|  |  |  |
| --- | --- | --- |
| **Category** | | **Title** |
| **NFR** | 1.A.4.a.i, 1.A.4.b.i,  1.A.4.c.i,  1.A.5.a | Small combustion |
| **SNAP** | 020100  020103  020104  020105  020106  020200  020202  020203  020204  020205  020300  020302  020303  020304 | Commercial/institutional plants  Commercial/institutional — Combustion plants < 50 MW  Stationary gas turbines  Stationary engines  Other stationary equipment  Residential plants  Residential — Combustion plants < 50 MW  Stationary gas turbines  Stationary engines  Residential — Other stationary equipment (Stoves, fireplaces, cooking)  Plants in agriculture, forestry and aquaculture  Combustion plants < 50 MW  Stationary gas turbines  Stationary engines |
| **ISIC** |  |  |
| **Version** | Guidebook 2016 |  |

**Changes in this chapter made since the last version**

**Compared to the Guidebook 2016 version, this chapter has been updated. The main change is the insertion of a new Tier 2 methodology for biomass fuels (Section 3.4). Additional text and guidance has been given in this section on how to use the Tier 2 approach. The basic idea is that each country should be able to use the Tier 2 approach with the information presented in this document. In addition, also the Tier 1 EFs for biomass have been updated, as well as some textual changes to Section 3.4.**

**Note that all the changes made to the EF tables have been marked with light blue color, so they are easily recognizable.**

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# Overview

This chapter covers the methods and data needed to estimate stationary combustion emissions under NFR sectors 1.A.4.a.i, 1.A.4.b.i, 1.A.4.c.i and 1.A.5.a. The sectors cover combustion installations activities in the following sectors which, for the purpose of this guidance, are considered to have a thermal capacity ≤ 50 MWth..

* 1.A.4.a.i — Commercial/institutional;
* 1.A.4.b.i — Residential;
* 1.A.4.c.i — Agriculture/forestry; and
* 1.A.5.a — Other (stationary combustion).

The activities essentially cover combustion in smaller-scale combustion units and installations than those in Chapter 1.A.1, Energy industries. The combustion technologies employed may be relevant to sectors in Chapter 1.A.1. Chapter 1.A.1 provides additional emission information for the activities in this chapter (and vice versa).

The sectors covered in this chapter include the following activities:

* commercial and institutional heating;
* residential heating/cooking;
* agriculture/forestry; and
* other stationary combustion (including military).

The open-field burning of agricultural residues is not included in this chapter. The range of activities relevant to sector 1.A.4 are summarised in chapter 2. The most important pollutants emitted to atmosphere are summarised in Table 1.1.

Table 1.1 Pollutants with potential for small combustion activities to be a key category

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Source releases | | | | | | | | | | | | | |
| Activity | PM (TSP) | PM10 | PM2.5 | Black Carbon (BC) | Oxides of sulphur | Oxides of nitrogen | Oxides of carbon | Hydrogen chloride, fluoride | Volatile organic compounds | Metals (excluding mercury and cadmium) and their compounds | Mercury, cadmium | PAH | Dioxins, PCB, HCB | Ammonia |
| Commercial / institutional plants | X | X | X | X | X | X | X | X | X | X | X | X | X |  |
| Residential plants | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Agriculture / forestry | X | X | X | X | X | X | X | X | X | X | X | X | X |  |

# Description of sources

## Process description

The small combustion installations included in this chapter are mainly intended for heating and provision of hot water in residential and commercial/institutional sectors. Secondary activities extend to the use of appliances within residential and commercial sectors for cooking. In the agricultural sector the heat generated by the installations is used also for crops drying and for heating greenhouses.

In some instances, combustion techniques and fuels can be specific to an NFR activity category; however most techniques are not specific to an NFR classification. The applications can be conveniently sub-divided considering the general size and the combustion techniques applied:

* residential heating — fireplaces, stoves, cookers, small boilers (< 50 kW);
* institutional/commercial/agricultural/other heating including:
  + heating — boilers, spaceheaters (> 50 kW),
  + smaller-scale combined heat and power generation (CHP).

The disaggregation in the emission factor tables for non-residential applications includes size classes for technologies which potentially have appliances with capacities of >50KWth but less than 1MWth, and greater than 1MWth and less than 50MWth. Emissions from smaller combustion installations are significant due to their numbers, different type of combustion techniques employed, and range of efficiencies and emissions. Many of them have no abatement measures nor low efficiency measures. In some countries, particularly those with economies in transition, plants and equipment may be outdated, polluting and inefficient. In the residential sector in particular, the installations are very diverse, strongly depending on country and regional factors including local fuel supply.

Figure 2‑1 Illustration of the main process in small combustion installations; figure adapted from 2006 IPCC Guidelines for National Greenhouse Gas Inventories



## Techniques

### Residential heating (1.A.4.b)

#### General

Small combustion appliances are used to provide thermal energy for heating and cooking. In small combustion installations a wide variety of fuels are used and several combustion technologies are applied. In the residential activity, smaller combustion appliances, especially older single household 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 larger combustion activities, with the exception of the simple design of smaller appliances like fireplaces and stoves.

The technologies for solid fuels and biomass utilization vary widely 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 include mineral and biomass solid fuels, with fuel size varying from a few mm to 300 mm. More detailed descriptions of techniques can be found in Kubica, et al., (2004). It can be helpful to consider residential combustion equipment in terms of appliances (manufactured products) and more basic equipment such as ‘traditional’ solid fuel fireplaces.

* Basic equipment – traditional solid fuel fireplaces, chimeneas, barbecues: such equipment is distinguished by being ‘open’ and consequently have no or very limited air controls. In addition, due to relatively low replacement rates (of buildings and equipment), solid fuel open fireplaces can be a significant part of residential heating stock. Although there may be oil and gas fired devices for which a ‘basic equipment’ label might be applicable, it is considered more appropriate to treat these as appliances.
* Appliances – providing a range of functions including roomheaters (stoves, inset appliances and slow heat release stoves), cookers, central heating boilers, water heaters with a wide range of performance and emission characteristics depending on fuel, age, technology and mode of use. At one extreme, older stoves and open inset appliances may have very limited controls and provide only modest improvement in efficiency and emission performance compared to basic equipment. However, modern wood log stoves and automatic appliances provide better management of the combustion process with improvement in emissions and efficiency. Similarly, modern gas and oil-fired appliances offer improved combustion management and associated emission benefits.

Within Europe, there is a range of regulatory instruments in place which provide a regulatory framework for gas appliances, construction products (solid fuel and liquid fuel appliances), boiler efficiency (gas and liquid fuel appliances) and also for ecodesign of energy-related products. These instruments have led to development of a range of appliance Standards for solid, gaseous and, to an extent, liquid fuel small combustion appliances

The following harmonised EN Standards cover solid fuel heating appliances:

| **EN Standard** | **Standard Description** | **Scope** |
| --- | --- | --- |
| EN 13229 | Inset appliances including open fires fired by solid fuels – requirements and test methods | Manually-stoked open freestanding roomheaters (stoves) and, open and closed inset roomheaters which are designed to be mounted within a fireplace recess or integrated into a building. Also includes roomheaters with boilers. |
| EN 13240 | Roomheaters fired by solid fuels – requirements and test methods | Manually-stoked closed freestanding roomheaters (stoves). Also includes roomheaters with boilers. |
| EN 14785 | Residential space heating appliances fired by wood pellets – requirements and test methods | Mechanically-stoked closed freestanding roomheaters (stoves) or closed inset roomheaters. Also includes roomheaters with boilers. |
| EN 15250 | Slow heat release appliances fired by solid fuels – requirements and test methods | Manually-stoked closed freestanding roomheaters (stoves) with thermal storage capacity. |
| EN 15821 | Multi-firing sauna stoves fired by natural wood logs – requirements and test methods | Manually-stoked sauna stoves. |
| EN 12815 | Residential cookers fired by solid fuels – requirements and test methods | Manually-stoked cookers (also providing space heating and includes cookers with boilers. |
| EN 12809 | Residential independent boilers fired by solid fuels – Nominal heat output up to 50 kW - requirements and test methods | Manual and mechanically-stoked solid fuel boilers (also providing space-heating). |
| EN303-5 | Heating boilers - Part 5 : heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW – Terminology, requirements, testing and marking | Manual and mechanically-stoked solid fuel boilers. |

#### Basic equipment

Solid fuel open fireplaces are the most simple combustion devices, and are often used or retained as supplemental heating appliances primarily for aesthetic reasons in residential dwellings. Many older buildings retain solid fuel open fireplaces and open fireplaces are commonly used in areas of fuel or energy poverty.

This type of fireplaceis of very simple design — a 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 losses when the fireplace is not being used. The heat energy is transferred to the dwelling mainly by radiation.

Open fireplaces are characterised by high, non-adjustable excess of the combustion air, which influences their efficiency and emissions. In open masonry fireplaces 80-90% of heat released during combustion is lost through the chimney (Artjushenko, 1985). In cases where combustion is poor, where the outside air is cold, or where the fire is allowed to smoulder (thus drawing outside air into a residence without producing appreciable radiant heat energy), a net heat loss may occur in a residence using a fireplace. Some fireplaces are equipped with back water jackets (Crowther, 1997). These can give thermal outputs of up to 12KWth and thus can provide central heating from low cost living-room equipment.

Open fireplaces are usually of masonry type and have very low efficiency while having significant emissions of total suspended particulates (TSP), Carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and polycyclic aromatic hydrocarbons (PAH) resulting from the incomplete combustion of the fuels.

Fuels for solid fuel open fireplaces include wood (logs), coal, anthracite and manufactured solid fuels. An open fire for wood logs may include a firebasket or grate to retain the fuel but commonly the fuel will be burnt directly on the hearth. A mineral fuel appliance will typically include a grate to support the firebed above an ash container and allow an air supply to the underside of the firebed.

Chimeneas and barbecues are outdoor appliances which burn wood and charcoal solid fuels. They are little different from an open fire in operation. Other types of outdoor solid fuel appliances include wood-fired pizza and other ovens which also tend to have very limited controls.

The emission factors associated with the equipment detailed here can be found in Table 3.12 for solid fuels excluding biomass and in Table 3.39 for wood fuels in open fire places.

#### Appliances

##### Fireplace appliances (insert and free standing)

Solid fuel fireplaces are manually-fired fixed bed combustion appliances. They differ from the open fire places detailed in above (under “Basic equipment”) in that they are defined appliances, whereas open fire places typically come as part of the overall construction of the property. Insert fireplaces fitted within a chimney aperture are appliances covered under EN standard EN 13229. The user intermittently adds solid fuels to the fire by hand. They can be distinguished into the following.

##### Partly-closed fireplaces

Equipped with louvers and glass doors to reduce the intake of combustion air. Distribution of the combustion air is not especially arranged or regulated and for that reason combustion conditions are not improved significantly compared with open fire places detailed above (under “Basic equipment”). Some masonry fireplaces are designed or retrofitted in that way in order to improve their overall efficiency.

The technologies described in this sub-section are covered by emission factors found in Table 3.12 for solid fuels excluding biomass and Table 3.39 for wood fuelled fire places.

##### Closed fireplaces

These fireplaces are equipped with front doors and have air flow control systems, which includes the distribution of combustion air to primary routes (grate) and secondary routes (panels), as well as a system to discharge the exhaust gases. In closed fireplaces combustion temperatures can increase up to 400oC or more, and the retention time of the gases in the combustion zone is longer compared with open fireplaces. 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 %, but can be as high as 80% depending on specific appliance.

Because the combustion mechanics of closed fireplaces are more efficient than open and partly closed fireplaces, they more closely resemble the emission profiles of stoves. It is therefore more appropriate to use the emission factors listed in Table 3.14 for solid fuels other than wood, and Table 3.40 for wood based fuels used in closed fireplaces.

Fuels used in solid fuel fireplaces are mainly log, lump wood, biomass briquettes, and charcoal**,** coal and coal briquettes. Multifuel appliances are available which can burn a range of solid fuels including manufactured solid fuels and wood.

##### Gas-fuelled fireplaces

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, NOX emissions are lower, but emissions of CO and NMVOC can be higher in comparison to gas-fired boilers. The technology described here are covered by emission factors found in Table 3.13 for gaseous fuelled fire places.

##### Stoves

Stoves are enclosed appliances in which hand supplied fuels are combusted to provide useful heat, which is transmitted to the surroundings by either radiation or convection. They can vary widely due to fuel 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; and
* Gas fuels.

The stoves utilizing solid fuels are usually used for space heating of rooms (room heaters), but also for cooking, and hot water preparation (boilers and water heaters), while liquid and gas stoves tend to be used mainly for space heating only.

##### Solid fuel stoves

The solid fuel stoves can be 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 (air flow under-fire, down-burning combustion) and downdraught (air flow from over-fire, up-burning combustion).

Downburning stoves (which make up the majority of older stoves) have higher emissions compared to upburning stoves. This is because the devolatised products of fuels are less completely combusted in low temperatures present in the reaction zone (between 400 – 600oC). On the contrary, in upburning techniques for solid fuels combustion the combustible gases are passing through a burning fuel bed with temperatures in excess of 600oC and thus are more completely oxidised. Variations on the down/up draught process include “S-draught” and “Cross-draught” processes; these variants allow a greater residence time of gases within the combustion zone so will also typically have lower pollutant emissions than the downburning stoves. Different kinds of solid fuels are used, such as coal and its products (usually anthracite, hard coal, brown coal, patent fuels, and brown coal briquettes) and biomass — wood logs, wood chips and wood pellets and briquettes. Coals of different grain sizes are used usually 20–40 mm, and above 40 mm, or mixtures of both. Peat is also occasionally used.

Solid fuel stoves are divided into two main subgroups for mode of heat transfer, radiating stoves and convection stoves which work through heat storing or heat accumulation. Radiating stoves are usually made as prefabricated iron or steel appliances; some of them provide water heating, indirect heating (boilers) and some are used as cooking stoves. Convection stoves may include masonary stoves, which are usually assembled on site with bricks, stone or ceramic materials. Under the EN standards stoves are covered by EN 13240 for conventional room heating typically covered by radiating stoves and EN 15250 for slow heat release appliances typically covered by convection appliances. Additionally the standard EN 14785 applies to residential space heating stoves which make use of wood pellet fuels.

##### Conventional, radiating stoves

Radiating stoves can be divided into coal and wood based fuel types. For coal fired stoves the appliance usually functions around the downburning methodology. For wood fired stoves both downburning and upburning methods are used. These appliances typically 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 (i.e. the ability to operate without user intervention) is low, lasting from three to eight 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.

The emission factors associated with this type of technology are covered within Table 3.14 for coal based fuel types and Table 3.40 for wood based fuel types.

*Masonry stoves (heat accumulating- convection methodology)*

The construction of masonry stoves varies depending on country and region, but will be based on bricks, stones, or a combination of both together with fireproof materials such as ceramic (e.g. volcanic rocks as seen in Finnish stoves for example). Sometimes these devices can come as prefabricated units. Because of the large thermal capacity of masonry materials they keep a room warm for many hours (8-12) or days (1-2) after the fire has burnt out, that is why they are called heat accumulating or heat storing stoves. Their combustion chamber can be equipped with horizontal strips or inclined, perpendicular baffles made of steel or fireproof material, which improve combustion quality and efficiency. Because of the increased residence time of fuels in the combustion zone there is a decrease in pollutant emissions compared to conventional radiating stoves. Their combustion efficiency ranges from 60 to 80 % and their autonomy from 8 to 12 hours (CITEPA, 2003). These stoves can be further divided into two sub-categories:

* Room heating stoves; some more advanced appliances employ counter flow systems for heat transfer and/or down draught combustion principles
* Heat accumulating cooking stoves can be divided further again into simple residential cooking and boiler cooking stoves. The former are equipped with a combustion chamber and hot plate zones for food preparation and room heating; the latter are simultaneously used as kitchen stoves, room heating and preparation of sanitary hot water (e.g. Russian Stoves).

The emission factors associated with this type of technology are covered within Table 3.14 for coal based fuel types and Table 3.40 for wood based fuel types.

The conventional radiating stoves detailed are characterised by high emissions. The further development of their design has resulted in new more advanced technologies which have better efficiencies and lower pollutant emission releases. The technologies detailed below represent the more advanced technologies which extend beyond the conventional radiating stoves that may be in use.

##### High-efficiency conventional stoves (including catalytic combuster stoves)

These appliances essentially cover traditional stoves with improved utilization of secondary air in the combustion chamber. Their efficiency is between 55 % and 75 % and emissions of pollutants are lower, their autonomy ranges from 6 to 12 hours.

As a sub-category of high-efficiency stoves, it is possible to equip stoves with a catalytic converter in order to reduce emissions caused by incomplete combustion, this is particularly the case for wood fuel based stoves. The catalytic converter (a cellular or honeycomb, ceramic substrate monolith covered with a very thin layer of platinum, rhodium, or combination of these) is usually placed inside the flue gas channel beyond the main combustion chamber. The catalyst efficiency of emission reduction depends on catalyst material, its construction – active surface area, and the conditions of flue gas flow inside the converter. Due to more complete oxidation of the fuels, energy efficiency also increases. However the catalyst will need frequent cleaning in order to maintain performance. Catalytic combustors are not common for coal stoves.

The emission factors which cover this type of appliance can be found in Table 3.41 covering the combustion of wood based fuels in high-efficiency stoves.

##### Advanced combustion stoves (including ecolabelling for wood 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.

Ecolabelling schemes for wood and biofuel based stoves are intended to earmark a set standard for improved efficiency and lower emissions, with a number of schemes in place such as Nordic swan (in Norway), Blue Angel (in Germany), and Flammerverte (in France). These schemes all set in place criteria for the ecolabelling largely based around the EN standards, which set in place the level of performance and function of appliances.

The emission factors which cover this type of appliance can be found in Table 3.19 covering the combustion of solid fuels other than biomass in advanced boilers, and Table 3.42 for ecolabelled stoves burning wood based fuels.

##### Pellet stoves

This is a type of advanced stove using an automatic feed for pelletized fuels such as wood pellets, which are distributed to the combustion chamber by a fuel feeder from small fuel storage. Modern pellets stoves are often equipped with active control system for supply of the combustion air. They reach high combustion efficiencies by providing the proper air/fuel mixture ratio in the combustion chamber at all times (CITEPA, 2003). For this reason they are characterized by high efficiency (between 80 % and 90 %) and low emissions of CO, NMVOC, TSP and PAH.

The emission factors which cover this type of appliance can be found in which covers the combustion of wood pellet fuels in modern pellet stoves.

##### Liquid/gas-fuelled stoves

The liquid/gas stoves have simple design; gas stoves are equipped with simple valves for fuel/air ratio adjustment and non-pre-mixing burners. For that reason emissions of NOX from these are lower in comparison to gas-fired 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.

The emission factors which cover this type of appliance can be found in Table 3.17 which covers the combustion of liquid/gas fuels in stoves.

#### *Small boilers (single household/domestic heating) — indicative capacity ≤ 50 kW output*

In general, boilers are devices which heat water for indirect heating. Small boilers of this capacity are used in flats and single houses. Designs are available for gaseous, liquid and solid fuels. They are mainly intended for generation of heat for the central heating system (including hot air systems) or hot water, or a combination of both. Boilers that meet these descriptions are covered by the EN standards EN12809 for residential independent boilers with capacity up to 50KWth and EN303-5 for manually and mechanically stoked boilers with capacity up to 500KWth.

##### Solid fuel small boilers

Small boilers for central heating for individual households are more widespread in temperate regions and usually have a nominal output between 12 kW to 50 kW. 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: over-fire boiler (overfeed burning — over-fire and under-fire — down-burning) and under-fire boiler (underfeed burning — over-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 periodically fed onto the top of the burning fuel bed. Over-fire burning in fixed bed is characterized by the relative low temperature (400 – 800oC) of the volatile matter in the oxidizing zone, by a local lack of oxygen as a result of poor mixing (Kubica, 2003). 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 (such as PM, CO, NMVOC and PAH) resulting from incomplete combustion of fuel may be very high particularly if they are operated at low load, this is often at the end or beginning of the heating seasons such as spring and autumn.

The emission factors which cover this type of appliance can be found in Table 3.15 which covers the combustion of coal in conventional boilers and Table 3.43 which covers the combustion of wood in conventional boilers.

##### 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 older designs, 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 grain coal. For both techniques, if an upgraded coal fuel such as briquettes replaces raw coal the emission in particular of the products of incomplete combustion are reduced by about 30% and even by as much as 90% (except for CO) for smokeless fuel and coke (Karcz et al, 1996, Kubica et al 1994 and Kubica et al 1997).

