SNAP CODE:

010203
020103
020202
020205
020302
020305
020106

SOURCE ACTIVITY TITLE: **SMALL COMBUSTION INSTALLATIONS**

NOSE CODE:

NFR CODE: 1A4a; 1A4bi; 1A4ci; 1A5a and small installations in 1A1a

Table 1: Relevant SNAP Codes

Source	**SNAP CODE**	**NFR category**
Small installations in district heating	010203	1A1a
Commercial / institutional	020103	1A4a
Residential	020202 020205	1A4bi
Agriculture / Forestry / Fishing	020302 020305	1A4ci
Other stationary (including military)	020106	1A5a

1 ACTIVITIES INCLUDED

This chapter covers emissions from small combustion installations, excluding industrial sources, with a thermal capacity ≤ 50 MW_{th}. However, some industrial sources of a lower capacity might have very similar emission characteristics to the ones described here in the category "medium size boilers". As long as there is no guidebook chapter addressing small industrial sources the data presented here might be used also as defaults for these sources.

Activities covered in this chapter are divided into the following categories:

- District heating
- Commercial and institutional
- Residential
- Agriculture / Forestry / Fishing, and
- Other (including military).

These activities can be further sub-divided considering the combustion techniques used:

- fireplaces
- stoves,
- small boilers (single household/domestic heating) – indicative capacity <50 kW_{th},
- medium size boilers (<50 MW_{th}),
    - manual feeding (indicative capacity <1MW_{th}),
    - automatic feeding,
- combined heat and power generation (CHP).

The open-field burning of the agricultural residues and stationary internal combustion engines are not included in this chapter.

2 CONTRIBUTION TO TOTAL EMISSIONS

Tab 2.1. Contribution to total Particulate Matter emissions from 2004 EMEP database

NFR Sector	Data	PM_{10}	$PM_{2.5}$	TSP
1 A 1 a - Public Electricity and Heat Production[a]	No. of countries reporting	26	26	27
	Lowest Value	0.2%	0.2%	0.2%
	Typical Contribution	11.7%	10.1%	12.8%
	Highest Value	48.8%	47.8%	48.4%
1 A 4 a - Commercial / Institutional[a]	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.1%
	Typical Contribution	3.9%	3.4%	4.5%
	Highest Value	19.3%	22.2%	29.5%
1 A 4 c - Agriculture / Forestry / Fishing	No. of countries reporting	23	23	23
	Lowest Value	0.1%	0.1%	0.2%
	Typical Contribution	4.3%	5.6%	3.4%
	Highest Value	17.4%	17.9%	21.9%
1 A 5 a - Other, Stationary (including Military)[a]	No. of countries reporting	7	7	7
	Lowest Value	0.0%	0.0%	0.0%
	Typical Contribution	0.1%	0.1%	0.1%
	Highest Value	0.5%	0.4%	0.6%

[a] Includes contribution from Chapter 111

This section covers emissions of CO, SO_2, NH_3, NO_x, NMVOC, TSP, PM10, PM2.5, heavy metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, selenium, zinc), PCDD/Fs, PAHs: benzo[a]pyrene, benzo[b]fluorantene, benzo[k]fluorantene and indeno[1,2,3-cd]pyrene.

The contribution of emissions from small combustion installations to the total emissions varies and depends on pollutants type and given country. A very important role is played by the emissions from small residential installations which are typically responsible for more than a third of the total particulate matter emissions of stationary combustion (UBA, 1998a; APEG, 1999; Olendrzynski et al., 2002) but in some countries this sector may dominate, e.g., in Austria (in 1995) more than 70% of PM emissions from stationary combustion are thought to have originated from this source (Winiwarter et al., 2001). The non-industrial SCI emission inventory for PM10 (which shows a similar trend for PM2.5) highlights the decrease in emissions from 2000 to 2020, predominantly due to the decline in the use of solid fuel. This source, however, remains significant due to the continued use of biomass. Emissions from this source are projected to decline overall due in main to the increased use of automatic feed boilers (Pye et al., 2004). In the year 2000, non-industrial combustion sources (i.e., in the residential and commercial sector) made the largest single contribution to total PM2.5 emissions in the 15 old Member States of the European Union (EU15), Norway and Switzerland (32 %), (Cofala et al., 2006). The emission source structure in the New Member States of the European Union is distinctively different to that of the EU-15+2 countries. Non-industrial combustion sources made by far the largest single contribution to total PM2.5 emissions in the EU-10 countries (45 %). The contribution of fuel combustion in commercial, residential and other small capacity installations to the total heavy metals emission in Europe in 1990 was for As 12.4%, for Cd 15.9% and for Hg 27.8% (Berdowski et al., 1997). Pye at al., (2005) have showed that the contribution Hg emission from SCIs account for 16% of total European emissions. Over half of emissions are from the industrial sector, with just over 20% coming from the residential sector. The major contribution by fuel type is from solid fuels, although biomass appears to be important in certain countries. Also emissions of PAH and PCDD/F from those activities are significant. For instance, residential use of solid fuels and biomass accounts for about half of the emissions of polycyclic aromatic hydrocarbons (COM(2003) 423 final) and one third of dioxin emissions in the EU (Quass U., et al., 2000). Those are characterized by seasonal variations, as it was reported that emission of B[a]P in winter is 10% higher than in summer (Baart et al., 1995). Many countries using coal (but also biomass) as a major part of domestic and commercial heating requirements have serious air pollution problems, one such a example is Poland; the TSP emissions from small combustion sources is 35% of the national total emissions, and up to 90% of the total TSP emissions from combustion activities (Olendrzynski et al., 2002). It was reported that the main source of PCDD/F (68% of national total) and PAH emission (87%) in Poland are non-industrial combustion plants (residential, district heating, agriculture, forestry). The share of heavy metals emissions such as Cd, As, Cr, Cu, Ni, Zn due to high emissions of TSP is also higher (respectively: 55%, 36%, 27%, 25%, 50%, 30%). In Belarus small combustion sources provide abut 40% of total PCDD/F emissions, and about 80% of indicator PAH emission (Kakareka et al., 2003). In general those sources have a more important contribution to the above-mentioned pollutants where a higher share of solid fuels exists in the fuel mix of the residential sector.

The estimated contribution of emissions released from small combustion installations to the total European emissions is presented in Table 2.2. These sources represent one of the strongest sources of particulate matter and even in the future they might remain an important contributor and their share might even increase for some pollutants and for some scenarios. It is also worthwhile to note that there are significant regional differences, e.g., in the EU-15, the share of this sector in particulate emissions has been typically below 20 % and is expected to decline further to about 12 and 17 % for PM10 and PM2.5, respectively; in the accession countries this share was in the 90’s above 30 % and is expected to decline to about 22 and 28 % for PM10 and PM2.5, respectively. Projections presented for 2010 are for illustrative purpose only and refer to the European energy scenarios developed by the PRIMES model (CEC, 2003 and CEPMEIP, 2002) and implemented in the RAINS model recently.

The emission contribution of residential sources in the future will depend strongly from the assumptions about fuel switching (coal to gas) that has been happening in the last decade, a trend that is expected to continue and eventually lead to lower emissions of particulate matter but possibly at a cost of increased emissions of other pollutants as for example NO_x. At the same time biomass becomes a more and more popular fuel used in the residential sector; its use is strongly encouraged in some countries and is seen as a part of the strategy to achieve reductions of CO_2, however installations burning biomass are often characterized by higher emissions of particulates (Williams et al., 2001; Kubica et al., 1997/2 and 2001/1; Houck et al., 1998/1). All this indicates that air emissions from this source will remain an important source and more attention is required to be focused on them.

Tab.2.2. Contribution to total emissions (RAINS model results)

Pollutant	**Year**		
	1990	**1995**	**2010**
Oxides of nitrogen	4.5%	5%	7%
Sulphur dioxide	11%	8%	7%
Ammonia	About 0.5% - 1%		
NMVOC(1)	7%	7%	7%
$PM_{2.5}$(2)	25%	25%	19%
PM_{10}(2)	22%	20%	15%

(Source: IIASA, 2004)

(1) Contributions vary widely from country to country, e.g. 1% - 3% in the Netherlands or Italy, 10%-15% in Austria and 25%-30% in Sweden,

(2) Contributions vary widely from country to country, e.g. 2%-4% in the Netherlands and 40%-50% in Austria and Sweden,).

Furthermore the influence of those sources on the local air quality could be significant due to the low height of the flue gas releases, even where their share in total emissions is not dominant. This is particularly the case in the regions where solid fuels are predominately used in the residential sector. For instance, the occasional exceeding of the SO_2 ambient air target value could still be expected in the UK in some areas after the year 2000 (The Air Quality Strategy for UK; 2000) because of this reason.

3 GENERAL

3.1 Description

The small combustion installations included in this chapter are mainly intended for space heating and preparation of the hot water in residential and commercials/institutional sectors. In the residential sector some of these installations are also used for cooking. In the agricultural sector the heat generated by the installations is used also for crops drying and for heating the greenhouses.

The attention should be turned on small combustion installations due to their huge number, different type of combustion techniques employed, and because of the difficult auditing of their performance. Considerable part of them have none or low efficiency dedusting equipment. In some countries, particularly those with economies in transition, plants and equipment are outdated, polluting and inefficient. Especially in the residential sector the installations are very diverse, strongly depending on country and region, local fuel supply and in certain cases still reflecting the traditional heating practices.

3.2 Definitions

Automatic feed boiler: boiler with fully automated fuel supply and adjustment of combustion air

Boiler: any technical apparatus in which fuels are oxidised in order to generate thermal energy, which is transferred to water or steam

Briquettes: refers to patent fuels from hard/sub-bituminous coal (NAPFUE 104) and brown coal briquettes (NAPFUE 106)

Brown coal: refers to brown coal/lignite (NAPFUE 105) of gross caloric value (GHV) less than 17435 kJ/kg and containing more than 31 % volatile matter on a dry mineral matter free basis

Charcoal: refers to temperature treated wood (NAPFUE 112)

Chimney: brick, metal or concrete stack used to carry the exhaust gases into the free atmosphere and to generate drought

CHP: in this chapter refers to a co-generation installation (Combined Heat and Power production) where steam produced in a boiler is used for both, power generation (in a steam turbine) and heat supply

Coke: refers to the solid residue obtained from hard coal (NAPFUE 107) or from brown coal (NAPFUE 108) by processing at high temperature in the absence of air

Efficiency: is the ratio of produced of output heat energy to energy introduced with the fuel, with reference to net (low) calorific value of fuel

Fireplace: usually very simple combustion chamber, with or without front door, in which fuels are oxidized to obtain thermal energy, which is transferred to the dwelling mainly by radiation

Gaseous fuels: refers to natural gas (NAPFUE 301), natural gas liquids (NAPFUE 302) and liquefied petroleum gases (LPG; NAPFUE 303), biogas (NAPFUE 309)

Hard coal*:* refers to coal of a gross caloric value greater than 17435 kJ/kg on ash-free but moisture basis that is: steam coal (NAPFUE 102, GHV>23865 kJ/kg), sub-bituminous coal (NAPFUE 103, 17435 kJ/kg<GHV<23865 kJ/kg) and anthracite

Installation: refers to any technical apparatus (fireplace, stoves, boiler) designed to generate heat energy

Liquid fuels: refers to kerosene (NAPFUE 206), gas oil (gas/diesel oil; (NAPFUE 204), residual oil, residual fuel oil (NAPFUE 203) and other liquid fuels (NAPFUE 225)

Manual feed boiler: boiler with manual periodical fuel supply

Patent fuels: refers to manufactured smokeless fuels from hard/sub-bituminous coal (NAPPFUE 104)

Peat: refers to peat-like fuels (NAPFUE 113)

Solid biomass fuel: refers to wood fuels which are wood and similar wood wastes (NAPFUE 111) and wood wastes (NAPFUE 116) and agricultural wastes used as fuels (straw, corncobs, etc; NAPFUE 117)

Solid fuels: refers to the subcategory of hard coal, brown coal, patent fuels, brown coal briquettes, coke, charcoal, peat, solid biomass fuels

Stove: simple appliance in which fuels are combusted to obtain thermal energy, which is transferred to the interior of the building by radiation and convection

Wood fuels: refers to wood and similar wood wastes (NAPFUE 111)

Some additional information on fuel properties could be found in Chapter Combustion Plants as Point Sources B111 and Combustion Plants as Point Sources B112.

3.3 Techniques

3.3.1 General

In small combustion installations a wide variety of fuels are used and several combustion technologies are applied. Especially older single household's installations are of very simple design, while some modern installations of all capacities are significantly improved. Emissions strongly depend on the fuel, combustion technologies as well as on operational practices and maintenance.

For the combustion of liquid and gaseous fuels, the technologies used are similar to those for production of thermal energy in industrial combustion activities, with the exception of the simple design of smaller appliances like fireplaces and stoves.

On the contrary the technologies for solid fuels and biomass utilization widely vary due to different fuel properties and technical possibilities. Small combustion installations employ mainly fixed bed combustion technology i.e. grate-firing combustion (*GF*) of solid fuels.

Solid fuels as well as a mixture of coal and biomass solid fuels, with grain size from a few mm to 80 mm, can be used.

The fluidised bed combustion technology can be also applied in small combustion installations. It is sporadically used within small combustion activities especially in district heating utilizing solid biomass.

A more detailed description of techniques is included in the EUR report Kubica, et al., 2004.

3.3.2 Fireplaces

Fireplaces were the first simple combustion devices, which were used by human beings. Fireplaces are used as supplemental heating appliances primarily for aesthetic reasons in residential dwellings. Based on the type of fuel used, the fireplaces can be subdivided into solid and gas fuelled fireplaces. Regarding the combustion conditions the fireplaces can be divided into open, partly closed and closed fireplaces. Based on the type of construction materials used, they can be divided into cut stone, and/or brick (masonry fireplaces), and cast iron or steel ones. Masonry fireplaces are usually built on site integrated into the building structure, while iron or steel are prefabricated.

3.3.2.1 Solid fuelled fireplaces

Regarding combustion techniques the solid fuelled fireplaces can be listed among the fixed bed combustion appliances. The user intermittently adds solid fuels to the fire by hand. They can be distinguished into:

Open fireplaces: this type of fireplaces is of very simple design - basic combustion chamber, which is directly connected to the chimney. Fireplaces have large openings to the fire bed. Some of them have dampers above the combustion area to limit the room air intake and resulting heat looses when fireplace is not being used. The heat energy is transferred to dwelling mainly by radiation. Open fireplaces are usually of masonry type and have very low efficiency while having significant emissions of TSP, CO, NMVOC and PAH resulting from the incomplete combustion of the fuels.

Partly closed fireplaces are equipped with louvers and glass doors to reduce the intake of combustion air. Some masonry fireplaces are designed or retrofitted in that way in order to improve their overall efficiency.

Closed fireplaces are equipped with front doors and may have distribution of combustion air to primary and secondary as well as a system to discharge the exhaust gases. They are prefabricated and installed as stand-alone units or as a fireplace inserts installed in existing masonry fireplaces. Because of the design and the combustion principle, closed fireplaces resemble stoves and their efficiency usually exceeds 50 %. They have similar emissions like stoves, i.e., lower than open, as well as, partly closed fireplaces. For this reason they can be rated among stoves.

Fuels used in solid fuel fireplaces are mainly: log, lump wood, biomass briquettes, and charcoal**,** coal and coal briquettes.

Traditional solid-fuelled fireplaces have high emissions and for that reason upgrade to a closed fireplace by installing inserts or their conversion to gas could reduce its emissions. Fireplaces might also be equipped with catalytic converters in an effort to limit emissions, but the control options are described in details later in chapter 3.5.

3.3.2.2 Gas fuelled fireplaces

The gas fireplaces are also of simple design; materials and equipment are similar to those of solid fuels fireplaces, yet equipped with a gas burner. Because of the simple valves employed for adjustment of fuel/air ratio and non-premixing burners, NO_x emissions are lower but emissions of CO and NMVOC are higher in comparison to the boilers using the same fuel.

3.3.3 Stoves

Stoves are simple appliances in which hand supplied fuels are combusted; useful heat is transmitted to the surroundings by radiation and convection. Depending on the main mode of heat transfer they are generally classified as radiating stoves or convection stoves (circulating, heat storing – heat accumulating). They can vary widely due to fuels type, application, design and construction materials, and also combustion process organisation. Due to the fuel properties they can be divided into the following subgroups:

- solid fuels
- liquid fuels
- gaseous fuels

The stoves utilizing solid fuels are usually used for heating of the rooms, but also for cooking, and hot water preparation (bath stove/furnace), while liquid and gas stoves are used for heating only.

3.3.3.1 Solid fuel stoves

The solid fuel stoves are classified on the basis of the combustion principle, which primarily depends on the airflow path through the charge of fuel in a combustion chamber. Two main types exist: up-draught (under-fire, down-burning combustion) and downdraught (up-burning combustion). The vast majority of older stoves are of the up-draught type, which is of simpler design, but has higher emissions.

The stoves can be made as prefabricated iron or steel appliances or masonry stoves, which are usually assembled on site with bricks, stone or ceramic materials. Regarding the main mode of heat transfer, solid fuel stoves can be divided into two main subgroups which are: radiating stoves, and heat storing - heat accumulating stoves.

Radiating stove; usually prefabricated iron or steel appliances; some of them used as cooking stoves. Radiating ordinary stoves are characterized by high emissions. The development of their design resulted in new constructions such as pellet stoves and stoves with advanced combustion process organization having higher efficiency and lower emissions. Considering the combustion process organization they can be differentiated as follows:

- *Conventional stoves* have poorly organised combustion process resulting in low efficiency (40% to 50%) and significant emissions of pollutants mainly originating from incomplete combustion (TSP, CO, NMVOC and PAH). Their autonomy is low, lasting from 3 to 8 hours. Those, which are equipped with hot plate zones, are used also for cooking - kitchen stoves. Some of them could also be used for hot water preparation.
- *Classic energy efficient stoves*; due to the utilization of secondary air in the combustion chamber their efficiency is between 55% to 75% and emission of pollutants are lower, their autonomy ranges from 6 to 12 hours.
- *Advanced combustion stoves*: These stoves are characterized by multiple air inlets and pre-heating of secondary combustion air by heat exchange with hot flue gases. This design results in increased efficiency (near 70% at full load) and reduced CO, NMVOC and TSP emissions in comparison with the conventional stoves.
- *Pellet stoves*: They can be fed only with pelletised fuels such as wood pellets, which are distributed to the combustion chamber by a fuel feeder from a small fuel storage. Pellets stoves are equipped with a fan and electronic control system for supply of the combustion air. For this reason they are characterized by high efficiency (above 80% up to 90%) and low emissions of CO, NMVOC, TSP and PAH.

Heat storing, heat accumulating stoves; depending on a country and regional tradition, masonry stoves are made of bricks, stones or combinations of both together with fireproof materials, such as ceramic (chamotte, faience). Sometimes they are made as prefabricated devices. Heat accumulating stoves are characterized with relatively low emissions of pollutants compared with the classical radiating stoves. Efficiency of masonry heating stoves ranges between 60% and 80%. Due to its function they can be diversified into:

- *Room heating stoves*; some more advanced of them employ contraflow system (Kubica et al, 2004) for heat transfer.
- *Heat accumulating cooking stoves* can be divided into two categories: simple residential cooking and boiler cooking stoves. The first ones are equipped with a combustion chamber with hot plate zones for food preparation and room heating; the second ones are simultaneously used as kitchen stove, room heating and hot water preparation (e.g. *"Russian stoves"*).

Catalytic combustor stove; Stoves, in particular for wood combustion, can be equipped with a catalytic converter in order to reduce emissions caused by incomplete combustion. Due to more complete oxidation of the fuels also energy efficiency increases. Catalytic combustors are not common for coal stoves.

Different kinds of solid fuels are used such as: coal and its products (usual anthracite, hard coal, brown coal, patent fuels, and brown coal briquettes) and biomass - lump wood and biomass pellets and briquettes. Coals of different grain sizes are used usually 20-40mm, and above 40mm, or mixtures of both. Peat is also occasionally used.

3.3.3.2 Liquid/gas fuelled stoves

The liquid/gas stoves have simple design; materials are alike for solid fuels stoves. Gas stoves are equipped with simple valves for fuel/air ratio adjustment and non-pre-mixing burners. For that reason emissions NO_x from these are lower in comparison to boilers. Simple liquid fuel stoves use evaporation systems for preparation of fuel/air mixture.

Regarding construction material and design, liquid and gas stoves are generally less diversified than those for solid fuels. They are made of steel and prefabricated.

3.3.4 Small boilers (single household/domestic heating) – indicative capacity ≤ 50 kW_{th}

Small boilers of this capacity are used in flats and single houses. All types of fuels could be used. They are mainly intended for generation of heat for the central heating system, but also hot water supply or combination of both.

3.3.4.1 Solid fuel small boilers

Small boilers for central heating for individual households are more widespread in temperate regions and usually have a nominal capacity between 12kW_{th} to 50kW_{th}. They use different types of solid fossil fuels and biomass usually depending on their regional availability. They could be divided into two broad categories regarding the organisation of combustion process: overfeed boiler (overfeed burning - over-fire and under-fire -, down-burning) and underfeed boiler (underfeed burning - upper-fire). They can be differentiated between conventional and advanced combustion boilers.

Conventional, coal/biomass boilers

Over-fire boilers: Over-fire boilers are commonly used in residential heating due to their simple operation and low investment cost. An incomplete combustion process takes place due to the non-optimal combustion air supply, which is usually generated by natural draught. The fuel is periodical fed onto the top of the burning fuel bed. The efficiency of the over-fire boiler is similar to the efficiency of conventional stoves, and is usually between 50% and 65%, depending on construction design and load. The emission of pollutants resulting from incomplete combustion of fuel may be very high particularly if they are operated at low load.

Under-fire boilers: Under-fire boilers have manual fuel feeding systems, and stationary or sloping grates. They have a two-part combustion chamber. The first part is used for storage of fuel and for partial devolatilization and combustion of the fuel layer. In the second part of the combustion chamber the combustible gases are oxidized. In the old design boilers natural draught is used. Combustion in under-fire boilers is more stable than in over-fire boilers, due to continuous gravity feed of fuel onto the fire bed. This results in higher energy efficiency (60-70%) and lower emissions in comparison to overfeed combustion.

Over-fire and under-fire boilers use all types of solid fuels except pellets, wood chips and fine-grained coal.

Advanced combustion boilers

Advance, under-fire coal boilers: In general the design and the combustion technique are similar to the conventional under-fire boiler. The main difference is that a fan controls the flue gases flow. Control system for the primary and secondary air might lead to increase in efficiency above 80% (usually between 70% and 80%).

Downdraught wood boilers: This type of boiler is considered state of the art in the lump wood combustion. It has two chambers, first one where the fuel is fed for partial devolatilisation and combustion of the fuel layer, and a secondary chamber, where burning of the released combustible gases occurs. The advantage of this boiler is that the flue gases are forced to flow down through holes in a ceramic grate and thus are burned at high temperature within the secondary combustion chamber and ceramic tunnel. Owing to the optimised combustion process, emissions due to incomplete combustion are low.

Stoker coal burners: The fuel with low ash contents and the grain size of between 4 mm up to 25 mm is automatically fed into to a retort by a screw conveyor. Stoker boiler is characterized by higher efficiency, usually above 80%. The advantage of stoker boiler is that it can operate with high efficiency within load range from 30% to nominal capacity. In a properly operated stoker, emissions of pollutants resulting from incomplete combustion are significantly lower, however NO_x increases due to the higher combustion temperature.

Wood pellet boiler has a fully automatic system for feeding of pellet fuels and for supply of combustion air, which is distributed into primary and secondary. The boilers are equipped with a smaller pellet storage, which is fuelled manually or by an automatic system from larger chamber storage. The pellets are introduced by screw into burner. These boilers are characterised by a high efficiency (usually above 80%) and their emissions are comparable to those of liquid fuel boilers.

3.3.4.2 Liquid/gas fuelled small boilers

These are usually two-function appliances used for hot water preparation and for heat generation for the central heating system. In the capacity range below 50 kW_{th} they are used mainly in single households. *Water-tube* low temperature boilers (temperature of water below 100^{o}C) (see 3.3.5.2) with open combustion chamber are usually used. These devices can be made of cast iron or steel. The boilers of capacity below 50 kW_{th}, can be divided into two main groups, i.e., standard boiler and condensation boilers.

