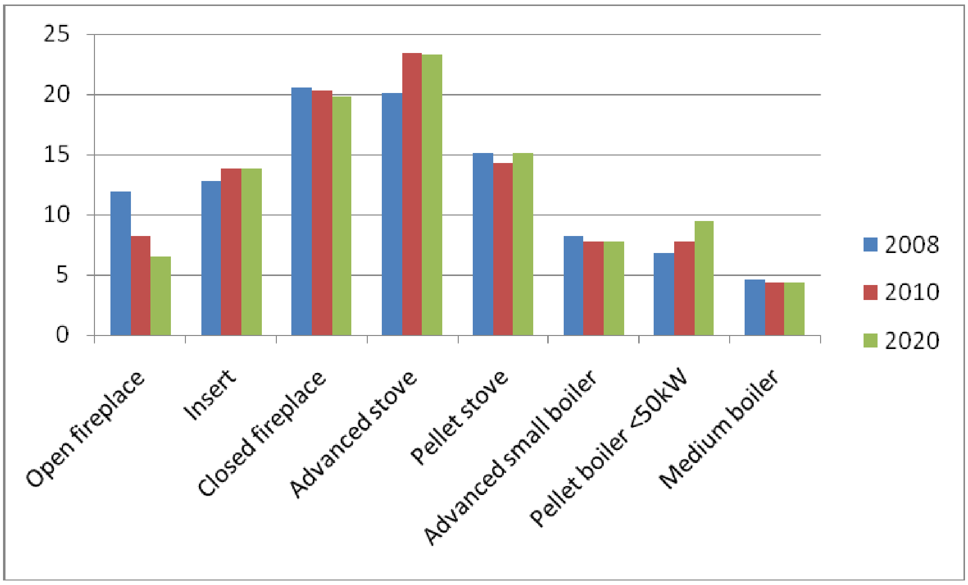


Figure 6-49: Market share changes for different appliances