The emission factors which cover this type of appliance can be found in Table 3.15 which covers the combustion of coal in conventional boilers and Table 3.43 which covers the combustion of wood in conventional boilers.

***Advanced combustion boilers***

##### Advanced, 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%). Some of these boiler types use pre-heated combustion air, which is usually cool outdoor air. The emissions of pollutants due to incomplete combustion processes are decreased in comparison with conventional boilers.

The emission factors which cover this type of appliance can be found in Table 3.19 which covers the combustion of coal in advanced stoves, but will also be expected to be representative for advanced boilers.

##### 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. Drowndraught wood boilers use a combination air fan and flue gas fan. The secondary combustion air is partly introduced in the grate and partly the secondary chamber. 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. Some of these boiler types employ lambda control probes to measure flue gas oxygen concentration and have precise combustion air control as well as staged-air combustion. Owing to the optimised combustion process, emissions due to incomplete combustion are low.

The emission factors which cover this type of appliance can be found in Table 3.42 which covers the combustion of wood in advanced stoves and boilers including ecolabelled appliances.

***Stoker coal burners***

For coal and wood, techniques referred to sometimes as ‘clean coal/biomass combustion’ are used. In this appliance the underfeed denotes that raw fuel is fed from below the plane of fuel ignition. Before the fuel reaches the plane of ignition the moisture is evaporated and some of the volatile matter is evolved. These gases then pass through the burning fuel bed where temperature is about 1100oC. The organic matter formed within the devolatization process is almost completely oxidised. 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. Primary air is supplied through the retort grate. The stoker boiler is characterized by higher efficiency, usually above 80 %. The advantage of stoker boilers 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, NOX increases due to the higher combustion temperature.

The emission factors which cover this type of appliance can be found in Table 3.19 which covers the combustion of coal in advanced stoves, and is also expected to be representative for advanced boilers.

***Wood boilers***

Automatic log-fired boilers are available. However, most small boilers are wood pellet or chip-fired. These have a fully automatic system for feeding of pellet or woodchip fuels and for supply of combustion air, which is distributed into primary (beneath the grate) and secondary (into the gas oxidation zone) air supplies. The boilers are equipped with a smaller pellet storage, which is fuelled manually or by an automatic system from a larger chamber storage. The operation of wood pellet boilers is similar to the function of wood pellet stoves; the pellets are introduced by screw into the burner. The burners can have different design such as underfeed burners, horizontally fed burners and overfed burners. These boilers are characterised by a high efficiency (usually above 80 %) and their emissions are comparable to those of liquid fuel boilers.

The emission factors which cover this type of appliance can be found in Table 3.44 which covers the combustion of wood pellets in modern wood pellet stoves and boilers.

***Liquid/gas-fuelled small boilers***

Gas/liquid boilers will typically have two functions, being used for hot water preparation and for heat generation for the central heating systems. In the capacity range below 50 kW output they are used mainly in single households. Water-tube low temperature boilers (temperature of water below 100 C) with open combustion chamber are usually applied in small combustion installations, which operate in the residential sector. These devices can be made of cast iron or steel. In respect of emissions, a principal distinction can be made between burners with and without a pre-mixing of fuel and combustion air: pre-mixing burners are characterized by homogenous short flames and a high conversion rate of fuel bounded nitrogen; non-premixing burners are characterized by heterogenous flames with under-stoichiometric reaction zones and a lower conversion rate of fuel bounded nitrogen. This latter type is characteristic for old combustion installations below 50KWth. For this reason emissions of NOX from non pre-mixing appliances have lower NOx emissions in comparison to new designs, which use burners with air pre-mixing systems, which gives a greater oxidation and breaking of bonds to increase NOX emissions. The boilers with capacity below 50 kW, can be divided into two main groups, i.e. standard boiler and condensing boilers.

***Standard boilers***

Standard boilers have an open combustion chamber, having maximum energy efficiency above 80 %, because of the comparatively high flue gas loses, with flue gases discharged at temperatures above 200oC, and the inlet/return water temperature usually above 60oC. Due to the very simple design of combustion process automation system they can have higher emissions of CO and VOC in comparison to larger boilers and industrial installations.

The emission factors which cover this type of appliance can be found in Table 3.16 which covers the combustion of natural gas in boilers and Table 3.18 which covers the combustion of gas-oil in boilers.

***Condensing boilers (room-sealed boilers)***

These devices recover more heat from the exhaust gases by condensing moisture released in the combustion process and can operate with efficiency more than 90 %. Therefore less flue is used and emissions are lower. The inlet/return water temperature is below 55oC to ensure the moisture in the flue gas will condense, which aids the high efficiency. In this case a two-function option of boiler operation (combination of water heating and surroundings heating) is preferred as this lowers the average inlet temperature. Condensation requires use of a corrosion proof stainless steel heat exchanger. The condensate, which contains sulphuric and nitric acids, is drained off into waste water systems where it is diluted sufficiently so as not to cause corrosion. The efficiency can be furthermore increased due to modification of design enabling preheating of combustion air with flue gases. Condensing boilers are mainly used by gaseous fuels, but oil-firing boilers are also available.

The emission factors which cover this type of appliance can be found in Table 3.16 which covers the combustion of natural gas in boilers and Table 3.18 which covers the combustion of gas-oil in boilers.

#### Cooking

##### Domestic cooking using solid fuel

These appliances are usually made of iron or steel and the combustion chamber is often covered with fire bricks; modern devices may incorporate a hot-water boiler for indirect heating of a dwelling. These appliances are also required to meet the standards set down within EN 12815 which covers residential cookers using solid fuels. Their autonomy is a few hours. Wood pellet oven appliances are a recent development. Pollutant emissions are quite high in old installations, while in the most recent ones, the use of secondary or tertiary air allows a better combustion control. Pellet ovens offer fully automatic operation and should provide similar emission levels to pellet stoves.

Outdoor pizza ovens and other oven devices are used in some countries. Solid fuel barbecues (outdoor cooking including ‘disposable’ single use barbecue packs) are used seasonally.

The emission factors which cover this type of appliance can be found in Table 3.14 which covers the combustion of solid fuels other than biomass within stoves, which can also be used for cooking. Table 3.40 covers emission factors for wood fired stoves, which can also be used for cooking.

##### Cooking using gas

Gas-fired units are widely used in the residential sector. These comprise hobs (including heating rings for pots) and ovens. Outdoor cooking uses bottled gas (LPG). Emission factors for this kind of technology are not currently well defined in the guidebook. The best suited emission factors to use will be provided within Table 3.16 for gas fired residential boilers.

#### Outdoor heating and other combustion

Residential and commercial use of outdoor heating has increased in some countries in recent years through the use of gas-fired patio heaters and similar devices. Traditional solid fuel fire pits and chimenea devices are also relevant.

Combustion appliances are used to heat stones used in saunas in Scandinavia (EN 15821 covers sauna stoves).

The emission factors which cover this type of appliance can be found in Table 3.13 which covers the combustion of natural gas within fire places, but can also be used to cover gas fired outdoor heating devices.

### Non-residential heating (1.A.4.a, 1.A.4.c, 1.A.5.a)

#### Overview

A general allocation of non-residential technologies and sizes is provided in the following table. For emission inventory purposes it is important to understand that the broad function/technology descriptions cover a range of combustion technologies and abatement technologies (in particular for solid fuels) with wide ranges in associated emission. The fuel descriptions also cover a wide range of fuel quality/properties. Note that where activity data is available (for example EU ETS data for energy installations >20MWth) it may be possible to disaggregate activity data to other size ranges.

| **Fuels** | **<1MWth** | **>1MWth** | **Function/ technology** | **Coverage** | **Comments** |
| --- | --- | --- | --- | --- | --- |
| Hard coal and brown coal | Y | Y | Boilers | Firetube boilers, smallest boilers likely use a fixed grate with underfeed or overfeed stoking, boilers will often have moving grate stokers of various types | Hot water boilers >1MWth for district or community heating |
|  | y | Y | Steam boiler | Firetube and watertube boilers, moving grate, fluid bed or pulverised fuel stoking | <1 MWth steam boilers likely to be rare. |
| (Solid) biomass | Y | - | Hot water boiler | Firetube boilers, smallest boilers likely fixed grate with underfeed or overfeed toking, boilers will often have moving grate stokers of various types | Machines >1MWth for district or community heating. Fuels either wood chip or wood pellet but a range of residues also burned. |
|  | - | Y | Steam boiler | Firetube and watertube boilers, moving grate, fluid bed or pulverised fuel stoking | Fuels either wood chip or wood pellet but a range of residues also burned. |
|  | Y | N | Ovens | Typically pizza or bread ovens, fairly simple devices | Restaurant ovens typically burn wood logs or wood briquettes |
|  | Y | N | Barbecue/grill | Charcoal grills/barbecues, fairly simple devices | Charcoal fuel |
| Liquid fuel | Y | - | Hot water boiler | Firetube boilers with one of more oil burners | Typically burn gas oil. Some condensing oil-fired boilers on market but typically non-condensing |
|  | Y | Y | Steam boiler | Firetube and watertube boilers with one of more oil burners | Larger machines can burn heavy or medium fuel oil. |
|  | Y | N | Air (space) heater | Including portable/movable units for spaceheating. | Smaller portable units may burn kerosene fuels. |
|  | Y | Y | Reciprocating engine | Typically providing electricity generation but also CHP. | Gas oil the nain fuel. Larger units may burn higher sulphur fuels. |
|  | - | Y | Gas turbine | Typically providing electricity generation but also fluid pumping/compression | Gas oil the main fuel. Larger units may burn higher sulphur liquid fuels. There are gas turbines smaller than 1 MWth but are comparatively rare. |
| Gaseous fuels | Y | - | Hot water boiler | Firetube boilers with one of more oil burners |  |
|  | - | Y | Steam boiler | Firetube (watertube on larger machines) boilers with one of more oil burners |  |
|  | Y | - | Air (space) heater | Including portable/movable units for spaceheating. | Smaller portable units may burn bottled gas. |
|  | Y | Y | Reciprocating engine | Typically providing CHP but also electricity generation and gas compression/fluidpumping. |  |
|  | - | Y | Gas turbine | Typically providing CHP but also electricity generation and gas compression/fluidpumping. | There are gas turbines smaller than 1 MWth but are comparatively rare. |
|  | Y | - | Ovens (Cooking) | Covers very small hotel/restaurant kitchens to larger commercial bakeries |  |
|  | Y | N | Hobs (Cooking) | Typically hotel/restaurant other kitchens |  |
|  | Y | Y | Drying/heating furnaces | Industrial (re)heat furnaces, curing furnaces, drying | Some industrial activity and emissions may be covered under industry reporting codes |

#### Boilers with indicative capacity up to 50 MWth

Boilers of such a capacity are used for heating in multi-dwelling residential buildings, office, school, hospital and apartment blocks and are commonly found small sources in commercial and institutional sector as well as in agriculture. The largest units are likely to be associated with other NFR sectors but are included. In this guidance, boilers have been distinguished into two groups (<1MWth and 1-50MWth) which provides a convenient but arbitrary separation between smaller ‘products’ and larger ‘bespoke’ equipment.

As noted below, 1MWth is a realistic threshold for manual stoking (although a manually—stoked modern non-residential boilers would be extremely unusual). In addition, typically, boilers <1MWth provide hot water and larger boilers provide steam. However, this should not be considered a definitive boundary; there are many hot water boilers >1MWth (for example in community or district heating plant) and small steam boilers are not uncommon in industry. The following technology descriptions provide some indication of the range of technologies that are applied.

##### Solid fuel boilers

Fixed and moving grate combustion technologies are commonly used for combustion of solid fuels in this capacity range. This is a well-established technology, and a great variety of fixed-grate and moving grate boilers are in use. Fixed grate technology is associated with the <1MWth size range.

In addition to fixed grate combustion, fluidised bed combustion boilers are in use in this capacity range, frequently for biomass combustion. Pulverised fuel or wood dust burners can also be present.

Installations can also be differentiated by stoking arrangement:

* manually fuelled; usually with a capacity lower than 1MWth;
* automatically fuelled; all sizes; and
* Some smaller boilers can be considered semi-automatic in that they have manually-fed hoppers (for coal fuels or wood pellets) or magazines (wood logs) however these are generally associated with single dwelling residential appliances (<50 kW) and the largest appliances are usually smaller than 150 kW output.

As a standard approach to inventory compilation for Tier 2, the emission factors are presented thus:

* Table 3.20 and Table 3.21 provide data on combustion of coal fired boilers for <1MWth and >1MWth - <50MWth respectively.
* Table 3.45 and Table 3.46 provide data on combustion of wood fired boilers for 1-50 MWth and 50 kWth – 1 MWth, respectively.

As a further step to disaggregating the emission estimates an higher Tier of data is provided for the <1MWth appliances. This reflects the difference in emissions between manual feed and automatic feed boilers. For inventory compilation dependent on available activity data the standard emission factor tables should be used for basic Tier 2 inventory compilation. Where available activity data allows the advanced tables may be used for <1MWth, these additional emission factor tables are presented thus:

* Table 3.22 and Table 3.23 provide data on combustion of coal fired boilers for <1MWth disaggregated between manual feed and automatic feed respectively.
* Table 3.45 and Table 3.46 provide data on combustion of wood fired boilers for <1MWth disaggregated between manual feed and automatic feed respectively.

**Manual feed boilers**

##### Coal boilers

Manually fed boilers in this capacity range apply two combustion techniques, under-fire and upper-fire, similar to the residential boilers of lower capacity range (see subsection 0 of the present chapter).

1. Overfeed boilers, under-fire boilers: coal fuels of different grain size (usually between 5 mm 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.
2. 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 is started from the top of the fuel charge. 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 tend to have better organisation of the combustion air compared with the ones used in single households.

##### Biomass/straw boilers

Manual stoking is usually associated with wood log boilers and straw and cereal bale combustion. The straw bales are fed to the combustion chamber by hand. Due to the very fast combustion of this type of biomass, such installations contain a hot-water accumulation system. For this reason they are used only in small-scale applications up to a nominal boiler capacity of 1 MWth. They are popular in the agricultural regions due to their relatively low costs and simple maintenance.

**Automatic feed boilers**

Most modern boilers are equipped with automatic feeding (including residential units). 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 particulate abatement equipment.

Fixed grate combustion is commonly used in the smaller appliances but moving grate combustion is commonly adopted for larger machines. Fuel is fed to the grate using as spreader stokers, overfeed stokers, and underfeed stokers.

Coal of smaller granulation or fine wood (wood pellet, chips or sawdust/residues) is charged on a mechanical moving grate. The combustion temperatures are between 1 000 °C and 1 300 °C. General applications are aimed at production of hot water, and/or low-pressure steam for commercial and institutional users, in particular for heating. Due to the 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

These are used for both coal and wood combustion. The fuel is fed into the combustion chamber through a screw conveyor (augur) and is transported to a retort when is oxidised.

##### Cigar straw boiler technology

This is 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

This uses a separate gasification system for the chipped wood fuels, and the subsequent 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 systems apply a fully automatic combustion process and consequently emissions are low.

##### Advance automatically stoked wood chip and wood pellet boilers

They generally have a high level of autonomy. Inverted combustion is generally used with forced draught providing the best performances. The combustion efficiency ranges from 85 to 90 % and the degree of autonomy depends on the degree of automation applied to fuel and ash handling equipment (ranges from 24 hours to all the heating season).

**Fluidised bed combustion**

Fluidised bed combustion (FBC) can be divided into bubbling fluidised bed (BFB) and circulating fluidised bed combustion (CFB), depending on the fluidisation velocity. FBC is particularly suitable for low-quality, high-ash content coal or other ‘difficult’ solid fuels including process residues and wastes.

##### Liquid/gas fuels

For gas and oil boilers the fuel and air are introduced as a mixture using dedicated burners in the combustion chamber. The burners on these small boilers tend to be self-contained units from specialist manufacturers which are fitted to a boiler.

Boilers fired with gaseous and liquid fuels are produced in a wide range of different designs and can be classified according to burner type, construction material, the type of medium transferring heat (hot water, steam) and their power, the water temperature in the water boiler (which can be low temperature ≤ 100 oC, medium-temperature > 100 oC to ≤ 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).

Emission factor tables covering the use of liquid fuels for commercial boilers are covered by Table 3.24 and Table 3.25, which detail the use of liquid fuels for <1MWth and >1MWth – 50MWth appliances respectively.

##### 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 MWth.

##### Steel boilers

Manufactured, up to a nominal capacity of 50 MWth, 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 and condensing boilers.

##### Water-tube boilers

Equipped with external steel water jacket. Water-tubes (water flows inside, exhaust gasses outside) are welded in the walls of the jacket.

##### Fire-tube boilers

In these boilers combustion gasses flow inside smoke tubes, which are surrounded by water. They are designed as cylinder or rectangular units.

##### Condensing boilers

Recover some of the latent heat of the water vapour in the flue gases to improve energy efficiency – commonly applied to small (<1MWth) gas-fired boilers but condensing technology has also been applied to small gas oil and wood pellet boilers.

**Non-residential cooking**

##### Cooking using solid fuel

The extent of solid fuel use in commercial cooking is not known, but is likely to be in specialised areas such as artisan bakeries and traditional wood-fired pizza ovens in restaurants. In addition, there is growing use of charcoal barbecues/grills by restaurants and catering/event hospitality organisations.

Emission factor tables for these sources are covered by Table 3.20 and Table 3.46 which detail emission factors for coal and wood, respectively, for the <1MWth sized appliances. Additionally, Table 3.22, and Table 3.23 (coal), Table 3.47 and Table 3.48 (wood) provide further disaggregation for <1MWth appliances between those that are manual feed and automatic feed respectively.

##### Cooking using gas

Gas-fired units are widely used in hotels, the commercial restaurants and non-commercial sectors (for example schools and hospitals). These comprise hobs (including heating rings for pots) and ovens.

The Ecodesign Lot 22 study (Mudgal et al, 2011) estimated annual natural gas use in various cooking uses as:

|  |  |
| --- | --- |
| **Cooking use** | **EU natural gas use,  kWh per oven per year** |
| Domestic oven | 183.7 |
| Restaurant ovens | 11,887 |
| Bakery convection ovens | 61,402 |
| Bakery rack ovens | 78,345 |

Outdoor cooking for catering/event hospitality uses bottled gas (LPG).

Emission estimation for cooking with natural gas should make use of the emission factors presented within Table 3.26 which covers gas boilers <1MWth, but can be used for cooking with gas as a proxy.

#### Non-residential space heating (direct heating)

Fireplaces and stoves are residential spaceheaters which may also find use in commercial and institutional premises. However, larger gas and oil-fired combustion units are used for heating in the commercial and industrial sectors. Units can be fixed (to ceilings and walls) or semi-portable.

#### Outdoor heating and other combustion

Commercial use of outdoor heating has increased in some countries in recent years through the use of gas-fired patio heaters and similar devices. Larger hot air furnaces are often used to heat work spaces, temporary buildings and marquees.

Combustion appliances are used to heat stones used in saunas in Scandinavia.

Steam cleaning equipment often incorporates an oil burner to provide hot water.

#### Gas turbines

‘Micro’ turbines are available providing small scale generation (typically 15-500 kWe) and provide gas turbine technology in the <1MWth size range. The technology is attractive for cogeneration and applicable to natural gas, produced fuel gas, biogases and liquid fuels. However, emission data for the technology are limited – particularly for pollutants other than NOX and CO. Consequently, Tier 2 factors for this technology <1MWth are not included in the guidebook. Manufacturers’ information and scientific literature indicate that low-NOX combustion technology can achieve NOX emissions comparable to levels achieved on larger gas turbines.

Gas turbines can utilise a range of gaseous fuels, such as natural gas or in some instances, process gases or gasification products. Liquid fuels are also used, such as light distillates (e.g. naphtha, kerosene or gas oil) but, in general, use of liquid fuels is limited to specific applications or as a standby fuel. Gas turbines are aero-derivative designs (i.e. based on multiple shaft engines derived from aircraft engine types) or industrial heavy-duty gas turbines (based on single shaft designs). Gas turbines for electricity generation can be open (simple) cycle units but are often installed as a part of a combined cycle gas turbine (CCGT). In a CCGT installation, a heat recovery steam generator (HRSG) is used to recover waste heat from the combustion gases providing steam to power a steam turbine which drives an alternator providing more electricity. The net rated efficiency of a modern CCGT is in excess of 50 %. Gas turbines are often found in co-generation plant, the gas turbine directly coupled to an electricity generator and the energy from hot exhaust gases recovered in a suitable HRSG (boiler) or used directly (for example drying). Supplementary burners are commonly used to provide additional heat input to the exhaust gases. Integrated coal gasification combined cycle gas turbine (IGCC) plants use fuel gas derived from coal. Note that for IGCC plants, the only emission relevant unit considered here is the gas turbine. Gas turbines are also used for gas compression/fluid transfer.