Standard boilers; with open combustion chamber, having a maximum energy efficiency above 80%, because of the fact that flue gases are discharged at a temperature above 200^{o}C and the inlet/return water temperature is usually above 60^{o}C. Due to very simple design of combustion process automation system they are characterized by higher emission of CO and VOC in comparison to medium size boilers and industrial installations.

Condensation boilers; with closed combustion chamber; can operate with efficiency more than 90%. Recovering part of the latent heat from flue gases contributes to increased energy efficiency. It is achieved by condensation of the water vapour from the flue gases, which, in the optimal operation, have a temperature below 60°C at the chimney inlet. Gaseous fuels are mainly used in condensation boilers.

3.3.5 Boilers with indicative capacity between 50 kW_{th} and 50 MW_{th}

Boilers of such a capacity are used in multiresidential houses, block of flats and are the most commonly found small sources in commercial and institutional sector as well as in agriculture.

3.3.5.1 Solid fuels fuelled boilers

Fixed bed combustion technology is mainly used for combustion of solid fuels in this capacity range. This is a well-established technology, and a great variety of fixed bed layer and moving layer boilers (travelling grate combustion, stokers) are in use. Installations are differentiated into two main subgroups:

- manually fuelled
- automatically fuelled

In addition to fixed bed combustion also fluidised bed combustion boilers are in use in this capacity range, mostly for biomass combustion.

3.3.5.1.1 Manual feed boilers

Due to economical and technical reasons manual feeding boilers usually have a nominal capacity lower than $1MW_{th.}$

Coal/wood boilers

Manually fed boilers in this capacity range apply two combustion techniques, under-fire and upper-fire, similar as in boilers of lower capacity range (see 3.3.4.1).

Overfeed boilers, under-fire boilers: Coal fuels of different grain size (usually between 5mm and 40 mm) or lump wood are used in this type of installations. Their thermal efficiency ranges from 60% to 80% and depends on the air distribution into primary/secondary system and secondary sub-chamber design. The emissions of pollutants, i.e., CO, NMVOC, TSP and PAH resulting from incomplete combustion are generally high.

Overfeed boilers, upper-fire boilers: Fine coal, or mixture of fine coal with biomass chips, which are periodically moved into combustion chamber are used in this type of boilers. The ignition of fuel charge is started from its top. Their efficiency ranges from 75% to 80%. The emissions of pollutants of TSP, CO, NMVOC, PAH are lower in comparison to overfeed boilers due to different combustion process organization, which is similar to stoker combustion.

Both the under-fire and upper-fire boilers, in this capacity range, have better organisation of the combustion air compared with the ones used in single households.

Biomass/straw boilers

Overfeed boilers, biomass/straw fixed grate boilers: These are developed and applied for straw and cereal bale combustion. The straw bales are fed to the combustion chamber by hand. Because of very fast combustion of this kind of biomass these installations contain hot water accumulation system. For this reason they are used only in small-scale applications up to a nominal boiler capacity of 1,5 MW_{th}. They are very popular in the agricultural regions due to their relatively low costs and simple maintenance.

3.3.5.1.2 Automatic feed boilers

The automatic feed boilers usually have a capacity above 1MW_{th}, but nowadays also lower capacity boilers are equipped with automatic feeding. In addition these installations have in general better control of the combustion process compared with manually fed ones. They typically require fuels of standardised and stable quality. These installations might also have dedusting equipment.

Moving bed (GF) combustion: They are commonly classified according to the way in which fuel is fed to the grate, as spreader stokers, overfeed stokers, and underfeed stokers.

The coal of smaller granulation or fine wood (e.g., chips or sawdust) is charged on a mechanical moving grate. The combustion temperatures are between 1000°C and 1300°C. The grate-fired installations are used also for co-combustion of coal with biomass. General applications are aimed at production of heat and/or hot water, and/or low-pressure steam for commercial and institutional users, in particular for district heating. Due to highly controlled combustion process of solid fuels in moving bed techniques and usually fully automatic process control systems the emissions of pollutants, resulting from incomplete combustion, is significantly lower in comparison to manual feed boilers.

Advanced techniques:

Underfeed coal/wood boilers; upper-fire burning, stoker boilers, underfeed rotating grate; are used for both coal and wood combustion. The process principle is combustion in underfeeding stoker. The fuel with low ash contents (wood chips, sawdust, pellets; particle sizes up to 50 mm, or coal up to 30 mm) is fed into the combustion chamber through a screw conveyor and is transported to a retort when is oxidised.

Cigar straw boiler is developed and applied for combustion of straw and cereal bales. The fuel bales are automatically transported to the combustion chamber by a hydraulic piston through an inlet tunnel into the combustion chamber.

Indirect combustor, gasification of wood biomass uses a separate gasification system for the chipped wood fuels, and the successive combustion of the product fuel gases in the gas boiler. An advantage of this technology is a possibility to use wet wood fuels of varying quality. This technique has low emissions of pollutants resulting from incomplete combustion of fuels.

Pre-ovens combustion system: Wood chip combustion installations are used in some countries, especially in the countryside, heating larger houses and farms. This system contains automatic chips fuel feeding by a screw and pre-ovens (well-insulated chamber) and could be connected to an existing boiler. Pre-ovens system applies full automatic combustion process and consequently emissions are low.

3.3.5.1.3 Fluidised bed combustion

The fluidised bed combustion (FBC) can be divided into bubbling fluidised bed (BFB) and circulating fluidised bed combustion (CFB), depending on the fluidisation velocity. The solid fuels are injected with combustion air through the bottom of the boiler into a turbulent bed. FBC is in particular adapted to poor quality, rich in ash coal. The FBC is most appropriate installation for co-combustion of coal with biomass and/or with waste fuels, or combustion of biomass. There are only few medium size installations of this type in operation.

3.3.5.2 Liquid/gas fuels

For gas and oil boilers the fuel and air are introduced as a mixture in the combustion chamber. The main distinction between gas/oil and coal pulverized combustion is the design of the individual burners of the boiler.

Boilers fired with gaseous and liquid fuels are produced in a wide range of different designs and are classified considering especially: burner configuration (injection burner or blow burner), material they are made of, the type of medium transferring heat (hot water, steam) and their power, the water temperature in the water boiler which can be: low temperature $\leq 100^oC$; medium-temperature $>100^oC$ to $\leq 115^oC$; high-temperature $> 115^oC$), the heat transfer method (water-tube, fire -tube) and the arrangement of the heat transfer surfaces (horizontal or vertical, straight or bent over tube).

Cast iron boilers produce mainly low-pressure steam or hot water. Typically, they are used in residential and commercial/institutional sectors up to a nominal boiler capacity of about 1,5 MW_{th}.

Steel boilers are manufactured, up to a nominal capacity of 50 MW_{th}, from steel plates and pipes by means of welding. Their characteristic feature is the multiplicity of their design considering the orientation of heat transfer surface. The most common are: water-tube boilers, fire-tube boilers, furnace-fire-tube boilers and condensation boilers.

Water-tube boilers; are equipped with external, cubicle, steel water jacket. Water-tubes (water flows inside, exhaust gasses outside) are welded in the opposite walls of the cubicle.

Fire-tube boilers; in these boilers combustion gasses flow inside smoke tube, which are surrounded by the water. They are designed as cylinder or cubicle.

Furnace-fire-tube boilers made of steel; these devices are produced as the horizontal cylinders. The cylinder made of rolled steel plate ends at both sides with bottoms. The front bottom in its lower part (under the cylinder axis) is equipped with a furnace tube, which plays the role of combustion chamber.

Condensation boilers partly utilize the latent heat of the water vapour in the flue gases due to its condensation in the heat exchanger. For that reason their efficiency is higher than for other boiler systems. Their efficiency is more than 90%. They could efficiently operate at lower inlet water temperatures. Besides high efficiency their advantage is also lower emission of NO_x.

3.3.6 Combined Heat and Power (CHP)

Requirements to increase the efficiency of the energy transformation and the use of renewable energy sources have led to the development of the smaller CHP units using in particular biomass and other by-products as fuels. The steam produced by the boiler is used by backpressure steam turbine (ST) with subsequent heat utilization. Electricity generation efficiency is slightly reduced, however the overall efficiency is improved compared with separate generation of power and heat. CHP using internal combustion engines are not covered in this chapter.

3.4 Emissions

Relevant pollutants are SO_2, NO_x, CO, NMVOC, particulate matter, heavy metals, PAH and PCDD/F. Emission of ammonia (NH_3) is of lower importance.

For solid fuels generally the emissions due to incomplete combustion are many times greater in small appliances than in bigger plants. This is particularly valid for manually fed appliances and poorly controlled automatic installations.

For both, gaseous and liquid fuels, the emissions of pollutants are not significantly higher in comparison to industrial scale boilers due to the quality of fuels and design of burners and boilers, except for gaseous and liquid fuelled fireplaces and stoves because of their simple organization of combustion process. For the above-mentioned installations the same pollutants are generated as for solid fuels but their quantities are in general significantly lower.

Emissions caused by incomplete combustion are mainly a result of insufficient mixing of combustion air and fuel in the combustion chamber (local fuel-rich combustion zone), an overall lack of available oxygen, too low temperature, short residence times and too high radical concentrations (Kubica, 1997/1 and 2003/1). The following components are emitted to the atmosphere as a result of incomplete combustion in small combustion installations: CO, PM and NMVOCs, PAHs as well as PCDD/F. Small amounts of NH_3 may also be released as a result of incomplete conversion of NH_3.

The main influencing parameters, which determine the emissions and species profiles of some pollutants from combustion plants, are given in Section 3.4 and 9 of chapter B111 on

"Combustion Plant as Point Sources". Because pollutants from incomplete combustion, in particular from solid fuels use, have a significant share they are further discussed here together with heavy metals since their emissions from biomass are different.

NH_3 – Small amounts of ammonia may be emitted as a result of incomplete combustion process of all solid fuels containing nitrogen. This occurs in cases where the combustion temperatures are very low (fireplaces, stoves, old design boilers). NH_3 emissions generally can be reduced by primary measures aiming to reduce products of incomplete combustion and increase of efficiency.

TSP, PM10, PM2.5 –Particulate matter in flue gases from combustion of fuels (in particular of solid fuels and biomass) might be defined as carbon, smoke, soot, stack solid or fly ash. Emitted particulate matter can be classified into three groups of fuel combustion products.

The first group is formed via gaseous phase combustion or pyrolysis as a result of incomplete combustion of fuels (the products of incomplete combustion - PIC): soot and organic carbon particles (OC) are formed during combustion as well as from gaseous precursors through nucleation and condensation processes (secondary organic carbon) as a product of aliphatic, aromatic radical's reactions in a flame reaction zone in the presence of hydrogen and oxygenated species: CO and some mineral compounds as catalytic species, and VOC, tar/heavy aromatic compounds species as a results of incomplete combustion of coal/biomass devolatilization/pyrolysis products (from the first combustion step), and secondary sulphuric and nitric compounds. Condensed heavy hydrocarbons (tar substances) are an important, and in some cases, the main contributor to the total level of particles emission, in small-scale solid fuels combustion appliances such as fireplaces, stoves and old design boilers.

The next groups (second and third) may contain ash particles or cenospheres that are largely produced from fuels mineral matter, they contain oxides and salts (S, Cl) of Ca, Mg, Si, Fe, K, Na, P, and heavy metals, and unburned carbon form from incomplete combustion of carbonaceous material (black carbon or elemental carbon – BC; Kupiainen, et al., 2004); this is called carbon-in-ash (or loss on ignition).

Particulate matter emission from SCIs, mainly from different residential and commercial solid fuel appliances is typically combined with high emission of PICs associated and/or adsorbed. Size distribution depends on combustion conditions. Optimization of solid fuel combustion process by introduction of continuously controlled conditions (automatic fuel feeding, distribution of combustion air) leads to decrease of TSP emission and to change of PM distribution (Kubica, 2002/1 and Kubica et al., 2004/4). Application of co-combustion of coal and biomass leads to decrease of TSP, mainly PIC that are OC, (Kubica et al., 1997/2 and Kubica, 2004/5). Several studies have shown that the use of modern and "low-emitting" residential biomass combustion technologies leads to particle emissions dominated by submicron particles ($< 1 \mu m$) and the mass concentration of particles larger than 10 μm is normally < 90 % for SCIs Boman et al., 2004 and 2005; Hays et al., 2003.

Heavy metals (HM) – Most of heavy metals considered (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Zn) are usually released as compounds associated and/or adsorbed with particles (e.g. sulfides, chlorides or organic compounds). Hg, Se, As and Pb are at least partially present in the vapour phase only. Less volatile elements tend to condensate onto the surface of smaller particles in the exhaust gases. Therefore the emission of heavy metals strongly depends on their contents in the fuels. Coal and its derivatives normally contain amounts several orders of magnitude higher than in oil (exceptionally for Ni and V in heavy oils) and in natural gas (about 2-5 µg/m^3; van der Most *et al.,* 1992). All "virgin" biomass also contains heavy metals. Their content depends on the type of biomass. Higher emission of Cd, and Zn were observed in comparison to those from coal. During the combustion of coal and biomass, particles undergo complex changes, which lead to vaporization of volatile elements. The rate of volatilization of heavy metal compounds depends on technology characteristics (type of boilers; combustion temperature) and on fuel characteristics (their contents of metals, fraction of inorganic species, such as chlorine, calcium, etc.). The chemical form of the mercury emitted may depend in particular on the presence of chlorine compounds. The nature of the combustion appliance used and any associated abatement equipment will also have an effect (Pye et al., 2005/1). Mercry emitted form SCIs, similarly to emission from large scale combustion, occurs in elementary form (elemental Mercury vapour Hg^0), reactive gaseous form (Reactive Gaseous Mercury, RGM) and total particulate form (Total Particulate Mercury, TPM), Pacyna et al, 2004. Whereas it Has been show by Pye et al., 2005, that In case of SCIs distribution of particular species of emitted mercury is different to the one observed under large scale combustion. Contamination of biomass fuels, such as impregnated or painted wood may cause significantly higher amounts of heavy metals emitted (e.g. Cr, As). Heavy metals emissions can be reduced by secondary emission reduction measures, with the exception of Hg, As, Cd and Pb . Pye et al., 2005, have showed that limited technical abatement options (e.g. removal of mercury from flue gases after combustion) were identified specifically for SCIs, and those that were tended to be via abatement equipment that would normally be implemented for other pollutants, and which would have only indirect benefits for mercury emission reduction.

PCDD/F – The emissions of dioxins and furans are highly dependent on the conditions under which cooling of the combustion and exhaust gases is carried on. Carbon, chlorine, a catalyst and oxygen excess are necessary for the formation of PCDD/F. They are found to be consequence of the de-novo synthesis in the temperature interval between 180^{o}C and 500^{o}C (Karasek et al., 1987). Coal fired stoves in particular were reported to release very high levels of PCDD/F when using certain kinds of coal (Quass U., et al., 2000). The emission of PCDD/F is significantly increased when plastic waste is co-combusted in residential appliances or when contaminated/treated wood is used. The emissions of PCDD/F can be reduced by introduction of advanced combustion techniques of solid fuels (Kubica, 2003/3).

PAH – Emissions of polycyclic aromatic hydrocarbons results from incomplete (intermediate) conversion of fuels. As for CO, and NMVOC emissions of PAH depend on the organization of the combustion process, particularly on the temperature (too low temperature favourably increases their emission), the residence time in the reaction zone and the availability of oxygen (Kubica K., 1997/1, 2003/1). It was reported that coal stoves and old type boilers (hand fuelled) emit several times higher amounts of PAH in comparison to new design boilers (capacity below 50kW_{th}), such as boilers with semi-automatic feeding (Kubica K., 2003/1, 2002/1,3). Technology of co-combustion of coal and biomass that can be applied in commercial/institutional and in industrial SCIs leads to reduction of emission PAHs, as well as TSP, NMVOCs and CO, Kubica et al., 1997/2 and 2004/5).

CO – Carbon monoxide is found in gas combustion products of all carbonaceous fuels, as an intermediate product of the combustion process and in particular for under-stoichiometric conditions. CO is the most important intermediate product of fuel conversion to CO_2; it is oxidized to CO_2 under appropriate temperature and oxygen availability. Thus CO can be considered as a good indicator of the combustion quality. The mechanisms of CO formation, thermal-NO, NMVOC and PAH are in general similarly influenced by the combustion conditions. The emissions level is also a function of the excess air ratio as well as of the combustion temperature and residence time of the combustion products in the reaction zone. Hence, small combustion installations of capacity above $1MW_{th}$, mainly with automatic feeding, have favourable conditions to achieve lower CO emission. Thus the emissions of CO from solid fuels fuelled small appliances are several thousand ppm in comparison to 50-100 ppm for industrial combustion chambers, used in power plants.

NMVOC – They are all intermediates in the oxidation of fuels. They can adsorb on, condense, and form particles. Similarly as for CO, emission of NMVOC is a result of too low temperature, too short residence time in oxidation zone, and/or insufficient oxygen availability. The emissions of NMVOC tend to decrease as the capacity of the combustion installation increases, due to the use of advanced techniques, which are typically characterized by improved combustion efficiency.

3.5 Controls

Reduction of emissions from combustion process can be achieved by either avoiding formation of such substances (primary measures) or by removal of pollutants from exhaust gases (secondary measures).

Primary measures. These actions, preventing or reducing emission comprise of several possibilities (Kubica, 2002/3, Pye et al., 2004):

- replacing of coal by upgraded solid derived fuel, biomass, oil, gas
- modification of fuels composition and improvement of their quality; preparation and improvement of quality of solid fuels, in particular of coal (in reference to S, Cl, ash contents, and fine sub-fraction contents); modification of the fuels granulation by means of compacting - briquetting, pelletizing; pre-cleaning – washing; selection of grain size in relation to the requirements of the heating appliances (stove, boilers) and supervision of its distribution; partial replacement of coal with biomass (implementation of co-combustion technologies enabling reduction of SO_2, and NOx), application of combustion modifier; catalytic and S-sorbent additives (limestone, dolomite), reduction and modification of the moisture contents in the fuel, especially in the case of solid biomass fuels
- selection of the combustion appliances type: replacement of low effective heating appliances with newly designed appliances, and supervision of their distribution by obligatory certification system; chimney sweeper supervision over residential and communal system heating
- improved construction of the combustion appliances; implementation of advanced technologies in fire places, stoves and boilers construction (implementation of BAT for combustion techniques and good combustion practice)

- control optimization of combustion process, mainly in small combustion installations capacity above $1MW_{th}$.

Co-combustion of coal and biomass that can be applied in commercial/institutional and in industrial SCIs leads to reduction of TSP and PIC emission, mainly PAHs, NMVOCs and CO, Kubica et al., 1997/2 and 2004/5).

Secondary emission reduction measures: For small combustion installations a secondary measure can be applied to remove emissions, in particular PM. In this way emissions of pollutants linked with the PM, such as heavy metals, PAHs and PCDD/F can also be significantly reduced due to their removal together with particulate matter. These measures/controls are characterized by various dedusting efficiency (Perry at al., 1997 and Bryczkowski at al., 2002) and may be used mainly in medium size sources in small combustion installations (capacity at least 1 MW_{th}), due to technical reasons. For particulate matter the following options can be considered:

- settling chambers; gravity separation where the low collection efficiency (about 35% of fine dust, which contains 90% PM below 75 µm) is the main disadvantage,
- cyclone separators; disadvantage - low collection efficiency - their efficiency for fine particles is 78-85% - when compared to other filtration options, such as electrostatic precipitators or fabric filters, also tar substances may condense inside the apparatus,
- for higher effectiveness (94-99%) units with multiple cyclones (cyclone batteries) are applied, and multi-cyclones for increased gas flow rates,
- electrostatic precipitators (their efficiency is between 99,5% to 99,9%) or fabric filters (with efficiency about 99,9%) are typically not used in medium combustion plants due to their high costs. Fabric filters, which are relatively cheaper, also have the added constraint of operating temperatures below 200ºC and high-pressure drop.

Wood combustion appliances, stoves in particular, can be equipped with a catalytic converter in order to reduce emissions caused by incomplete combustion. The catalytic converter (a cellular or honeycomb, heat ceramic monolith covered with a very small amount of platinum, rhodium, or combination of these) is usually placed inside the flue gas channel beyond the main combustion chamber. When the flue gas passes through catalytic combustor, some pollutants are oxidized. The catalyst efficiency of emission reduction depends on the catalyst material, its construction – active surface, the conditions of flue gases flow inside converter (temperature, flow pattern, residence time, homogeneity, type of pollutants). For wood stoves with forced draught, equipped with catalytic converter (Hustad, *et al.*, 1995) the efficiency of emission reduction of pollutants is as follows: CO 70-93%,, CH_4 29-77%, other hydrocarbons more than 80%, PAH 43-80% and tar 56-60%. Reduction of CO emissions from stoves equipped with catalytic converter is significant in comparison to an advanced downdraught staged-air wood stove under similar operating conditions, (Skreiberg, 1994). However, the catalysts needs frequent inspection and cleaning. The lifetime of a catalyst in a wood stove with proper maintenance is usually about 10,000 hours.

Secondary measures with reference to, NO_x and SO_2 cannot be applied for small combustion installations from a technical and economical point of view. Because of the significant share of PM and the linked substances, technical methods for their reduction are currently under intense development especially for small sources of capacity below $1MW_{th}$.

Due to the heterogeneity of SCIs across Europe, and the difference in energy markets, it is clear that technical measures for emission reduction will be implemented on a country-by-country basis, taking into consideration such differences. Primary (preventative) technical controls (such as replacement of appliance or change in type of fuel) will be used for smaller SCIs, while secondary abatement measures will be more applicable to larger institutional and industrial plant, Pye et al., 2005/1.

4 SIMPLER METHODOLOGY

4.1 General

This simpler methodology is intended for calculating and reporting emissions when the contribution of sources **1A1a; 1A4a; 1A4bi; 1A4ci; 1A5a (and small installations in 1A1a)** in the national totals is small or for the first assessment of emissions from these sources when there are no data available for application of the detailed methodology.

The simpler methodology described in this chapter refers to the calculation of the emissions, based on the split of the small combustion sources in the relevant sectors only with regard to the fuel used and anticipates the application of default emission factors. It covers all relevant emissions that are: SO_2, CO, NMVOC, NO_x, NH_3, TSP, PM10, PM2.5, heavy metals, PCDD/PCDF and PAH.

4.2 Applicability

The simpler methodology does not take into account differences in the emissions due to the wide variety of technologies, which is present among these sources, neither the different level of maintenance nor the influence of locally specific fuels. This is why the simpler approach might lead to a significant uncertainty in the estimated emissions. Moreover this approach does not take into account the penetration of new technologies, and thus might not represent appropriately the trends in emissions. **Therefore the simpler methodology should be applied only if the contribution of these sources in the national totals is small or for the first assessment of emissions from these sources when there are no data available for application of the detailed methodology.** In most cases when the share of solid fuels in covered sector is significant, the detailed methodology should be applied.

4.3 Methodology

The simpler methodology involves applying an appropriate emission factor to activity data given at the level of sectors (commercial/institutional, residential, agriculture and others). Within each sector only different fuels are distinguished. Default emission factors to facilitate this approach are provided in section 8.1.

Emissions can be estimated at different levels of complexity; it is useful to think in terms of three tiers[1]:

Tier 1: a method using readily available statistical data on the intensity of processes ("activity rates") and default emission factors. These emission factors assume a linear relation between the intensity of the process and the resulting emissions. The Tier 1 default emission factors also assume an average or typical process description.

Tier 2: is similar to Tier 1 but uses more specific emission factors developed on the basis of knowledge of the types of processes and specific process conditions that apply in the country for which the inventory is being developed.

Tier 3: is any method that goes beyond the above methods. These might include the use of more detailed activity information, specific abatement strategies or other relevant technical information.

By moving from a lower to a higher Tier it is expected that the resulting emission estimate will be more precise and will have a lower uncertainty. Higher Tier methods will need more input data and therefore will require more effort to implement.

For the Tier 1 simpler methodology, where limited information is available, a default emission factor can be used together with activity information for the country or region of interest with limited or no specification on the type of technology or the type and efficiency of control equipment. For a Tier 2 approach an approximation may be made of the most representative technologies, thereby allowing the use of more appropriate default factors if more detailed activity data are available.