Emission factor tables for gas turbines can be found in Table 3.28 and Table 3.29 which cover the use of natural gas and gas oil respectively.

#### Reciprocating engines

Stationary engines are spark-ignition engines and compression-ignition engines (2- and 4-stroke) with electrical outputs ranging from less than 100 kW to over 20 MW. Both types represent relevant emission sources. Such units are common as island generators (away from a supply grid), small combined heat and power CHP units, or for cogeneration and standby or emergency uses.

Engines can utilise a range of gaseous fuels, such as natural gas or in some instances, process gases or gasification products. Gas engines are typically spark-ignition engines. Liquid fuel types are more commonly compression ignition types. Emission factor tables for reciprocating engines can be found in Table 3.30 and Table 3.31 which cover the use of natural gas and gas oil respectively.

#### Cogeneration and 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 small CHP units. Use of steam boiler plus back-pressure turbine for electricity generation is the traditional approach and can allow use of biomass fuels. However, use of small-scale internal combustion cogeneration technology (gas turbine or stationary engine with heat recovery) is increasingly common. The cogeneration technology can be applied in comparatively small applications using small gas-fired reciprocating engines, but large reciprocating engines and gas turbines are also applied. Tri-generation (CHP and cooling) is also applied using this technology.

There are examples of small-scale wood gasification technology, primarily for waste wood streams, but also capable of operation on non-waste wood.

## Emissions

Relevant pollutants are SO2, NOX, CO, NMVOC, particulate matter (PM), black carbon (BC), heavy metals, PAH, polychlorinated dibenzo-dioxins and furans (PCDD/F) and hexachlorobenzene (HCB). 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. However, ‘ultra-low’ NOX burner technology is available for gas combustion in larger appliances. In general, natural gas fuels have far lower potential for emission of sulphur and metal compounds than oils and solid fuels because natural gas contains lower quantities of such components – this also applies to NOX emissions as natural gas does not contain significant quantities of compounds with bound nitrogen.

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, NH3 , PAHs as well as PCDD/F. However, natural gas is a simpler fuel (principally methane with other low molecular weight hydrocarbons) and the potential for emission of complex organic compounds (PAH and PCDD/F) is limited compared to oils and solid fuels.

Note that the inventory methodologies for Greenhouse gas emissions (carbon dioxide, methame and nitrous oxide) are not included – refer to IPCC guidance (IPCC, 2006).

*NH3* —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). NH3 emissions can generally be reduced by primary measures aiming to reduce products of incomplete combustion and increase efficiency.

*TSP, PM10, PM2.5* —particulate matter in flue gases from combustion of fuels (in particular of solid mineral fuels and biomass) may 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 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 result 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 mineral matter in the fuel; they contain oxides and salts (S, Cl) of Ca, Mg, Si, Fe, K, Na, P, heavy metals, and unburned carbon formed from incomplete combustion of carbonaceous material; black carbon or elemental carbon — BC (Kupiainen, et al., 2004).

Particulate matter emission and size distribution from small installations largely 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 a decrease of TSP emission and to a change of PM distribution (Kubica, 2002/1 and Kubica et al., 2004/4). 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 μm) and the mass concentration of particles larger than 10 μm is normally < 10 % for small combustion installations (Boman et al., 2004 and 2005, Hays et al., 2003, Ehrlich et al, 2007).

As described above, small combustion activities can have a wide range of particulate emissions and, this emission may be partitioned between filterable and condensable fractions. The proportions are variable and determination of particulate fraction emissions is highly dependent on the measurement approach.

However, there are different conventions and standards for measuring particulate emissions. Particulate emissions can be defined by the measurement technique used including factors such as the type and temperature of filtration media and whether condensable fractions are measured. A range of filterable PM measurement methods are applied around the world typically with filter temperatures of 70-160°C (the temperature is set by the test method).  A condensable fractions can be determined directly by recovering condensed material from chilled impinger systems downstream of a filter – note that this is condensation without dilution and can require additional processing to remove sampling artefacts. Another approach for total PM includes dilution where sampled flue or exhaust gases are mixed with ambient air (either using a dilution tunnel or dilution sampling systems) and the filterable and condensable components are collected on a filter at lower temperatures (but depending on the method this can be 15-52°C). The use of dilution methods, however, may be limited due to practical constraints with weight and/or size of the equipment.

A wide range of PM measurement techniques have been applied for particulate measurements including type approval standards defined to address national emission regulations. Methods used in research projects can differ significantly from type approval methods. The methodologies applied can be split into dilution methods (including use of dilution tunnels or systems applying dilution after sampling) and direct sampling methods. The latter methods include conventional industrial stack emission test methods such EN13284-1 and ISO 9096 and national methods applied in (for example) Sweden and Germany for small and large-scale combustion plant.

The dilution methods (NS3058/9, BS3841, USEPA 5G, AS/NZS 4012/3) tend to be used on residential appliances to collect the filterable and condensable PM fractions which are associated with the relatively poor combustion conditions associated with solid fuel, batch-fed, manually-controlled appliances operating under natural draught.

USEPA Method 5H is designed to assess wood-burning stoves and provides a direct sampling method coupled with collection of the condensable fraction by chilling the sampled flue gases downstream of the filter.

There are key differences in the test protocols adopted for type approval of residential and other small appliances (multiple tests at single output, multiple tests at multiple outputs and single tests at multiple outputs). Other key differences include use of natural wood logs or a standard wood crib, constant or natural draught and ignition processes. None of the type approval methods assess emissions during ignition from cold.

The characteristics of the measurement methodologies, and hence PM collected, mean that it can be difficult to compare reported emission data. A comparative study (Nussbaumer et al., 2008/1) of the different sampling methods for small-scale biomass appliances showed that the emission factors determined when using a dilution tunnel are between 2.5 and 10 times higher than when only taking into account the solid particles measured directly in the chimney. This range is also reported by Bäfver (2008). A test on a wood stove carried out by the Danish Technological Institute showed a ratio of approximately 4.8 between an in-stack measurement and a measurement in a dilution tunnel (Winther, 2008).

The PM emission factors (for TSP, PM10 and PM2.5) can represent the total primary PM emission, or the filterable PM fraction. The basis of the emission factor is described (see individual emission factor tables).

*Black carbon (BC)* – Black carbon is formed from incomplete combustion of organic compounds with lack of oxygen to fully oxidize the organic species to carbon dioxide and water.

BC is the term for a range of carbon containing compounds. It covers partly large polycyclic species, charred plants to highly graphitized soot. Black carbon originates from fossil fuel and biomass combustion and the properties of the resulting BC such as atmospheric lifetime and optical properties, are dependent on combustion temperature, oxygen concentration during combustion and for biomass burning also of wood moisture.

Combustion of fuels is the main source of BC emission. The same emission control techniques that limit the emission of PM will also reduce the emission of BC. However, measurement data that addresses the abatement efficiencies for BC are still very few. ***This means that in general it is assumed that the BC emission is reduced proportionally to the PM emission.*** The BC emission factors are expressed as percentage of the PM2.5 emission. In many references elemental carbon (EC) is used synonymously with BC. However, organic carbon (OC) is contributing to the light absorption of particles but to a lesser extent than EC. To ensure the widest possible dataset all data for EC has been treated as part of the data basis for the BC EFs. Furthermore, it should be noted that the BC percentages depend on whether condensables are taken into account in the PM2.5 emission factor, since the BC or EC is only present in the solid (filterable) part and not in the gases that form particles upon cooling (the condensables).

*Heavy metals (HM)* —the emission of heavy metals strongly depends on their contents in the fuels. Coal and its derivatives normally contain levels of heavy metals which are several orders of magnitude higher than in oil (except for Ni and V in heavy oils) and natural gas. All ‘virgin’ biomass also contains heavy metals. Their content depends on the type of biomass.

Most 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. sulphides, chlorides or organic compounds). Hg, Se, As and Pb are at least partially present in the vapour phase. Less volatile metal compounds tend to condensate onto the surface of smaller particles in the exhaust gases.

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).

Mercury emitted from small combustion installations (SCIs), similarly to emission from large scale combustion, occurs in elementary form (elemental mercury vapour Hg0), reactive gaseous form (reactive gaseous mercury (RGM)) and total particulate form (TPM) (Pacyna et al, 2004). Meanwhile, it has been shown (Pye et al., 2005) that in the 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). With the exception of Hg, As, Cd and Pb (which have a significant volatile component), heavy metals emissions can be reduced by secondary (particulate) emission reduction measures.

*PCDD/F* — the emissions of dioxins and furans are highly dependent on the conditions under which cooling of the combustion and exhaust gases is carried out. Carbon, chlorine, a catalyst and oxygen excess are necessary for the formation of PCDD/F. They are found to be consequence of the de-novo synthesis in the temperature interval between 180 oC and 500 oC (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).

HCB — emissions of HCB from combustion processes are highly uncertain but, on the whole, processes resulting in PCDD/F formation lead also to HCB emissions (Kakeraka, 2004).

*PAH* —emissions of polycyclic aromatic hydrocarbons results from incomplete (intermediate) conversion of fuels. Emissions of PAH depend on 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 50 kWth), 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 PAH emissions, 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 CO2; it is oxidized to CO2 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 with automatic feeding (and perhaps oxygen ‘lambda’ sensors) offer favourable conditions to achieve lower CO emission. For example, the emissions of CO from solid fuelled small appliances can be several thousand ppm in comparison to 50–100 ppm for industrial combustion chambers, used in power plants.

*NMVOC* — for small combustion installations (e.g. residential combustion) emissions of NMVOC can occur in considerable amounts; these emissions are mostly released from inefficiently working stoves (e.g. wood-burning stoves). VOC emissions released from wood-fired boilers (0.510 MW) can be significant. Emissions can be up to ten times higher at 20 % load than those at maximum load (Gustavsson et al, 1993). NMVOC 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 low combustion temperature, 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.

*Sulphur oxides* — in the absence of emission abatement, the emission of SO2 is dependent on the sulphur content of the fuel. The combustion technology can influence the release of SO2 with (for solid mineral fuels) higher sulphur retention in ash than is commonly associated with larger combustion plant.

*Nitrogen oxides* — emission of NOX is generally in the form of nitric oxide (NO) with a small proportion present as nitrogen dioxide (NO2). Although emissions of NOX are comparatively low in residential appliances compared to larger furnaces (due in part to lower furnace temperatures), the proportion of primary NO2 is believed to be higher.

## 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).

The key measure for residential appliances is combustion control; emission of PM, CO, NMVOC and PAH are very dependent on combustion control, and measures to improve this include better control of temperature, air distribution and fuel quality. A modern enclosed fireplace burning fuel of the correct quality is less polluting than an open fire.

Primary measures which change appliance population or fuel quality are not directly relevant to current emissions except for trying to assess how far national or regional policies may have been implemented. The timing or progress of implementation of national measures for primary measures is also relevant for projections.

*Primary* measures: there are several common possibilities (Kubica, 2002/3, Pye et al., 2004):

* 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 fuel size range); 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 SO2, 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;
* replacing of coal by upgraded solid derived fuel, biomass, oil, gas;
* control optimization of combustion process;
* management of the combustion appliance population: replacement of low efficiency heating appliances with newly designed appliances, and supervision of their distribution by obligatory certification system; supervision over residential and communal system heating; and
* improved construction of the combustion appliances; implementation of advanced technologies in fire places, stoves and boilers construction (implementation of Best Available Techniques (BAT) for combustion techniques and good combustion practice).

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 tend to be applied in accordance with national emission control requirements which vary considerably. For particulate matter the following options can be considered:

* settling chambers: gravity separation characterised by a low collection efficiency and ineffective for the fine particulate fraction;
* cyclone separators: commonly applied but have a comparatively low collection efficiency for fine particles (< 85 %);
* for higher effectiveness (94–99 %), units with multiple cyclones (cyclone batteries) are applied, and multi-cyclones allow for increased gas flow rates; and
* electrostatic precipitators (their efficiency is between 99.5 % to 99.9 %) or fabric filters (with efficiency about 99.9 %) can be applied to the larger facilities in the ≤50 MWth range, but are likely to be excessive for smaller facilities.

The range of emission control encompasses manually-fired residential appliances with no control measures through to large boilers with fabric filters. Although emission control may be limited for small appliances, automatic biomass heating boilers as small as 100 kW output are commonly fitted with a cyclone.

Small (residential) 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 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 %, CH4 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. Modern wood appliances are generally not fitted with catalytic control systems.

FBC furnaces can incorporate lime injection into the combustion bed to capture SO2.

# Methods

## Choice of method

Figure 3‑1 presents the procedure to select the methods for estimating process emissions from the relevant activities. The main idea behind the decision tree is to use detailed information whenever it is available. If detailed information (e.g. in the form of measurements or modelling tools) is available, this should be used as much as possible.

If the source category is a key source, a Tier 2 or better method must be applied and detailed input data must be collected. Small combustion is likely to be a key source for multiple pollutants. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is easier to obtain the necessary input data for this approach than to collect facility level or appliance data needed for a Tier 3 estimate.

Figure 3‑1 Decision tree for source category 1.A.4 Small combustion



For the combustion activities in this chapter it is unlikely that a facility-specific approach could be adopted because detailed information on individual installations is unlikely to be available. However, modelling of the NFR sector and appliance population is consistent with a Tier 3 approach.

Despite this source being a key source for multiple pollutants, it was found that many Parties apply Tier 1 approaches in the absence of the data and information needed for a Tier 2 approach. Especially for biomass this is an issue, since PM emissions from small combustion of solid biomass are the largest source of primary PM2.5 emissions in Europe. To overcome this, a specific Tier 2 approach for solid biomass has been developed, which is accompanied by default information on how to split between technologies/appliances. This way, each Party should be able to report their emissions from small combustion of solid biomass using the Tier 2 approach.

## Tier 1 default approach

### Algorithm

The Tier 1 approach for process emissions from small combustion installations uses the general equation:

 (1)

where:

Epollutant = the emission of the specified pollutant,

ARfuelconsumption = the activity rate for fuel consumption,

EFpollutant = the emission factor for this pollutant.

This equation is applied at the national level, using annual national fuel consumption for small combustion installations in various activities.

In cases where specific abatement options are to be taken into account, a Tier 1 method is not applicable and a Tier 2 or, if practical, Tier 3 approach must be used.

### Default emission factors

Factors are provided for major fuel classifications and applying a distinction between residential and non-residential (institutional, commercial, agricultural and other) activities which can have significantly different emission characteristics. This distinction is an economical one and is made following the split which is typically available in the energy statistics. For the Tier 1 approach, it is assumed that the residential plants are typically of a size < 50 kWth, while non-residential plants are typically between 50 kWth – 50 MWth. However, it should be noted that this is not always hold in practice. For the Tier 1 approach however, which is only to be applied for non-key sources, this simplification can be made.

Table 3.1 Summary of Tier 1 emission factor categories

|  |  |
| --- | --- |
| **Activity** | **Description** |
| 1.A.4.b.i Residential combustion | Small stationary combustion in stallations for heating and cooking in residential applications. |
| 1.A.4.a.i, 1.A.4.c.i, 1.A.5.a Non-residential  (institutional/commercial plants, plants in agriculture/forestry/aquaculture and other stationary plants (including military)) | Small combustion installations applied in stationary institutional/commercial plants, stationary plants in agriculture/forestry/aquaculture and other stationary applications |

The general Tier 1 fuel types are provided in Table 3.2. Different hard and brown coal fuels are treated as one fuel type. Liquid fuels (heavy fuel oil and other liquid fuel) are treated as one fuel type. Similarly, natural gas and derived gases are also treated as one fuel type in the Tier 1 approach.

Where ‘Guidebook 2006’ is referenced in the tables, the emission factor is taken from chapter B216 of the 2006 Guidebook. The original reference could not be determined and the factor represents an expert judgement based on the available data.

Table 3.2 Summary of Tier 1 fuels

|  |  |
| --- | --- |
| Tier 1 Fuel type | Associated fuel types |
| Hard coal and  Brown coal | Coking coal, other bituminous coal, sub-bituminous coal, coke, manufactured ‘patent’ fuel  Lignite, oil shale, manufactured ‘patent’ fuel, peat |
| Gaseous fuels | Natural gas, natural gas liquids, liquefied petroleum gas, gas works gas, coke oven gas, blast furnace gas |
| Liquid fuels | Residual fuel oil, refinery feedstock, petroleum coke, orimulsion, bitumen, gas oil, kerosene, naphtha, shale oil |
| Biomass | Wood, wood pellets, charcoal, vegetable (agricultural) waste |

Default Tier 1 emission factors are provided in Table 3.3 to Table 3.10.

#### Residential combustion (1.A.4.b.i)

Table 3.3 Tier 1 emission factors for NFR source category 1.A.4.b, using hard coal and brown coal

| **Tier 1 default emission factors** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Hard Coal and Brown Coal | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 110 | g/GJ | 36 | 200 | Guidebook (2006) chapter B216 |
| CO | 4600 | g/GJ | 3000 | 7000 | Guidebook (2006) chapter B216 |
| NMVOC | 484 | g/GJ | 250 | 840 | Guidebook (2006) chapter B216 |
| SOx | 900 | g/GJ | 300 | 1000 | Guidebook (2006) chapter B216 |
| NH3 | 0.3 | g/GJ | 0.1 | 7 | Guidebook (2006) chapter B216 |
| TSP | 444 | g/GJ | 80 | 600 | Guidebook (2006) chapter B216 |
| PM10 | 404 | g/GJ | 76 | 480 | Guidebook (2006) chapter B216 |
| PM2.5 | 398 | g/GJ | 72 | 480 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 130 | mg/GJ | 100 | 200 | Guidebook (2006) chapter B216 |
| Cd | 1.5 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Hg | 5.1 | mg/GJ | 3 | 6 | Guidebook (2006) chapter B216 |
| As | 2.5 | mg/GJ | 1.5 | 5 | Guidebook (2006) chapter B216 |
| Cr | 11.2 | mg/GJ | 10 | 15 | Guidebook (2006) chapter B216 |
| Cu | 22.3 | mg/GJ | 20 | 30 | Guidebook (2006) chapter B216 |
| Ni | 12.7 | mg/GJ | 10 | 20 | Guidebook (2006) chapter B216 |
| Se | 1 | mg/GJ | 1 | 2.4 | Expert judgement based on Guidebook (2006) chapter B216 |
| Zn | 220 | mg/GJ | 120 | 300 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 800 | ng I-TEQ/GJ | 300 | 1200 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 230 | mg/GJ | 60 | 300 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 330 | mg/GJ | 102 | 480 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 130 | mg/GJ | 60 | 180 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 110 | mg/GJ | 48 | 144 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

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.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.4 Tier 1 emission factors for NFR source category 1.A.4.b, using gaseous fuels

| **Tier 1 default emission factors** | | | | | |
| --- | --- | --- | --- | --- | --- |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Gaseous fuels | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 51 | g/GJ | 31 | 71 | \* |
| CO | 26 | g/GJ | 18 | 42 | \* |
| NMVOC | 1.9 | g/GJ | 1.1 | 2.6 | \* |
| SOx | 0.3 | g/GJ | 0.2 | 0.4 | \* |
| TSP | 1.2 | g/GJ | 0.7 | 1.7 | \* |
| PM10 | 1.2 | g/GJ | 0.7 | 1.7 | \* |
| PM2.5 | 1.2 | g/GJ | 0.7 | 1.7 | \* |
| BC | 5.4 | % of PM2.5 | 2.7 | 11 | \* |
| Pb | 0.0015 | mg/GJ | 0.0008 | 0.003 | \* |
| Cd | 0.00025 | mg/GJ | 0.0001 | 0.0005 | \* |
| Hg | 0.68 | mg/GJ | 0.3 | 1.4 | \* |
| As | 0.12 | mg/GJ | 0.06 | 0.24 | \* |
| Cr | 0.00076 | mg/GJ | 0.0004 | 0.0015 | \* |
| Cu | 0.000076 | mg/GJ | 0.00004 | 0.00015 | \* |
| Ni | 0.00051 | mg/GJ | 0.0003 | 0.0010 | \* |
| Se | 0.011 | mg/GJ | 0.004 | 0.011 | \* |
| Zn | 0.0015 | mg/GJ | 0.0008 | 0.003 | \* |
| PCDD/F | 1.5 | ng I-TEQ/GJ | 0.8 | 2.3 | \* |
| Benzo(a)pyrene | 0.56 | µg/GJ | 0.19 | 0.56 | \* |
| Benzo(b)fluoranthene | 0.84 | µg/GJ | 0.28 | 0.84 | \* |
| Benzo(k)fluoranthene | 0.84 | µg/GJ | 0.28 | 0.84 | \* |
| Indeno(1,2,3-cd)pyrene | 0.84 | µg/GJ | 0.28 | 0.84 | \* |
| \* average of Tier 2 EFs for residential gaseous fuel combustion for all technologies | | | | | |