Consequently the simplest methodology (Tier 1) is to combine an activity rate (AR) with a comparable, representative, value of the emissions per unit activity, the emission factors (EF). The basic equation is:

$$\text{Emission} = AR \times EF$$

In the energy sector, for example, fuel consumption would be activity data and mass of material emitted per unit of fuel consumed would be a compatible emission factor.

NOTE: The basic equation may be modified, in some circumstances, to include emission reduction efficiency (abatement factors).

The Tier 2 methodology is a modified version of this basic equation:

$$\text{Emission} = \sum((AR_1 \times EF_1) + (AR_2 \times EF_2) + \ldots.(AR_n \times EF_n))$$

Default emission factors for this purpose are provided in Sections 8.1 and 8.2.

1 The term "Tier" is used in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and adopted here for easy reference and to promote methodological harmonization.

4.4 Emission factors

The simpler methodology envisages the use of default emission factors, which are given for all relevant pollutants. The default emission factors to be used within simple methodology for residential sector are given in Table 8.1a. For commercial/ institutional, agriculture and other sectors, where installations have on average higher capacity, default emission factors are given in Table 8.1b. These default emission factors were derived for conventional technologies.

However the default emission factors for SO_2 for fossil liquid and solid fuels should be used only in exceptional cases even within the simpler methodology. Sulphur content of the coal fuels used may vary significantly from country to country. Similarly there could be pronounced differences in sulphur content of the liquid fuels due to different levels of standards and legislation applied.

In the following a calculation procedure for SO_2 emission factor for coals and heating oils is proposed:

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

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

Average sulphur retention in ash $\overline{\alpha_{s,k}}$ is not relevant for liquid fuels and for these fuels should be taken as zero. For the coal fuels the default value of 0.1 should be taken in the absence of national data.

4.5 Activity data

In most cases the statistical information include data on annual fuels consumption in households, services and agriculture. Only in some cases data on fuels used by small consumers are available, which might include all sectors except mobile sources, industry and energy transformation. To fill these data gaps the following sources could be used:

- Information from the fuel suppliers and individual companies
- Energy conservation/climate change mitigation studies for relevant sectors
- Residential, commercial/institutional and agriculture sector surveys
- Energy demand modelling

The data from various sources should be compared taking into account their inherent uncertainties in order to obtain the best assessment. To improve reliability of the activity data appropriate efforts should be made in order to ensure that the institution responsible for national energy statistics includes evaluation and reporting of the fuel consumption at the adequate level of sectorial disaggregation in their regular activity.

Also when data on the fuel consumption are provided at an appropriate level of sectorial split, they should be checked for possible anomalies. Wood and other type biomass and in some cases also gas oil consumption in the households requires particular consideration.

The self-supply and direct purchase of the wood from farmers might not be taken into account when energy statistics are based mainly on the data obtained from the fuel suppliers. This could lead to a significant underestimation of the wood consumption especially in the countries with abundant wood supplies and greater share of heating with stoves and small solid fuel boilers. In that case the data on wood consumption should be adjusted. Consultation with the forestry experts and/or energy demand modelling is recommended. Wood consumption should be consistent with the related data reported to the UNFCCC.

Activity data may also be affected by the improper sectorial attribution of gas oil consumption. Due to the tax difference cheaper gas oil sold to households might be in particular circumstances used instead of diesel oil in vehicles and off–road machinery. In that case not only sectorial distribution of emissions is affected, but also emissions of certain pollutants at the national level could be underestimated due to the difference in emission factors. Evidence of such a situation could be obtained by energy demand modelling of the households and complementary bottom–up modelling of the fuel consumption of the mobile sources. Irregular changes in the time series of the gas and diesel oil quantities sold, not correlated with changes in economic situation could also indicate such phenomena. Inventorying agencies are encouraged to make most appropriate adjustments, however they have to be well documented.

5 DETAILED METHODOLOGY

5.1 General

This detailed methodology is intended for calculating emissions when the contribution of sources **1A1a; 1A4a; 1A4bi; 1A4ci; 1A5a (and small installations in 1A1a)** in the national totals is significant or data are available which enable its application.

The detailed methodology described in this chapter refers to the calculation of the emissions, based on the split of the small combustion sources not only to different fuel types, but also to different types of installations, which are found in those sectors. Default emission factor given for the detailed methodology, national emission factors or combination of both could be used.

The detailed methodology applies the same approach like the simpler methodology by using activity data and emission factors to estimate the emissions. The main difference is that the detailed methodology involves more country specific information like the specific emission factors for main installation types, further subdivision of the main installation types including those with control measures and/or use of the locally specific fuels. Development of the detailed methodology has to be focused to the combinations of the main installation types/fuels used, which consume most fuels and/or have the greatest share of the emissions from the considered sources.

5.2 Applicability

The detailed methodology envisages a more detailed split of the combustion installations. For that reason the national circumstances are taken more into account, especially if national emission factors are used. **The detailed methodology should be used when the considered sources have significant share of the national totals or significant changes of emissions are expected. However the application of the detailed methodology is recommended always when a country has more detailed or more specific, yet reliable enough information than those needed for the simpler methodology.**

5.3 Methodology

The annual emission is determined by an activity data and an emission factor:

$$E_i = \sum_{j,k} EF_{i,j,k} \cdot A_{j,k} \quad , \qquad (1)$$

where

E_i annual emission of pollutant *i*

$EF_{i,j,k}$ default emission factor of pollutant *i* for source type *j* and fuel *k*

$A_{j,k}$ annual consumption of fuel *k* in source type *j*

The main source types are:

- fire places,
- stoves,
- small boilers (single household/domestic heating) – indicative capacity <50 kW_{th},
- medium size boilers (<50 MW_{th}),
  - manual feeding (indicative capacity <1MW_{th}),
  - automatic feeding,

All those source types are not relevant for all sectors, as for instance fireplaces and stoves are mainly used in the residential sector.

The detailed methodology (equivalent to Tier 3) to estimate emissions of pollutants from combustion plant >50 MW_{th} is based on measurements or estimations using plant specific emission factors - guidance on determining plant specific emission factors is given in the Measurement Protocol Annex.

In many countries, operators of combustion plant >50MWth will report emissions to comply with regulatory requirements and this data can be used to help compile the national inventory.

The recommended detailed methodology to estimate emissions of PM from combustion activities is based on measurements and/or estimations using technology-specific emission factors.

Information on the type of the process and activity data, for example combustion and abatement technologies, is required to assign appropriate emission factors.

5.4 Emission factors

The detailed methodology envisages the use of default emission factors (Tables 8.2 a-g) developed for this purpose or their substitution/complementing with national emission factors.

The development of national emission factors should be focused on a combination of installation types and fuels, where specific national circumstances exist and/or contribution to the emission is the highest. When deriving specific emission factors the emphasis has to be given in taking into account also start–up emissions. These could, especially in the case of stoves and solid fuel small boilers, significantly influence the emissions of the total combustion cycle. For medium size installations data obtained from environmental inspectorates could be used taking into account whether there are representative or not.

5.5 Activity data

The detailed methodology requires further allocation of the fuel consumed according to the installation types. Those data are generally not available in the regular statistics reports. In most cases the inventorying agency would have to use surrogate data to assess the activity data at the required level of desegregation. National approaches have to be developed depending on the availability and quality of surrogate data. Some examples of surrogate data sources are:

- Residential, commercial/institutional and agriculture sector surveys
- Energy conservation/climate change mitigation studies for relevant sectors
- Energy demand modelling
- Information from the fuel suppliers
- Information from producers and sellers of heating appliances
- Chimney sweeping organisations

Particularly in the case of households it should be emphasised, that the surveys have to be based on a representative sample. In some countries the means of heating of the households are regionally very inhomogeneous with significantly greater share of solid fuel stoves and boilers in traditionally coal mining regions and at some rural areas. Additional data could be obtained from the chimneysweeper organisations and from environmental inspectorates particularly for the commercial-institutional sector.

Another important source of data could be dwelling statistics. Within the scope of national census the data on dwellings, occupied by the households are usually collected. Data on individual dwelling might include:

- number of residents,
- area of the dwelling,
- type of building (individual house, attached house, block of flats),
- construction year,
- existence or not of central heating,
- central heating boiler in the flat or common for block of flats
- fuels used for heating.

Dwelling statistics could be used to extrapolate results of the household survey or to perform detailed energy demand/emission modelling. Especially in the case where household emissions represent an important share in national totals or are of a great relevance due to local air pollution it is recommended to perform such an exercise. Detailed energy demand/emission modelling may be usually performed at local or regional level, however the extension to the national level does not pose significant additional requirements. To justify the additional effort required for energy demand/emission modelling of the households, the emission inventorying agency might find it appropriate to initiate a common project with other stakeholders, as for instance agencies competent for energy conservation, climate change mitigation or energy supply.

In the following a **brief outline of the energy demand/emission modelling** based on a dwelling census is given. The demand for useful energy for space heating could be calculated from the area of the flat and specific heat loses which depend on building code implied by the construction year of the building and ratio of outer building surface to dwellings surface. The latter could be characterised by the type of the building.

Required useful energy depends on the climatologically parameters, which are characterised by heating degree-days and the level of the heating, which is higher when the dwelling is equipped with the central heating. The heating energy demand is partly covered by gains of energy due to use of household electrical appliances and heat released directly by the residents. The heat gains could be considered as proportional to the number of residents. The remaining part of the required useful energy is supplied by the heating system. The fuel consumption depends on efficiency of the heating installation, which is characterised by the installation type and fuel used.

Where fossil fuels or biomass are used and no central heating exists it could be considered that stoves are used for space heating. The data on the use of fireplaces (i.e. number and average fuel use) has to be obtained from other sources, where relevant. Preparation of the hot water in households has also to be taken into the account, as it is at least partly supplied by the central heating boilers or special small boilers using natural gas.

Model parameters as for instance specific heat losses have to be determined at the national level due to differences in building code and practices. In some cases where there are significant climatic differences within the country, which are reflected in the different building codes for certain regions, it might be necessary, to derive and apply regionally specific heat loses. In almost all cases the heating degree-days have to be used at higher spatial resolution than country level.

Energy demand/emission modelling is the most appropriate to be performed at the level of the individual flat. In principle it could be possible to obtain data from the National Statistical office at such a level of details, however with individual dwellings located at the level of statistical district or within a grid large enough to satisfy the criteria of security of personal and individual data.

The census is usually performed once every 10-years. Thus the method has to be developed to periodically up-date the input data, most preferably on the basis of household surveys extrapolation complemented by the data from the fuel suppliers.

6 RELEVANT ACTIVITY STATISTICS

National or international statistics should be used e.g. fuels use and consumption. The following statistical publications could be recommended:

Statistical Office of the European Communities (EUROSTAT): NEWCRONOS database

Statistical Office of the European Communities (EUROSTAT): Energy Consumption in households – European Union and Norway, 1995 survey - Central and eastern European countries, 1996 survey

Statistical Office of the European Communities (EUROSTAT): Energy Consumption in the service sector – Surveys of EU Member states

7 POINT SOURCE CRITERIA

This section is not relevant since this chapter covers area sources only.

8 EMISSION FACTORS, QUALITY CODES AND REFERENCES

Default emissions factors contained in the following tables are estimated representative values derived from collected data that are quoted later in Annex 1 as well as national experts judgments.

For the calculation of default emission factors for a simple methodology for residential sources, NFR: 1A4bi (Table 8.1a) the share of fireplaces, stoves and boilers fuelled by solid coal fuels, biomass and gaseous fuels was assumed as 5%, 65% and 30%, respectively and the emissions factors were taken from the detailed methodology tables. Within solid coal fuels a figure of about 5% was assumed for briquettes. For liquid fuels the share of stoves was assumed as 10% and boilers as 90%. Because the share of biomass and coal advanced stove and boilers was assumed to be currently lower than 5% in most of the countries they haven't been taken into consideration. For the activities NFR: 1A4a, 1A4ci, 1A5a and 1A1a (table 8.1b) the share of coal, gas and oil boilers with capacity between 50kW and 1MW and from 1MW to 50MW was assumed as 50% and 50% respectively. For coal fuels boilers the share of briquettes was assumed to be 5% similar to activity NFR 1A4bi. However the share of wood boilers with capacity between 50kW and 1MW and above 1MW to 50MW was assumed to be 60% and 40% respectively.

Automatic fuelled solid and biomass installations, as stokers and other automatic feed boilers, especially those larger than 1 MW, are usually equipped with some particulate matter control equipment. In this case mainly settling chambers and cyclones to reduce primary coarse particles and related pollutants. They are characterised by low collection efficiency, i.e., about 35% and 85% of dust, respectively. This collection efficiency refers to the 90% of PM below 75 µm. The default emission factors for the detailed methodology (Tables 8.2d, 8.2e and 8.2f) make allowance for using of this type of dedusting systems. In the modern installations also advanced dedusting equipment are employed.

8.1 Default Emission Factors For Use With Simpler Methodology

A summary of default emission factors for uses the simpler methodology for estimating emissions is provided in the following Tables.

Table 8.1a Default emission factors for the simple methodology of residential sources, NFR: 1A4bi

Pollutant	Emission factors				Units
	Solid coal fuels [1)]	Gaseous fuels [2)]	Liquid fuels [3)]	Wood [4)]	
Ammonia	0,3	Neg.	Neg.	3,8	g/GJ
Sulphur dioxide	900 [5)]	0,5	140 [6)]	20,0	g/GJ
Nitrogen dioxide	109,7	57,0	68,0	74,5	g/GJ
Total suspended particulate matter	443,6	0,5	6,0	730,0 [8)]	g/GJ
PM10	404,1	0,5	3,7	695,3 [8)]	g/GJ
PM2.5	397,5	0,5	3,7	694,8 [8)]	g/GJ
Arsenic	2,5	NA. [7)]	0,9	1,0	mg/GJ
Cadmium	1,5	NA	1,5	1,4	mg/GJ
Chromium	11,2	NA	15,5	2,9	mg/GJ
Copper	22,3	NA	7,9	8,6	mg/GJ
Mercury	5,1	0,0	0,0	0,5	mg/GJ
Nickel	12,7	NA	240,0	4,4	mg/GJ
Lead	130,0	NA	15,5	40,0	mg/GJ
Selenium	120,0	NA	0,0	0,5	mg/GJ
Zinc	220,0	NA	8,5	130,0	mg/GJ
Dioxins and furans	800,0	0,5	10,0	700,0	I-Teqng/GJ
PAH Σ 1-4	800,0	NA	75,0	700,0	mg/GJ
Benzo(a)pyrene	230,0	NA	22,0	210,0	mg/GJ
Benzo(b)fluoranthene	330,0	NA	25,7	220,0	mg/GJ
Benzo(k)fluoranthene	130,0	NA	12,5	130,0	mg/GJ
Indeno(1,2,3_cd)pyrene	110,0	NA	14,8	140,0	mg/GJ
Carbon monoxide	4602,5	31,0	46,0	5300,0	g/GJ
Non methane VOC	484,3	10,5	15,5	925,0	g/GJ

N.B: The emission factors in this table reflect the finding that much of the combustion equipment used in a domestic environment is relatively old, manually fuelled, and the penetration of new technologies is slow.

1) Use this "Solid coal fuels" default for all raw coals as well as for the derived coal fuels such as patent fuels, coke and other manufactured coal fuels
2) Use this "Gaseous fuels" default for natural gas, liquefied petroleum gas (LPG), and other gaseous fuels
3) Use this "Liquid fuels" default for gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
4) Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
5) 900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY
6) 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY. Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available
7) NA - not applicable
8) Emission factors, from more recent European and North American work, indicate the figures for burning prepared wood fuel are considerably lower, possibly by a factor of 2-3.

Table 8.1b Default emission factors for the simple methodology of the sources, NFR: 1A4a, 1A4ci, 1A5a and 1A1a

Pollutant	Emission factors				Units
	Solid coal fuels [1)]	Gaseous fuels [2)]	Liquid fuels [3)]	Wood [4)]	
Ammonia	NA [5)]	NA	NA	NA	g/GJ
Sulphur dioxide	839,5 [6)]	0,5	140 [7)]	38,4	g/GJ
Nitrogen dioxide	173,1	70,0	100,0	150,0	g/GJ
Total suspended particulate matter	124,2	NA	27,5	156,4	g/GJ
PM10	117,2	NA	21,5	149,9	g/GJ
PM2.5	107,7	NA	16,5	149,1	g/GJ
Arsenic	4,0	NA	1,0	1,4	mg/GJ
Cadmium	1,8	NA	0,3	1,8	mg/GJ
Chromium	13,5	NA	12,8	6,5	mg/GJ
Copper	17,5	NA	7,2	4,6	mg/GJ
Mercury	7,9	0,0	0,1	0,7	mg/GJ
Nickel	13,0	NA	260,0	2,0	mg/GJ
Lead	134,2	NA	16,0	24,8	mg/GJ
Selenium	1,8	NA	NA	NA	mg/GJ
Zinc	200,0	NA	8,0	113,6	mg/GJ
Dioxins and furans	202,6	2,0	10,0	326,0	I-Teq ng/GJ
PAH Σ 1-4	146,7	NA	17,6	155,2	mg/GJ
Benzo(a)pyrene	45,5	NA	5,2	44,6	mg/GJ
Benzo(b)fluoranthene	58,9	NA	6,2	64,9	mg/GJ
Benzo(k)fluoranthene	23,7	NA	4,0	23,4	mg/GJ
Indeno(1,2,3_cd)pyrene	18,5	NA	2,2	22,3	mg/GJ
Carbon monoxide	931,0	25,0	40,0	1596,0	g/GJ
Non methane VOC	88,8	2,5	10,0	146,4	g/GJ

N.B The table assumes a 20% penetration rate for new technologies.

1) Use this "Solid coal fuels" default for all raw coals as well as for the derived coal fuels such as patent fuels, coke and other manufactured coal fuels
2) Use this "Gaseous fuels" default for natural gas, liquefied petroleum gas (LPG), and other gaseous fuels
3) Use this "Liquid fuels" default for gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
4) Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
5) NA - not applicable
6) 900 g/GJ of sulphur dioxide corresponds to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY
7 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY. Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available.

8.2 Default emission factors which could be used with Detailed Methodology

A summary of default emission factors that could be used within the detailed methodology for estimating emissions is provided in the following Tables.

Table 8.2a Default emission factors for fireplaces

Pollutant	Emission factors			Units
	Coal fuels [1]	Gaseous fuels [2]	Wood [3]	
Ammonia	5	NA[4]	10	g/GJ
Sulphur dioxide	500 [5]	0,5	10	g/GJ
Nitrogen dioxide	60	50	50	g/GJ
Total suspended particulate matter	350	0.5	900	g/GJ
PM10	330	0.5	860	g/GJ
PM2.5	330	0.5	850	g/GJ
Arsenic	1.5	NA	0.5	mg/GJ
Cadmium	0,5	NA	2	mg/GJ
Chromium	10	NA	1	mg/GJ
Copper	20	NA	8	mg/GJ
Mercury	3	0.01	0.4	mg/GJ
Nickel	10	NA	2	mg/GJ
Lead	100	NA	40	mg/GJ
Selenium	1	NA	0.5	mg/GJ
Zinc	200	NA	100	mg/GJ
Dioxins and furans	500	1,5	800	I-Teq ng/GJ
PAH Σ 1-4	450	NA	600	mg/GJ
Benzo(a)pyrene	100	NA	180	mg/GJ
Benzo(b)fluoranthen	170	NA	180	mg/GJ
Benzo(k)fluoranthen	100	NA	100	mg/GJ
Indeno(1,2,3-cd)pyrene	80	NA	140	mg/GJ
Carbon monoxide	5000	50	6000	g/GJ
Non methane VOC	600	20	1300	g/GJ

1) Use this “Solid coal fuels” default for all raw coals as well as for the derived coal fuels such as patent fuels, coke and other manufactured coal fuels
2) Use this “Gaseous fuels” default for natural gas, natural gas liquids, and liquefied petroleum gas (LPG), and other gaseous
3) Use this “Wood” default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
4) NA - not applicable
5) 500 g/GJ of sulphur dioxide is adequate to 0.8 % S of coal fuels of lower heating value of fuel on a dry basis 29 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.

Table 8.2b Default emission factors for domestic stoves

Pollutant	Emission factors					Units
	Coal fuels [1)]	Briquettes [2)]	Gaseous fuels [3)]	Liquid fuels [4)]	Wood [5)]	
Ammonia	NA [6)]	NA	NA	NA	5	g/GJ
Sulphur dioxide	900 [7)]	500 [8)]	0.5	140 [9)]	10	g/GJ
Nitrogen dioxide	100	100	50	50	50	g/GJ
Total suspended particulate matter	500	200	0.5	15	850	g/GJ
PM10	450	100	0.5	10	810	g/GJ
PM2.5	450	100	0.5	10	810	g/GJ
Arsenic	1.5	1	NA	0.5	0.5	mg/GJ
Cadmium	1	0.7	NA	0.3	1	mg/GJ
Chromium	10	5	NA	5	2	mg/GJ
Copper	20	10	NA	3	8	mg/GJ
Mercury	5	3	0.01	0.03	0.4	mg/GJ
Nickel	10	7	NA	100	2	mg/GJ
Lead	100	70	NA	5	40	mg/GJ
Selenium	2	0.5	NA	NA	0.5	mg/GJ
Zinc	200	120	NA	5	100	mg/GJ
Dioxins and furans	1000	300	1.5	10	800	I-Teq ng/GJ
PAH Σ 1-4	920	220	NA	180	820	mg/GJ
Benzo(a)pyrene	250	50	NA	50	250	mg/GJ
Benzo(b)fluoranthen	400	90	NA	60	240	mg/GJ
Benzo(k)floranthene	150	40	NA	30	150	mg/GJ
Indeno(1,2,3_cd)pyrene	120	40	NA	40	180	mg/GJ
Carbon monoxide	5000	4000	30	100	6000	g/GJ
Non methane VOC	600	300	10	20	1200	g/GJ

[1)] Use this "Coal fuels" default for all raw coals
[2)] Use this "Briquettes" default for patent fuels, coke and other manufactured coal fuels
[3)] Use this "Gaseous fuels" default for natural gas, natural gas liquids, and liquefied petroleum gas (LPG), and other gaseous
[4)] Use this "Liquid fuels" default for burning oil (kerosene), gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
[5)] Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
[6)] NA - not applicable
[7)] 900 g/GJ of sulphur dioxide is adequate to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.
[8)] 500 g/GJ of sulphur dioxide is adequate to 0.8 % S of briquettes of lower heating value of fuel on a dry basis 29 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.
[9)] 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available.

Table 8.2c Default emission factors for small (single household scale, capacity ≤50 kWth) boilers

Pollutant	Emission factors					Units
	Coal fuels [1]	Briquettes[2]	Gaseous fuels[3]	Liquid fuels[4]	Wood[5]	
Ammonia	NA[6]	NA	NA	NA	NA	g/GJ
Sulphur dioxide	900 [7]	500 [8]	0.5	140 [9]	30	g/GJ
Nitrogen dioxide	130	200	70	70	120	g/GJ
Total suspended particulate matter	400	120	0.5	5 [10]	500	g/GJ
PM10	380	100	0.5	3 [10]	475	g/GJ
PM2.5	360	100	0.5	3 [10]	475	g/GJ
Arsenic	5	3	NA	1	2	mg/GJ
Cadmium	3	0,7	NA	2	2	mg/GJ
Chromium	15	10	NA	20	5	mg/GJ
Copper	30	20	NA	10	10	mg/GJ
Mercury	6	3	0.01	0.03	0.6	mg/GJ
Nickel	20	13	NA	300	10	mg/GJ
Lead	200	120	NA	20	40	mg/GJ
Selenium	2	1.5	NA	NA	0.5	mg/GJ
Zinc	300	200	NA	10	200	mg/GJ
Dioxins and furans	500	200	NA	10	500	I-Teq ng/GJ
PAH Σ 1-4	710	150	NA	30	510	mg/GJ
Benzo(a)pyrene	270	50	NA	10	130	mg/GJ
Benzo(b)fluoranthen	250	50	NA	11	200	mg/GJ
Benzo(k)fluoranthen	100	30	NA	5	100	mg/GJ
Indeno(1,2,3_cd)pyrene	90	20	NA	4	80	mg/GJ
Carbon monoxide	4000	3000	30	40	4000	g/GJ
Non methane VOC	300	200	10	15	400	g/GJ

1) Use this "Coal fuels" default for all raw coals
2) Use this "Briquettes" default for patent fuels, coke and other manufactured coal fuels
3) Use this "Gaseous fuels" default for natural gas, natural gas liquids, and liquefied petroleum gas (LPG), and other gaseous
4) Use this "Liquid fuels" default for burning oil (kerosene), gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
5) Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
6) NA - not applicable
7) 900 g/GJ of sulphur dioxide is adequate to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY
8) 500 g/GJ of sulphur dioxide is adequate to 0.8 % S of briquettes of lower heating value on a dry basis 29 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.
9) 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available.
10) Proposed emission factor is representative for light fuel oil; typical emissions from residential boilers burning heavy fuel oil would be about 10 times higher than this value.

Table 8.2d Default emission factors for medium size (>50 kWth to ≤1 MWth) boilers

Pollutant	Emission factors					Units
	Coal fuels[1)]	Briquettes[2)]	Gas fuels[3)]	Liquid fuels[4)]	Wood[5)]	
Ammonia	NA [6)]	NA	NA	NA	NA	g/GJ
Sulphur dioxide	900 [7)]	500 [8)]	0,5	140 [9)]	50	g/GJ
Nitrogen dioxide	160	150	70	100	150	g/GJ
Total suspended particulate matter	200	100	NA	5 [10)]	250	g/GJ
PM10	190	80	NA	3 [10)]	240	g/GJ
PM2.5	170	80	NA	3 [10)]	240	g/GJ
Arsenic	5	4	NA	1	2	mg/GJ
Cadmium	3	0.7	NA	0.3	2	mg/GJ
Chromium	15	10	NA	20	10	mg/GJ
Copper	30	20	NA	10	5	mg/GJ
Mercury	7	3.5	0.01	0.1	0.6	mg/GJ
Nickel	20	13	NA	300	2	mg/GJ
Lead	200	100	NA	20	30	mg/GJ
Selenium	2	1.5	NA	NA	NA	mg/GJ
Zinc	300	160	NA	10	150	mg/GJ
Dioxins and furans	400	100	2	10	500	I-Teq ng/GJ
PAH; Σ 1-4	320	90	NA	26	280	mg/GJ
Benzo(a)pyrene	100	30	NA	8	80	mg/GJ
Benzo(b)fluoranthen	130	40	NA	9	120	mg/GJ
Benzo(k)fluoranthen	50	10	NA	6	40	mg/GJ
Indeno(1,2,3-cd)pyrene	40	10	NA	3	40	mg/GJ
Carbon monoxide	2000	1500	30	40	3000	g/GJ
Non methane VOC	200	100	3	15	250	g/GJ

1) Use this "Coal fuels" default for all raw coals
2) Use this "Briquettes" default for patent fuels, coke and other manufactured coal fuels
3) Use this "Gaseous fuels" default for natural gas, natural gas liquids, and liquefied petroleum gas (LPG), and other gaseous
4) Use this "Liquid fuels" default for burning oil (kerosene), gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
5) Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
6) NA - not applicable
7) 900 g/GJ of sulphur dioxide is adequate to 1.2 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY
8) 500 g/GJ of sulphur dioxide is adequate to 0.8 % S of briquettes of lower heating value on a dry basis 29 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY
9) 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available.
10) Proposed emission factor is representative for light fuel oil; typical emissions from residential boilers burning heavy fuel oil would be about 10 times higher than this value.

Table 8.2e Default emission factors for medium size (>1 MWth to ≤50 MWth) boilers

Pollutant	Emission factors				Units
	Coal fuels[1)]	Gaseous fuels[2]	Liquid fuels[3)]	Wood fuels[4)]	
Ammonia	NA[5)]	NA	NA	NA	g/GJ
Sulphur dioxide	900 [6)]	0.5	140 [7)]	30	g/GJ
Nitrogen dioxide	180	70	100	150	g/GJ
Total suspended particulate matter	80	NA	50 [8)]	70	g/GJ
PM10	76	NA	40 [8)]	67	g/GJ
PM2.5	72	NA	30 [8)]	65	g/GJ
Arsenic	4	NA	1	1	mg/GJ
Cadmium	1	NA	0,3	2	mg/GJ
Chromium	15	NA	2	3	mg/GJ
Copper	10	NA	3	5	mg/GJ
Mercury	9	0.01	0.1	0.8	mg/GJ
Nickel	10	NA	200	2	mg/GJ
Lead	100	NA	10	20	mg/GJ
Selenium	2	NA	NA	NA	mg/GJ
Zinc	150	NA	5	80	mg/GJ
Dioxins and furans	100	2	10	200	I-Teq ng/GJ
PAH Σ 1-4	45	NA	5	40	mg/GJ
Benzo(a)pyrene	13	NA	1	12	mg/GJ
Benzo(b)fluoranthen	17	NA	2	14	mg/GJ
Benzo(k)fluoranthen	9	NA	1	8	mg/GJ
Indeno(1,2,3-cd)pyrene	6	NA	1	6	mg/GJ
Carbon monoxide	200	20	40	300	g/GJ
Non methane VOC	20	2	5	60	g/GJ

1) Use this "Coal fuels" default for all raw coals
2) Use this "Gaseous fuels" default for natural gas, natural gas liquids, and liquefied petroleum gas (LPG), and other gaseous
3) Use this "Liquid fuels" default for burning oil (kerosene), gas oil (gas/diesel oil), fuel oil (residual oil, residual fuel oil) and other liquid fuels
4) Use this "Wood" default for wood, peat and similar wood fuels (wood wastes) and agricultural wastes use as fuels (straw, corncobs, etc)
5) NA - not applicable
6) 900 g/GJ of sulphur dioxide is adequate to 1.2 % S of coal fuel of lower heating value on dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.
7) 140 g/GJ of sulphur dioxide corresponds to 0.3 % S of liquid fuel of lower heating value 42 GJ/t. If data on the sulphur content exist use equation No (2); see: 4. SIMPLER METHODOLOGY Because the sulphur content of liquid fuels is defined also by national regulations, compilers of the emission inventory should consider the national standards for sulphur content as well as information on average sulphur content on the market, if available.
8) Proposed emission factor is more representative for heavy fuel oil; typical emissions from boilers burning light fuel oil would be about 10% of this value, see table 8.2c.

Table 8.2f Default emission factors for advanced coal combustion techniques <1MWth

Pollutant	Emission factors			Units
	Advanced stove	Manual boiler	Authomatic boiler	
Ammonia	NA [1)]	NA	NA	g/GJ
Sulphur dioxide	450 [2)]	450 [2)]	450 [2)]	g/GJ
Nitrogen dioxide	150	200	200	g/GJ
Total suspended particulate matter	250	150	80	g/GJ
PM10	240	140	76	g/GJ
PM2.5	220	130	72	g/GJ
Arsenic	1.5	4	0.5	mg/GJ
Cadmium	1	2	2	mg/GJ
Chromium	10	10	1	mg/GJ
Copper	15	15	8	mg/GJ
Mercury	5	6	8	mg/GJ
Nickel	10	15	2	mg/GJ
Lead	100	150	80	mg/GJ
Selenium	2	2	0.5	mg/GJ
Zinc	200	200	100	mg/GJ
Dioxins and furans	500	200	40	I-Teq ng/GJ
PAH Σ 1-4	510	290	50	mg/GJ
Benzo(a)pyrene	150	90	17	mg/GJ
Benzo(b)fluoranthen	180	110	18	mg/GJ
Benzo(k)fluoranthen	100	50	8	mg/GJ
Indeno(1,2,3-cd)pyrene	80	40	7	mg/GJ
Carbon monoxide	2000	1500	400	g/GJ
Non methane VOC	300	100	20	g/GJ

1) NA - not applicable

2) 450 g/GJ of sulphur dioxide is adequate to 0.6 % S of coal fuel of lower heating value on a dry basis 24 GJ/t and average sulphur retention in ash as value of 0.1. If data on the sulphur content exists use equation No (2), see: 4. SIMPLER METHODOLOGY.

Table 8.2g Default emission factors for advanced wood combustion techniques <1MW

Pollutant	Emission factors					Units
	Advanced fireplaces	Advanced stove	Pellet stove	Manual boiler	Authomatic boiler	
Ammonia	NA[1)]	NA[1)]	NA	NA	NA	g/GJ
Sulphur dioxide	20	20	20	20	20	g/GJ
Nitrogen dioxide	90	90	90	150	150	g/GJ
Total suspended particulate matter	250	250	80	80	70	g/GJ
PM10	240	240	76	76	66	g/GJ
PM2.5	240	240	76	76	66	g/GJ
Arsenic	0.5	0.5	0.5	1	0.5	mg/GJ
Cadmium	1.0	1.0	0.5	0.3	0.5	mg/GJ
Chromium	8	8	3	2	4	mg/GJ
Copper	2	2	1	3	2	mg/GJ
Mercury	0.4	0.4	0.4	0.5	0.6	mg/GJ
Nickel	2	2	2	200	2	mg/GJ
Lead	30	30	20	10	20	mg/GJ
Selenium	0.5	0.5	NA	NA	NA	mg/GJ
Zinc	80	80	80	5	80	mg/GJ
Dioxins and furans	300	300	50	300	30	I-Teq ng/GJ
PAH Σ 1-4	290	290	50	150	40	mg/GJ
Benzo(a)pyrene	100	100	15	50	12	mg/GJ
Benzo(b)fluoranthen	90	90	16	60	14	mg/GJ
Benzo(k)fluoranthen	40	40	10	20	8	mg/GJ
Indeno(1,2,3-cd)pyrene	60	60	9	20	6	mg/GJ
Carbon monoxide	4500	3000	500	3000	300	g/GJ
Non methane VOC	450	250	20	250	20	g/GJ

[1)] NA - not applicable

Table 8.2.h Default mercury emission factor speciation for different fuels

Fuel	Installation	Hg^0 (gas)	Hg^{+2}	Hg (partic.); Hg^{PM}
Hard Coal	Stove / Fireplaces	0.3	0.35	0.35
	Boiler manual fuelled - all SCI sectors	0.4	0.4	0.2
	Boiler autom. (stoker) - all SCI sectors	0.5	0.4	0.1
Biomass	Manual fuelled (stove boiler) - all SCI sectors	0.6	0.3	0.1
	Automatic fuelled- all SCI sectors	0.65	0.3	0.05
Liquid fuels	SCIs (all sectors) Light fuel oil	0.75	0.2	0.05
	SCIs AFF, Com-Inst Heavy fuel oil	0.65	0.35	0.1
Natural gas	SCIs (all sectors)	0.8	0.15	0.05

9 SPECIES PROFILES

See section 8.2 for reference emission factors for species profiles.

10 UNCERTAINTY ESTIMATES

Uncertainties of emission data result from the uncertainties related to both the emission factors and the statistical information on the activities covered by small combustion installations.

The uncertainty of emission factors from small combustion installation sources is a function of the combustion technique, calibration and sampling frequency of direct measurements, and how representative the tested installation is for the whole population of sources (often referred as a typical source). In addition some of the measurement standards and sampling systems used currently for small combustion installations were developed for large-scale installations. For that reason the typical range of the uncertainty of an individual measurement for small combustion installations is greater than in larger installations. Emissions caused by combustion of solid fuels in particular, depend on the combustion technique used, the type of installation and its maintenance, capacity and age. In addition also operation condition such as load, the period of combustion cycle - start-up, steady state and shut down conditions, as well as quality of fuels and the stability of its properties play an important role.

Experimental emission data sets (described in various reports referring to specific measurement campaigns, journal articles, modelling work, and compilations) which were used in this chapter to derive typical emission factors are often lacking detailed description/characterization of various parameters, e.g., data on fuel quality used, the operational parameters, and the methodology used to measure concentration of pollutants in the flue gases as well as methodology for emission factor calculation. In accordance with the quality rating of uncertainty estimation (Pulles T. at al., 2001) these uncertainties data could be estimated for each pollutant, fuels and techniques as presented in Table 10.1, where:

- A – an estimate based on a large number of measurements made at a large number of facilities that fully represent the sector
- B – an estimate based on a large number of measurements made at a large number of facilities that represent a large part of the sector
- C - an estimate based on a number of measurements made at a small number of representative facilities, or an engineering judgement based on a number of relevant facts
- D - an estimate based on single measurements, or an engineering calculation derived from a number relevant

Tab.10.1. Uncertainties rating of emission factors from small combustion installations

Pollutants	Gas and liquid fuels		Solid fuel			
			Manual fuelled		Automatic fuelled	
	Rating	Typical error range, %	Rating	Typical error range %	Rating	Typical error range %
Oxides of nitrogen	B	20 - 60	B	20 - 60	B	20 – 60
Sulphur dioxide	B	20 - 60	B	20 - 60	B	20 – 60
Ammonia	C	50 - 150	C	50 - 150	C	50 – 150
PM	C	50 - 150	C	50 - 150	C	50 – 150
Heavy metals [1)]	C	50 - 150	C	50 - 150	C	50 – 150
PAH	C	50 - 150	C	50 - 150	C	50 – 150
Dioxins	D	100-300	D	100 -300	D	100-300
CO	B	20 - 60	B	20 - 60	B	20 – 60
NMVOC	C	50 - 150	C	50 - 150	C	50 – 150

[1)] Uncertainty of evaluation of mercury emission factors for small of biomass combustion installations (manual and automatic fuelled appliances) was rated at 100 – 300% (D), Pye et al., (2005)

The table above gives a rough qualitative estimation of the typical uncertainty of default emission factors. The uncertainty estimation represents an application of qualitative data rating schemes for all pollutants in this chapter and main group of techniques. Any such qualitative summary is subjective and individual opinions may differ.

Activity data for fossil fuels for the sources covered in this chapter typically have higher uncertainties than those for other stationary combustion sources. For biomass fuels consumption estimates are less accurate than for fossil fuels, in particularly where self-supply and direct purchase from farmers prevail.

11 WEAKEST ASPECTS/PRIORITY AREAS FOR IMPROVEMENT IN CURRENT METHODOLOGY

The weakest aspects discussed here are mainly related to emission factors, but also to the estimation of activities.

11.1 Emission factors

Improvement of emission factors is necessary in order to obtain more accurate emission estimates for residential activities due to a wide variety of employed combustion techniques and different types of fuels used. Type of installation and fuel used is critical to emissions of air pollutants, especially in the case of coal and biomass combustion where high levels of pollutants such as TSP, CO, NMVOC and PAH come from incomplete combustion.

This improvement should focus on preparing individual emission factors for individual techniques currently used, both old and new. The emission factors of pollutants such as TSP, CO, NMVOC and PAH, affected by the poor performance of the used combustion technology, can be reduced by introducing measures (or new technologies) to improve combustion efficiency, although some pollutants, e.g., NO_x and heavy metals (Hg, Cd, As) might increase.

For particulate matter (especially fine fraction), PAHs, PCDD/Fs, NMVOCs, and heavy metals small combustion installations contribute a high proportion of total emission and generation of specified data for this source should be the priority. The fuel specific emission factors cited from different sources (Annex 1, table A1 1 – A1 48) are often not representative and refer to the typically observed range. Establishing a measurement program that would allow characterisation of techniques and fuels used as well as development of inventory for small sources should be of high priority. Such a program could also investigate national and regional specific parameters (climatic, cultural, level of control, etc.) relevant for emissions.

Emission factors are related usually to full load conditions. Due to common low load of the small combustion installations and a high number of start-ups per year (e.g up to 1,000 times a year for solid fossil fuels and biomass stoves with manual fuel charging) the emissions are higher in comparison to full load conditions.

In order to assess the relevance of start–ups and low load conditions, a detailed investigation should be performed for small combustion installation, in particular manual fuelled with capacity of below 1 MW_{th}.

Sampling methods developed for industrial and other larger combustion plants are not suitable for small residential sources, especially for particulate matter and particulate related pollutants like PAH, heavy metals and PCDD/F. Further work should be invested to clarify this influence as well as influence of laboratory conditions (mainly regarding to the natural and forced draught) with respect to the emission factors published.

11.2 Activities

Collecting more reliable information on actual consumption of biomass, in particular “virgin” wood, waste wood, and straw, is essential in order to improve the accuracy of emission estimates for this sector. Uncertainties also occur due to the fact, that fuel such as coal or wood can be also used as mixtures. Also methodologies for estimation of the quantity of contaminated/ treated wood combusted, crucial for PAH and dioxin emissions, have to be developed. The same is valid also for the assessment of the residential waste combusted in the residential sector.

Further work should be carried out to differentiate between fuel coal used in manual and automatic boilers with capacity below 1$MW_{th,}$ as well as to distinguish between various fuel wood types, e.g., log wood, chips and pellets.

Since the current international (and possibly a number of national) statistics do not represent this sector well, the establishment of a “communication line” with the respective agencies to discuss ways of improving collection and reporting of activity data in this sector should be considered.

12 SPATIAL DISAGGREGATION CRITERIA FOR AREA SOURCES

Spatial disaggregation of annual emissions when using top-down approach could be performed by using surrogate data. For the residential sector the emissions could be taken as proportional to the population density. Because in most countries the means of heating in residential greatly differs among urban and rural settlements and also among the regions (usually coal is much more used in traditionally mining regions), this approach could be taken only as a last resort. In general the following steps could be taken for disaggregation of the emissions from the residential sector (Loibel, 1993):

- Differentiated in spatial areas: administrative units, inhabited areas, settlement areas divided in low and high density populated
- Determination of per capita emission factor depending on population density, type of fuel and main installation types used in for each spatial area

If emissions have been determined by bottom-up energy modelling, the spatial disagreagation is straightforward.

For commercial/institutional sector emissions could be disaggregated according to the number of employees in the considered spatial unit. It has however to be checked that the number of employees are given as actually employed per spatial unit and not according to the headquarters site.

13 TEMPORAL DISAGGREGATION CRITERIA

Most heating related emissions covered in this chapter are released due to heating of buildings and are therefore released predominantly during the heating season. In the residential sector a smaller part of emissions are released year-round due to preparation of hot water. In agriculture crops drying and greenhouse heating is seasonal.

Building heating demand is related to ambient temperature and user behaviour. Influence of ambient temperature is correlated to heating degree-days, which could be found usually in publications of meteorological services for different towns/cities. The user behaviour is reflected in different load and emissions during workdays and weekends. Daily fluctuations of load depend also on combustion techniques, for instance manually feed stoves and boilers, and on working hours distribution, and are for that reason country specific.

14 ADDITIONAL COMMENTS

The default emission factors given in the tables in Section 8 are derived from various measurements, of which some are laboratory measurements and some are in-field measurements. In order to derive representative default emission factors from available data, expert judgement is necessary. This has taken into account the variations in fuels, technologies and firing practices as well as the various conditions due to national conditions, to the best of our current knowledge. The default emission factors are general and derived to be as representative as possible for real conditions with the current knowledge. More in-field measurement would improve the basis for and the quality of the default emission factors.

15 SUPPLEMENTARY DOCUMENTS

16 VERIFICATION PROCEDURES

Verification of the emissions can be undertaken by calculating the emissions using the default factors given in Section 8.1 of this chapter and comparing the results with a mean profile.

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ANNEX 1: COMPILATION OF EMISSION DATA

In this annex compilation of various emission data is given to enable users comparison with their own data.

Table A1 1 Emission factors for coal small combustion installations

Installation	*Pollutants*						
	g/GJ					*mg/GJ*	
	SO_2	*NOx*	*CO*	*NMVOC[1)]*	*VOC[1)]*	*PAH*	*BaP*
Domestic open fire	n.d	n.d	n.d.	14[1)]	n.d.	n.d.	n.d.
Domestic closed stoves	2) 420	75	1500	n.d.	60	n.d.	n.d.
	3) 104[1)]	8[1)]	709[1)]	n.d.	n.d.	n.d.	n.d.
Domestic boiler	4) 17.2[1)]	6.2[1)]	1.8[1)]	n.d.	0.02[1)]	n.d.	n.d.
Small commercial or institutional boiler	n.d.	n.d.	416[2)]	n.d.	n.d.	n.d.	0.1[2)]

Source: Hobson M., et al., 2003; [1)] none information about NMVOC and VOC standard reference usual CH_4 or C_3H_8 are used; [2)] Original data in g/kg; [3)] Original data in g/kg for recalculation H_u of 24 GJ/t (d.b.) was assumed; 4) coal stove; 5)-roomheater 12.5 kW, anthracite; 6)-boiler, bituminous coal; n.d.- no data;

Table A1 2 Emission factors for combustion of manufactured solid fuels

Installation	*Pollutants*						
	g/GJ					*Mg/GJ*	
	SO_2	*NO_x*	*CO*	*NMVOC[1)]*	*VOC[1)]*	*PAH*	*BaP*
Domestic open fire	2) n.d	n.d	n.d.	n.d.	5.0 – 20	n.d.	n.d.
Domestic closed stoves	3) n.d.	n.d.	121-275[2)]	10.5[2)]; 16.1[2)]	n.d.	n.d.	n.d.
	4) 75[2)] and 127[2)]	4[2)] and 7[2)]	1125[2)]; 1193[2)]	n.d.	n.d.	n.d.	n.d.
Domestic boiler	5) 371	382	12,400	n.d.	91	n.d.	n.d.
	6) n.d.	64-73	140-7,400	n.d.	0-500[7)]	n.d.	n.d.
Small commercial or institutional boiler	8) n.d.	35	270	n.d.	2[7)]	n.d.	n.d.

Source: Hobson M., et al., (2003; [1)] none information about NMVOC and VOC standard reference usual CH_4 or C_3H_8 are used; [2)] Original data in g/kg; 3) 10kW open fire, smokeless coal brands; 4)-stoves, charcoal and char briquettes; 4) 12.5kW roomheater, coke and manuf. briq.; 5)-UNECE TFEIP: Dutch fig. for coke use; 6)-UNECE TFEIP: Sweden, pellet boilers, 1.8-2MW; [7)] as THC: 8) UNECE TEFIP: Sweden, briquette boilers 1.8-2MW; n.d.- no data

Table A1 3 Range of emissions value from coal small appliances, which employ fixed bed combustion with counter-current techniques (manually fuelled)

Types of	*Efficie*	*Assort*	*Emissions factor of pollutants*

appliances	*ncy %*	*ment of fuel*	*CO G/GJ*	*SO_2[a)] g/GJ*	*NO_x G/GJ*	*TSP g/GJ*	*16 PAH g/GJ*	*B(a)P mg/GJ*	*VOC (C_3) g/GJ*
Standard stove	45 – 75	Un-assortment coal	3,500 – 12,500	200 – 800	100 – 150	700 – 900	20 – 40	200 – 600	500 – 700
Masonry stove	60 – 75		2500 – 11,000	200 – 800	100 – 200	600 – 1,200	15 – 25	150 – 350	400 – 800
Kitchen stove	40 – 60		3,600 – 11,000	200 – 800	50 – 150	300 – 1000	50 – 90	400 – 650	500 – 1100
Standard boiler	50 – 67		1,800 – 7,000	200 – 800	50 – 150	150 – 500	30 – 90	600 – 900	400 – 1200
Advanced boiler	76 – 82	Assort ment coal,	200 – 1,500	200 – 800	150 – 200	50 – 100	0.2 – 0.6	2 – 30	60 – 120

Source: Kubica, 2003/1; [a)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; this emission factors are for of sulphur content between 0.5% and 1.0% with oxidation efficiency of sulphur about 90%.

Table A1 4 Range of emissions from coal small appliances, which employ fixed bed combustion with co-current techniques (in principle automatic fuelled)

Types of appliances	*Efficiency %*	*Assortment of fuel*	*Emissions factor of pollutants*						
			CO g/GJ	*SO_2[a)] g/GJ*	*NO_x G/GJ*	*TSP g/GJ*	*16 PAH g/GJ*	*B(a)P mg/GJ*	*VOC (C_3) g/GJ*
Advanced boiler [b)]	76 – 80	Fine coal	2,800 – 1,100	250 – 750	150 – 200	50 – 200	0.2 – 0.8	3 – 50	100 – 250
Burners boiler	77 – 84	Fine coal	1,500 – 400	250 – 750	150 – 250	30 – 120	0.2 – 2.0	5 – 50	2 – 50
Stoker, retort boiler	77 – 89	5 – 25[c)] mm	120 – 800	130 – 350	150 – 300	30 – 60	0.1 – 0.7	1 – 20	1 – 50

Source: Kubica, 2003/1; [a)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; this emission factors are for of sulphur content between 0.5% and 1.0% with oxidation efficiency of sulphur about 90%; [b)] – manually fuelled; [c)] – for capacity above 50kW grain size 5 – 30 mm.