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.5 Tier 1 emission factors for NFR source category 1.A.4.b, using liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 1 default emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | 'Other' Liquid Fuels | | | | |
| **Not applicable** | HCB, PCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 51 | g/GJ | 31 | 72 | \* |
| CO | 57 | g/GJ | 34 | 80 | \* |
| NMVOC | 0.69 | g/GJ | 0.4 | 1.0 | \* |
| SOx | 70 | g/GJ | 42 | 97 | \* |
| TSP | 1.9 | g/GJ | 1.1 | 2.6 | \* |
| PM10 | 1.9 | g/GJ | 1.1 | 2.6 | \* |
| PM2.5 | 1.9 | g/GJ | 1.1 | 2.6 | \* |
| BC | 8.5 | % of PM2.5 | 4.8 | 17 | \* |
| Pb | 0.012 | mg/GJ | 0.01 | 0.02 | \* |
| Cd | 0.001 | mg/GJ | 0.0003 | 0.001 | \* |
| Hg | 0.12 | mg/GJ | 0.03 | 0.12 | \* |
| As | 0.002 | mg/GJ | 0.001 | 0.002 | \* |
| Cr | 0.20 | mg/GJ | 0.10 | 0.40 | \* |
| Cu | 0.13 | mg/GJ | 0.07 | 0.26 | \* |
| Ni | 0.005 | mg/GJ | 0.003 | 0.010 | \* |
| *Se* | 0.002 | *mg/GJ* | 0.001 | 0.002 | \* |
| Zn | 0.42 | mg/GJ | 0.21 | 0.84 | \* |
| PCDD/F | 5.9 | ng I-TEQ/GJ | 1.2 | 30 | \* |
| Benzo(a)pyrene | 80 | ug/GJ | 16 | 120 | \* |
| Benzo(b)fluoranthene | 40 | ug/GJ | 8 | 60 | \* |
| Benzo(k)fluoranthene | 70 | ug/GJ | 14 | 105 | \* |
| Indeno(1,2,3-cd)pyrene | 160 | ug/GJ | 32 | 240 | \* |
| \* average of Tier 2 EFs for residential liquid fuel combustion for all technologies | | | | | |

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.6 Tier 1 emission factors for NFR source category 1.A.4.b, using biomass 3) 5)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 1 default emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Solid biomass | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 50 | g/GJ | 30 | 150 | Pettersson et al. (2011) |
| CO | 4000 | g/GJ | 1000 | 10000 | Pettersson et al. (2011) and Goncalves et al. (2012) |
| NMVOC | 600 | g/GJ | 20 | 3000 | Pettersson et al. (2011) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996b) |
| NH3 | 70 | g/GJ | 35 | 140 | Roe et al. (2004) |
| TSP (total particles) | 800 | g/GJ | 400 | 1600 | Alves et al. (2011) and Glasius et al. (2005) 1) |
| PM10 (total particles) | 760 | g/GJ | 380 | 1520 | Alves et al. (2011) and Glasius et al. (2005)  1) |
| PM2.5 (total particles) | 740 | g/GJ | 370 | 1480 | Alves et al. (2011) and Glasius et al. (2005)  1) |
| BC (based on total particles) | 10 | % of PM2.5 | 2 | 20 | Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989) |
| TSP (solid particles only) | 200 | g/GJ | 400 | 1600 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| PM10 (solid particles only) | 160 | g/GJ | 380 | 1520 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| PM2.5 (solid particles only) | 140 | g/GJ | 370 | 1480 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| BC (based on solid particles only) | 53 | % of PM2.5 | 11 | 100 | Denier van der Gon et al. (2015) applied on Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989) 4) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| PCBs | 0.06 | g/GJ | 0.006 | 0.6 | Hedman et al. (2006) 2) |
| PCDD/F | 800 | ng I-TEQ/GJ | 20 | 5000 | Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005) |
| Benzo(a)pyrene | 121 | mg/GJ | 12 | 1210 | Goncalves et al. (2012); Tissari et al. (2007);  Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011) |
| Benzo(b)fluoranthene | 111 | mg/GJ | 11 | 1110 |
| Benzo(k)fluoranthene | 42 | mg/GJ | 4 | 420 |
| Indeno(1,2,3-cd)pyrene | 71 | mg/GJ | 7 | 710 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
2. Assumed equal to conventional boilers.
3. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
4. Emission factors for solid particles are calculated from the total particulate EFs by applying the ratio of emission factors for solid / total particles reported in Denier van der Gon et al. (2015). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.
5. The emission factors for solid biomass combustion in the Tier 1 approach are identical to the Tier 2 emission factors for conventional stoves, in view of the fact that stoves are the key contributor to (PM) emissions from biomass.

#### Commercial/institutional, agricultural and other stationary combustion (1.A.4.a, 1.A.4.c, 1.A.5)

Table 3.7 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using hard and brown coal

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 1 default emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Hard Coal and Brown Coal | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 173 | g/GJ | 150 | 200 | Guidebook (2006) chapter B216 |
| CO | 931 | g/GJ | 150 | 2000 | Guidebook (2006) chapter B216 |
| NMVOC | 88.8 | g/GJ | 10 | 300 | Guidebook (2006) chapter B216 |
| SOx | 900 | g/GJ | 450 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 124 | g/GJ | 70 | 250 | Guidebook (2006) chapter B216 |
| PM10 | 117 | g/GJ | 60 | 240 | Guidebook (2006) chapter B216 |
| PM2.5 | 108 | g/GJ | 60 | 220 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | See Note |
| Pb | 134 | mg/GJ | 50 | 300 | Guidebook (2006) chapter B216 |
| Cd | 1.8 | mg/GJ | 0.2 | 5 | Guidebook (2006) chapter B216 |
| Hg | 7.9 | mg/GJ | 5 | 10 | Guidebook (2006) chapter B216 |
| As | 4 | mg/GJ | 0.2 | 8 | Guidebook (2006) chapter B216 |
| Cr | 13.5 | mg/GJ | 0.5 | 20 | Guidebook (2006) chapter B216 |
| Cu | 17.5 | mg/GJ | 5 | 50 | Guidebook (2006) chapter B216 |
| Ni | 13 | mg/GJ | 0.5 | 30 | Guidebook (2006) chapter B216 |
| Se | 1.8 | mg/GJ | 0.2 | 3 | Guidebook (2006) chapter B216 |
| Zn | 200 | mg/GJ | 50 | 500 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 203 | ng I-TEQ/GJ | 40 | 500 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 45.5 | mg/GJ | 10 | 150 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 58.9 | mg/GJ | 10 | 180 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 23.7 | mg/GJ | 8 | 100 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 18.5 | mg/GJ | 5 | 80 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

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.

No information was specificcaly available for small boilers. The BC share is taken as the same value as for residential sources and referenced to Zhang et al. (2012).

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.8 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using gaseous fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 1 default emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Gaseous Fuels | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 74 | g/GJ | 46 | 103 | \* |
| CO | 29 | g/GJ | 21 | 48 | \* |
| NMVOC | 23 | g/GJ | 14 | 33 | \* |
| SOx | 0.67 | g/GJ | 0.40 | 0.94 | \* |
| TSP | 0.78 | g/GJ | 0.47 | 1.09 | \* |
| PM10 | 0.78 | g/GJ | 0.47 | 1.09 | \* |
| PM2.5 | 0.78 | g/GJ | 0.47 | 1.09 | \* |
| BC | 4.0 | % of PM2.5 | 2.1 | 7 | \* |
| Pb | 0.011 | mg/GJ | 0.006 | 0.022 | \* |
| Cd | 0.0009 | mg/GJ | 0.0003 | 0.0011 | \* |
| Hg | 0.54 | mg/GJ | 0.26 | 1.0 | \* |
| As | 0.10 | mg/GJ | 0.05 | 0.19 | \* |
| Cr | 0.013 | mg/GJ | 0.007 | 0.026 | \* |
| Cu | 0.0026 | mg/GJ | 0.0013 | 0.0051 | \* |
| Ni | 0.013 | mg/GJ | 0.006 | 0.026 | \* |
| Se | 0.058 | mg/GJ | 0.015 | 0.058 | \* |
| Zn | 0.73 | mg/GJ | 0.36 | 1.5 | \* |
| PCDD/F | 0.52 | ng I-TEQ/GJ | 0.25 | 1.3 | \* |
| Benzo(a)pyrene | 0.72 | ug/GJ | 0.20 | 1.9 | \* |
| Benzo(b)fluoranthene | 2.9 | ug/GJ | 0.7 | 12 | \* |
| Benzo(k)fluoranthene | 1.1 | ug/GJ | 0.3 | 2.8 | \* |
| Indeno(1,2,3-cd)pyrene | 1.08 | ug/GJ | 0.30 | 2.9 | \* |
| \* average of Tier 2 EFs for commercial/institutional gaseous fuel combustion for all technologies  The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions | | | | | |

Table 3.9 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 1 default emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Liquid Fuels | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 303.3 | g/GJ | 308 | 718 | \* |
| CO | 40.3 | g/GJ | 40 | 93 | \* |
| NMVOC | 12.9 | g/GJ | 15 | 35 | \* |
| SOx | 23.7 | g/GJ | 28 | 66 | \* |
| TSP | 11.6 | g/GJ | 12 | 28 | \* |
| PM10 | 11.6 | g/GJ | 12 | 28 | \* |
| PM2.5 | 10.7 | g/GJ | 12 | 28 | \* |
| BC | 56.0 | % of PM2.5 | 33 | 78 | \* |
| Pb | 2.0 | mg/GJ | 0.04 | 0.16 | \* |
| Cd | 0.6 | mg/GJ | 0.003 | 0.011 | \* |
| Hg | 0.4 | mg/GJ | 0.04 | 0.17 | \* |
| As | 4.2 | mg/GJ | 0.02 | 0.06 | \* |
| Cr | 0.6 | mg/GJ | 0.10 | 0.40 | \* |
| Cu | 2.0 | mg/GJ | 0.11 | 0.43 | \* |
| Ni | 0.4 | mg/GJ | 0.004 | 0.015 | \* |
| Se | 2.1 | mg/GJ | 0.06 | 0.22 | \* |
| Zn | 36.0 | mg/GJ | 15 | 58 | \* |
| PCDD/F | 2.6 | *ng I-TEQ/GJ* | 0.3 | 7.1 | \* |
| Benzo(a)pyrene | 1.9 | µg/GJ | 0.2 | 1.9 | \* |
| Benzo(b)fluoranthene | 15.0 | µg/GJ | 1.5 | 15 | \* |
| Benzo(k)fluoranthene | 1.7 | µg/GJ | 0.2 | 1.7 | \* |
| Indeno(1,2,3-cd)pyrene | 1.5 | µg/GJ | 0.2 | 1.5 | \* |
| \* average of Tier 2 EFs for commercial/institutional liquid fuel combustion for all technologies | | | | | |

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.10 Tier 1 emission factors for NFR source category 1.A.4.a/c, 1.A.5.a, using solid biomass 5)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tier 1 emission factors | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Solid biomass | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 91 | g/GJ | 20 | 120 | Lundgren et al. (2004) 1) |
| CO | 570 | g/GJ | 50 | 4000 | EN 303 class 5 boilers, 150-300 kW |
| NMVOC | 300 | g/GJ | 5 | 500 | Naturvårdsverket, Sweden |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996b) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 2) |
| TSP | 150 | g/GJ | 75 | 300 | Naturvårdsverket, Sweden |
| PM10 | 143 | g/GJ | 71 | 285 | Naturvårdsverket, Sweden 3) |
| PM2.5 | 140 | g/GJ | 70 | 279 | Naturvårdsverket, Sweden 3) |
| BC | 28 | % of PM2.5 | 11 | 39 | Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) 4) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCBs | 0.06 | µg/GJ | 0.006 | 0.6 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Larger combustion chamber, 350 kW
2. Assumed equal to low emitting wood stoves
3. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
4. Assumed equal to advanced/ecolabelled residential boilers
5. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
6. The TSP, PM10 and PM2.5 emission factors have been reviewed and they represent filterable PM.

### Activity data

Information on the use of energy suitable for estimating emissions using the Tier 1 simpler estimation methodology, is available from national statistics agencies, from the Eurostat energy balances or the International Energy Agency (IEA). These usually distinguish between residential fuel consumption and commercial/institution/agricultural fuel consumption, and are therefore easily combined with the emission factors presented for residential and non-residential fuel use.

Further guidance is provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 on Stationary combustion [www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2\_Volume2/V2\_2\_Ch2\_Stationary\_Combustion.pdf](http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf)

## Tier 2 technology-specific approach for non-biomass fuels

### Algorithm

The Tier 2 approach is similar to the Tier 1 approach, using activity data and emission factors to estimate the emissions. The main difference is that the detailed methodology requires more fuel, technology and country-specific information. Development of the detailed methodology has to be focused to the combinations of the main installation types/fuels used in the country.

Please note that this section does NOT contain the Tier 2 methodology for solid biomass combustion, for the Tier 2 method for small combustion of solid biomass fuels please refer to Section 3.4.

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

, (1)

where

 = annual emission of pollutant *i*,

 = default emission factor of pollutant *i* for source type *j* and fuel *k*,

 = annual consumption of fuel *k* in source type *j*.

For example, the sources may be characterised as:

* residential heating : fire places, water heaters, stoves, boilers, cookers;
* non-residential heating : space heating, boilers; and
* CHP.

The non-residential activities need to be apportioned to the appropriate NFR activity sectors.

### Technology-specific emission factors

Technology-specific emission factors for different fuels and technologies are shown for plants < 50 kWth and for plants >50 kWth in particular. These classifications are chosen to reflect the different emission characteristics for smaller and larger plants, respectively. In general the smaller plants (<50 kWth) are mostly residential plants and the larger plants (50 kWth – 50 MWth) are mostly non-residential, however it should be noted that this assumption does not always hold.

An overview of the Tier 2 emission factor tables and a link to the technology description in chapter 2.2 is shown in Table 3.11.

The Tier 2 emission factors can be used with knowledge of equipment populations and sectors to develop aggregate factors or emissions for the NFR subsectors. The development of national emission factors should consider the combination of installation types and fuels in the country and, where relevant, emission controls. When deriving specific emission factors, the emphasis has to be given to taking into account 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. The emission factors for small combustion plants burning wood take into account the whole combustion cycle.

Table 3.11 Tier 2 emission factor tables

|  | **Tier** | **Fuel** | **Sector** | **Technology name** | **Chapter 2.2 technology name** | **Applicable EN standard** |
| --- | --- | --- | --- | --- | --- | --- |
| Table 3.12 | 2 | Solid fuels (excluding biomass) | Small size (<50 kWth) | Open fireplaces | Basic equipment – open fireplaces | EN 13229 |
| Table 3.13 | 2 | Gaseous fuels | Small size (<50 kWth) | Partly closed/closed fireplaces | Appliances – Fireplaces | EN 15821 (outdoor heaters) |
| Table 3.14 | 2 | Solid fuels (excluding biomass) | Small size (<50 kWth) | Conventional stoves | Conventional radiating stoves burning solid fuels excluding biomass | EN 13240 /  EN 15250 / EN12815 (cookers) |
| Table 3.15 | 2 | Solid fuels (excluding biomass) | Small size (<50 kWth) | Conventional boilers <50kW | Conventional under-fire boilers burning solid fuels excluding biomass | EN 303-5 /  EN 12809 |
| Table 3.16 | 2 | Gaseous fuels | Small size (<50 kWth) | Conventional boilers < 50 kW | Standard domestic boilers including condensing boilers | EN 303-5 /  EN 12809 |
| Table 3.17 | 2 | Gas oil | Small size (<50 kWth) | Conventional stoves | Conventional stoves burning liquid/gas fuels | EN 13240/  EN 15250 |
| Table 3.18 | 2 | Gas oil | Small size (<50 kWth) | Conventional boilers < 50 kW | Standard domestic boilers including condensing boilers | EN 303-5 /  EN 12809 |
| Table 3.19 | 2 | Coal | Small size (<50 kWth) | Advanced stoves | Advanced and ecolabelled stoves | EN 13240 /  EN 15250 |
| Table 3.20 | 2 | Coal | Medium size (50 kWth – 50 MWth) | Standard boilers >50KWth <1MWth | Standard boilers including fixed and moving grate technologies |  |
| Table 3.21 | 2 | Coal | Medium size (50 kWth – 50 MWth) | Standard boilers >1MWth <50MWth | Standard boilers including fixed and moving grate technologies |  |
| Table 3.22 | 2 | Coal | Medium size (50 kWth – 50 MWth) | Boilers <1MWth – manual feed technology | Advanced Tier inventory compilation for manual feed <1MWth |  |
| Table 3.23 | 2 | Coal | Medium size (50 kWth – 50 MWth) | Boilers <1MWth – automatic feed technology | Advanced Tier inventory compilation for automatic feed <1MWth |  |
| Table 3.24 | 2 | Fuel oil | Medium size (50 kWth – 50 MWth) | Standard boilers >50KWth <1MWth | Standard boilers using liquid based fuels |  |
| Table 3.25 | 2 | Fuel oil | Medium size (50 kWth – 50 MWth) | Standard boilers >1MWth <50MWth | Standard boilers using liquid based fuels |  |
| Table 3.26 | 2 | Gaseousl gas | Medium size (50 kWth – 50 MWth) | Standard boilers >50KWth <1MWth | Gas fired boilers |  |
| Table 3.27 | 2 | Gaseous fuel | Medium size (50 kWth – 50 MWth) | Standard boilers >1MWth <50MWth | Gas fired boilers |  |
| Table 3.28 | 2 | Gaseous fuel | Medium size (50 kWth – 50 MWth) | Gas turbines | Gas turbines |  |
| Table 3.29 | 2 | Gas oil | Medium size (50 kWth – 50 MWth) | Gas turbines | Gas turbines |  |
| Table 3.30 | 2 | Gaseous fuel | Medium size (50 kWth – 50 MWth) | Stationary reciprocating engines | Stationary reciprocating engines |  |
| Table 3.31 | 2 | Gas oil | Medium size (50 kWth – 50 MWth) | Stationary reciprocating engines | Stationary reciprocating engines |  |

#### Small-size (<50 kWth) combustion installations, mostly applied in residential heating technologies (1.A.4.b.i)

Table 3.12 Tier 2 emission factors for source category 1.A.4.b.i, fireplaces burning solid fuel (except biomass)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Solid Fuel (not biomass) | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Fireplaces, Saunas and Outdoor Heaters | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 60 | g/GJ | 36 | 84 | Guidebook (2006) chapter B216 |
| CO | 5000 | g/GJ | 3000 | 7000 | Guidebook (2006) chapter B216 |
| NMVOC | 600 | g/GJ | 360 | 840 | Guidebook (2006) chapter B216 |
| SOx | 500 | g/GJ | 300 | 700 | Guidebook (2006) chapter B216 |
| NH3 | 5 | g/GJ | 3 | 7 | Guidebook (2006) chapter B216 |
| TSP | 350 | g/GJ | 210 | 490 | Guidebook (2006) chapter B216 |
| PM10 | 330 | g/GJ | 198 | 462 | Guidebook (2006) chapter B216 |
| PM2.5 | 330 | g/GJ | 198 | 462 | Guidebook (2006) chapter B216 |
| BC | 9.839 | % of PM2.5 | 3 | 30 | Engelbrecht et al., 2002 |
| Pb | 100 | mg/GJ | 60 | 140 | Guidebook (2006) chapter B216 |
| Cd | 0.5 | mg/GJ | 0.3 | 0.7 | Guidebook (2006) chapter B216 |
| Hg | 3 | mg/GJ | 1.8 | 4.2 | Guidebook (2006) chapter B216 |
| As | 1.5 | mg/GJ | 0.9 | 2.1 | Guidebook (2006) chapter B216 |
| Cr | 10 | mg/GJ | 6 | 14 | Guidebook (2006) chapter B216 |
| Cu | 20 | mg/GJ | 12 | 28 | Guidebook (2006) chapter B216 |
| Ni | 10 | mg/GJ | 6 | 14 | Guidebook (2006) chapter B216 |
| Se | 1 | mg/GJ | 0.6 | 1.4 | Guidebook (2006) chapter B216 |
| Zn | 200 | mg/GJ | 120 | 280 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 500 | ng I-TEQ/GJ | 300 | 700 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 100 | mg/GJ | 60 | 140 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 170 | mg/GJ | 102 | 238 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 100 | mg/GJ | 60 | 140 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 80 | mg/GJ | 48 | 112 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