Table A1 5 Emission value of coal combustion in stove and small boilers derived from measurement campaign in Poland

Parameter	*Unit*	*Advance under-fire boiler 30 kW*		*Advance upper-fire, retort boiler*		*Stove 5.7 kW*	
		Coal J	*Coal W*	*50 kW*	*150 kW*	*Coal J*	*Coal W*
Thermal efficiency	%	67,8	70,9	82,9	82,0	54,7	51,2
CO	g/GJ	3939	2994	48	793	3271	2360
SO_2	g/GJ	361,6	282,8	347,8	131,5	253,0	211,0

NO_x as NO_2	g/GJ	190,3	162,3	172,9	160,0	81,2	104,0
VOCs (C_3)	g/GJ	514,2	483,1	6,1	4,8	486,0	700,0
Dust; TSP	g/GJ	227,0	294,0	267	30,0	523,0	720,0
16 PAHs	Mg/GJ	26688	29676	87,2	0,2	39500	32800
PCDD/F	Ng I-Teq/GJ	285.0	804.1	n.d.	n.d.	n.d.	n.d.

Source: Kubica, UN-ECE TFEIP, 2002/1; n.a. = no data

Table A1 6 Emission factors for advanced coal fire small boilers (< 1MW) in Poland. Voluntary standard requirements

Pollutants	***Advanced under-fire boilers; manual fuelled***	***Advanced upper-fire boilers, automatic fuelled***
	Emission factors (g/GJ)	
Carbon monoxide, CO	≤2000	≤1000
Nitrogen dioxide; NOx as NO_2	≤150	≤200
Sulphur dioxide; SO_2 [1)]	≤400	≤400
Dust; TSP	≤120	≤100
TOC [2)]	≤80	≤50
16 PAHs acc. EPA	≤1.2	≤0.8
Benzo(a)pyrene; B(a)P	≤0.08	≤0.05

Source: Kubica, 2003/1; Kubica, UN-ECE TFEIP, (2002/1); [1)] Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; this emission factors was established for sulphur content of content <0.6%; [2)] TOC is a sum of organic pollutants both in the gaseous phase, as well as on particles organic solvent soluble except $C_1 – C_5$ (Kubica 2003/1)

Table A1 7 Emission values of co-combustion of coal and wood in small and medium boilers in Poland

Parameter	***Unit***	***Automatic fuelled burner boiler 25 kW***		***Fluidized bed boiler 63 MW***		***Travelling grate combustion; 10 MW***		***Travelling grate combustion, 25 MW***	
		Coal	***80%m/m coal 20% wood***	***Coal***	***91% w/w coal 9% wood***	***Coal***	***92% w/w coal; 8% wood***	***Coal***	***97% w/w coal 3% dry sewage sludge***
Thermal efficiency	%	79.1	81.6	87.4	86.2	81.1	81.4	84.4	85.7
CO	g/GJ	254	333	35.2	41.5	120	63	23.8	24.7
SO_2	g/GJ	464	353	379	311	290	251	490	557
NO_x as NO_2	g/GJ	269	232	109	96	150	155	137	141
VOCs (C_3)	g/GJ	14.0	9.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Dust; TSP	g/GJ	50.3	37.6	6.6	7.7	735	948	133	111
16 PAHs	Mg/GJ	401	207	346	121	126	117	269	63

Source: Kubica, et al., 2003/2; n.d. = no data

Table A1 8 Emission factors for combustion of biomass; comparison between poor and high standard furnace design

Emissions	*Poor standard*	*High standard*
Excess air ratio, λ	2 – 4	1.5 – 2
CO; g/GJ	625 – 3125	13 – 156
CxHy[2)]; g/GJ	63 – 312	< 6
PAH; mg/GJ	62 – 6250	< 6.2
Particles, after cyclone; g/GJ	94 – 312	31 – 94

Source: van Loo, 2002; [1)] Original data in mg/m^3_o at 11% O_2, for recalculation H_u of 16 GJ/t and $10m^3$/kg of flue gases were assumed; [2)] none information about CxHy standard reference usual CH_4 or C_3H_8 are used

Table A1 9 Emission factors for pellet burners in Sweden

Type of the burners	*TSP (g/GJ)*	*CO_2 (%)*	*O_2 (%)*	*THC[1)] (g/GJ)*	*NOx (g/GJ)*	*Effect (kW)*
Pellet burner (continuous operation)						
Nominal effect	22	9.5	11.1	3	73	10.7
6kW capacity	4	6.0	14.6	78	70	6.2
6kW generated power*	28	4.8	15.8	31	68	6.2
3kW generated power	65	3.7	16.9	252	66	3.2
Pellet burner (electric ignition)						
Nominal effect	16	13.0	7.4	1	70	22.2
6kW generated power	64	9.1	11.3	60	64	6.1
6kW generated power+	-	10.6	9.7	41	174	6.3
3kW generated power	15	8.6	11.9	10	67	3.1

Source: Bostrom, 2002; [1)] none information about THC standard reference usual CH_4 or C_3H_8 are used
*High ventilation, [+] Wood with high ash content

Table A1 10 Emission factors for wood boiler in Sweden

Type of the burners	*TSP (g/GJ)*	*CO_2 (%)*	*O_2 (%)*	*THC[1)] (g/GJ)*	*CO (g/GJ)*	*NOx (g/GJ)*
Water cooled boiler						
Intermittent log burning	89	6.8	13.4	1111	4774	71
Water cooled boiler						
Operation using accumulator	103	8.3	11.8	1500	5879	67
Intermittent log burning	n.d.	5.6	13.4	4729	16267	28
Cold-start	2243	6.9	14.6	2958	8193	64

Source: Bostrom; (2002); [1)] none information about THC standard reference usual CH_4 or C_3H_8 are used; n.d.= no data

Table A1 11 Arithmetic average emission values for wood combustion. The data were collected from investigations in various IEA countries (Norway, Switzerland, Finland, UK and Denmark)

Techniques	*NO_X (g/GJ)*	*CO (g/GJ)*	*VOC [a)] (g/GJ)*	*THC as CH_4 (g/GJ)*	*Particles, TSP (g/GJ)*	*PAH (mg/GJ)*
Cyclone furnaces	333	38	2.1	n.d.	59	n.d.
Fluidized bed boilers	170	0	n.d.	1	2	4
Pulverised fuel burners	69	164	n.d.	8	86	22
Grate plants	111	1846	n.d.	67	122	4040
Stoker burners	98	457	n.d.	4	59	9
Wood boilers	101	4975	n.d.	1330	n.d.	30
Modern wood-stoves	58	1730	n.d.	200	98	26
Traditional wood-stoves	29	6956	671	1750	1921	3445
Fireplaces	n.d.	6716	520	n.d.	6053	105

Source: van Loo, (2002); [a)] none information about VOC standard reference usual CH_4 or C_3H_8 are used; n.d. – no data

Table A1 12 Arithmetic averages of emission value from biomass combustion in small-scale applications

Techniques	*Load [kW]*	*Excess air ratio*	*CO [g/GJ]*	*C_xH_y [a)] [g/GJ]*	*Part. TSP [g/GJ]*	*NO_X [g/GJ]*	*Temp. [^oC]*	*Efficiency [%]*
Wood – stoves	9.33	2.43	3116	363	81	74	307	70
Fire place inserts	14.07	2.87	2702	303	41	96	283	74
Heat storing stoves	13.31	2.53	1723	165	34	92	224	78
Pellet stoves	8.97	3.00	275	7	28	92	132	83
Catalytic wood-stoves	6.00	n.d.	586	n.d.	n.d.	n.d.	n.d.	n.d.

Source: van Loo, 2002; Original date in mg/m^3_o at 13% O_2, for recalculation H_u of 16 GJ/t and $10m^3$/kg of flue gases were assumed; [a)] none information about CxHy standard reference usual CH_4 or C_3H_8 are used; n.d. – no data

Table A1 13 Emissions from small industrial wood chips combustion applications in the Netherlands (g/GJ)

Type of operation	*Combustion principle*	*Draught control*	*Capacity kW*	*CO*	*CxHy [a)]*	*NO_x*	*TSP*	*Efficiency %*
Manual	Horizontal grate	Natural uncontrolled	36	1494	78	97	13	85
		Forced uncontrolled	34.6	2156	81	108	18	83.5
			30	410	13	114	21	90
Automatic	Stoker boiler	Forced controlled	~40	41	2	74	50	85.4
			320	19	2	116	32	89.1

Source: van Loo, 2002; Original date in mg/m^3_o at 11% O_2, for recalculation H_u of 16 GJ/t and $10m^3$/kg of flue gases were assumed; [a)] none information about CxHy standard reference usual CH_4 or C_3H_8 are used; n.d. – no data

Table A1 14 Emission value from biomass combustion in small-scale applications derived from measurement campaign in Poland

Techniques	*Capacity [kW]*	*SO_2 [g/GJ]*	*CO [g/GJ]*	*VOC as C_3 [g/GJ]*	*TSP [g/GJ]*	*NO_X [g/GJ]*	*16 PAH g/GJ*	*Efficiency [%]*
Wood – log, stoves	5.7	9.8	6290	1,660	1,610	69	33,550	64.4
Upper fire stocker, pellet combustion	25	29	200	21	9.9	179	71	80.4
Pellet burners	20.5	6.0	58.5	7.2	29.7	295	122	85.7
Gasifire, pre-oven	20.0	21.0	1226	6.8	15.6	78.9	480	83.9

Source: Kubica, et al., 2002/2

Table A1 15 Emission value of biomass combustion in small and medium boilers derived from measurement campaign in Poland

Parameter	*Unit*	*Straw fixed grate boiler 65 kW*		*Advance under-fire boiler 30 kW*		*Automatic boilers*	
						3,5 MW	*1,5 MW*
		Rape straw	*Wheat straw*	*Briquettes of sawdust*	*Lump pine wood*	*Mixture of cereal straws*	
Thermal efficiency	%	81.	84.2	81.3	76	90.1	84.3
CO	g/GJ	2230	4172	1757	2403	427	1484
SO_2	g/GJ	127,1	66,5	15,9	4,8	74,6	151,0
NO_x (as NO_2)	g/GJ	105,3	76,1	41,6	31,7	110,1	405,0
VOC (as C_3)	g/GJ	n.a.	n.a.	176,1	336,4	n.a.	n.a.
TSP	g/GJ	654,0	901,0	39,0	116,0	31,5	109,0
TOC [1)]	g/GJ	59,4	39,4	98,6	176,0	18,1	39,0
16 PAHs acc EPA	Mg/GJ	9489	3381	9100	9716	197	0,4
PCDD/F	ng I-TEQ/GJ	840.9	746.2	107.5	1,603	n.a.	n.a.

Source: Kubica, 2003/1; Kubica, UN-ECE TFEIP, (2002/1

Table A1 16 Emission factors for 1.75 MW and 2 MW boilers in Sweden

Fuel	*Effect (%)*	*O_2 (%)*	*CO (g/GJ)*	*THC (g/GJ)[a)]*	*CH_4 (g/GJ)*	*TSP (g/GJ)*	*NO_X (g/GJ)*	*NH_3 (g/GJ)*
Pellets	20	4	7400	500	400	43	17	6
Pellets	50	7	1600	17	<1	43	27	1
Pellets	100	4	140	<1	<1	32	37	<1
Briquettes	100	6.3	270	2	<1	36	35	<1
Logging residue	100	6.5	42	<1	<1	71	74	<1

Wood chips	100	7.2	3900	48	31	51	25	2

Source: Bostrom C-A, UN-ECE TFEIP (2002); [a] none information about CxHy standard reference usual CH_4 or C_3H_8 are used

Table A1 17 Emission factors for biomass small combustion installations

Installation	*Pollutants*						
	g/GJ					*mg/GJ*	
	SO_2	*NOx*	*CO*	*NMVOC*	*VOC*	*PAH*	*BaP*
Domestic open fire	n.d	n.d	4,000	n.d	90-800	13,937; 10,062; 7,937[1,2]	n.d
Domestic closed stoves	3) n.d.	29	7,000	1750[5]	670	3,500	n.d
	4) n.d.	58	1,700	200[5]	n.d	26	n.d
Domestic boiler	6) n.d.	101	5,000	1,330[5]	n.d	n.d	n.d
Small commercial or institutional boiler	7) n.d.	25	3,900	n.d	n.d.	n.d.	n.d.
	8) n.d	n.d.	n.d.	480	n.d	n.d.	n.d.
	9) n.d.	n.d.	n.d.	96	n.d.	n.d.	n.d.

Source: Hobson M., et al., 2003; [1] none information about NMVOC and VOC standard reference usual CH_4 or C_3H_8 are used [2] Original data in g/kg for recalculation H_u of 16 GJ/t was assumed and PAH that is ∑16 PAH; 3) traditional wood stove; 4) modern wood stove; [5] THC as CH_4; 6)-wood boilers; 7) wood chips boilers 1.8-2MW; 8) wood, charcoal, 120 kW boiler, benchmark; 9) wood, charcoal, 120kW, improved boiler; n.d.- no data

Table A1 18 Emission factors for domestic combustion processes (g/GJ) in the Netherlands

Pollutant	*Fuel*				
	Natural gas	*Oil*	*LPG*	*Petroleum*	*Coal*
VOC[1]	6.3	15	2	10	60
SO_2	0.22	87	0.22	4.6	420
N_2O	0.1	0.6	0.1	0.6	1.5
NOx (as NO_2)	57.5	50	40	50	75
CO	15.8	60	10	10	1500
CO_2	55920	73000	66000	73000	103000
TSP	0.3	5	10	2	200
PM10	0.3	4.5	2	1.8	120
Particles >PM10	-	0.5	-	0.2	80

Source: Hesling D., 2002; [1] none information about VOC standard reference - usual CH_4 or C_3H_8 are used

Table A1 19 Emission factors for small combustion installations of gas and oil fuels (g/GJ) derived from measurement campaign in Poland

Pollutant	*Fuel*							
	Natural gas				*Oil*			
	35 kW	*218 Kw*	*210 kW*	*650 kW*	*35 kW*	*195 kW*	*400 kW*	*650 kW*
NMVOC as C_3 [1]	8.9	7.8	6.2	0.6	5	4.2	10	2.1
SO_2 [1]	-	-	-	-	110	112	140	120.3
NOx (as NO_2) [1]	142	59,1	24.6	38.4	43	56.4	60	56.7

CO [1]	10.3	30.9	21.2	15.3	46	44	45	33.6
TOC [1]	5.5	6.4	4.2	4.5	25	20.8	15	7.5
SO_2 [2]	n.d.	-	-	-	115-145 aver.130	-	-	-
NOx (as NO_2) [2]	17 – 22 aver. 20	-	-	-	35 – 55 aver. 40	-	-	-
CO [2]	7 - 12 aver. 9	-	-	-	10-12 aver.11	-	-	-

Source: [1] Kubica et al., 1999; [2] Kubica et al., 2005/2 The measurements were done in the field; n.d. – no data

Table A1 20 Emission factors for small combustion installations of gas and oil fuels (g/GJ) derived from measurement campaign in Poland

Pollutant	*Fuel*						
	Natural gas					*Oil*	
	2.1 MW	*11.0 MW*	*5.8 MW*	*4.6 MW*	*2.3 MW*	*1.7 MW*	*2.2 MW*
NOx (as NO_2)	64	30	29	38	23	66	63
CO	3.1	0.0	0.0	3.6	0.4	0.0	1.4
SO_2	n.m.	n.m.	n.m.	n.m.	n.m.	105	69
TSP	n.m.	0.2	0.2	n.m.	0.1	n.m.	0.2

Source: Czekalski B et al., 2003

Table A1 21 Emission factors for gas fired small combustion installations

Installation	*Pollutants*						
	g/GJ					*mg/GJ*	
	SO_2	*NOx*	*CO*	*NMVOC* [1]	*VOC* [1]	*PAH*	*BaP*
Open fire	0.5	50	20	6	n.d.	n.d	n.d.
Close stoves	0.5	50	10	3	n.d.	n.d.	n.d.
Domestic boiler	0.2; 0.5	40.2; 57.5	8.5; 15.8	3.0; 15.0	5 – 30	n.d	1.5 [2]
Small commercial or institutional boiler	n.d.	n.d.	n.d.	1.0; 5.0	5.0	n.d.	0.1 [1] 38 [3]
Agricultural heater	0.22	65	10	n.d.	30	n.d.	n.d.
CHP Steam, gas turbine;	n.d.	179	43	2.1	n.d.	n.d.	n.d.

Source: Hobson M., et al., 2003; [1] none information about VOC standard reference usual CH_4 or C_3H_8 are used [1] Original data in mg/t for recalculation H_u of 35 GJ/t was assumed; [2] mg/1000xm^3; n.d. - no data

Table A1 22 Emission factors for LPG small combustion installations

Installation	*Pollutants*						
	g/GJ					*mg/GJ*	
	SO_2	*NOx*	*CO*	*NMVOC* [1]	*VOC* [1]	*PAH*	*BaP*
Open fire	None						
Close stoves	n.d.	n.d.	454 [1]	447 [1]	n.d	n.d	n.d
Domestic boiler	0.22	40	10	n.d.	2	n.d.	n.d.

Small commercial or institutional boiler	n.d.	n.d.	n.d.	n.d.	2	n.d.	n.d.
Agricultural heater	0.22	40	10	n.d.	2	n.d.	n.d.
CHP Steam, gas turbine;	None						

Source: Hobson M., et al., 2003; [1] none information about VOC standard reference usual CH_4 or C_3H_8 are used
[1] Original data in g/kg for recalculation H_u of 42 GJ/t was assumed; n.d.- no data

A1 23 Emission factors for burning oil (kerosene) small combustion installations

Installation	***Pollutants***						
	g/GJ					***mg/GJ***	
	SO_2	***NOx***	***CO***	***NMVOC[1]***	***VOC [1]***	***PAH***	***BaP***
Domestic open fire	None						
Domestic closed stoves	n.d.	n.d.	421[2]; 1,478[2]	354[2]; 1,457[2]	n.d	n.d	n.d
Domestic boiler	87	50	60	1.5; 7.5	15	n.d.	0.1
Small commercial or institutional boiler	n.d.	n.d.	n.d.	1.0; 5.0	n.d.	n.d.	n.d.
Agricultural heater	0.22	50	10	n.d.	10	n.d.	n.d.
CHP Steam, gas turbine;	None						

Source: Hobson M., et al., 2003; [1] none information about VOC standard reference usual CH_4 or C_3H_8 are used
[2] Original data in g/kg t for recalculation Hu of 42 GJ/t was assumed; n.d.- no data

Table A1 24 Emission factors for fuel oil small combustion installations

Installation	***Pollutants***							
	g/GJ						***Mg/GJ***	
	SO_2	***NOx***	***CO***	***PM10***	***NMVOC[1]***	***VOC[1]***	***PAH***	***BaP***
Domestic open fire	None							
Domestic closed stoves	None							
Domestic boiler	n.d.	n.d.	n.d.	8.0-50	n.d.	10	n.d.	0.08[2]
Small commercial or institutional boiler	[3] 449	62.4	15.6	3.1	n.d.	0.6	n.d.	n.d.
	[4] 467	61.4	15.4	18.5	n.d.	0.6	n.d..	n.d.
	[5] 488	169	15.4	26.4	n.d.	0.9	n.d.	n.d.
	n.d	n.d	n.d.	3-23	n.d.	8	n.d.	0.1[2]; 0.5[2]; 0.5[2]
Agricultural heater	n.d.	n.d.	n.d.		n.d.	n.d.	n.d.	0.08[2]
CHP [6]	n.d	186	14		2.1	6.8	n.d.	0.1[2]

Source: Hobson M., et al., 2003); [1)] none information about VOC standard reference, usual CH_4 or C_3H_8 are used; [2)] Original data in g/Mt for recalculation H_u of 42 GJ/t was assumed; [3)] 1.5 % of S; [4)] 4.5 % of S; [5)] 5.5 % of S; [6)] power station; n.d.- no data

Table A1 25 Emission of pollutants for gaseous, liquid and coal fuels for small combustion installations in Italy

Installation		***Pollutants***						
		g/GJ						
		SO_2	***NOx***	***CO***	***VOC[1)]***	***TSP***	***PM10***	***PM2.5***
Natural gas	Range	0.22-0.5	7.8-350	20-50	0.5-10	0.03-3	0.03-3	0.03-0.5
	Aver.	0.5	50	25	5	0.2	0.2	0.2
LPG	Range	9.7-150	30-269	20-40	0.1-15	0.2-50	0.2-50	0.2-50
	Aver.	100	50	20	3	5	5	5
Burning oil	Range	69-150	24-370	5-40	1.1-48	1.5-60	1.5-60	1.5-50
	Aver.	150	150	16	10	40	40	30
Coal	Range	60 – 2,252	45-545	100-5,000	3-600	70-350	10-400	30-200
	Aver.	650	150	2,000	200	150	140	70

Source: Caserini S. 2004; [1)] none information about VOC standard reference usual CH_4 or C_3H_8 are used

Table A1 26 Sectoral emission factors for firing appliances in Germany in the household and small consumer sectors, in 1995 (Pfeiffer et al. 2000)

Sector	***Fuel***	***Pollutants***				
		g/GJ				
		SO_2	***NOx as NO_2***	***CO***	***CO_2***	***TSP***
Household	High rank coal and products	456	51	4,846	95,732	254
	High rank coals	380	49	5,279	95,930	278
	Briquettes	561	54	4,246	95,457	221
	Coke from high rank coals	511	60	6,463	106,167	15
	Brown coal briquettes	261	71	3,732	96,021	86
	Natural wood	7	50	3,823	103,093	42
	Distillate oil	77	46	25	73,344	1.6
	Natural gas	0.5	38	14	55,796	0.03
Small consumers	High rank coal and products	419	108	564	95,930	278
	High rank coals	419	108	564	95,930	278
	Coke from high rank coals	370	61	1.498	106,167	12
	Brown coal briquettes	234	87	4.900	95,663	59
	Natural wood and wood wastes	9.1	78	2.752	101,099	45
	Distillate oil	77	47	14	73,344	1.7

	Residual oil	384	162	9.9	75,740	38
	Natural gas	0.5	31	11	55,796	0.03

Table A1 27 Emission factors of CO, NOx and SO_2 for advanced combustion techniques of coal and biomass

Source	*Installation/Fuel*	*Pollutants [g/GJ]*		
		SO_2	*NOx as NO_2*	*CO*
BLT, 2000/1	Wood boilers with two combustion chambers and sonar Lambda	n.d.	100	141
BLT, 2005/1	Wood pellets and chip boiler 25 kW 100%; 33% of capacity	n.d.	127; n.d.	186; 589
	Pellets and wood chips boiler 43 kW - 100% and 33% of capacity	n.d.	110; 71	60; 37
	Wood boiler 60 kW, air dry oak 100% and 33% of capacity	n.d.	79; n.d.	127; 720
	Boiler, wood chips 25kW 100% and 33% of capacity	n.d.	115; n.d.	23; 358
	Pellets boiler 46.7 kW 100% and 33% of capacity	n.d.	110; 118	118; 172
BLT, 2003	Pellets and briq., boiler 7.7 – 26 kW 100% and 33% of capacity	n.d.	67; n.d.	7; 44
BLT, 1999	Wood chips, boiler 500kW 100% and 33% of capacity	n.d.	123; n.d.	16; 126
BLT, 2004/1	Wood chips, boiler 20kW 100% and 33% of capacity	n.d.	44; n.d.	17; 108
BLT, 2004/2	Wood log and briq., boiler 50kW 100% and 33% of capacity	n.d.	109; n.d.	44; n.d.
BLT, 2000/2	Wood briq., chamber boiler 60 kW 100% and 33% of capacity	n.d.	88; n.d.	30; 120
BLT, 2005/2	Wood log, chamber boiler 27 kW	n.d.	78	131
Houck et al., 2001[1)]	Fireplaces; dry wood	n.d.	n.d.	4010
Hübner et al.,2005[1,2)]	Boiler < 50kW; Pelleted wood	n.d.	n.d.	120
	Boiler; Chopped wood log	n.d.	n.d.	790 – 1,400
	Boiler; Coke	n.d.	n.d.	2,400
	Boiler; Wood and coke	n.d.	n.d.	3,500
	Boiler; Wood, brown coal briquettes	n.d.	n.d.	4,200
	Boiler; Wood logs (beech, spruce)	n.d.	n.d.	3,800
	Boiler; Wood (beech, spruce), coke	n.d.	n.d.	2,100
	Stove; Wood, brown coal briquettes wood	n.d.	n.d.	2100
	Stove; Beach wood logs	n.d.	n.d.	2100 - 4,700
	Stove; Wood	n.d.	n.d.	1500
	Stove; Spruce wood (small logs)	n.d.	n.d.	2,400
	Stove; Wood (small logs)	n.d.	n.d.	1,600

	Stove; Wood briquettes	n.d.	n.d.	4,600
Johansson at al., 2001 [1)]	Pellet boilers with fixed grates with moving scrapes 1,75 – 2,5 MW	n.d.	30 - 50	20 - 100
Houck et al., 2000 [1)]	Conventional stove, cordwood	n.d.	n.d.	7,200
	Pellet stoves, softwood	n.d.	n.d.	1,400 – 1,630
	Pellets stove, hardwood	n.d.	n.d.	125; 188; 219
	Pellets boiler, top-feed, softwood	n.d.	n.d.	146; 449; 510
	Pellets boiler, bottom-feed softwood	n.d.	n.d.	112; 169
Boman et al., 2005	Pellet stove 4.8 kW (high load)	n.d.	31 – 36; aver. 33	52 – 100; aver. 88
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	29 – 33; aver. 31	243 – 383; aver. 299
	Natural-draft wood stove, 9 kW; Birch Pine Spruce	n.d.	37 – 71; aver. 50	1,200–7,700; aver. 3,800
	Pellet stove, 4- 9,5 kW; Pine and Spruce (high load)	n.d.	57 – 65; aver. 61	110 – 170; aver. 140
	Pellet stove, 4- 9,5 kW; Pine and Spruce (low load 30%)	n.d.	52 – 57; aver. 54	320 – 810; aver. 580
Kubica, 2004/2	Pellet boilers			
Kubica at al., 2005/4	Automatic fuelled coal boilers - stocker; Pea coal (qualified size)	120-450; aver. 260	96 – 260; aver. 190	90 – 850 aver. 280
	Automatic fuelled coal boilers; Fine coal (qualified coal size)	355–600 aver. 420	70 – 200 aver. 145	60 – 800 aver. 450
Kubica K.; 2004/1	Conventional stove 5kW	253	81	2272
Kubica, 2004/2	Boiler, stocker; wood pellets	n.d.	n.d.	300 – 500
	Chamber boiler, top feed; fine coal	250 - 700	100 - 150	1,100-2,800
	Automatic boiler, stocker; pea coal	130 - 350	100 - 250	120 – 800
	Automatic coal boiler; fine coal	250 - 700	100 - 250	400 – 1500
	Chamber boiler, advanced techniq.; qualified size coal	150 - 550	150 - 250	50 – 100
Kubica et al., 2005/1	Boilers with moving grate 5-32 MW	n.d.	116 - 137	10 – 24
	Boilers with moving grate 0.3 – 0.6MW	n.d.	146 - 248	36 – 363[4)]
	Automatic fuelled coal boiler, fine coal	n.d.	140	130
	Automatic fuelled coal boiler – stocker	n.d.	70 – 220	120 – 800
	Boiler, bottom feed, nut coals	n.d.	150 - 200	200 – 1500
	Boiler, top feed, nut coals	n.d.	50 - 150	1,800 – 3,500
	Boiler, bottom feed, log wood	n.d.	32	2403
	Boiler, bottom feed, wood briquettes	n.d.	42	1757
	Automatic fuelled boiler – stocker 30 kW, pellets	n.d.	200	200
	Automatic fuelled boiler, wood chips	n.d.	150	880

Kubica at al., 2005/2[3)]	Automatic fuelled coal boiler – stocker, ≤25 kW (120 pieces); Pea coal	n.d.	67 – 207; aver. 161	104 – 320; aver. 150
	Automatic fuelled coal boiler, ≤35 kW (68 pieces); Fine coal,	155– 496 aver. 252	64 – 208; aver. 122	119 – 435; aver. 232

[1)] Original factors in g/kg of fuels, for recalculation H_u of 24 GJ/t (d.b.) for hard coal was, of 17 GJ/t (d.b.) for lignite and brown coal, of 30 GJ/t (d.b.) for anthracite, of 30 GJ/t (d.b.) for coke; of 16 GJ/t for wood, of 42 GJ/t for oil and of 35 GJ/t for natural gas were assumed; [(2)] Capacity of all boilers < 50kW and all stove <10kW; [3)] A measurements was done in the field; n.d. – no data

Table A1 26 Wood Burning Appliance Emission Factors in British Columbia (Gulland, 2003)

Installation	***Pollutants [1)]***						
	g/GJ						
	SO_2	***NOx***	***CO***	***VOC[1)]***	***TSP***	***PM10***	***PM2.5***
Fireplace							
Conventional With Glass Doors	12.5	87.5	6,162.5	1,312.5	843.75	812.5	806.25
Convent. Without Glass Doors	12.5	87.5	4,856.3	406.3	1,206.3	1,156.3	1,156.3
Advanced Technology	12.5	87.5	4,400	437.5	318.75	300	300
Insert; Conventional	12.5	87.5	7,212.5	1,331.3	900	850	850
Insert; Catalytic	12.5	87.5	4,400	437.5	318.8	300	300
Insert; Advanced Technology	12.5	87.5	4,400	437.5	318.8	300	300
Woodstove							
Conventional	12.5	87.5	6,250	2,218.8	1,537.5	1,450	1,450
Conventional, Not Air-Tight	12.5	87.5	6,250	2,218.8	1,537.5	1,450	1,450
Conventional, Air-Tight	12.5	87.5	7,212.5	1,331.3	900	850	850
Advanced Technology	12.5	87.5	4,400	437.5	318.8	300	300
Catalytic	12.5	87.5	4,400	437.5	318.8	300	300
Pellet Stove	12.5	87.5	550	94	75	69.7	64
Boilers							
Central Furnace/ Boiler (inside)	12.5	87.5	4,281.3	1,331.3	881.3	831.3	831.3
Central Furnace/ Boiler (outside)	12.5	87.5	4,281.3	1,331.3	881.3	831.3	831.3
Other Equipment	12.5	87.5	7,212.5	1,331.3	900	850	850

[1)] Original factors in kg/tonne of fuels, for recalculation H_u of 16 GJ/t for wood was assumed

Table A1 29 Emission factors for particulate matter reported in the literature for coal and manufactured solid fuels combustion [g/GJ]

Source	*Installation type*	*PM2.5*	*PM10*	*TSP*
BUWAL, 2001 [1)]	Small furnaces	n.d.	110	270
	Domestic boiler	n.d.	90	150
CEPMEIP, 2002 [1)]	Residential, brown coal	70	140	350
	Residential, hard coal ('high')	60	120	300
	Residential, hard coal ('low')	25	50	100
	Residential, low grade hard coal	100	200	800
Pfeiffer et al., 2000 [1)]	Residential, hard coal	n.d.	n.d.	260 – 280
	Residential, brown coal briquettes	n.d.	n.d.	120 – 130
	Residential, coke	n.d.	n.d.	14
Spitzer et al., 1998 [1)]	Residential heating	n.d.	n.d.	153±50%
	Single family house boiler, stoves	n.d.	n.d.	94±54%
Winiwarter et al, 2001 [1)]	Residential plants	75	85	94
	Domestic stoves, fireplaces	122	138	153
UBA, 1999a [1)]	Domestic furnaces, hard coal	n.d.	n.d.	250
	Domestic furnaces, brown coal	n.d.	n.d.	350
EPA, 1998a [1)]	Small boilers, top loading	n.d.	n.d.	291
	Small boilers, bottom loading	n.d.	n.d.	273
	Hard coal, stoker firing	n.d.	n.d.	1,200
	Pulverized lignite boilers	n.d.	n.d.	1,105
Meier & Bischoff, 1996 [1)]	Grate firing, lignite	n.d.	n.d.	2,237
Hobson M. et al, 2003	Domestic open fire; <10 kW, coal	n.d.	375[2)]-459[2)]	n.d.
	Domestic open fire; <10 kW, smokeless coal brands	n.d.	38-67[2)]	n.d.
	Domestic open fire; <10 kW, pet coke blends	n.d.	96-117[2)]	n.d.
	Domestic open fire; <5 kW coal	n.d.	1,683[2)]	n.d.
	Domestic closed stove; US EPA, developing stoves charcoal	n.d.	n.d.	100[2)]
	Domestic closed stove; US EPA, developing stoves char briquette	n.d.	n.d.	121[2)]
	Domestic closed stove; CRE; <10 kW, smokeless coal brands	n.d.	42-50[2)]	n.d.
	Domestic closed stove; CRE; <10 kW, pet coke blends	n.d.	108-133[2)]	n.d.
	Domestic boilers; ERA research, Boiler Efis, bituminous coal	n.d	250[2)]	n.d.
	Domestic boilers; UNECE TFEIP, Dutch figures for coke use	n.d.	6	n.d.
	UNECE TFEIP; Sweden, briquette boilers 1.8-2 MW	n.d.	n.d.	36
Kubica, 2004/1	Conventional stove 5kW	n.d.	n.d.	523
	Chamber boiler, top feed; fine coal	n.d.	n.d.	50 - 200

Source	*Installation type*	*PM2.5*	*PM10*	*TSP*
Kubica, 2004/2	Automatic fuelled coal boiler, stocker	n.d.	n.d.	30 - 60
	Automatic fuelled boiler, fine coal	n.d.	n.d.	30 - 120
	Chamber boiler, qualified size coal; distribution of combustion air	n.d.	n.d.	50 - 150
Kubica et al., 2005/1	Boilers with moving grate 5-32 MW	n.d.	n.d.	58 - 133
	Boilers with moving grate 0.3 – 0.6MW	n.d.	n.d.	51 - 64
	Automatic fuelled coal boiler, fine coal	n.d.	n.d.	50
	Automatic fuelled coal boiler – stocker	n.d.	n.d.	30 - 60
	Boiler, bottom feed, nut coals	n.d.	n.d.	50 - 100
	Boiler, top feed, nut coals	n.d.	n.d.	300 - 1100
Kubica at al., 2005/2 [3)]	Automatic fuelled coal boiler – stocker, 25 kW (120 pieces)	n.d.	n.d.	54- 133 aver. 78
	Automatic fuelled coal boiler, fine coal, 25 and 35 kW (68 pieces)	n.d.	n.d.	70 – 380 aver. 187
Kubica et al., 2005/3	Hard coal; stoves and boilers < 1MW	25-100 aver.65	25-1050 aver.270	30-1,200 aver.360
	Hard coal; boilers > 1MW <50MW	70-122 aver.70	90-250 aver.110	25-735 aver.140
	Brown coal Residential/Commercial/Institutional/	140	260	350
	Coke Residential/Commercial/Institutional/	30 -80 aver.80	96-108 aver.90	14-133 aver.110
Krucki A. et al., 2006 [2)]	Automatic fuelled coal boiler – stocker, 100 kW	n.d.	n.d.	98
	Automatic fuelled coal boiler, fine coal, 25 kW	n.d.	n.d.	13
	Automatic fuelled coal boiler, fine coal, 90 kW	n.d.	n.d.	16
Lee et al., 2005 [2)]	Open fire place	n.d.	1,200	n.d.

[1)] as quoted in Klimont et al., 2002; 2) Original data in g/kg for recalculation Hu of 24 GJ/t (d.b.) was assumed.
[3)] The measurements were done in the field; n.d. – no data

Table A1 30 Particulate matter size fractions reported in the literature for coal combustion [percent of TSP emissions]

Source	*Installation type*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
UBA, 1999a [1)]	Domestic furnaces, hard coal	n.d.	90 %	100 %
EPA, 1998a [1)]	Small boilers, top loading	14 %	37 %	100 %
	Small boilers, bottom loading	25 %	41 %	100 %
Hlawiczka et al., 2002	Domestic furnaces, hard coal	n.m.	76 %[2)]	100 %

[1)] as quoted in Klimont et al., 2002
[2)] Original data 76 % of PM was emitted as the size fractions up to 12 µm.

Table A1 31 Particulate matter emission factors reported in the literature for wood burning [g/GJ]

Source	*Installation type*	$PM_{2.5}$	PM_{10}	*TSP*
BUWAL, 2001 [1)]	Domestic open fire places	n.d.	150	150
	Domestic furnaces	n.d.	150	150
	Domestic small boilers, manual	n.d.	50	50
	Small boilers, automatic loading	n.d.	80	80
Karvosenoja, 2000 [1)]	Domestic furnaces	n.d.	n.d.	200 – 500
Dreiseidler, 1999 [1)]	Domestic furnaces	n.d.	n.d.	200
Baumbach, 1999 [1)]	Domestic furnaces	n.d.	n.d.	50 – 100
Pfeiffer et al., 2000 [1)]	Residential and domestic	n.d.	n.d.	41-65
CEPMEIP, 2002 [1)]	'High emissions'	270	285	300
	'Low emissions'	135	143	150
Winiwarter et al, 2001 [1)]	Residential plants	72	81	90
	Domestic stoves, fireplaces	118	133	148
NUTEK, 1997 [1)]	Single family house boiler, conventional	n.d.	n.d.	1,500
	Single family house boiler, modern with accumulator tank	n.d.	n.d.	17
Smith, 1987 [1)]	Residential heating stoves <5 kW	n.d.	n.d.	1,350
	Residential cooking stoves <5 kW	n.d.	n.d.	570
BUWAL, 1995 (1992 Swiss limit value) [1)]	up to 1 MW	n.d.	n.d.	106
Spitzer et al., 1998 [1)]	Residential heating	n.d.	n.d.	148±46%
	Single family house boiler, stoves	n.d.	n.d.	90±26%
Zhang et al., 2000 [1)]	Firewood in China	n.d.	n.d.	760-1,080
Houck and Tiegs, 1998/1 [3)]	Conventional stove	n.d.	n.d.	1,680
	Conventional stove with Densified Fuel	n.d.	n.d.	1,200
	Non-catalytic stove	n.d.	n.d.	490
	Catalytic stove	n.d.	n.d.	440
	Masonry Heater	n.d.	n.d.	250
	Pellet stove	n.d.	n.d.	130
	Fireplace, conventional	n.d.	n.d.	8,600
	Double-Shell Convection, Nat. Draft	n.d.	n.d.	4,600
	ConvectionTubes, "C" Shaped, Glass Door	n.d.	n.d.	4,000
	Double-Shell Convection, Blower, Glass Doors	n.d.	n.d.	1,900
	Masonry Fireplace with Shaped Fire Chambers and Gladd Doors	n.d.	n.d.	1,200
	Fireplace, non-catalytic insert	n.d.	n.d.	500
	Fireplace, catalytic insert	n.d.	n.d.	450
	Fireplace, pellet insert	n.d.	n.d.	130
EPA, 1998b [(1,2)]	Open fireplaces	n.d.	805	875
	Wood stove	n.d.	724	787

Source	***Installation type***	$PM_{2.5}$	PM_{10}	***TSP***
Hobson M. et al, 2003	UNECE TFEIP,Sweden, wood chips boilers 1.8-2 MW	n.d.	n.d.	51
	Open fire <5kW, seas. Hardwood[2)]	n.d.	494	n.d.
	Domestic open fire: hundreds of sources studies[2)]	n.d	n.d.	738
CITEPA, Paris, 2003	Open fire places	698	713	750
	Conventional closed fireplaces and inserts	288	295	310
	Conventional closed stoves and cooking	288	295	310
	Hand stoked log wood boiler	233	238	250
	Automatically stoked wood boiler	9	10	10
EPA, 1998a [4)]	Boilers, bark	n.d.	n.d.	2,266
Lammi et al., 1993 [4)]	Fluidized bed in large boilers	n.d.	n.d.	1,000-3,000
	Grate firing in large boilers	n.d.	n.d.	250-1,500
Tullin et al.; 2000	Wood/pellet boilers and stoves	n.d.	n.d.	50
	Old wood boiler	n.d.	n.d.	1,000
Hays et al. (2003) [2)]	Wood stove	143.8 – 637.5	n.d.	n.d.
	Fireplaces	537.5	n.d.	n.d.
BLT, 2000/1	Wood boilers with two combustion chambers and sonar Lambda	n.d.	n.d.	20
BLT, 2005/1	Wood pellets and chip boiler 25 kW	n.d.	n.d.	14
	Pellets and wood chips boiler 43 kW - 100% and 33% of capacity	n.d.	n.d.	23; 9
	Wood boiler 60 kW	n.d.	n.d.	28
	Boiler, wood chips 25kW	n.d.	n.d.	18
	Pellets boiler 46.7 kW- 100% and 33% of capacity	n.d.	n.d.	5; 12
BLT, 2003	Pellets and briq., boiler 7.7 – 26 kW	n.d.	n.d.	4
BLT, 1999	Wood chips, boiler 500kW	n.d.	n.d.	28
BLT, 2004/1	Wood chips, boiler 20kW	n.d.	n.d.	8
BLT, 2004/2	Wood log and briq., boiler 50kW	n.d.	n.d.	16
BLT, 2000/2	Wood briq., chamber boiler 60 kW	n.d.	n.d.	10
BLT, 2005/2	Wood log, chamber boiler 27 kW	n.d.	n.d.	12
McDonald et. al., 2000 [2)]	Fireplaces	As PM2.5.	n.d.	180 – 560; aver. 380
	Woodstove	n.d.	n.d.	140 – 450; aver. 270
Lee et al., 2005 [2)]	Open fire place	n.d.	425	n.d.
Gullet et al., 2003	Fireplace, Pine	n.d.	n.d.	147
	Fireplace, Artificial logs (wax and sawdust)	n.d.	n.d.	483
	Stove, Oak	n.d.	n.d.	504
Fine et al.; 2002 [2)]	Fireplaces; Hardwood - Yellow Poplar	n.d.	n.d.	425 ± 50
	Fireplaces; Hardwood - White Ash	n.d.	n.d.	206 ± 19

Source	***Installation type***	***PM$_{2.5}$***	***PM$_{10}$***	***TSP***
	Fireplaces; Hardwood - Sweetgum	n.d.	n.d.	218 ± 25
	Fireplaces; Hardwood - Mockernut Hickory	n.d.	n.d.	425 ± 56
	Fireplaces; Softwood - Loblolly Pine	n.d.	n.d.	231 ± 25
	Fireplaces; Softwood - Slash Pine	n.d.	n.d.	100 ± 19
Fine et al.; 2001 [2)]	Conventional masonry fireplaces; Hardwood - Red Maple Northern	n.d.	n.d.	206 ± 19
	Conventional masonry fireplaces; Hardwood - Red Oak	n.d.	n.d.	356 ± 19
	Conventional masonry fireplaces; Hardwood – Paper Birch	n.d.	n.d.	169 ± 19
	Conventional masonry fireplaces Softwoods - Eastern White Pine	n.d.	n.d.	713 ± 125
	Conventional masonry fireplaces Softwoods - Eastern Hemlock	n.d.	n.d.	231 ± 25
	Conventional masonry fireplaces Softwoods - Balsam Fir	n.d.	n.d.	300 ± 31
	Fireplaces; wood	170 -710	n.d.	n.d.
Boman et al., 2004	Pellet burner boilers 10-15 kW, overfeeding of the fuel; Sawdust, Logging Residues and Bark	n.d.	n.d.	114-377 aver. 240
	Pellet burner boilers 10-15 kW, horizontal feeding of the fuel; Sawdust, Logging Residues and Bark	n.d.	n.d.	57-157 aver. 95;
	Pellet burner boilers 10-15 kW, underfeeding of the fuel; Sawdust, Logging Residues and Bark	n.d.	n.d.	64-192 aver. 140
Broderick et al. 2005 [2)]	All masonry and factory-built (zero clearance)	n.d.	n.d.	590
	Fireplaces, all cordwood	n.d.	n.d.	810
	Fireplaces, all dimensional lumber	n.d.	n.d.	410
	Fireplaces, all with closed doors	n.d.	n.d.	350
	Fireplaces, all with open doors	n.d.	n.d.	690
	Fireplaces, all masonry fireplaces	n.d.	n.d.	660
	Fireplaces, all factory-built fireplaces	n.d.	n.d.	580
	Fireplaces, cordwood, factory-built, open doors	n.d.	n.d.	870
	Fireplaces, dimensional lumber, factory built, open doors	n.d.	n.d.	510
	All fireplaces, all wood types	n.d.	n.d.	Aver. 590
	All factory-built fireplaces with open door, cordwood	n.d.	n.d.	Ave. 840
Gaegauf et al., 2001	Wood roomheaters	n.d.	n.d.	70 ± 25
	Wood accumulating stoves	n.d.	n.d.	167 ±44
	Wood log boilers	n.d.	n.d.	28 ±11
	Pellet boilers	n.d.	n.d.	20 ±0.4
	Pellet roomheaters	n.d.	n.d.	54 ± 3

Source	*Installation type*	$PM_{2.5}$	PM_{10}	*TSP*
	Wood chip boilers - dry fuel	n.d.	n.d.	94 ± 13
	Wood chip boilers - wet fuel	n.d.	n.d.	48 ± 6
	Wood chip boilers - residuals	n.d.	n.d.	64 ± 7
Johansson at al., 2001 [7)]	Pellet boilers with fixed grates with moving scrapes 1,75 – 2,5 MW	n.d.	n.d.	35 – 40
Nussbaumer, 2001 [2)]	All automatic wood furnaces	n.d.	n.d.	< 110
	Understoker furnaces	n.d.	n.d.	< 55
	Log wood boilers	n.d.	n.d.	34
	Wood chips boiler [5)]	n.d.	n.d.	68
	Wood residues, boiler [5)]	n.d.	n.d.	70
	Urban waste wood, boiler [6)]	n.d.	n.d.	1.5
Houck et al., 2000 [2)]	Conventional stove, cordwood	n.d.	n.d.	750
	Pellet stoves, softwood	n.d.	n.d.	80 – 170
	Pellets stove, hardwood	n.d.	n.d.	125; 190;220
	Pellets boiler, top-feed, softwood	n.d.	n.d.	27.5; 37.5; 62.5
	Pellets boiler, bottom-feed softwood	n.d.	n.d.	16.3; 25.0
Houck et al., 2005 [2)]	Conventional Stove Woodstove	890	n.d.	n.d.
	Catalytic Certified Woodstove	430	n.d.	n.d.
	Noncatalytic Certified Woodstove	330	n.d.	n.d.
	Pellet Stove Exempt	160	n.d.	n.d.
	Certified Pellet stove	160	n.d.	n.d.
Boman et al., 2005	Pellet stove 4.8 kW (high load)	n.d.	n.d.	11 – 20 aver. 15
	Pellet stove 4.8 kW (low load 2.3 kW)	n.d.	n.d.	32 – 81 aver. 51
	Natural-draft wood stove, 9 kW; Birch Pine Spruce	n.d.	n.d.	37 – 350 aver. 160
	Pellet stove, 4- 9,5 kW; Pine and Spruce (high load)	n.d.	n.d.	15 – 17; aver. 16
	Pellet stove, 4- 9,5 kW; Pine and Spruce (low load 30%)	n.d.	n.d.	21 – 43 aver. 34
Krucki et al., 2006 [(2)]	Biomass boiler, two stage combustor 95 kW, log wood	n.d.	n.d.	34
	Biomass boiler, two stage combustor 22 kW, log wood	n.d.	n.d.	13
Kubica, 2004/1	Conventional stove 5kW	n.d.	n.d.	1,610
Kubica, 2004/2	Pellet burner/boilers	n.d.	n.d.	20 – 60
	Chamber boiler (hand fuelled), log wood	n.d.	n.d.	70 – 175
Kubica et al., 2005/1	Boiler, bottom feed, log wood	n.d.	n.d.	116
	Boiler, bottom feed, wood briquettes	n.d.	n.d.	39
	Automatic fuelled boiler – stocker 30 kW, pellets	n.d.	n.d.	6
	Automatic fuelled coal boiler, wood chips	n.d.	n.d.	60

Source	***Installation type***	$PM_{2.5}$	PM_{10}	***TSP***
Kubica et al., 2005/3	Residential/Commercial/Institutional/	9-698 aver.450	10-713 aver.490	17-4000 aver.520
	Boilers > 1MW <50MW	9-170 aver.80	60-214 aver.80	20-500 aver.100
Hedberg et al., 2002 [2)]	Commercial soapstone stove, birch logs	6 – 163 aver. 81	n.d.	n.d.
Johansson et al, 2006	Single family house boiler, modern with accumulator tank	n.d.	n.d.	26-450
Johansson et al, 2006	Single family house boiler, conventional	n.d.	n.d.	73-260
Johansson et al, 2004 a	Single family house boiler, modern with accumulator tank	n.d.	n.d.	23-89
Johansson et al, 2004 a	Single family house boiler, conventional	n.d.	n.d.	87-2200
Johansson et al, 2006	Single family house boiler, conventional	n.d.	n.d.	73-260
Johansson et al, 2004 a	Pellets burners/boiler	n.d.	n.d.	12-65
Ohlström, 2005	Wood log stove	90 [8)]	n.d.	100
	Sauna	190 [8)]	n.d.	200
	Pellets burner	70 [8)]	n.d.	n.d.
	Pellets burner	25 [8)]	n.d.	35
	Wood chips/pellets boiler 30-50 kW	15 [8)]	n.d.	20
	Wood chips boiler 30-50 kW	10 [8)]	n.d.	20
	Pellets boiler 30-50 kW	10 [8)]	n.d.	15
	Wood chips/pellets stoker[6] 50-500 kW	20 [8)]	n.d.	40
	Wood chips stoker 30-500 kW[6]	30 [8)]	n.d.	50
	Pellets stoker 50-500 kW[6]	10 [8)]	n.d.	20
	Wood chips grate boiler 5-20 MW	20-55 [6)]		
	Wood chips Fluidized bed 20-100 MW	2-20 [7)]		
	Wood chips grate boiler 20-100 MW[7]	3-10		
	Wood chips grate boiler 10 MW[6]	3 [8)]	n.d.	10
Paulrud et al. 2006.	Wood log stove	n.d	n.d	22-181
Johansson et al, 2004b	Pellets stove	30-55	30-58	n.d.
	Pellets burner/boiler	10-60	10-75	n.d.
Glasius et al, 2005	Wood stove	n.d.	n.d.	200-5500
Schauer et. al., 2001	Open fire place	330-630	n.d.	n.d.
Purvis et. al., 2000	Open fire place	n.d.	n.d.	170-780
Wierzbicka, 2005	Moving grate 1.5 MW Saw dust, low load	36 [6,8)]	n.d.	
	Moving grate 1.5 MW Saw dust, Medium load	28 [6,8)]	n.d.	
	Moving grate 1.5 MW Saw dust, high load	25 [6,8)]	n.d.	n.d.
	Moving grate 1.5 MW pellets, low load	20 [6,8)]	n.d.	n.d.