500 g/GJ of sulphur dioxide is equivalent to 0.8 % S of coal fuels of lower heating value of fuel on a dry basis 29 GJ/t and an average sulphur retention in ash value of 0.1.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.13 Tier 2 emission factors for source category 1.A.4.b.i, fireplaces burning natural gas

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Natural gas | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Stoves, Fireplaces, Saunas and Outdoor Heaters | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 60 | g/GJ | 36 | 84 | DGC (2009) |
| CO | 30 | g/GJ | 18 | 42 | DGC (2009) |
| NMVOC | 2.0 | g/GJ | 1.2 | 2.8 | Zhang et al. (2000) |
| SOx | 0.3 | g/GJ | 0.18 | 0.42 | DGC (2009) |
| TSP | 2.2 | g/GJ | 1.3 | 3.1 | Zhang et al. (2000) |
| PM10 | 2.2 | g/GJ | 1.3 | 3.1 | \* |
| PM2.5 | 2.2 | g/GJ | 1.3 | 3.1 | \* |
| BC | 5.4 | % of PM2.5 | 2.7 | 11 | Hildemann et al. (1991), Muhlbaier (1981) \*\* |
| Pb | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| Cd | 0.00025 | mg/GJ | 0.00013 | 0.00050 | Nielsen et al. (2013) |
| Hg | 0.1 | mg/GJ | 0.0013 | 0.68 | Nielsen et al. (2010) |
| As | 0.12 | mg/GJ | 0.060 | 0.24 | Nielsen et al. (2013) |
| Cr | 0.00076 | mg/GJ | 0.00038 | 0.0015 | Nielsen et al. (2013) |
| Cu | 0.000076 | mg/GJ | 0.000038 | 0.00015 | Nielsen et al. (2013) |
| Ni | 0.00051 | mg/GJ | 0.00026 | 0.0010 | Nielsen et al. (2013) |
| Se | 0.011 | mg/GJ | 0.0038 | 0.011 | US EPA (1998) |
| Zn | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| PCDD/F | 1.5 | ng I-TEQ/GJ | 0.80 | 2.3 | UNEP (2005) |
| Benzo(a)pyrene | 0.56 | ug/GJ | 0.19 | 0.56 | US EPA (1998) |
| Benzo(b)fluoranthene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| Benzo(k)fluoranthene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| Indeno(1,2,3-cd)pyrene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| \* assumption: EF(TSP) = EF(PM10) = EF(PM2.5). The TSP, PM10 and PM2.5 emission factors represent filterable PM | | | | | |
| \*\* average of EFs from the listed references | | | | | |

Table 3.14 Tier 2 emission factors for source category 1.A.4.b.i, stoves burning solid fuel (except biomass)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Solid Fuel (not biomass) | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Stoves | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 100 | g/GJ | 60 | 150 | Guidebook (2006) chapter B216 |
| CO | 5000 | g/GJ | 3000 | 7000 | Guidebook (2006) chapter B216 |
| NMVOC | 600 | g/GJ | 360 | 840 | Guidebook (2006) chapter B216 |
| SOx | 900 | g/GJ | 540 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 500 | g/GJ | 240 | 600 | Guidebook (2006) chapter B216 |
| PM10 | 450 | g/GJ | 228 | 480 | Guidebook (2006) chapter B216 |
| PM2.5 | 450 | g/GJ | 216 | 480 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 100 | mg/GJ | 60 | 240 | Guidebook (2006) chapter B216 |
| Cd | 1 | mg/GJ | 0.6 | 3.6 | Guidebook (2006) chapter B216 |
| Hg | 5 | mg/GJ | 3 | 7.2 | Guidebook (2006) chapter B216 |
| As | 1.5 | mg/GJ | 0.9 | 6 | Guidebook (2006) chapter B216 |
| Cr | 10 | mg/GJ | 6 | 18 | Guidebook (2006) chapter B216 |
| Cu | 20 | mg/GJ | 12 | 36 | Guidebook (2006) chapter B216 |
| Ni | 10 | mg/GJ | 6 | 24 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 1.2 | 2.4 | Guidebook (2006) chapter B216 |
| Zn | 200 | mg/GJ | 120 | 360 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 1000 | ng I-TEQ/GJ | 300 | 1200 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 250 | mg/GJ | 150 | 324 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 400 | mg/GJ | 150 | 480 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 150 | mg/GJ | 60 | 180 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 120 | mg/GJ | 54 | 144 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.15 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning solid fuel (except biomass)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Solid Fuel (not biomass) | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Small (single household scale, capacity <=50 kWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 158 | g/GJ | 80 | 300 | US EPA, 1998 |
| CO | 4787 | g/GJ | 3000 | 7000 | US EPA, 1998 |
| NMVOC | 174 | g/GJ | 87 | 260 | US EPA, 1998 |
| SOx | 900 | g/GJ | 540 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 261 | g/GJ | 130 | 400 | US EPA, 1998 |
| PM10 | 225 | g/GJ | 113 | 338 | Tivari et al., 2012 |
| PM2.5 | 201 | g/GJ | 100 | 300 | Tivari et al., 2012 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 200 | mg/GJ | 60 | 240 | Guidebook (2006) chapter B216 |
| Cd | 3 | mg/GJ | 0.6 | 3.6 | Guidebook (2006) chapter B216 |
| Hg | 6 | mg/GJ | 3 | 7.2 | Guidebook (2006) chapter B216 |
| As | 5 | mg/GJ | 0.9 | 6 | Guidebook (2006) chapter B216 |
| Cr | 15 | mg/GJ | 6 | 18 | Guidebook (2006) chapter B216 |
| Cu | 30 | mg/GJ | 12 | 36 | Guidebook (2006) chapter B216 |
| Ni | 20 | mg/GJ | 6 | 24 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 1.2 | 2.4 | Guidebook (2006) chapter B216 |
| Zn | 300 | mg/GJ | 120 | 360 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 500 | ng I-TEQ/GJ | 300 | 1200 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 270 | mg/GJ | 150 | 324 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 250 | mg/GJ | 150 | 480 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 100 | mg/GJ | 60 | 180 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 90 | mg/GJ | 54 | 144 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions

Table 3.16 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning natural gas

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Natural Gas | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Small (single household scale, capacity <=50 kWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 42 | g/GJ | 25 | 59 | DGC (2009) |
| CO | 22 | g/GJ | 18 | 42 | DGC (2009) |
| NMVOC | 1.8 | g/GJ | 1.1 | 2.5 | Italian Ministry for the Environment (2005) |
| SOx | 0.30 | g/GJ | 0.18 | 0.42 | DGC (2009) |
| TSP | 0.20 | g/GJ | 0.12 | 0.28 | BUWAL (2001) |
| PM10 | 0.20 | g/GJ | 0.12 | 0.28 | BUWAL (2001) |
| PM2.5 | 0.20 | g/GJ | 0.12 | 0.28 | \* |
| BC | 5.4 | % of PM2.5 | 2.7 | 11 | Hildemann et al. (1991), Muhlbaier (1981) \*\* |
| Pb | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| Cd | 0.00025 | mg/GJ | 0.00013 | 0.00050 | Nielsen et al. (2013) |
| Hg | 0.1 | mg/GJ | 0.0013 | 0.68 | Nielsen et al. (2010) |
| As | 0.12 | mg/GJ | 0.060 | 0.24 | Nielsen et al. (2013) |
| Cr | 0.00076 | mg/GJ | 0.00038 | 0.0015 | Nielsen et al. (2013) |
| Cu | 0.000076 | mg/GJ | 0.000038 | 0.00015 | Nielsen et al. (2013) |
| Ni | 0.00051 | mg/GJ | 0.00026 | 0.0010 | Nielsen et al. (2013) |
| Se | 0.011 | mg/GJ | 0.0038 | 0.011 | US EPA (1998) |
| Zn | 0.0015 | mg/GJ | 0.0008 | 0.003 | Nielsen et al. (2013) |
| PCDD/F | 1.5 | ng I-TEQ/GJ | 0.80 | 2.3 | UNEP (2005) |
| Benzo(a)pyrene | 0.56 | ug/GJ | 0.19 | 0.56 | US EPA (1998) |
| Benzo(b)fluoranthene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| Benzo(k)fluoranthene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| Indeno(1,2,3-cd)pyrene | 0.84 | ug/GJ | 0.28 | 0.84 | US EPA (1998) |
| \* assumption: EF(PM10) = EF(PM2.5). The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions | | | | | |
| \*\* average of EFs from the listed references | | | | | |

Table 3.17 Tier 2 emission factors for source category 1.A.4.b.i, stoves burning liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Gas oil | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Stoves | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 34 | g/GJ | 20 | 48 | UBA (2008) |
| CO | 111 | g/GJ | 67 | 155 | UBA (2008) |
| NMVOC | 1.2 | g/GJ | 0.7 | 1.7 | UBA (2008) |
| SOX | 60 | g/GJ | 36 | 84 | UBA (2008) |
| TSP | 2.2 | g/GJ | 1.3 | 3.1 | UBA (2008) |
| PM10 | 2.2 | g/GJ | 1.3 | 3.1 | UBA (2008) |
| PM2.5 | 2.2 | g/GJ | 1.3 | 3.1 | UBA (2008) |
| BC | 13 | % of PM2.5 | 7.5 | 26 | Bond et al. (2004) |
| Pb | 0.012 | mg/GJ | 0.006 | 0.024 | Pulles et al. (2012) |
| Cd | 0.001 | mg/GJ | 0.00025 | 0.001 | Pulles et al. (2012) |
| Hg | 0.12 | mg/GJ | 0.03 | 0.12 | Pulles et al. (2012) |
| As | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Cr | 0.2 | mg/GJ | 0.1 | 0.40 | Pulles et al. (2012) |
| Cu | 0.13 | mg/GJ | 0.065 | 0.26 | Pulles et al. (2012) |
| Ni | 0.005 | mg/GJ | 0.0025 | 0.01 | Pulles et al. (2012) |
| Se | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Zn | 0.42 | mg/GJ | 0.21 | 0.84 | Pulles et al. (2012) |
| PCDD/F | 10 | ng I-TEQ/GJ | 2 | 50 | UNEP (2005) |
| Benzo(a)pyrene | 80 | ug/GJ | 16 | 120 | Berdowski et al. (1995) |
| Benzo(b)fluoranthene | 40 | ug/GJ | 8 | 60 | Berdowski et al. (1995) |
| Benzo(k)fluoranthene | 70 | ug/GJ | 14 | 105 | Berdowski et al. (1995) |
| Indeno(1,2,3-cd)pyrene | 160 | ug/GJ | 32 | 240 | Berdowski et al. (1995) |

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.18 Tier 2 emission factors for source category 1.A.4.b.i, boilers burning liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Gas oil | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Small (single household scale, capacity <=50 kWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 69 | g/GJ | 41 | 97 | Italian Ministry for the Environment (2005) |
| CO | 3.7 | g/GJ | 2 | 5 | Italian Ministry for the Environment (2005) |
| NMVOC | 0.17 | g/GJ | 0,06 | 0,51 | Italian Ministry for the Environment (2005) |
| SOX | 79 | g/GJ | 47 | 111 | Italian Ministry for the Environment (2005) |
| TSP | 1.5 | g/GJ | 1 | 2 | Italian Ministry for the Environment (2005) |
| PM10 | 1.5 | g/GJ | 1 | 2 | \* |
| PM2.5 | 1.5 | g/GJ | 1 | 2 | \* |
| BC | 3.9 | % of PM2.5 | 2 | 8 | US EPA (2011) |
| Pb | 0.012 | mg/GJ | 0.006 | 0.024 | Pulles et al. (2012) |
| Cd | 0.001 | mg/GJ | 0.0003 | 0.001 | Pulles et al. (2012) |
| Hg | 0.12 | mg/GJ | 0.03 | 0.12 | Pulles et al. (2012) |
| As | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Cr | 0.2 | mg/GJ | 0.1 | 0.4 | Pulles et al. (2012) |
| Cu | 0.13 | mg/GJ | 0.065 | 0.26 | Pulles et al. (2012) |
| Ni | 0.005 | mg/GJ | 0.0025 | 0.01 | Pulles et al. (2012) |
| Se | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Zn | 0.42 | mg/GJ | 0.21 | 0.84 | Pulles et al. (2012) |
| PCDD/F | 1.8 | ng I-TEQ/GJ | 0.4 | 9 | Pfeiffer et al. (2000) |
| Benzo(a)pyrene | 80 | ug/GJ | 16 | 120 | Berdowski et al. (1995) |
| Benzo(b)fluoranthene | 40 | ug/GJ | 8 | 60 | Berdowski et al. (1995) |
| Benzo(k)fluoranthene | 70 | ug/GJ | 14 | 105 | Berdowski et al. (1995) |
| Indeno(1,2,3-cd)pyrene | 160 | ug/GJ | 32 | 240 | Berdowski et al. (1995) |
| \* assumption: EF(TSP) = EF(PM10) = EF(PM2.5) | | | | | |

The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions

Table 3.19 Tier 2 emission factors for source category 1.A.4.b.i, advanced stoves burning coal fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Coal Fuels | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Advanced coal combustion techniques <1MWth - Advanced stove | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 150 | g/GJ | 50 | 200 | Guidebook (2006) chapter B216 |
| CO | 2000 | g/GJ | 200 | 3000 | Guidebook (2006) chapter B216 |
| NMVOC | 300 | g/GJ | 20 | 400 | Guidebook (2006) chapter B216 |
| SOx | 450 | g/GJ | 300 | 900 | Guidebook (2006) chapter B216 |
| TSP | 250 | g/GJ | 80 | 260 | Guidebook (2006) chapter B216 |
| PM10 | 240 | g/GJ | 76 | 250 | Guidebook (2006) chapter B216 |
| PM2.5 | 220 | g/GJ | 72 | 230 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 100 | mg/GJ | 80 | 200 | Guidebook (2006) chapter B216 |
| Cd | 1 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Hg | 5 | mg/GJ | 3 | 9 | Guidebook (2006) chapter B216 |
| As | 1.5 | mg/GJ | 1 | 5 | Guidebook (2006) chapter B216 |
| Cr | 10 | mg/GJ | 5 | 15 | Guidebook (2006) chapter B216 |
| Cu | 15 | mg/GJ | 10 | 30 | Guidebook (2006) chapter B216 |
| Ni | 10 | mg/GJ | 5 | 20 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 1 | 2.4 | Guidebook (2006) chapter B216 |
| Zn | 200 | mg/GJ | 120 | 300 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 500 | ng I-TEQ/GJ | 40 | 600 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 150 | mg/GJ | 13 | 180 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 180 | mg/GJ | 17 | 200 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 100 | mg/GJ | 8 | 150 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 80 | mg/GJ | 6 | 100 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

450 g/GJ of sulphur dioxide is equivalent to 0.6 % S of coal fuel of lower heating value on a dry basis, 24 GJ/t and average sulphur retention in ash value of 0.1.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

#### Medium size (50 kWth – 50 MWth) combustion installations, mostly used in non-residential applications (1.A.4.a.i, 1.A.4.c.i, 1.A.5.a)

Table 3.20 Tier 2 emission factors for small non-residential sources (> 50 kWth to ≤ 1 MWth) boilers burning coal fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Coal Fuels | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Medium size (>50 kWth to <=1 MWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 160 | g/GJ | 150 | 200 | Guidebook (2006) chapter B216 |
| CO | 2000 | g/GJ | 200 | 3000 | Guidebook (2006) chapter B216 |
| NMVOC | 200 | g/GJ | 20 | 300 | Guidebook (2006) chapter B216 |
| SOx | 900 | g/GJ | 450 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 200 | g/GJ | 80 | 250 | Guidebook (2006) chapter B216 |
| PM10 | 190 | g/GJ | 76 | 240 | Guidebook (2006) chapter B216 |
| PM2.5 | 170 | g/GJ | 72 | 220 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 200 | mg/GJ | 80 | 300 | Guidebook (2006) chapter B216 |
| Cd | 3 | mg/GJ | 1 | 5 | Guidebook (2006) chapter B216 |
| Hg | 7 | mg/GJ | 5 | 9 | Guidebook (2006) chapter B216 |
| As | 5 | mg/GJ | 0.5 | 8 | Guidebook (2006) chapter B216 |
| Cr | 15 | mg/GJ | 1 | 20 | Guidebook (2006) chapter B216 |
| Cu | 30 | mg/GJ | 8 | 50 | Guidebook (2006) chapter B216 |
| Ni | 20 | mg/GJ | 2 | 30 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Zn | 300 | mg/GJ | 100 | 500 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 400 | ng I-TEQ/GJ | 40 | 500 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 100 | mg/GJ | 13 | 150 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 130 | mg/GJ | 17 | 180 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 50 | mg/GJ | 8 | 100 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 40 | mg/GJ | 6 | 80 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

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.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.21 Tier 2 emission factors for non-residential sources, medium-size (> 1 MWth to ≤ 50 MWth) boilers burning coal fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Coal Fuels | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Medium size (>1 MWth to <=50 MWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 180 | g/GJ | 150 | 200 | Guidebook (2006) chapter B216 |
| CO | 200 | g/GJ | 150 | 3000 | Guidebook (2006) chapter B216 |
| NMVOC | 20 | g/GJ | 10 | 300 | Guidebook (2006) chapter B216 |
| SOx | 900 | g/GJ | 450 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 80 | g/GJ | 70 | 250 | Guidebook (2006) chapter B216 |
| PM10 | 76 | g/GJ | 60 | 240 | Guidebook (2006) chapter B216 |
| PM2.5 | 72 | g/GJ | 60 | 220 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 100 | mg/GJ | 80 | 200 | Guidebook (2006) chapter B216 |
| Cd | 1 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Hg | 9 | mg/GJ | 5 | 10 | Guidebook (2006) chapter B216 |
| As | 4 | mg/GJ | 0.5 | 5 | Guidebook (2006) chapter B216 |
| Cr | 15 | mg/GJ | 1 | 20 | Guidebook (2006) chapter B216 |
| Cu | 10 | mg/GJ | 8 | 30 | Guidebook (2006) chapter B216 |
| Ni | 10 | mg/GJ | 2 | 20 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Zn | 150 | mg/GJ | 100 | 300 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 100 | ng I-TEQ/GJ | 40 | 500 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 13 | mg/GJ | 10 | 150 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 17 | mg/GJ | 10 | 180 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 9 | mg/GJ | 8 | 100 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 6 | mg/GJ | 5 | 80 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

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.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.22 Tier 2 emission factors for non-residential sources, manual boilers burning coal fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Coal Fuels | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Advanced coal combustion techniques <1MWth - Manual Boiler | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 200 | g/GJ | 150 | 300 | Guidebook (2006) chapter B216 |
| CO | 1500 | g/GJ | 200 | 3000 | Guidebook (2006) chapter B216 |
| NMVOC | 100 | g/GJ | 20 | 300 | Guidebook (2006) chapter B216 |
| SOx | 450 | g/GJ | 300 | 900 | Guidebook (2006) chapter B216 |
| TSP | 150 | g/GJ | 80 | 250 | Guidebook (2006) chapter B216 |
| PM10 | 140 | g/GJ | 76 | 240 | Guidebook (2006) chapter B216 |
| PM2.5 | 130 | g/GJ | 72 | 220 | Guidebook (2006) chapter B216 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 150 | mg/GJ | 80 | 200 | Guidebook (2006) chapter B216 |
| Cd | 2 | mg/GJ | 1 | 3 | Guidebook (2006) chapter B216 |
| Hg | 6 | mg/GJ | 5 | 9 | Guidebook (2006) chapter B216 |
| As | 4 | mg/GJ | 0.5 | 5 | Guidebook (2006) chapter B216 |
| Cr | 10 | mg/GJ | 1 | 15 | Guidebook (2006) chapter B216 |
| Cu | 15 | mg/GJ | 8 | 30 | Guidebook (2006) chapter B216 |
| Ni | 15 | mg/GJ | 2 | 20 | Guidebook (2006) chapter B216 |
| Se | 2 | mg/GJ | 0.5 | 3 | Guidebook (2006) chapter B216 |
| Zn | 200 | mg/GJ | 100 | 300 | Guidebook (2006) chapter B216 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 200 | ng I-TEQ/GJ | 40 | 500 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 90 | mg/GJ | 13 | 150 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 110 | mg/GJ | 17 | 180 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 50 | mg/GJ | 8 | 100 | Guidebook (2006) chapter B216 |
| Indeno(1,2,3-cd)pyrene | 40 | mg/GJ | 6 | 80 | Guidebook (2006) chapter B216 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

450 g/GJ of sulphur dioxide corresponds 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.

The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions

Table 3.23 Tier 2 emission factors for non-residential sources, automatic boilers burning coal fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Coal Fuels | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Advanced coal combustion techniques <1MWth - Automatic Boiler | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 165 | g/GJ | 100 | 250 | US EPA, 1998 |
| CO | 350 | g/GJ | 175 | 700 | Thistlethwaite, 2001 |
| NMVOC | 23 | g/GJ | 10 | 100 | US EPA, 1998 |
| SOx | 450 | g/GJ | 400 | 1000 | Guidebook (2006) chapter B216 |
| TSP | 82 | g/GJ | 41 | 164 | Thistlethwaite, 2001 |
| PM10 | 78 | g/GJ | 39 | 156 | Struschka et al., 2008 |
| PM2.5 | 70 | g/GJ | 35 | 140 | Struschka et al., 2008 |
| BC | 6.4 | % of PM2.5 | 2 | 26 | Zhang et al., 2012 |
| Pb | 167 | mg/GJ | 83 | 335 | Thistlethwaite, 2001 |
| Cd | 1 | mg/GJ | 0.5 | 1.5 | Thistlethwaite, 2001 |
| Hg | 16 | mg/GJ | 8 | 32 | Thistlethwaite, 2001 |
| As | 46 | mg/GJ | 4.6 | 92 | Thistlethwaite, 2001 |
| Cr | 6 | mg/GJ | 2 | 18 | Thistlethwaite, 2001 |
| Cu | 192 | mg/GJ | 19.2 | 400 | Thistlethwaite, 2001 |
| Ni | 37 | mg/GJ | 3.7 | 74 | Thistlethwaite, 2001 |
| Se | 17 | mg/GJ | 1.7 | 34 | Thistlethwaite, 2001 |
| Zn | 201 | mg/GJ | 50 | 500 | Thistlethwaite, 2001 |
| PCB | 170 | µg/GJ | 85 | 260 | Kakareka et al. (2004) |
| PCDD/F | 40 | ng I-TEQ/GJ | 20 | 500 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 0.079 | mg/GJ | 0.008 | 0.8 | Thistlethwaite, 2001 |
| Benzo(b)fluoranthene | 1.244 | mg/GJ | 0.12 | 12.4 | Thistlethwaite, 2001 |
| Benzo(k)fluoranthene | 0.845 | mg/GJ | 0.08 | 8.5 | Thistlethwaite, 2001 |
| Indeno(1,2,3-cd)pyrene | 0.617 | mg/GJ | 0.06 | 6.2 | Thistlethwaite, 2001 |
| HCB | 0.62 | µg/GJ | 0.31 | 1.2 | Guidebook (2006) chapter B216 |

Note:

450 g/GJ of sulphur dioxide corresponds 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.

The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions

Table 3.24 Tier 2 emission factors for non-residential sources, medium-sized (> 50 kWth to ≤ 1 MWth) boilers liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i | Commercial / institutional: stationary | | | |
| 1.A.4.c.i | Stationary | | | |
| 1.A.5.a | Other, stationary (including military) | | | |
| **Fuel** | Fuel oil (Distillate fuel oil) | | | | |
| **SNAP (if applicable)** | 20100 | Commercial and institutional plants | | | |
| 20300 | Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Fuel oil (Distillate fuel oil)  combustion in boilers ≤ 1MW | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | Se | | | | |
| **Not estimated** | NH3, TSP, BC, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, PCB , HCB, PCDD/F | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 100 | g/GJ | 50 | 150 | Guidebook (2006) chapter B216 |
| CO | 40 | g/GJ | 24 | 40 | Guidebook (2006) chapter B216 |
| NMVOC | 15 | g/GJ | 9 | 15 | Guidebook (2006) chapter B216 |
| SOX | 140 | g/GJ | 84 | 140 | Guidebook (2006) chapter B216 |
| PM10 | 3 | g/GJ | 0.75 | 6 | Guidebook (2006) chapter B216 |
| PM2.5 | 3 | g/GJ | 0.75 | 6 | Guidebook (2006) chapter B216 |
| Pb | 20 | mg/GJ | 5 | 40 | Guidebook (2006) chapter B216 |
| Cd | 0.3 | mg/GJ | 0.075 | 0.6 | Guidebook (2006) chapter B216 |
| Hg | 0.1 | mg/GJ | 0.025 | 0.2 | Guidebook (2006) chapter B216 |
| As | 1 | mg/GJ | 0.25 | 2 | Guidebook (2006) chapter B216 |
| Cr | 20 | mg/GJ | 5 | 40 | Guidebook (2006) chapter B216 |
| Cu | 10 | mg/GJ | 2.5 | 20 | Guidebook (2006) chapter B216 |
| Ni | 300 | mg/GJ | 75 | 600 | Guidebook (2006) chapter B216 |
| Zn | 10 | mg/GJ | 2.5 | 20 | Guidebook (2006) chapter B216 |
| Dioxins and Furans | 10 | I-TEQng/GJ | 2.5 | 20 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 8 | mg/GJ | 2 | 16 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 9 | mg/GJ | 2.25 | 18 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 6 | mg/GJ | 1.5 | 12 | Guidebook (2006) chapter B216 |
| Indeno (1,2,3-cd)pyrene | 3 | mg/GJ | 0.75 | 6 | Guidebook (2006) chapter B216 |

Note:

140 g/GJ of of SOx as 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 appropriate equation to adjust value.

Table 3.25 Tier 2 emission factors for non-residential sources, medium sized (> 1 MWth to ≤ 50 MWth) boilers liquid fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i | Commercial / institutional: stationary | | | |
| 1.A.4.c.i | Stationary | | | |
| 1.A.5.a | Other, stationary (including military) | | | |
| **Fuel** | Fuel oil (Residual fuel oil) | | | | |
| **SNAP (if applicable)** | 20100 | Commercial and institutional plants | | | |
| 20300 | Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Fuel oil (Residual oil) combustion in boilers > 1MW | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3, TSP, BC, PCB, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 100 | g/GJ | 50 | 150 | Guidebook (2006) chapter B216 |
| CO | 200 | g/GJ | 120 | 200 | Guidebook (2006) chapter B216 |
| NMVOC | 15 | g/GJ | 9 | 15 | Guidebook (2006) chapter B216 |
| SOX | 140 | g/GJ | 84 | 140 | Guidebook (2006) chapter B216 |
| PM10 | 40 | g/GJ | 10 | 80 | Guidebook (2006) chapter B216 |
| PM2.5 | 30 | g/GJ | 7.5 | 60 | Guidebook (2006) chapter B216 |
| Pb | 10 | mg/GJ | 2.5 | 20 | Guidebook (2006) chapter B216 |
| Cd | 0.3 | mg/GJ | 0.075 | 0.6 | Guidebook (2006) chapter B216 |
| Hg | 0.1 | mg/GJ | 0.025 | 0.2 | Guidebook (2006) chapter B216 |
| As | 1 | mg/GJ | 0.25 | 2 | Guidebook (2006) chapter B216 |
| Cr | 20 | mg/GJ | 5 | 40 | Guidebook (2006) chapter B216 |
| Cu | 3 | mg/GJ | 0.75 | 6 | Guidebook (2006) chapter B216 |
| Ni | 200 | mg/GJ | 50 | 400 | Guidebook (2006) chapter B216 |
| Zn | 5 | mg/GJ | 1.25 | 10 | Guidebook (2006) chapter B216 |
| PCDD/F | 10 | I-TEQ ng/GJ | 2.5 | 20 | Guidebook (2006) chapter B216 |
| Benzo(a)pyrene | 13 | mg/GJ | 3.25 | 26 | Guidebook (2006) chapter B216 |
| Benzo(b)fluoranthene | 17 | mg/GJ | 4.25 | 34 | Guidebook (2006) chapter B216 |
| Benzo(k)fluoranthene | 9 | mg/GJ | 2.25 | 18 | Guidebook (2006) chapter B216 |
| Indeno (1,2,3-cd)pyrene | 6 | mg/GJ | 1.5 | 12 | Guidebook (2006) chapter B216 |

Note:

140 g/GJ of SOx as 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 appropriate equation to adjust value.

Table 3.26 Tier 2 emission factors for non-residential sources, medium-sized (> 50 kWth to ≤ 1 MWth) boilers burning natural gas

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Natural Gas | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Medium size (>50 kWth to <=1 MWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 73 | g/GJ | 44 | 103 | Italian Ministry for the Environment (2005) |
| CO | 24 | g/GJ | 18 | 42 | Italian Ministry for the Environment (2005) |
| NMVOC | 0.36 | g/GJ | 0.2 | 0.5 | UBA (2008) |
| Sox | 1.4 | g/GJ | 0.83 | 1.95 | Italian Ministry for the Environment (2005) |
| TSP | 0.45 | g/GJ | 0.27 | 0.63 | Italian Ministry for the Environment (2005) |
| PM10 | 0.45 | g/GJ | 0.27 | 0.63 | \* |
| PM2.5 | 0.45 | g/GJ | 0.27 | 0.63 | \* |
| BC | 5.4 | % of PM2.5 | 2.7 | 11 | Hildemann et al. (1991), Muhlbaier (1981) \*\* |
| Pb | 0.0015 | mg/GJ | 0.00075 | 0.003 | Nielsen et al. (2013) |
| Cd | 0.00025 | mg/GJ | 0.00013 | 0.0005 | Nielsen et al. (2013) |
| Hg | 0.1 | mg/GJ | 0.0013 | 0.68 | Nielsen et al. (2010) |
| As | 0.12 | mg/GJ | 0.060 | 0.24 | Nielsen et al. (2013) |
| Cr | 0.00076 | mg/GJ | 0.00038 | 0.0015 | Nielsen et al. (2013) |
| Cu | 0.000076 | mg/GJ | 0.000038 | 0.00015 | Nielsen et al. (2013) |
| Ni | 0.00051 | mg/GJ | 0.00026 | 0.001 | Nielsen et al. (2013) |
| Se | 0.011 | mg/GJ | 0.0037 | 0.011 | US EPA (1998) |
| Zn | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| PCDD/F | 0.5 | ng I-TEQ/GJ | 0.3 | 0.8 | UNEP (2005) |
| Benzo(a)pyrene | 0.56 | g/GJ | 0.19 | 0.56 | US EPA (1998) |
| Benzo(b)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Benzo(k)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Indeno(1,2,3-cd)pyrene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| \* assumption: EF(TSP) = EF(PM10) = EF(PM2.5). The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions | | | | | |
| \*\* average of EFs from the listed references | | | | | |

Table 3.27 Tier 2 emission factors for non-residential sources, medium sized (> 1 MWth to ≤ 50 MWth) boilers burning natural gas

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Natural Gas | | | | |
| **SNAP (if applicable)** |  |  | | | |
| **Technologies/Practices** | Medium size (>1 MWth to <=50 MWth) boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 40 | g/GJ | 30 | 55 | DGC (2009) |
| CO | 30 | g/GJ | 15 | 30 | DGC (2009) |
| NMVOC | 2 | g/GJ | 1.2 | 2.8 | DGC (2009) |
| SOx | 0.3 | g/GJ | 0.2 | 0.4 | DGC (2009) |
| TSP | 0.45 | g/GJ | 0.27 | 0.63 | Italian Ministry for the Environment (2005) |
| PM10 | 0.45 | g/GJ | 0.27 | 0.63 | \* |
| PM2.5 | 0.45 | g/GJ | 0.27 | 0.63 | \* |
| BC | 5.4 | % of PM2.5 | 2.7 | 11 | Hildemann et al. (1991), Muhlbaier (1981) \*\* |
| Pb | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| Cd | 0.00025 | mg/GJ | 0.00013 | 0.00050 | Nielsen et al. (2013) |
| Hg | 0.1 | mg/GJ | 0.0013 | 0.68 | Nielsen et al. (2010) |
| As | 0.12 | mg/GJ | 0.060 | 0.24 | Nielsen et al. (2013) |
| Cr | 0.00076 | mg/GJ | 0.00038 | 0.0015 | Nielsen et al. (2013) |
| Cu | 0.000076 | mg/GJ | 0.000038 | 0.00015 | Nielsen et al. (2013) |
| Ni | 0.00051 | mg/GJ | 0.00026 | 0.0010 | Nielsen et al. (2013) |
| Se | 0.011 | mg/GJ | 0.0037 | 0.011 | US EPA (1998) |
| Zn | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| PCDD/F | 0.5 | ng I-TEQ/GJ | 0.3 | 0.8 | UNEP (2005) |
| Benzo(a)pyrene | 0.56 | g/GJ | 0.19 | 0.56 | US EPA (1998) |
| Benzo(b)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Benzo(k)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Indeno(1,2,3-cd)pyrene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| \* assumption: EF(TSP) = EF(PM10) = EF(PM2.5). The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions | | | | | |
| \*\* average of EFs from the listed references | | | | | |

Table 3.28 Tier 2 emission factors for non-residential sources, gas turbines burning natural gas

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.b.i 1.A.4.c.i | Commercial / institutional: stationary Residential plants Agriculture / forestry / fishing: Stationary | | | |
| **Fuel** | Natural Gas | | | | |
| **SNAP (if applicable)** | 020104 020203 020303 | Comm./instit. - Stationary gas turbines Residential - Gas turbines Agri./forest/aqua. - Stationary gas turbines | | | |
| **Technologies/Practices** | Gas Turbines | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 48 | g/GJ | 29 | 67 | Nielsen et al. (2010) |
| CO | 4.8 | g/GJ | 1.8 | 42 | Nielsen et al. (2010) |
| NMVOC | 1.6 | g/GJ | 1.0 | 2.2 | Nielsen et al. (2010) |
| Sox | 0.5 | g/GJ | 0.30 | 0.70 | BUWAL (2001) |
| TSP | 0.2 | g/GJ | 0.12 | 0.28 | BUWAL (2001) |
| PM10 | 0.2 | g/GJ | 0.12 | 0.28 | BUWAL (2001) |
| PM2.5 | 0.2 | g/GJ | 0.12 | 0.28 | \* |
| BC | 2.5 | % of PM2.5 | 1.5 | 3.5 | England et al. (2004), Wien et al. (2004) and US EPA (2011) |
| Pb | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| Cd | 0.00025 | mg/GJ | 0.00013 | 0.00050 | Nielsen et al. (2013) |
| Hg | 0.1 | mg/GJ | 0.0013 | 0.68 | Nielsen et al. (2010) |
| As | 0.12 | mg/GJ | 0.060 | 0.24 | Nielsen et al. (2013) |
| Cr | 0.00076 | mg/GJ | 0.00038 | 0.0015 | Nielsen et al. (2013) |
| Cu | 0.000076 | mg/GJ | 0.000038 | 0.00015 | Nielsen et al. (2013) |
| Ni | 0.00051 | mg/GJ | 0.00026 | 0.0010 | Nielsen et al. (2013) |
| Se | 0.011 | mg/GJ | 0.0038 | 0.011 | US EPA (1998) |
| Zn | 0.0015 | mg/GJ | 0.00075 | 0.0030 | Nielsen et al. (2013) |
| PCDD/F | 0.5 | ng I-TEQ/GJ | 0.3 | 0.8 | UNEP (2005) |
| Benzo(a)pyrene | 0.56 | g/GJ | 0.19 | 0.56 | US EPA (1998) |
| Benzo(b)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Benzo(k)fluoranthene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| Indeno(1,2,3-cd)pyrene | 0.84 | g/GJ | 0.28 | 0.84 | US EPA (1998) |
| \* assumption: EF(PM10) = EF(PM2.5)  The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions | | | | | |

Table 3.29 Tier 2 emission factors for non-residential sources, gas turbines burning gas oil

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.b.i 1.A.4.c.i | Commercial / institutional: stationary Residential plants Agriculture / forestry / fishing: Stationary | | | |
| **Fuel** | Gas Oil | | | | |
| **SNAP (if applicable)** | 020104 020203 020303 | Comm./instit. - Stationary gas turbines Residential - Gas turbines Agri./forest/aqua. - Stationary gas turbines | | | |
| **Technologies/Practices** | Gas Turbines | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 83 | g/GJ | 50 | 116 | Nielsen et al. (2010) |
| CO | 2.6 | g/GJ | 2 | 4 | Nielsen et al. (2010) |
| NMVOC | 0.18 | g/GJ | 0.018 | 1.8 | US EPA (2000) |
| SOx | 46 | g/GJ | 28 | 65 | \* |
| TSP | 9.5 | g/GJ | 6 | 13 | Nielsen et al. (2010) |
| PM10 | 9.5 | g/GJ | 6 | 13 | \*\* |
| PM2.5 | 9.5 | g/GJ | 6 | 13 | \*\* |
| BC | 33.5 | % of PM2.5 | 20.1 | 46.9 | Hildemann et al. (1991) and Bond et al. (2006) |
| Pb | 0.012 | mg/GJ | 0.006 | 0.024 | Pulles et al. (2012) |
| Cd | 0.001 | mg/GJ | 0.00025 | 0.001 | Pulles et al. (2012) |
| Hg | 0.12 | mg/GJ | 0.03 | 0.12 | Pulles et al. (2012) |
| As | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Cr | 0.2 | mg/GJ | 0.1 | 0.4 | Pulles et al. (2012) |
| Cu | 0.13 | mg/GJ | 0.065 | 0.26 | Pulles et al. (2012) |
| Ni | 0.005 | mg/GJ | 0.0025 | 0.01 | Pulles et al. (2012) |
| Se | 0.002 | mg/GJ | 0.0005 | 0.002 | Pulles et al. (2012) |
| Zn | 0.42 | mg/GJ | 0.21 | 0.84 | Pulles et al. (2012) |
| PCDD/F | 1.8 | ng I-TEQ/GJ | 0.4 | 9 | Pfeiffer et al. (2000) |
| \* estimate based on 0.1 % S and LHV = 43.33 TJ/1000 tonnes | | | | | |
| \*\* assumption: EF(TSP) = EF(PM10) = EF(PM2.5).  The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions | | | | | |

Table 3.30 Tier 2 emission factors for non-residential sources, reciprocating engines burning gas fuels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.b.i 1.A.4.c.i | Commercial / institutional: stationary Residential plants Agriculture / forestry / fishing: Stationary | | | |
| **Fuel** | Natural gas | | | | |
| **SNAP (if applicable)** | 020105 020204 020304 | Comm./instit. - Stationary engines Residential - Stationary engines Agri./forest/aqua. - Stationary engines | | | |
| **Technologies/Practices** | Stationary reciprocating engines | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | PCB, HCB | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 135 | g/GJ | 81 | 189 | Nielsen et al. (2010) |
| CO | 56 | g/GJ | 34 | 78 | Nielsen et al. (2010) |
| NMVOC | 89 | g/GJ | 53 | 125 | Nielsen et al. (2010) |
| SOx | 0.5 | g/GJ | 0.05 | 1 | BUWAL (2001) |
| TSP | 2 | g/GJ | 1 | 3 | BUWAL (2001) |
| PM10 | 2 | g/GJ | 1 | 3 | BUWAL (2001) |
| PM2.5 | 2 | g/GJ | 1 | 3 | \* |
| BC | 2.5 | % of PM2.5 | 1.5 | 3.5 | England et al. (2004), Wien et al. (2004) and US EPA (2011) |
| Pb | 0.04 | mg/GJ | 0.02 | 0.08 | Nielsen et al. (2010) |
| Cd | 0.003 | mg/GJ | 0.00075 | 0.003 | Nielsen et al. (2010) |
| Hg | 0.1 | mg/GJ | 0.025 | 0.1 | Nielsen et al. (2010) |
| As | 0.05 | mg/GJ | 0.0125 | 0.05 | Nielsen et al. (2010) |
| Cr | 0.05 | mg/GJ | 0.025 | 0.1 | Nielsen et al. (2010) |
| Cu | 0.01 | mg/GJ | 0.005 | 0.02 | Nielsen et al. (2010) |
| Ni | 0.05 | mg/GJ | 0.025 | 0.1 | Nielsen et al. (2010) |
| Se | 0.2 | mg/GJ | 0.05 | 0.2 | Nielsen et al. (2010) |
| Zn | 2.9 | mg/GJ | 1.5 | 5.8 | Nielsen et al. (2010) |
| PCDD/F | 0.57 | ng I-TEQ/GJ | 0.11 | 2.9 | Nielsen et al. (2010) |
| Benzo(a)pyrene | 1.2 | g/GJ | 0.24 | 6 | Nielsen et al. (2010) |
| Benzo(b)fluoranthene | 9 | g/GJ | 1.8 | 45 | Nielsen et al. (2010) |
| Benzo(k)fluoranthene | 1.7 | g/GJ | 0.34 | 8.5 | Nielsen et al. (2010) |
| Indeno(1,2,3-cd)pyrene | 1.8 | g/GJ | 0.36 | 9 | Nielsen et al. (2010) |
| \* assumption: EF(PM10) = EF(PM2.5).  The TSP, PM10 and PM2.5 emission factors have been reviewed and it is unclear whether they represent filterable PM or total PM (filterable and condensable) emissions | | | | | |