Source	*Installation type*	*PM2.5*	*PM10*	*TSP*
	Moving grate 1.5 MW pellets, medium load	19 [6, 8)]	n.d.	n.d.
	Moving grate 1 MW forest residue, medium load	676 [6,8)]	n.d.	n.d.
	Moving grate 1 MW forest residue, high load	57 [6,8)]	n.d.	n.d.
Strand. et al, 2004	Moving grate 6 MW forest residue, high load	43 [6,8)]	n.d.	n.d.
	Moving grate 12 MW forest residue, high load	77 [6,8)]	n.d.	n.d.
	Moving grate 0.9 MW pellets, low load	10 [6, 8)]	n.d.	n.d.

[1)] as quoted in Klimont et al., 2002; [(2)] Original factors in lb/ton or in g/kg for recalculation H_u of 16 GJ/t were assumed; [3)] Original factors are estimated per Unit of Heat Delivered no conversion was made; [4)] The data for large scale combustion for illustration only; [5)] Cyclone separator-dust control; [6)] Filter separator-dust control; [7)] PM mainly 0.1-0.3 µm; [7)] Typically more than 80 % of all particles are smaller than 1 µm. The mean particle size is typically around 0.1 µm (between 50 nm to 200 nm); [8)] Measured as PM1 n.d. – no data

!!! Yellow color indicates the data obtained from Karin and Susanne. Because I didn't receive complete description of references (Name, year, title and source) I could not to add them to point 7 References. May be some of them are the same as I introduced. **References are added (SP)!!!**

Table A1 32 Particulate matter size fraction distribution reported in the literature for wood burning [percent of TSP emissions] (as quoted in Klimont et al., 2002)

Source	*Sector*	*PM2.5*	*PM10*	*TSP*
Dreiseidler, 1999	Domestic furnaces	n.d.	90 %	100 %
	Wood pellets	84.4 %	94.6 %	100 %
EPA, 1998b[1)]	Residential wood except for pellet stove	93 %	97 %	100 %
Baumbach, 1999	Domestic furnaces	96 %	99.7 %	100 %
UMEG, 1999	Small boilers	79 %	92 %	100 %

[1)] Houck et al., 1998

Table A1 33 Particulate matter emission factors used in RAINS for wood burning in Europe [g/GJ] (as quoted in Klimont et al., 2002)

Sector	*PM2.5*	*PM10*	*TSP*
Eastern Europe			
Fireplaces, stoves	279	288	300
Small domestic boilers	93 – 230	96 – 240	100 – 250
Large residential boilers	77 – 150	89 – 0.180	100 – 200
Industry [1)]	185	214	240
Western Europe			
Fireplaces, stoves	67 – 186	70 – 192	72 – 200
Small domestic boilers	60 – 167	62 – 170	65 – 180
Large residential boilers [1)]	50 – 120	60 – 134	65 – 150

Industry [1)]	185	214	240

[1)] The data are enclosed for illustration

Table A1 34 Particulate matter emission factors reported in the literature for stationary combustion of heavy fuel oil [g/GJ]

Source	*Sector*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
UBA, 1989 [1)]	Residential	n.d.	45	50
UBA, 1998 [(2)]	Residential	n.d.	8-27	9-30
CEPMEIP, 2002 [1)]	Residential	40	50	60
Pfeiffer et al, 2000 [1)]	Residential	n.d.	n.d.	38
Lammi et al, 1993 [1)]	5-50 MW	n.d.	n.d.	25-150
Ohlström, 1998 [1)]	5-50 MW	n.d.	n.d.	1-390 [(4)]
Berdowski et al., 1997 [1)]	Residential	30	50	n.d.
Hobson M. et al, 2003	Small com. or institutional boilers; ERA research; boiler 1.5% S	n.d.	3.1	n.d.
	Small com. or institutional boilers; ERA research; boiler 4.5% S	n.d.	18.5	n.d.
	Small com. or institutional boilers; ERA research; boiler 5.5% S	n.d.	26.4	n.d.

[1)] as quoted in Klimont et al., 2002;
[2)] as quoted in Dreiseidler et al., 1999;
[3)] as quoted in Berdowski et al., 1997;
[4)] Average value 32 g/GJ.

Table A1 35 Particulate matter size fraction distributions reported in the literature for stationary combustion of heavy fuel oil [percent of TSP] (as quoted in Klimont et al., 2002)

Source	*Sector*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
EPA, 1998a	Residential boilers	23 %	62 %	100 %
CEPMEIP, 2002	Residential	67 %	83 %	100 %

Table A1 36 Particulate matter emission factors reported in the literature for stationary combustion of light fuel oil [g/GJ] (as quoted in Klimont et al., 2002)

Source	*Sector*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
BUWAL, 2001	Domestic furnaces	n.d.	1	1
	Domestic boilers	n.d.	0.2	0.2
CEPMEIP, 2002	Residential and domestic	5	5	5
UBA, 1989	Industry, residential	n.d.	n.d.	1.5
UBA, 1998	All	n.d.	n.d.	1.5
Pfeiffer et al., 2000	Residential	n.d.	n.d.	1.7
	Domestic	n.d.	n.d.	1.6
Ohlström, 1998	0-50 MW plants	n.d.	n.d.	3 - 100[(1)]

Berdowski et al., 1997	Residential sector	30	30	n.d.

1) Average value 70 g/GJ

Table A1 37 Particulate matter size fraction distributions reported in the literature for stationary combustion of light fuel oil [%](as quoted in Klimont et al., 2002)

Source	*Sector*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
EPA, 1998a	Domestic boilers	42%	55%	100%
APEG, 1999 (1)	Residential sector	76-94%	100 %	n.d.
Berdowski et al., 1997 (1)	Domestic	60 %	100 %	n.d.

1) The values refer to PM10 and not to TSP

Table A1 38 Percentage of particle fraction PM10 referring to the sectoral emission factors for particles [%]

Source	*Fuel*	*Households*	*Small consumers*	*Households and Small consumers*
Struschka et al., 2003	High rank coals and products	100	97	99
	Brown coal briquettes	96	n.d.	96
	Wood	97	94	96
	Distillate oil	100	100	100
Ehrlich et al., 2001	Biomass	n.d.	n.d.	> 90
Gaegauf et al., 2001	Biomass	n.d.	n.d.	95 1)
Houck et al., 2005	Biomass	n.d.	n.d.	84 2)
Boman et al., 2005	Biomass (pellet burners)	n.d.	n.d.	100 3)

1) 95% PM below 0.4 µm; 2) Approximately 81% of PM is PM2.5; 3) It was found, in principle, that all PM can be considered as PM_1 with an average PM1 of 89.5% ± 7.4% of total PM.

Table A1 39 Particulate matter emission factors reported in the literature for stationary combustion of natural gas [g/GJ]

Source	*Sector*	*$PM_{2.5}$*	*PM_{10}*	*TSP*
BUWAL, 2001 1)	Domestic furnaces	n.d.	0.5	0.5
	Domestic boilers	n.d.	0.2	0.2
CEPMEIP, 2002 1)	Residential and domestic	0.2	0.2	0.2
Pfeiffer et al., 2000 1)	Residential and domestic	n.d.	n.d.	0.03
UBA, 1989; UBA, 1998 1)	All	n.d.	0.095	0.1
Hobson M. et al, 2003	UNECE TFEIP; Dutch date for domestic gas use	n.d.	0.3	n.d.
	ERA; research boiler Efs.	n.d.	4.8	n.d.
	UNECE TFEIP; Dutch date for agricultural gas use	n.d.	0.15	n.d.

EPA, 1998a [1)]	All, no control	n.d.	n.d.	0.9

[1)] as quoted in Klimont et al., 2002; n.d. – no data

Table A1 40 Particulate matter emission factors used in the RAINS model for residential stationary combustion of liquid and gaseous fuels [g/GJ] (as quoted in Klimont et al., 2002)

Fuel	*PM2.5*	*PM10*	*TSP*
Heavy fuel oil	9.5	24.7	38
Light fuel oil	0.7	0.9	1.7
Natural gas	0.03-0.2	0.03-0.2	0.03-0.2

Table A1 41 Emission factors of heavy metals from coal and wood combustion in advanced underfeed burning boiler 30kW (a), and from straw combustion in fixed grate boiler 65kW (b), [mg/GJ]

Heavy metals	*Coal/J 20-40mm (a)*	*Coal/W 20-40mm (a)*	*Coal/W 5-30mm (a)*	*Briquette / sawdust (a)*	*Lump wood (a)*	*Rape straw (b)*	*Wheat straw (b)*
As	7.4	1.7	4.5	9.5	5.3	3.7	14.3
Cd	5.5	2.0	3.3	25.6	22.0	21.1	13.5
Cr	16.5	3.0	15.8	13.4	6.6	3.6	13.5
Cu	37.6	476	52.6	92.8	34.8	3154	60.8
Hg	1.9	11.7	1.4	0.1	1.2	0.7	1.0
Ni	41.8	20.4	16.0	22.8	14.8	138.4	21.2
Pb	787	375	252	218	191	54.1	68.0
Se	3.0	2.4	3.2	1.0	1.2	0.8	5.1
Zn	275	n.m.	155	178	261	195	282
TSP; g/GJ	227	294	126.2	39	116	654	901

Source: Wiliams et al., 2001

Table A1 42 Heavy metals emission factors from oil combustion, [mg/GJ]

Source	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
All combustion (Pacyna J., and Pacyna, 2001)	0.5	1.2	23.8	11.9	1.4	476	47.6	23.8
Small combustion (Berdowski et al., 1997)	23.8	7.1	59.5	13.1	n.d.	833	23.8	23.8
Distillate fuel oil (Compilation of Air.., 1996)	1.7	4.5	23.8	n.d.	1.2	7.4	3.8	n.d

No6 fuel oil (Compilation of Air.., 1996)	3.6	0.9	0.2	4.8	0.2	229	4.0	79.0
Emission Factors Manual, 1993	14.3	11.9	33.3	11.9	3.6	714	26.2	14.3
Small and medium boilers-non controlled (authors estimates)	0.5	1.2	11.4	8.6	1.2	1,047	30.0	38.6

Source: Kakareka et al., 2003; Original factors in g/ton, for recalculation H_u of 42 GJ/t was assumed; n.d. = no data

Table A1 43 Heavy metals emission factors from coal combustion, [mg/GJ]

Source	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
All combustion (Pacyna J., and Pacyna, 2001)	8.3	4.2	70.8	58.3	20.8	83.3	41.7	62.5
Small combustion (Berdowski et al., 1997)	10.4	4.2	29.2	41.7	9.2	52.1	208	417
High level of abatement (Compilation of Air..,1996)	8.3	1.2	5.4	n.d	1.7	5.8	8.8	n.d.
Domestic furnaces (Determination of Mean… 1996)	6.7	6.7	n.d.	n.d.	n.d.	n.d.	27.5	n.d
Small consumers (Determination of Mean… 1996)	7.9	4.2	2.5	3.3	n.d.	n.d.	238	12.5
Small and medium boilers-non controlled (authors estimates)	125	1.7	51.8	58.3	8.3	21.7	54.2	225
Small and medium boilers - limited controlled (authors estimates)	37.5	0.4	15.4	17.5	8.3	6.3	16.7	67.5

Source: Kakareka et al., 2003; Original factors in g/ton, for recalculation H_u of 24 GJ/t (d.b.) was assumed; n.d. = no data

Table A1 44 Heavy metals emission factors from wood combustion, mg/GJ.

Source	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
Industrial combustion (Berdowski et al., 1997)	n.d	6.3	1.9	12.5	6.3	1.9	12.5	125
Small combustion (Berdowski et al., 1997)	n.d.	2.5	10.6	15.0	6.3	1.9	15.0	125
Traditional domestic wood furnace (Compilation of Air.., 1996)	n.d.	0.7	<0.1	n.d.	n.d.	0.4	n.d.	n.d.
Domestic furnace (Determination of Mean.., 1996)	0.2	1.9	5.6	10.0	n.d	1.1	11.9	263

Small consumers (Determination of Mean.., 1996)	1.9	2.5	13.1	17.5	n.d	0.9	83.8	428.1
Wood combustion (Emission Factors Manual .., 1993)	n.d.	<6.3	n.d.	<6.3	0 – 12.5	<3.1	<3.1	125
Small and medium boilers - non controlled (authors estimates) [1)]	0	1.3	3.8	13.8	0	2.5	15.6	269
Small and medium boilers - limited controlled (authors estimates) [1)]	0	1.3	1.3	4.4	0	0.6	5.0	81.3
Household furnaces – non controlled (auth. estimates) [1)]	0	0.6	1.9	7.5	0	1.9	9.4	156.3
Commercial soapstone stove, birch logs [2)]	2.5 – 29 aver. 16	0 – 99 Aver. 38	2.5– 131 aver. 39	4.3 – 5.0 aver. 4.4	16 -269 aver.119	0.6 – 19 aver. 4	4.5 – 58 aver. 21	93 - 769 aver.469
Chips diff. type of wood [3)]	n.d.	0.03-1.2 aver. 0.4	3.2 – 4.4 aver. 3.8	0.6 - 1.3 aver. 1.1	0.8-2.1 aver. 1.3	0.2 – 0.5 aver. 0.4	0.7-3.0 aver.1.8	44-4.2 aver.18

Source: [1)] Kakareka et al., 2003, [2)] Hedberg et al., 2002, Kubica, 2006 [3)]; Original factors in g/ton, for recalculation H_u of 16 GJ/t was assumed; n.d. – no data

Table A1 45 Heavy metals emission factors from peat combustion, g/GJ.

Source	*As*	*Cd*	*Cr*	*Cu*	*Hg*	*Ni*	*Pb*	*Zn*
Industrial combustion (Berdowski et al., 1997)	4.2	10.5	3.2	21.1	6.3	3.2	21.1	5.3
Small combustion (Berdowski et al., 1997)	4.2	4.2	17.9	25.3	6.3	17.9	25.3	5.3
Small and medium boilers - non controlled (authors estimates)	13.7	7.4	40	47.4	n.d.	37.9	54.7	210
Small and medium boilers - limited controlled (authors estimates)	4.2	2.1	11.6	14.7	n.d	10.5	15.8	63.2
Household furnaces – non controlled (authors estimates)	6.3	3.2	17.9	22.1	n.d.	15.8	25.3	94.7

Source: Kakareka et al., 2003; Original factors in g/ton, for recalculation H_u of 9.5 GJ/t was assumed; n.d. = no data

Table A1 46 Review of range and estimated average mercury emission factor for different type of fuels (without abatement) Pye S. et al; 2005

Fuel	*Range (kg/TJ)*		*Average (kg/TJ)*	*Uncertainty [1)]*
	Low	*High*		
Natural gas	0.0000006	0.00015	0.00001	C
Gasoline	0.0000050	0.00047	0.00003	C
Diesel oil	0.0000095	0.000071	0.000025	
Light fuel oil	0.0000024	0.00012	0.000025	
Heavy fuel oil	0.000006	0.015	0.0001	

Bituminous coal	0.00039	0.070	0.009	C
Smokeless fuel	0.00064	0.00099	0.00075	C
Coke	0.00060	0.015	0.0035	
Brown coal (Lignite)	0.005	0.13	0.007	C
Wood	0.00010	0.00188	0.0005	D
Waste wood	0.00025	0.0034	0.0008	
Straw	0.00007	0.0022	0.001	

[1)] Pulles et al., 2001

Table A1 47 Mercury emission factors by sector-fuel-technology; Pye et al., (2005) and Kubica et al., (2006/1)

Sector	*Fuel*	*Technology*	*Emission factors in kg/TJ*
AFF	Biomass	Medium boilers (automatic) <50 MW using wood, waste, biomass	0.0008
		Medium boilers (manual) <1 MW using wood, waste, biomass	0.0006
		Single house boilers (automatic) <50 kW using wood, waste, biomass	0.00055
		Single house boilers (manual) <50 kW using wood, waste, biomass	0.0008
	Gaseous fuel	LPG	0
		Natural Gas	0.00001
	Liquid fuel	Diesel / Light fuel oil	0.000025
		Gasoline	0.00003
		Heavy fuel oil	0.0001
	Solid fuel	Medium boilers (automatic) <50 MW using brown coal	0.007
		Medium boilers (automatic) <50 MW using coke / briquettes	0.0035
		Medium boilers (automatic) <50 MW using hard coal	0.009
		Medium boilers (manual) <1 MW using brown coal	0.0055
		Medium boilers (manual) <1 MW using coke / briquettes	0.003
		Medium boilers (manual) <1 MW using hard coal	0.007
		Single house boilers (manual) <50 kW using brown coal	0.006
		Single house boilers (manual) <50 kW using coke / briquettes	0.0035
		Single house boilers (manual) <50 kW using hard coal	0.009
Commercial-Institutional	Biomass	Medium boilers (automatic) <50 MW using wood, waste, biomass	0.0008
		Medium boilers (manual) <1 MW using wood, waste, biomass	0.00055
	Gaseous fuel	LPG	0
		Natural Gas	0.00001
	Liquid fuel	Diesel / Light fuel oil	0.000025
		Gasoline	0.00003
		Heavy fuel oil	0.0001
	Solid fuel	Medium boilers (automatic) <50 MW using brown coal	0.007
		Medium boilers (automatic) <50 MW using coke / briquettes	0.0035
		Medium boilers (automatic) <50 MW using hard coal	0.009
		Medium boilers (manual) <1 MW using brown coal	0.006

		Medium boilers (manual) <1 MW using coke / briquettes	0.003
		Medium boilers (manual) <1 MW using hard coal	0.007
Residential	Biomass	Fireplaces using wood, waste, biomass	0.0004
		Single house boilers (automatic) <50 kW using wood, waste, biomass	0.00055
		Single house boilers (manual) <50 kW using wood, waste, biomass	0.0005
		Stoves using wood, waste, biomass	0.0004
	Gaseous fuel	LPG	0
		Natural Gas	0.00001
	Liquid fuel	Diesel / Light fuel oil	0.000025
		Gasoline	0.00003
		Heavy fuel oil	NA
	Solid fuel	Fireplaces	0.003
		Single house boilers (manual) <50 kW using brown coal	0.007
		Single house boilers (manual) <50 kW using coke / briquettes	0.003
		Single house boilers (manual) <50 kW using hard coal	0.006
		Single house boilers (automatic) <50 kW using hard coal	0.009
		Stoves using brown coal	0.004
		Stoves using hard coal	0.006

Table 208 Mercury emission factor speciation for different fuels (as quoted in Pye et al., 2005)

Fuel	*Installation*	Hg^0 *(gas)*	Hg^{+2}	*Hg (partic.);* Hg^{PM}	*Uncertainty*[1)]	*Source*
Hard Coal	Power plant	0.5	0.4	0.1	-	Pacyna et.al., 2004
	Residential	0.5	0.4	0.1	C	
	General	0.5	0.4	0.1	-	Senior, 2004
	Power plant	0.5	0.4	0.1	-	
	Power station stack monit.	0.269	0.695	0.036	-	Pye, 2005/2
	Domestic coal burning	0.4	0.4	0.2	C	
	FBC [a)]	0.55-0.6	0.4	<0.05	-	Moritomi, 2005
	FBC [b)]	0.05 – 0.10	0.8	0.15 – 0.10	-	
	Research facility design to replicate typical power plant	0.2	0.8	-	-	Tan et a., 2004
	Stove	0.6		0.4	-	Bartle et al., 1996
	Power plant	0.42	0.58	-	-	Hlawiczka, et al., 2003
	Stove / Fireplaces	0.3	0.35	0.35	C	Pye et al., 2005/1
	Boiler manual fuelled - all SCI sectors	0.4	0.4	0.2	C	
	Boiler autom. (stoker) - all SCI sectors	0.5	0.4	0.1	C	

Brown coal	Power plant	0.61	0.39	~ 0.01	-	Hlawiczka, et al., 2003
Biomass	Manual fuelled (stove boiler) - all SCI sectors	0.6	0.3	0.1	D	Pye et al., 2005/1
	Automatic fuelled- all SCI sectors	0.65	0.3	0.05	D	Pye et al., 2005/1
Liquid fuels	General for oil	0.5	0.4	0.1	-	Pacyna et.al., 2004
		0.5	0.4	0.1	-	Senior, 2004
		0.51	0.39	0.1	-	Pye, 2005/2
	SCIs (all sectors) Light fuel oil	0.75	0.2	0.05	C	Pye et al., 2005/1
	SCIs AFF, Com-Inst Heavy fuel oil	0.65	0.35	0.1	C	Pye et al., 2005/1
Natural gas	SCIs (all sectors)	0.8	0.15	0.05	C	Pye et al., 2005/1

[a] high content of volatile matter in coal (about 40%) of Cl; [b] coal rich Cl (2304 ppm) content; [1]Pulles et al., 2001; An uncertainty rating has not been given to non-SCI categories (as indicated by the dashes in the uncertainty column).

Table A1 49 Average emission values of PAHs [mg/GJ] and PCDD/F [ng I-Teq/GJ] from solid fuels combustion in stove

Fuel	*PAH Σ 1-4*	*B(a)P [x]*	*B(b)F [x]*	*B(k)F [x]*	*I_P [x]*	*PCDD/F*
Cokes	13.4	4.3	3.8	3.2	2.0	1,470
Coal	145.4	41.8	45.3	19.2	39.1	7,740
Wood	35.2	10.4	10.8	5.0	9.0	320

Source: Thanner G., et al., 2002; [x] the factors were assessed by recalculation original data in ng/Nm^3.