Table 3.31 Tier 2 emission factors for non-residential sources, reciprocating engines burning gas oil

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR Source Category** | 1.A.4.a.i 1.A.4.b.i 1.A.4.c.i | Commercial / institutional: stationary Residential plants Agriculture / forestry / fishing: Stationary | | | |
| **Fuel** | Gas Oil | | | | |
| **SNAP (if applicable)** | 020105 020204 020304 | Comm./instit. - Stationary engines Residential - Stationary engines Agri./forest/aqua. - Stationary engines | | | |
| **Technologies/Practices** | Reciprocating Engines | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** | NH3 | | | | |
| **Pollutant** | **Value** | **Unit** | **95% confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 942 | g/GJ | 565 | 1319 | Nielsen et al. (2010) |
| CO | 130 | g/GJ | 78 | 182 | Nielsen et al. (2010) |
| NMVOC | 50 | g/GJ | 30 | 70 | BUWAL (2001) |
| SOx | 48 | g/GJ | 29 | 67 | BUWAL (2001) |
| TSP | 30 | g/GJ | 18 | 42 | BUWAL (2001) |
| PM10 | 30 | g/GJ | 18 | 42 | BUWAL (2001) |
| PM2.5 | 30 | g/GJ | 18 | 42 | \* |
| BC | 78 | % of PM2.5 | 47 | 109 | Hernandez et al. (2004) |
| Pb | 0.15 | mg/GJ | 0.075 | 0.3 | Nielsen et al. (2010) |
| Cd | 0.01 | mg/GJ | 0.005 | 0.02 | Nielsen et al. (2010) |
| Hg | 0.11 | mg/GJ | 0.055 | 0.22 | Nielsen et al. (2010) |
| As | 0.06 | mg/GJ | 0.03 | 0.12 | Nielsen et al. (2010) |
| Cr | 0.2 | mg/GJ | 0.1 | 0.4 | Nielsen et al. (2010) |
| Cu | 0.3 | mg/GJ | 0.15 | 0.6 | Nielsen et al. (2010) |
| Ni | 0.01 | mg/GJ | 0.005 | 0.02 | Nielsen et al. (2010) |
| Se | 0.22 | mg/GJ | 0.11 | 0.44 | Nielsen et al. (2010) |
| Zn | 58 | mg/GJ | 29 | 116 | Nielsen et al. (2010) |
| PCB | 0.13 | ng/GJ | 0.013 | 0.13 | Nielsen et al. (2010) |
| PCDD/F | 0.99 | ng I-TEQ/GJ | 0.20 | 5.0 | Nielsen et al. (2010) |
| Benzo(a)pyrene | 1.9 | g/GJ | 0.19 | 1.9 | Nielsen et al. (2010) |
| Benzo(b)fluoranthene | 15 | g/GJ | 1.5 | 15 | Nielsen et al. (2010) |
| Benzo(k)fluoranthene | 1.7 | g/GJ | 0.17 | 1.7 | Nielsen et al. (2010) |
| Indeno(1,2,3-cd)pyrene | 1.5 | g/GJ | 0.15 | 1.5 | Nielsen et al. (2010) |
| HCB | 0.22 | g/GJ | 0.022 | 0.22 | Nielsen et al. (2010) |
| \* assumption: EF(PM10) = EF(PM2.5)  The TSP, PM10 and PM2.5 emission factors represent filterable PM emissions | | | | | |

### Abatement

A limited number of add-on technologies exist that are aimed at reducing the emissions of primarily PM in these sectors. The resulting emission can be calculated by extending the technology-specific emission factor with an abated emission factor as given in the formula:

 (5)

However, as abatement technology is rarely specified in terms of efficiency, it may be more relevant to develop abated emission factors from the final emission concentrations achieved using abatement.

Guidance on estimating emission factors from concentrations is provided at subsection 4.3 of the present chapter.

### Activity data

Advancement of inventory approach from Tier 1 to Tier 2 requires the further disaggregation of fuel use from national totals down into fuel use by specific technology types. Information on fuel use at this level of aggregation is expected to be more limited and would likely require additional surveying/research by the inventory agency to help derive the data needed for further disaggregation. It is recommended to use country specific information on the split of these technology types. This section provides guidance on how to split the Tier 1 activity data (which is typically available from statistics) into different technologies for Tier 2.

#### Default datasets (in case no country specific information is available)

Table 3-42 provides a default split for residential and commercial/institutional fuel use covering the main technology types for this sector (fire places, boilers and stoves) for solid fuels except biomass. This data has been derived from the the Greenhouse gas and Air pollution Interactions and Synergies (GAINS) model based on data for 2010 recorded as petajoules of energy and represents a weighted average of the EU28 Member States. For ease of use this has been converted into percentage splits by fuel and technology to allow inventory compilers to disaggregate national totals of data. In developing the ratios for the EU it is recognised that the likely ratios will vary geographically dependent on available fuels and local climatic / cultural variations for the residential sector. Therefore, if solid fuels are important for small combustion in your country, it is good practiceto consult the GAINS model (<http://gains.iiasa.ac.at/models/index.html>) for country specific appliance type splits.

Table 3.32 Disaggregation of residential solid fuel use (excl. biomass) across main technology types based on GAINS model

|  |  |  |
| --- | --- | --- |
| **Fuel type** | **Technology Type** | **EU28 Average ratios of fuel splits** |
| Brown coal/lignite | Fire places | 0% |
|  | Residential boilers (automatic feed) | 0% |
|  | Residential boilers (manual feed) | 75% |
|  | Stoves | 25% |
| Hard coal | Fire places | 0% |
|  | Residential boilers (automatic feed) | 1% |
|  | Residential boilers (manual feed) | 51% |
|  | Stoves | 48% |
| Derived coal (coke) | Fire places | 0% |
|  | Residential boilers (automatic feed) | 0% |
|  | Residential boilers (manual feed) | 70% |
|  | Stoves | 30% |

Alternatively, Table 3.33 provides data for non-residential fuel use covering the sectoral split of energy usage, energy usage by different size energy classes, and number of plant in operation. The data in Table 3.33 has been based on a study completed by contractor (Grebot et al, 2014) on behalf of the European Commission to look at control options for emissions from appliances below 50MWth. The data within the table was derived based on surveys sent out to Member State Competent Authorities in 2012/2013 and extrapolation to cover gaps where they existed in order to develop a complete data-set. The study focussed upon the size range 1MWth to 50MWth and also included data held within the (GAINS) model managed by the International Institute for Applied Systems Analysis (IIASA). The study did not include the 50kWth – 1MWth appliances within the survey element as the scope was defined by the Medium Combustion Plant Directive (MCPD). Table 3.33 includes data for this size class based on trend analysis and extrapolation of data for the other size classes quoted within the table.

Table 3.33 can be used alongside national energy statistics to help further disaggregate data into a format for usage with the emission factor tables covered within the Guidebook on the 50kWth – 1MWth and 1MWth – 50MWth categories. However, care is required noting the high level of uncertainty for data within Table 3.33 and the fact that this presents an EU average for 27 Member States. Any regional or national variation is not be captured within the table and Inventory Agencies are also recommended to make use of the methods detailed in section 0 in developing estimates at Tier 2 approach.

Table 3.33 Summary of EU27 data-set taken from the European Commission study on ‘Analysis of the impacts of various options to control emissions from combustion of fuels in installations with a total rated thermal input below 50MW (2014)’

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Datum** | **50Kwth - 1MWth** | **1-5 MWth** | **5-20 MWth** | **20-50 MWth** |
| Number of plants | 569,045 | 113,809 | 23,868 | 5,309 |
| Percentage of plants based on total | 80% | 16% | 3% | 1% |
| Sectoral distribution1 |  |  |  |  |
| Public electricity generation | 11% | 11% | 8% | 16% |
| Public heat generation | 23% | 25% | 29% | 40% |
| Tertiary (i.e. non-residential) | 13% | 5% | 2% | 0% |
| Hospitals | 6% | 6% | 1% | 2% |
| Greenhouses | 13% | 13% | 40% | 4% |
| Food industry | 4% | 4% | 3% | 6% |
| Industry | 18% | 18% | 14% | 28% |
| Others (University) | 5% | 5% | 0% | 1% |
| Others (CHP) | 1% | 1% | 0% | 0% |
| Others | 6% | 11% | 3% | 3% |
| Technology type2 |  |  |  |  |
| Boilers | 80% | 80% | 82% | 81% |
| Engines / turbines / others | 20% | 20% | 18% | 19% |
| Capacity of plants (GWth) | 300,000 | 273,714 | 232,367 | 177,099 |
| Fuel consumption: |  |  |  |  |
| Biomass (PJ) | 168 | 163 | 160 | 182 |
| Other solid fuel (PJ) | 56 | 49 | 46 | 74 |
| Liquid fuel (PJ) | 236 | 213 | 290 | 206 |
| Natural gas (PJ) | 1,272 | 1,268 | 1,704 | 844 |
| Other gaseous fuel (PJ) | 169 | 277 | 125 | 104 |
| Total fuel consumption (PJ) | 1,902 | 1,971 | 2,325 | 1,410 |
| Fuel consumption as percentage: |  |  |  |  |
| Biomass (%) | 9% | 8% | 7% | 13% |
| Other solid fuel (%) | 3% | 2% | 2% | 5% |
| Liquid Fuel (%) | 12% | 11% | 12% | 14% |
| Natural gas (%) | 67% | 64% | 73% | 60% |
| Other gaseous consumption (%) | 9% | 15% | 6% | 8% |
| SO2 emissions (kt) | **-** | 103 | 130 | 68 |
| NOX emissions (kt) | **-** | 210 | 227 | 117 |
| Dust emissions (kt) | **-** | 17 | 20 | 16 |

Note 1: The sectoral distribution is a weighted average derived from a small sample of Member States which reported this information.

Note 2: The technology type split is significantly influenced by the 80:20 assumption which has been used to fill the majority of Member States, for which this information was not available.

#### Other methodologies for further disaggegation of activity data for more advanced calculation (Tier 2 and Tier 3 approaches)

Development of emission estimates following a Tier 1 approach will only require data on national levels of fuel consumption. The advancement to Tier 2 and Tier 3 approach requires more detailed information disaggregated to technology type. This kind of information is expected to be more limited. While Table 3.32 and Table 3.33 provide a useful breakdown of the appliances on the EU market prior to 2014 (noting the accession of Croatia to form the EU28), additional methodologies can be used to help inventory agencies develop the necessary activity data for Tier 2 and Tier 3 level approach. This includes gathering data by collecting:

* information from the fuel suppliers and individual companies;
* energy conservation/climate change mitigation studies for relevant sectors;
* residential, commercial/institutional and agriculture sector surveys; and
* energy demand modelling.

The data from different sources should be compared, taking into account their inherent uncertainties in order to obtain the best assessment of appliance population and fuel use.

Equally to improve reliability of the activity data, appropriate efforts should be made in order to encourage the institution responsible for national energy statistics to report the fuel consumption at the adequate level of sectoral disaggregation in their regular activity which could include energy classes for the below 50MWth category.

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

The Tier 2 methodology requires further allocation of the fuel consumed according to the installation types. This is particularly relevant to the residential sector where, for example, the proportion of solid fuel burned in traditional low technology appliances is important to understand the significance of the emissions. The data needed are generally not available in statistical 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; and
* information from chimney sweeping organisations.

Particularly in the case of the residential sector 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 a significantly greater share of solid-fuel stoves and boilers in traditionally coal mining regions and in some rural areas. Additional data could be obtained from the chimney-sweeper organisations and from environmental inspectorates, particularly for the commercial-institutional sector.

As described in Broderick & Houck (2003), a number of circumstances should be considered when preparing and conducting a survey study of residential wood consumption. More technical issues related to surveys are provided in Eastern Research Group (2000), which provides a detailed description on issues to be considered, when conducting a survey, e.g. survey techniques, sample size, elaboration of questions, handling of answers etc. In relation to residential wood consumption, it is important to include a clear definition of volume of wood, as a number of measures are used, e.g. loose volume of logs (logs thrown into e.g. a box), stacked volume of logs (around 70 % of loose volume) and stacked volume before cutting into logs. It can also be beneficial to include drawings in the survey to assist both respondents and surveyors. Section 3.5.1 provides further discussion on the use of biomass within residential and non-residential settings. This includes discussion around emissions and the affect that operational settings and maintenance can have on emissions. It also highlights the importance around the nature of the fuel itself, different types of wood with varying organic, moisture and oil content will affect the emissions produced, as will the nature of the wood (logs vs pellets) burnt within appliances.

In order to estimate emissions from residential wood combustion it is necessary to include appliance population per installation type, to ensure use of appropriate emission factors. Sales statistics are valuable data sources for this purpose. Sales statistics from the past can be used to estimate the population of old appliances and statistics for more recent years can be used to incorporate substitution rates to newer appliances. Another or an additional approach is surveys, which can be used to estimate the appliance population on type level at the time of surveying. Sales statistics should be used to estimate substitution rates in order to make time series for the appliance population.

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

* number of residents;
* area of the dwelling;
* type of building (individual house, attached house, block of flats);
* construction year;
* primary (and secondary) heating source;
* existence or not of central heating; and
* 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 a key source or are of a great relevance due to local air quality, 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, such as, for instance, agencies involved in energy conservation, climate change mitigation or energy supply.

Data from national or regional housing registers can be used to estimate the energy demand for households, based on e.g. area and construction year. National or regional models or statistics on residential energy consumption for space heating can be applied to estimate the residential heating demand from e.g. area and age of the dwellings.

Another approach to estimate the heating demand for different housing types, is to gather consumption data for other heating practices, e.g. district heating, and calculate a mean consumption for each housing type. The housing types should be in agreement with the types that can be identified in the national housing register. Also information on energy ratings could be included.

The Odyssee-Mure project provided data on heat consumption in residences in a number of European countries. Average heat consumption for residential space heating based on Odyssee (2012), are included in the table below and might be applied, if country specific data are not available.

Table 3.34 Energy consumption for residential space heating in selected European countries (Odyssee-Mure project, the Odyssee database (2012))

| **Party** | **Heat consumption for residential space heating \*, MJ/m2** |
| --- | --- |
| European Union | 525.131 |
| Austria | 622.341 |
| Belgium | 896.896 |
| Bulgaria | 321.409 |
| Croatia | 416.823 |
| Czech Rep. | 654.534 |
| Denmark | 571.015 |
| Estonia | 693.783 |
| Finland | 746.278 |
| France | 567.273 |
| Germany | 633.611 |
| Greece | 430.970 |
| Hungary | 568.762 |
| Ireland | 534.639 |
| Italy | 342.077 |
| Latvia | 903.062 |
| Lithuania | 567.693 |
| Netherlands | 425.459 |
| Poland | 646.948 |
| Portugal | 55.049 |
| Romania | 663.094 |
| Slovakia | 509.279 |
| Slovenia | 658.428 |
| Spain | 211.285 |
| Sweden | 537.448 |
| United Kingdom | 558.961 |

To estimate the wood combustion in residential plants from the heating demand, it is necessary to include information on other heating sources in the dwellings. The price level of heating from different sources could be used as indicator for the proportion of the total heating demand, covered by the different heating sources. For example, if a dwelling is registered having both district heating and a wood stove, the share of the heating demand covered by residential wood combustion will depend on the price per energy unit of wood compared to district heating. The share of the different heating sources (wood and district heating in this example) will vary regionally according to variations between regions in the price for the different heating sources. As price levels, accessibility and consumer behaviour all affect the choice of heating source, surveys might be of great value to evaluate the share of the residential heating demand covered by wood combustion.

The table below propose RWC shares of total energy demand. It is good practice to apply country specific shares as both heating supply and demand vary significantly between countries. For example it should be considered, if the wood consumption, and thereby the share, is higher in countries or regions with large forest lands, where wood might be easily accessible.

|  |  |
| --- | --- |
| **Primary heating source** | **RWC share of heating demand** |
| Wood | 1.0 |
| Expensive compared to wood | 0.6 |
| Similar price level as wood | 0.5 |
| Cheap compared to wood | 0.2 |

Determining residential wood consumption is further complicated, as firing is not only due to the heating demand in dwellings but also for create cosy domesticity. The extent of wood firing for cosiness varies between countries and should be considered as it can induce an increased wood consumption. This might be examined through surveys.

## Tier 2 technology-specific approach for solid biomass fuels

### Algorithm

The Tier 2 approach is similar to the Tier 1 approach, using activity data and emission factors to estimate the emissions. The main difference is that the detailed methodology requires more fuel, technology and country-specific information. Development of the detailed methodology has to be focused to the combinations of the main installation types/fuels used in the country.

This section provides guidance for estimating emissions from the combustion of solid biomass. Given the importance of this source to (specifically) PM emission in most countries, a specific methodology has been elaborated. This methodology is a Tier 2 methodology, but in addition to the regular Tier 2 methodologies this method provides default technology splits that Parties may use to apply the Tier 2 approach. The thought behind this idea is that they will therefore be able to provide a more accurate estimate compared to the earlier Tier 1 approach for residential biomass combustion.

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

, (1)

where

 = annual emission of pollutant *i*,

 = default emission factor of pollutant *i* for appliance type *j* and fuel *k*,

 = annual consumption of fuel *k* in appliance type *j*.

In order to use this inventory, data must be available on:

* The total annual consumption of solid biomass
* How this solid biomass is split over the various fuels *k* (e.g. different wood types)
* How the use of solid biomass is split over the different appliance types *i*

Ideally, this information should be available from national statistics or national studies, reflecting the specific situation in the country. However, in case this information is not available, this Tier 2 methodology provides default information on how to split the technologies used for the combustion of solid biomass over the different appliance types and fuel types.

This methodology splits the small combustion of wood in several appliance and fuel types as explained in the next sections.

### Appliance type split factors

This section provides default factors to split your total fuel consumption over the various appliance types. The split is based on the appliance types given by Klimont et al. (2002) and Kupiainen and Klimont (2007), for which data are also available from the IIASA GAINS model for various years.

The appliance types are explained in the table below.

Table 3.35 Appliance types distinguished in the IIASA GAINS model

|  |  |  |
| --- | --- | --- |
| **Abbreviation** | **Appliance type** | **Corresponding EF table(s)** |
| FPLACE | Fireplace | Table 3.39 |
| STOVE | Heating stove\* | Table 3.40, Table 3.41, Table 3.42 |
| SHB\_A | Single house boiler, automatic feed | Table 3.44 |
| SHB\_M | Single house boiler, manual feed | Table 3.43 |
| MB\_A | Medium boiler, automatic feed (between 1 – 50 MWth) | Table 3.45, Table 3.48 |
| MB\_M | Medium boiler, manual feed | Table 3.47 |

\* Generally, the use of biomass stoves for cooking can be considered negligible in Europe.

This information is to be used only if no data from the country itself is available on the split of different appliance types. The split is estimated by taking the energy balances as a starting point to split between residential, commercial/institutional and other sectors. The allocation to stoves and boilers were proposed by IIASA and discussed with countries in the country consultations. More information on the estimation of these fractions is available in Klimont et al. (2016).

Most countries in the UNECE domain are included in the split factors provided in Table 3.36 to Table 3.38 (for years 2000, 2005 and 2010, respectively). For countries not included, it is good practice to select a country most resembling the countries listed. For the years in between the provided years, interpolation/extrapolation may be used to estimate the appliance type contributions in the other years. In addition, GAINS also contains these split for projected future years, therefore it can also be used for the most reporting of emissions from the most recent years as well as projections reporting.