Table A1 50 Emission factors of PCDD/F reported in the literature for small combustion installations [ng I-Teq/GJ]

Source	*Sector*	*Fuel*	*PCDD/Fs*
Hobson M., et al., 2003	Domestic open fire	Yorkshire housecoal; CPL Research, open fire <5 kW	120.8[1]
		Hardwood seasoned; CPL Research, open fire <5 kW	14.4[1]
	Small commercial or institutional boiler	Bituminous coal; AEAT Research; coal boiler, rated 500 kW	2,125[1]
		Wood; AEAT Research; 1,5MW boiler with cyclone abatement	787.5
Davies M., et al., (1992)	Domestic open fire	Smokeless fuel, bituminous coal, anthracite	87.5 – 238[1]
	Small commercial institutional inst.	Traveling grate 5.8 MW	66.7[1]
		Traveling grate 63 MW	29.2[1]

UNEP Chemicals (2003)	Stoves	Coal	70
		Contaminated wood/biomass	1,500
		Virgin wood/biomass	100
		Oil	10
		Natural gas	1.5
	Boilers, motors – turbines. Flaring	Landfill/biogas combustion[2)]	8
Geueke K.-J. et al 2000[1)]	Stoves	Lignite Germany	70; 58[1)]
		Lignite Czech Rep	20; 21[1)]
		Anthracite	95; 175[1)]
		Hard coal Poland	633; 1,430[1)]
Pfeiffer F. et al., 2000 [3)]	Stoves	Wood; masonry heater, 32.5kW	39
		Wood; Tiled with insert, 5.5-14.3kW	9; 27; 49
		Gas heater old convection,4.3kW	1.5
		Gas heater new convection6.2kW	1.7
		Gas old water heater 23.3kW	4.1
		Gas new water heater 19.2kW	2.0
		Oil heater, tiled stove-old burner,8.3kW	3.2
		Oil heater, tiled stove-new burner, 9 kW	1.6
	Domestic boilers	Gas boilers -old, 36.6kW	1.2
		Gas boilers, new,15.8kW	2.3
		Gas boilers, new, 19.0kW	1.8
		Gas boilers, new, 17.5kW	1.4
		Gas boilers, new, 19.9kW	2.0
		Oil boilers - old, 25.6kW	2.9
		Oil boiler, old, solid and gas also, 19.4kW	2.9
		Oil boiler, old, solid and gas also, 20.8kW	0.6
		Oil boiler new, cast iron, 20.2 kW	1.0
		Oil boiler new, steel-20.1-0.9	0.9
Grochowalski A. (2002)	Stoves	Coal stoves	6,000; 11,500 [1)]
	Small commercial institutional and district heating	Moving grate firing boiler; new construction – 1985	11.8; 49.0 [1)]
		Moving grate firing boiler; old construction – 1950	90.0; 151.0 [1)]
		Fluidized bed combustion	104.6; 274.2[1)]
Kubica (2002/1, 2003/1)	Household boilers	Coal automatic fuelled, stoker boiler, upper fire, 30 kW	57.2
Williams, et al. (2001)	Household, advanced manual fuelled boiler, 30 kW	Coal J	285.0
		Coal W	804.0; 540.1
		Pine wood log	1603.3
		Sawdust briquette	107.4
		Coal and pine sawdust briquette (33%)	431.1
		Coal and sewage sludge briquette (13.8%)	277.1
		Mixture of coal and sawdust	795.6
		Mixture of coal and rape straw	740.9

	Household boilers, agricultural small comb. installation	Straw (rape) manual fuelled boiler, 65kW	840.3
		Straw (wheat) manual fuelled boiler, 65kW	746.2
Quass U., et al. 2000	Stoves, simple design	Lignite Germany	117.6
		Lignite Czech Rep.	39.4
		Anthracite	145.0
		Hard coal briquette Germany	310.4
		Coke Germany	26.6
		Hard coal Poland	1,127
	Stoves, modern design	Lignite Germany	192.9
		Lignite Czech Rep.	69.4
		Anthracite	364.3
		Hard coal briquette Germany	186.7
		Coke Germany	90.3
		Hard coal Poland	3,687
Kakareka, (2003)	Household stoves:	Peat	263
		Wood	312.5
	Small and medium boiler	Oil	5
		Coal: non controlled combustion	104
		Coal; partly controlled combustion	42
		Peat: non controlled combustion	263
		Peat; partly controlled combustion	105
		Wood: non controlled combustion	312.5
		Wood: partly controlled combustion	62.5
Casserini S. et al. (2003)	Residential heating	Liquid fuel	3.9
		Wood	500
		Coal	3.2
Pfeiffer F., et al. (2000)[3)]	Households (Germany)	High rank coal and products	27.4
		High rank coals	20.3
		Briquettes	37.3
		Coke from high rank coals	39.4
		Brown coal briquettes	23.3
		Natural wood	29.5
		Distillate oil	2.5
		Natural gas	1.9
	Small consumers (Germany	High rank coal and products	5.1
		High rank coals	5.1
		Coke from high rank coals	23.7
		Brown coal briquettes	12.8
		Natural wood	411.5
		Distillate oil	2.8
		Residual oil	n.d.
		Natural gas	1.6
Lee et al., 2005	Open fire place	Coal	90
	Open fire place	Wood	11
Gullet et al., 2003	Fireplace	Oak	18
	Fireplace	Pine	74

	Fireplace	Artificial logs (wax and sawdust)	70
	Woodstove	Oak	13
Hübner et al., 2005	Boilers	Pelleted wood	21
		Chopped wood log	3- 2000
		coke	87
		Wood and coke	280
		Wood brown coal briquettes	380
	Stove	Hard coal, brown coal briquettes wood	48 – 2400
		Beach wood logs	45 – 4500
		Wood	2300
		Spruce wood (small logs)	1000
		Small wood logs	150
		Wood briquettes	27
	Boilers	All solid fuels	750
	Stove	All solid fuels	380

1) Original factors in g/kg of fuels, for recalculation H_u of 24 GJ/t (d.b.) for hard coal was, of 17 GJ/t (d.b.) for lignite and brown coal, of 30 GJ/t (d.b.) for anthracite, of 30 GJ/t (d.b.) for coke; of 16 GJ/t for wood, of 42 GJ/t for oil and of 35 GJ/t for natural gas were assumed; (2) The date for comparison to natural gas combustion only; 3) PCDD/F given as toxicity equivalent according to the NATO/CCMS (1988) calculation method; n.d. – no data

Table A1 51 Average emission values of PAHs [mg/GJ] from solid fuels combustion in small combustion installations

Source	*Installation type*	*PAH Σ 1-4*	*B(a)P*	*B(b)F*	*B(k)F*	*I_P*
Kakareka, (2003)[1)]	Household stoves: - peat - wood	 336 1,280	 84 312	 168 643	 42 169	 42 156
	Small and medium boiler: - oil	0.6	0.1	0.2	0.1	0.2
	Small and medium boiler coal: - non controlled - partly controlled	 342 102.5	 83.3 25.0	 150 45.0	 58.3 17.5	 50.0 15
	Small and medium boiler peat: - non controlled - partly controlled	 336.4 101	 84.2 25.3	 168 50.5	 42.1 12.6	 42.1 12.6
	Small and medium boiler wood: - non controlled - partly controlled	 1,280 385	 312 93.8	 643 194	 169 50.0	 156 46.9
Kubica K. et al; (1994)	Household stoves with water jacket: - coal - briquette/smokeless fuel	 6,742 195.7	 938 21.3	 5,696 153		 108 21.4
Kubica K., (1996)	Conventional stove: - coal A - coal B	 590 1,410	 180 290	 210 710	 90 200	 110 210

Kubica K. et al; (1997/3; 2002/2)	Conventional stove: - wood log - wood pellets	 1,210 267.7	 390 131.1	 380 65.0	 180 30.4	 260 41.2
	Advanced wood pellets burner	15.3	4.4	6.3	3.3	1.3
	Upper-fire, automatic stocker boiler: - pellet	33	5	18	8	2
	Advanced under fire coal boiler 20kW: - fine coal - fine coal/chips wood (80/20)	 56 17	 13 6	 22 5	 9 1	 12 5
Kubica K.; (2003/1)	Conventional coal boiler 30kW	1,520	450	750	170	150
	Advanced coal boiler manual fuelled 30 kW	326	82	130	80	34
	Automatic fuelled coal boiler 30 kW	33	5	18	8	2
Williams, et al. (2001)	Advanced under-fire boiler, manual 30kW - coal WI - wood - sawdust briquettes - coal WI briquettes - straw (65 kW)	 850 610 120 42 165	 290 120 50 10 80	 280 220 50 20 50	 120 180 20 10 20	 60 90 10 2 15
Kubica K., et al, (1997/3)	Manual fuelled coke boiler 150 kW	21.3 [1)]	6.0	12	3.3	n.d.
	Automatic fuelled coal boiler, retort; 150 kW	95 [1)]	27	40	19	9
Kubica K. et al; (2003/3)	Commercial, institutional and district heat.; Moving grate firing coal boiler 10MW	13.2	5.2	4.4	2.0	1.6
	Commercial, institutional and district heat; Moving grate firing coal boiler 10MW	8.0	2.5	4.4	1.0	0.1
	Fluidized bed combustion	21.0	6.7	8.5	4.0	1.8
EPA (1996) [1)]	Conventional stove	375.0	125.0	187.5	62.5	0.0
	Non-catalytic stove	1062.5	187.5	125.0	125.0	625.0
	Catalytic stove	500.0	125.0	125.0	125.0	125.0
Pfeiffer F., et al (2000) Households (Germany) [3)]	High rank coal and products	270	n.d.	n.d.	n.d.	n.d.
	High rank coals	60	n.d.	n.d.	n.d.	n.d.
	Briquettes	580	n.d.	n.d.	n.d.	n.d.

	Coke from high rank coals	100	n.d.	n.d.	n.d.	n.d.
	Brown coal briquettes	440	n.d.	n.d.	n.d.	n.d.
	Natural wood	490	n.d.	n.d.	n.d.	n.d.
	Distillate oil	1.8	n.d.	n.d.	n.d.	n.d.
Pfeiffer F., et al (2000) Small consumers (Germany) [3]	Coke from high rank coals	130	n.d.	n.d.	n.d.	n.d.
	Natural wood	210	n.d.	n.d.	n.d.	n.d.
	Distillate oil	0.2	n.d.	n.d.	n.d.	n.d.
Lee et al., 2005 [1)]	Open fire place, coal	830	330	210	100	190
	Open fire place, wood	97	40	19	13	25
Gullet et al., 2003	Fireplace, Oak	101	36	21	26	18
	Fireplace, Pine	62	19	14	17	12
	Fireplace, Artificial logs (wax and sawdust)	115	34	26	31	24
	Woodstove, Oak	94	35	23	28	8
Kubica K.; (2004/1)	Conventional stove 5kW	6,3050	2,240	3,630		480
	Conventional coal boiler manual fuelled 30kW	335.0	68.1	209.8		67.1
	Advanced coal boiler manual fuelled 30 kW	13.1	4.5	8.1		1.5
	Automatic fuelled coal boiler – stocker 30 kW	6.3	3.6	2.2		0.5
Boman et al., 2005	Natural-draft wood stove Wood	683-6,500 aver.1,950	16-2,400 aver. 610	30-2,500 aver. 680	9.3-1,000 aver. 250	13-1,500 aver. 410
	Pellet stove (high load); modern certified Swedish	0.9-3.47 aver. 1.1	0.84-0.17 aver. 0.3	0.06 - 1.1 aver.0.6		0.0-3.3 aver. 0.8
	Pellet stove (low load); modern certified Swedish	6.8 – 65 aver. 28.1	1.8-16 aver. 6.7	3.6 - 32 aver. 14		1.4 – 17 aver. 7.4
	Pellet stove (high load); classic North American	0.9-3.47 aver. 1.1	0.84-0.17 aver. 0.3	0.06 - 1.1 aver.0.6		0.0-0.09 aver.0.04
	Pellet stove (low load); classic North American	0.87-5.1 aver.2.7	0.32– 1.3 aver.0.75	0.55 – 1.8 aver. 1.1		0.00-2.00 aver.0.81
Oanh et al., 1999	Stove, charcoal	33.8	5.5	0.5	27.8	n.d.
	Stove, coal briquettes	106.6	12.6	24	70	n.d.
	Open burning in pile wood	144.1	43.0	28.4	23.6	49.1
Hedberg et al., 2002 [1)]	Commercial soapstone stove, birch logs	38 -2,630 aver. 610	13-1,000 aver. 225	19-1,630 aver. 380	<6 - <6 <6	n.d.
Kubica, 2004/2	Residential; coal	765	248	323	124	69

	Residential; wood	712	211	216	131	154
	Residen./Comm./Institut. Coal	563	195	245	68	55
	Residen./Comm./Institut. Coal	458	143	171	73	71

[1)] Original factors in g/kg of fuels, for recalculation H_u of 24 GJ/t (d.b.) for coal was, of 16GJ/t for wood, of 42GJ/t for oil and of 35GJ/t for natural gas were assumed; [(2)] The original date of PAH without the description of PAH type; [3)] PAH it is the sum of the 8 cancerogenic PAHs: anthracene, benzo(a)pyrene, benzo(a)anthracene, indeno(1,2,3-cd)pyrene, chrysene (+triphenylene), dibenzo(a,h)antracene, benzo(b+j+k)fluoranthene and benzo(ghi)perylene; n.d. – no data

Table A1 52 Emission factors of VOC and NMVOC [as C_3H_8] reported in the literature for small combustion installations [g/GJ]

Source	*Sector/appliances*	*Fuel*	*VOC*	*NMVOC*
Hobson M., et al., 2003	Domestic open fire	Bituminous coal; BCC Research, domestic open grate	n.d.	583[1)]
		Manufactured fuels; BCC Research, domestic coke use	5-20	n.d.
		Wood; BCC Research; UK use of wood in domestic appliances	90-800	n.d.
	Domestic boilers	Bituminous coal; BCC Research, 17 kW underfeed boiler	n.d.	25
		Bituminous coal; BCC Research, 13 kW, gravity feed, anthracite	n.d.	71
		Hard coal 35kW boiler, benchmark	n.d	195
		Hard coal 35kW boiler, improved	n.d.	40
		Brown coal 35kW boiler, bench.	n.d.	380
		Brown coal 35 kW boiler, improved	n.d.	76
		Coke, 35 kW boiler, benchmark	n.d.	220
		Coke, 35 kW boiler, improved	n.d.	44
		Wood, charcoal, 35 kW boiler, benchmark	n.d.	480
		Burning oil, 35 kW boiler, benchmark	n.d.	7.5
		Burning oil, 35 kW boiler, improved	n.d.	1.5
		Kerosene; BCC Research; UK use of kerosene in dom. appliances	15	n.d.
		Gas, 35 kW boiler, benchmark	n.d.	15
		Gas, 35 kW boiler, improved	n.d.	3
		Gas; BCC Research; UK use of gas in domestic appliances	5.0-30	n.d.
	Small commercial or institutional boiler	Bituminous coal; BCC Research; 0.9-48 MW boilers	n.d.	2.1
		Hard coal 200kW boiler, benchm.	n.d	30
		Hard coal 200kW boiler, improved	n.d.	6
		Brown coal 200kW boiler, benchm	n.d.	30

		Coke; BCC Research; industrial coke use	1.0-30	n.d.
		Coke, 200 kW boiler, benchmark	n.d.	30
		Coke, 200 kW boiler, improved	n.d.	6
		Fuel oil; BCC Research; UK use of residual fuel oil in industry	8	n.d.
		Burning oil, 200 kW boiler, benchm	n.d.	5.0
		Burning oil, 200 kW boiler, benchm	n.d.	1.0
		LPG; BCC Research; UK use of LPG in commercial appliances	5	n.d.
		GAS; BCC Research; UK use of gas in commercial appliances	5	n.d.
		Gas, 200 kW boiler, benchmark	n.d.	5.0
		Gas, 200 kW boiler, improved	n.d.	1.0
	CHP	Fuel oil; BCC Research; UK use of fuel oil in power plant	6.8	n.d.
		Oil, 200 kW boiler, impr. & abate	n.d.	1
CITEPA (2003)	Open fireplaces	Wood combustion	n.d.	1,700
	Closed fireplaces and inserts			1,600
	Conventional stoves		n.d.	1,600
	Advanced stoves		n.d	30
	Non-certified boilers		n.d.	1,600
	Advanced boilers class 1		n.d.	400
	Advanced boilers class 3		n.d.	40
Kubica, UN-ECE TFEIP, (2002/1)	Stove	Coal J	486	n.d.
		Coal W	700	n.d.
		Wood log	1,660	n.d.
Williams, et al. (2001)	Boiler manual fuelled, 30kW	Coal J	514.2	n.d.
		Coal W	483.1	n.d.
		Coal WII	448.9	n.d.
		Pine wood log	336.4	n.d.
		Sawdust briquette	176.1	n.d.
		Coal and pine sawdust briquette (33%)	214.7	n.d.
		Coal and sewage sludge briquette (13.8%)	1058.9	n.d.
		Mixture of coal and sawdust	286.4	n.d.
		Mixture of coal and rape straw	326.8	n.d.
Kubica K., (2002/2)	Stocker boiler, 25kW	Coal	14.0	n.d.
		Wood pellet	21.0	n.d.
Pfeiffer F., (2000) [a)]	Households (Germany)	High rank coal and products	342	137
		High rank coals	324	130

		Briquettes	366	146
		Coke from high rank coals	13	7.9
		Brown coal briquettes	296	217
		Natural wood	393	301
		Distillate oil	1.3	1.3
		Natural gas	1.6	0.71
	Small consumers (Germany)	High rank coal and products	11	4.5
		High rank coals	11	4.5
		Coke from high rank coals	36	21
		Brown coal briquettes	427	350
		Natural wood	258	186
		Distillate oil	2.6	2.6
		Residual oil	n.d.	n.d.
		Natural gas	0.51	0.39
EPA (Environmental Protection Agency); 1996	Wood stove	Conventional	n.d.	1656
		Non-catalytic	n.d.	375
		Catalytic	n.d.	469
BLT, 2005/1 [a)]	Boiler 25 kW	Wood pellets and chips	7	n.d.
	Boiler 43 kW; 100% and 33% of capacity	Pellets and wood chips	2	n.d.
	Boiler 60 kW	Wood	27	n.d.
	Boiler, 25kW	Wood chips	6	n.d.
	Boiler 46.7 kW; 100% capacity; 33% of capacity	Wood pellets	3; 5	n.d.
BLT, 2003 [a)]	Boiler 7.7 – 26 kW	Wood pellets and briquettes	1	n.d.
BLT, 1999 [a)]	Boiler 500kW	Wood chip; 100% and 30% of capacity	<1; 1	n.d.
BLT, 2004/1 [a)]	Boiler 20kW	Wood chips	2	n.d.
BLT, 2004/2 [a)]	Boiler 50kW	Wood logs and briquettes	4	n.d.
BLT, 2000/1 [a)]	Boilers, two chambers and sonar Lambda	Wood logs	3	n.d.
BLT, 2000/2 [a)]	Chamb. boiler 60kW	Wood briquettes	2	n.d.
BLT, 2005/2 [a)]	Chamber boiler 27 kW	Wood logs	9	n.d.
McDonald et. al., 2000 [1)]	Fireplaces		1.4–14.5 aver. 7.5	n.d.
	Woodstove		6.2-55.3 aver. 23	n.d.
Johansson at al., 2001	Boilers, fixed grates, moving scrapes 1.75– 2.5 MW	Wood pellets	1.4	n.d.
Boman et al., 2005	Natural-draft stove, 9 kW	Wood; Birch Pine Spruce	n.d.	1 – 2500 aver. 600

	Pellets stove 4- 9,5 kW; (high load)	Pellets: Pine Spruce	n.d.	0,85 – 2 aver. 2
	Pellet stove, 4- 9,5 kW; (low load 30%)	Pellets: Birch Pine Spruce	n.d.	14 – 22 aver. 19
Kubica, 2004/2	Pellet boilers	Wood pellets; Pine	5–18 aver.7	n.d.
	Chamber boiler, top feed	Fine coal	100 - 250	n.d.
	Automatic coal boiler, stocker	Pea coal (qualified coal size)	1- 50 aver.11	n.d.
	Automatic coal boiler	Fine coal (qualified coal size)	2 – 50 aver.20	n.d.
	Chamber boiler, advanced techniq.	Qualified size coal	60 - 120	n.d.

[1)] Original factors in g/kg of fuels, for recalculation H_u of 24 GJ/t (d.b.) for coal was, of 16GJ/t for wood, of 42GJ/t for oil and of 35GJ/t for natural gas were assumed; n.d. – no data; [a)] VOC and NMVOC as C; [b)] VOC as OGC

Table A1 53 Emission factors for the CHP plant types and aggregated emission factors for the decentralized CHP plants

Pollutants	*Unit*	*Natural gas engines*	*Biogas engines*	*Gas turbine*	*Municipal waste CHP*	*Straw CHP*	*Wood CHP*	*Decentr. CHP plants*
NH_3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
NO_x	g/GJ	168	540	124	124	131	69	154
NMVOC	g/GJ	117	13	1.4	<1	<0.8	<3.4	55
CO	g/GJ	175	>273	6	<8	63	79	98
SO_2	g/GJ	n.d.	19	n.d.	<24	47	<1.8	10
TSP	g/GJ	0.76	2.63	0.10	<2.02	3.97	7.94	1.6
PM10	g/GJ	0.189	0.451	0.061	1.126	0.133	1.944	0.6
PM2.5	g/GJ	0.161	0.206	0.051	1.084	0.102	1.226	0.5
PCDD/F	I-Teq ng/GJ	n.d.	n.d.	n.d.	157	22	1	47
PAH [B(a)P-eq.]	mg/GJ	<0.023	<0.003	<0.005	<0.006	<0.154	<0.008	<0.020
B(a)P	mg/GJ	0.003	0.001	<0.009	<0.022	<0.003	<0.003	<0.003
B(b)F	mg/GJ	0.042	0.001	0.001	0.002	0.157	0.002	<0.026
B(k)F	mg/GJ	0.024	<0.0004	<0.002	<0.0008	<0.091	<0.003	<0.015

I_P	mg/GJ	0.006	<0.0011	<0.003	<0.0009	<0.023	<0.002	<0.004
As	mg/GJ	n.d.	n.d.	n.d.	<6.8	<2.1	<2.4	2.2
Cd	mg/GJ	n.d.	n.d.	n.d.	<4.8	<0.8	<1	1.5
Cr	mg/GJ	n.d.	n.d.	n.d.	<2.5	<1.6	<2.4	0.9
Cu	mg/GJ	n.d.	n.d.	n.d.	<10.1	<1.7	<2.7	3.1
Hg	mg/GJ	n.d.	n.d.	n.d.	<7.4	<0.6	<0.8	2.2
Ni	mg/GJ	n.d.	n.d.	n.d.	<4.8	<1.7	<2.4	1.6
Pb	mg/GJ	n.d.	n.d.	n.d.	<123	<6.2	<3.7	36.3

Source: Nielsen M. *et al.*, (2003); [1)] none information about NMVOC standard reference usual CH_4 or C_3H_8 are used; n.d. - no data

Abbreviations

B[a]P benzo[a]pyrene,
B[b]F benzo[b]fluorantene,
B[k]F benzo[k]fluorantene
CxHy volatile hydrocarbons could be expressed as THC, see below
I_P - indeno[1,2,3-cd]pyrene
I-Teq in line with DRAFT GUIDELINES FOR ESTIMATING AND REPORTING EMISSIONS DATA, EB.AIR/GE.1/2002/7; 2 July 2002 the emissions of different congeners of PCDD/F are given in toxicity equivalents I-Teq in comparison to 2,3,7,8,-TCDD by using the system proposed by the NATO Committee on the Challenges of Modern Society (NATO-CCMS) in 1988
H_u (d.b.) lower heating value of fuel on a dry basis
NMVOC Non-methane volatile organic compounds (VOC) means any organic compound except methane having at 293.15 K a vapor pressure of 0.01 kP or more, or having a corresponding volatility under the particular conditions of use.
PM10 Particulate matter with an aerodynamic diameter less than 10 µm
PM2.5 Particulate matter with an aerodynamic diameter less than 2.5 µm
PAH Polycyclic Aromatic Hydrocarbons
PCDD/F Polychlorinated dioxins and furans
TSP Total suspended particulate matter
THC in line with EPA Method 25A as well as EN 12619 THC (Total Hydrocarbon Compounds) means “total gaseous organic concentration of vapors consisting primarily of alkanes, alkenes, and/or arenes (aromatic hydrocarbons). They are determined by using on-line flame ionisation analyser (FID). The concentration is expressed in terms of propane (or other appropriate organic calibration gas) or in terms of carbon.” Gaseous organic concentration (ppm v/v) usually expressed in terms of propane or methane in this case the relation is about 1.8:1.

VOC	Volatile organic compounds means any organic compound except methane having at 293.15 K a vapor pressure of 0.01 kP or more, or having a corresponding volatility under the particular conditions of use.