Table 3.36 Appliance type split according to IIASA GAINS model for the year 2000

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year:** | **2000** | **FPLACE** | **MB\_A** | **MB\_M** | **SHB\_A** | **SHB\_M** | **STOVE** |
| **Albania** | | 0% | 1% | 6% | 0% | 2% | 91% |
| **Austria** | | 1% | 6% | 0% | 4% | 62% | 27% |
| **Belarus** | | 0% | 1% | 14% | 0% | 2% | 83% |
| **Belgium** | | 8% | 0% | 0% | 4% | 4% | 85% |
| **Bosnia-Herzegovina** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Bulgaria** | | 0% | 0% | 2% | 0% | 2% | 96% |
| **Croatia** | | 6% | 0% | 0% | 0% | 25% | 69% |
| **Cyprus** | | 8% | 0% | 0% | 25% | 33% | 33% |
| **Czech Republic** | | 1% | 3% | 0% | 0% | 36% | 59% |
| **Denmark** | | 1% | 6% | 8% | 8% | 34% | 43% |
| **Estonia** | | 6% | 1% | 1% | 0% | 25% | 67% |
| **Finland** | | 5% | 13% | 2% | 3% | 19% | 58% |
| **France** | | 6% | 4% | 0% | 0% | 11% | 79% |
| **Germany** | | 8% | 0% | 0% | 25% | 33% | 33% |
| **Greece** | | 6% | 0% | 0% | 6% | 25% | 62% |
| **Hungary** | | 0% | 9% | 0% | 0% | 46% | 46% |
| **Iceland** | | - | - | - | - | - | - |
| **Ireland** | | 20% | 0% | 0% | 0% | 5% | 75% |
| **Italy** | | 62% | 0% | 0% | 0% | 9% | 29% |
| **Kosovo** | | - | - | - | - | - | - |
| **Latvia** | | 6% | 5% | 5% | 0% | 15% | 68% |
| **Lithuania** | | 8% | 4% | 4% | 0% | 38% | 47% |
| **Luxembourg** | | 6% | 3% | 1% | 6% | 24% | 60% |
| **FYR of Macedonia** | | 0% | 1% | 9% | 0% | 2% | 88% |
| **Malta** | | - | - | - | - | - | - |
| **Moldova** | | 0% | 1% | 10% | 0% | 2% | 87% |
| **Montenegro** | | - | - | - | - | - | - |
| **Netherlands** | | 77% | 3% | 0% | 0% | 0% | 19% |
| **Norway** | | 5% | 0% | 0% | 0% | 1% | 94% |
| **Poland** | | 4% | 1% | 8% | 0% | 12% | 75% |
| **Portugal** | | 21% | 0% | 0% | 7% | 17% | 55% |
| **Romania** | | 0% | 0% | 1% | 0% | 2% | 96% |
| **Russian Federation** | | 1% | 0% | 2% | 0% | 11% | 85% |
| **Serbia** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Slovakia** | | 5% | 0% | 0% | 0% | 15% | 80% |
| **Slovenia** | | 0% | 0% | 0% | 2% | 89% | 9% |
| **Spain** | | 6% | 2% | 1% | 6% | 24% | 61% |
| **Sweden** | | 6% | 4% | 2% | 7% | 65% | 15% |
| **Switzerland** | | 1% | 27% | 0% | 8% | 42% | 21% |
| **Turkey** | | 0% | 0% | 0% | 1% | 11% | 87% |
| **Ukraine** | | 0% | 1% | 12% | 1% | 10% | 76% |
| **United Kingdom** | | 7% | 29% | 4% | 36% | 10% | 14% |

Table 3.37 Appliance type split according to IIASA GAINS model for the year 2005

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year:** | **2005** | **FPLACE** | **MB\_A** | **MB\_M** | **SHB\_A** | **SHB\_M** | **STOVE** |
| **Albania** | | 0% | 0% | 4% | 0% | 2% | 93% |
| **Austria** | | 1% | 9% | 0% | 7% | 58% | 25% |
| **Belarus** | | 0% | 2% | 17% | 0% | 2% | 80% |
| **Belgium** | | 7% | 2% | 1% | 4% | 4% | 82% |
| **Bosnia-Herzegovina** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Bulgaria** | | 0% | 0% | 2% | 0% | 2% | 96% |
| **Croatia** | | 6% | 0% | 0% | 0% | 29% | 65% |
| **Cyprus** | | 8% | 0% | 0% | 42% | 17% | 33% |
| **Czech Republic** | | 1% | 5% | 0% | 1% | 37% | 55% |
| **Denmark** | | 1% | 4% | 5% | 20% | 26% | 44% |
| **Estonia** | | 6% | 4% | 2% | 0% | 24% | 65% |
| **Finland** | | 5% | 13% | 2% | 3% | 19% | 58% |
| **France** | | 6% | 7% | 0% | 0% | 10% | 77% |
| **Germany** | | 8% | 0% | 0% | 42% | 17% | 33% |
| **Greece** | | 6% | 0% | 0% | 6% | 25% | 62% |
| **Hungary** | | 1% | 9% | 0% | 1% | 41% | 48% |
| **Iceland** | | - | - | - | - | - | - |
| **Ireland** | | 19% | 1% | 0% | 0% | 5% | 75% |
| **Italy** | | 60% | 0% | 0% | 0% | 9% | 31% |
| **Kosovo** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Latvia** | | 6% | 7% | 6% | 2% | 13% | 67% |
| **Lithuania** | | 7% | 3% | 2% | 2% | 39% | 47% |
| **Luxembourg** | | 6% | 4% | 1% | 6% | 24% | 59% |
| **FYR of Macedonia** | | 0% | 0% | 3% | 0% | 2% | 94% |
| **Malta** | | - | - | - | - | - | - |
| **Moldova** | | 0% | 1% | 10% | 0% | 2% | 87% |
| **Montenegro** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Netherlands** | | 78% | 3% | 0% | 0% | 0% | 19% |
| **Norway** | | 4% | 0% | 0% | 0% | 0% | 94% |
| **Poland** | | 4% | 2% | 5% | 0% | 12% | 77% |
| **Portugal** | | 21% | 0% | 0% | 14% | 14% | 52% |
| **Romania** | | 0% | 1% | 6% | 0% | 2% | 91% |
| **Russian Federation** | | 1% | 5% | 27% | 0% | 8% | 59% |
| **Serbia** | | 0% | 0% | 0% | 0% | 2% | 98% |
| **Slovakia** | | 5% | 0% | 0% | 0% | 15% | 80% |
| **Slovenia** | | 0% | 0% | 0% | 5% | 86% | 8% |
| **Spain** | | 6% | 2% | 1% | 6% | 24% | 61% |
| **Sweden** | | 6% | 7% | 2% | 14% | 58% | 12% |
| **Switzerland** | | 1% | 28% | 0% | 11% | 39% | 21% |
| **Turkey** | | 0% | 0% | 0% | 1% | 11% | 87% |
| **Ukraine** | | 0% | 1% | 12% | 1% | 10% | 76% |
| **United Kingdom** | | 8% | 25% | 4% | 38% | 11% | 15% |

Table 3.38 Appliance type split according to IIASA GAINS model for the year 2010

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year:** | **2000** | **FPLACE** | **MB\_A** | **MB\_M** | **SHB\_A** | **SHB\_M** | **STOVE** |
| **Albania** | | 0% | 1% | 3% | 1% | 4% | 91% |
| **Austria** | | 1% | 9% | 0% | 10% | 57% | 24% |
| **Belarus** | | 0% | 3% | 15% | 1% | 4% | 77% |
| **Belgium** | | 8% | 1% | 1% | 4% | 4% | 83% |
| **Bosnia-Herzegovina** | | 0% | 0% | 0% | 1% | 5% | 94% |
| **Bulgaria** | | 0% | 0% | 1% | 1% | 4% | 93% |
| **Croatia** | | 6% | 0% | 0% | 0% | 27% | 67% |
| **Cyprus** | | 5% | 45% | 0% | 32% | 5% | 14% |
| **Czech Republic** | | 2% | 5% | 0% | 8% | 32% | 53% |
| **Denmark** | | 1% | 3% | 2% | 25% | 23% | 45% |
| **Estonia** | | 6% | 3% | 1% | 0% | 24% | 66% |
| **Finland** | | 5% | 13% | 2% | 3% | 19% | 58% |
| **France** | | 6% | 7% | 0% | 0% | 10% | 77% |
| **Germany** | | 8% | 0% | 0% | 58% | 8% | 25% |
| **Greece** | | 6% | 0% | 0% | 12% | 19% | 62% |
| **Hungary** | | 2% | 15% | 0% | 5% | 37% | 41% |
| **Iceland** | | - | - | - | - | - | - |
| **Ireland** | | 17% | 2% | 0% | 1% | 4% | 76% |
| **Italy** | | 59% | 0% | 0% | 0% | 7% | 34% |
| **Kosovo** | | 0% | 0% | 0% | 1% | 5% | 94% |
| **Latvia** | | 7% | 6% | 4% | 3% | 12% | 67% |
| **Lithuania** | | 7% | 4% | 2% | 3% | 38% | 47% |
| **Luxembourg** | | 6% | 7% | 0% | 12% | 17% | 58% |
| **FYR of Macedonia** | | 0% | 1% | 4% | 1% | 4% | 89% |
| **Malta** | | - | - | - | - | - | - |
| **Moldova** | | 0% | 2% | 10% | 1% | 4% | 83% |
| **Montenegro** | | 0% | 0% | 0% | 1% | 5% | 94% |
| **Netherlands** | | 78% | 2% | 0% | 0% | 0% | 20% |
| **Norway** | | 4% | 1% | 0% | 0% | 0% | 94% |
| **Poland** | | 4% | 3% | 5% | 1% | 10% | 77% |
| **Portugal** | | 20% | 1% | 0% | 14% | 14% | 51% |
| **Romania** | | 0% | 1% | 3% | 1% | 4% | 91% |
| **Russian Federation** | | 1% | 5% | 20% | 1% | 9% | 65% |
| **Serbia** | | 0% | 0% | 0% | 1% | 5% | 94% |
| **Slovakia** | | 4% | 2% | 1% | 0% | 11% | 82% |
| **Slovenia** | | 0% | 0% | 0% | 8% | 84% | 7% |
| **Spain** | | 6% | 4% | 0% | 12% | 18% | 60% |
| **Sweden** | | 5% | 7% | 1% | 16% | 58% | 12% |
| **Switzerland** | | 1% | 28% | 0% | 16% | 35% | 20% |
| **Turkey** | | 0% | 0% | 0% | 2% | 11% | 86% |
| **Ukraine** | | 0% | 10% | 54% | 1% | 4% | 31% |
| **United Kingdom** | | 7% | 31% | 0% | 38% | 10% | 14% |

### Fuel type split factors and combustion practices

#### Different solid biomass types

Apart from the appliance types, also the type of biomass is an important parameter to consider in the estimation of emissions from small combustion of wood. For example, soft and hard wood, wood from different tree types will all have different emission characteristics. Some specific emission factors are available and presented in the Tier 3 section of this chapter.However, it should be recognized that especially activity data are difficult to collect. Therefore, in the absence of any information it may be assumed that the emission factors provided in Section 3.4.4 provide an average of the wood types/conditions available.

In the case of pellets however, the situation is different. Pellet stoves have very different emission characteristics, therefore it is important to investigate the share of pellets in the overall wood consumption for small combustion. In some cases this information may be availalbe from national statistics. In case no country specific information is available, it is good practice to assume the appliance types SHB\_A (automatic feed single house boilers) are fuelled by wood pellets. Specific emission factors for small boilers fuelled by pellet stoves are available in the following section.

#### Impact of different combustion, operating practices and stoves’ age

In small scale wood burning most the majority of the PM emissions consist of volatized and either partially or unburned high molecular tarry components coming from the fuel because of heat. Highest particulate emissions occur when the fire is hot enough to release these tarry components from the wood but still too cool for these components to burn. Besides a low temperature, burning of released tarry components can also be inhibited under oxygen-starved conditions.

The main conditions determining the release of particles are:

* **Start-up phase:** During the start-up phase that takes place during the time between ignition and full steady burning, PM, CO and NMVOC emission can be very high, for above discussed reasons. Any means of operation that extends start-up phase usually increases emission and any means of operation that maximizes full steady burning period decreases emissions. During the start-up phase emissions can be the 10-fold of emission during steady burning. Conditions during start-up may be repeated when fresh fuel is added to the fire. Tarry components are released from the added fuel but the fire is not yet hot enough to fully burn these components. According to Nussbaumer et al. (2008/2) the start-up phase accounts for roughly 50% of the total PM emissions, keeping in mind this fraction can variate significantly depending on the conditions.
* **Phase out phase:** Another phase critical for emissions is the final phase of the fire when no fresh fuel is added anymore and the temperature and burning rate of the fire is decreasing. In this phase wood smoldering can occur, which causes very high emissions again, far exceeding the emission during steady full burning. Smoldering conditions can be very prolongued if the fire is left to die and extinguish naturally by itself. Similar conditions occur when the fire is regulated downwards or extinguished by decreasing or completely eliminating the oxygen supply. Under oxygen starved conditions the components released from the fuel becaused of heat can then no longer fully combust and emissions strongly increase when the fire is subdued in this way. Almost full elimination of the oxygen supply results in prolongued smoldering, and volatile components are still released from the fuel but can no longer burn, resulting in high emissions of particles.
* **Way of operating:** ignition of the fire from the top results in 50-80% lower emissions than ignition from the bottom, since when the fuel is ignited from the bottom there can be a lack of oxygen and therefore incomplete combustion, while the flames are initially cooled from the logs lying on top of the fire (Nussbaumer et al., 2008/2). If a one-stage fuel chamber is used and the fuel chamber is filled with wood logs for more than 50%, PM emissions may be 5-10 times larger compared to ideal conditions, while for two-stage fuel chambers the performance is much better (Nussbaumer et al. 2008/2).
* **Impact of fire temperature**: As a general rule, the higher the temperature the lower the emission. As mentioned above, emissions can be very high when the fire is no longer hot enough the to let the released volatile components spontaneously catch fire and combust, yet still so hot that the release rate of these components from the fuel is still high. Fire temperature is partially determined by the type of appliance but is strongly influenced by operating conditions as well. Any practice that reduces fire temperature below the temperature needed for spontaneous combustion of volatile components, either resulting in local “cool zones” or in a cooler fire altogether (e.g. by letting the fire become too spread-out) has the potential to increase emissions by orders of magnitude.
* **Water content of the fuel:** A factor that is considered under operating conditions is the wood moisture content. A high moisture content (e.g. above 20%) will significantly prolongue the start-up phase, as evaporating moisture may keep the fire too cool to fully burn the released volatile tarry components. Evaporation of moisture present in the fuel also promotes steam stripping of tarry components from the wood. Steam stripping results in an increased release of these components and in combination with a cooler fire results in significantly higher emission as well (Simoneit, 2002).

The effect of above discussed operating practices is particularily strong for smaller appliances (e.g. below 50 kWth) for which tarry and other semi-volatile matter dominates particulate emission. In larger appliances the fire temperature is often significantly higher so that these components released from the fuel fully combust anyway. Also air supply is much more optimized compared to conventional small appliances, and the flue gasses are better mixed because of the higher turbulence of the flame, which prevent cool partially burned parts of the flue gas to escape. The fire is usually regulated by the supply rate of the fuel rather then the oxygen supply. In larger appliances particulate emissions as a result from ash suspension due to the higher flame turbulence (which does usually not occur in smalle appliances) may surpass the emission due to the release of partially or unburned volatile components from the fuel. For these larger appliances many of the operation conditions discussed above may have much less effect, or may even have an opposite effect (e.g. fuel moisture). For instance, US EPA (1989) reports that reducing wood moisture increased the particulate emission factor. Also US EPA AP42 chapter on wood residue combustion in boilers reports higher value for dry than wet wood for Filterable (17.5% for TSP, 19.5% for PM10 and 25% for PM2.5). This is likely related to the fact that if there is more water, there is less wood per kg which, if burning the same, will generate less PM per kg of wood combusted.

Another important observation is that stoves that have been in use for several years emit more particulates than brand new stoves. SINTEF Energy Research (Seljeskog et al., 2013) reports that wood stove testing in Norway has shown that, depending on the quality of each specific stove type and each stove specific technical solution themselves, normal use over several years might lead to increased air leakage with the inherent result of higher particle emissions. Leakage means that air is introduced into the stove in wrong places, and not at the secondary air inlet area where it is supposed to mix with hot flue gases and burnout the remaining particle matter. Here leakages cool down parts of the combustion zone and prevent particle burnout. Further studies are needed to quantified such effects in more detail.

### Technology-specific emission factors for solid biomass combustion

This section provides the emission factors for the combustion of solid biomass in 4 different appliance type categories. These match with the appliance type splits provided in Section 3.4.2. For the boilers, the appliance type split factors distinguish between automatic feed and manual feed. This split is not available in the emission factor tables

An important notice is that this Tier 2 methodology provides two sets of emission factors for particles (TSP, PM10 and PM2.5) depending on whether or notcondensables are included, which in turn depends on the measurement technique used (Nussbaumer et al., 2008/1):

1. Solid particles only: this refers to sampling of particles on a heated filter, through a probe, from undiluted flue gas in the chimney at a fixed gas temperature. Using this technique, the PM formed due to cooling and dilation of hot flue gases (the condensable fraction) is not taken into account.
2. Total particles: this refers to sampling of filterable particles in a dilution tunnel with a filter holder gas temperature < 35°C (e.g. Norwegian standard NS 3058-2). Due to the cooling and dilution, condensable organic material in the hot flue gas condenses on the filter. Therefore, when PM is measured using this technique both the filterable and condensable PM are included.

It should be noted that for BC also two fractions are provided, because the fraction of BC in PM2.5 depends strongly on the measurement technique used for PM2.5 (BC is typically not present in the condensable fraction).

For reporting, only either PM emissions based on total particles or PM emissions based on solid particles only should be used. A consistent PM reporting based on one of the two approaches is encouraged. It should be noted clearly in the IIR what the reported emissions represent, total particles or solid particles only.

#### Fireplaces

This section provides the default emission factors for wood burning in fireplaces. These emission factors resemble traditional (open) fireplaces. For more efficient closed fireplaces, it is recommended to use the emission factors for high-efficiency stoves (Table 3.41).

Table 3.39 Tier 2 emission factors for source category 1.A.4.b.i, open fireplaces burning wood 4)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Open fireplaces | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 50 | g/GJ | 30 | 150 | Pettersson et al. (2011) 1) |
| CO | 4000 | g/GJ | 1000 | 10000 | Goncalves et al. (2012) |
| NMVOC | 600 | g/GJ | 20 | 3000 | Pettersson et al. (2011) and McDonald et al. (2000) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996/1) |
| NH3 | 74 | g/GJ | 37 | 148 | Roe et al. (2004) |
| TSP (total particles) | 880 | g/GJ | 440 | 1760 | Alves et al. (2011) 2) |
| PM10 (total particles) | 840 | g/GJ | 420 | 1680 | Alves et al. (2011) 2) |
| PM2.5 (total particles) | 820 | g/GJ | 410 | 1640 | Alves et al. (2011) 2) |
| BC (based on total particles) | 7 | % of PM2.5 | 2 | 18 | Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), Fine et al. (2002), Kupiainen & Klimont (2004) |
| TSP (solid particles only) | 270 | g/GJ | 135 | 540 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) 5) |
| PM10 (solid particles only) | 260 | g/GJ | 130 | 520 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) 5) |
| PM2.5 (solid particles only) | 240 | g/GJ | 120 | 480 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) 5) |
| BC (based on solid particles only) | 24 | % of PM2.5 | 7 | 60 | Denier van der Gon et al. (2015) applied on  Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), Fine et al. (2002), Kupiainen & Klimont (2004) 5) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCBs | 0.06 | µg/GJ | 0.006 | 0.6 | Hedman et al. (2006) 3) |
| PCDD/F | 800 | ng I-TEQ/GJ | 20 | 5000 | Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005)1) |
| Benzo(a)pyrene | 121 | mg/GJ | 12 | 1210 | Goncalves et al. (2012); Tissari et al. (2007);  Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011) |
| Benzo(b)fluoranthene | 111 | mg/GJ | 11 | 1110 |
| Benzo(k)fluoranthene | 42 | mg/GJ | 4 | 420 |
| Indeno(1,2,3-cd)pyrene | 71 | mg/GJ | 7 | 710 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed equal to conventional stoves
2. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3. Assumed equal to conventional boilers.
4. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
5. Emission factors for solid particles are calculated from the total particulate EFs by applying the ratio of emission factors for solid / total particles reported in Denier van der Gon et al. (2015). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

#### Stove

This section provides the default emission factors for wood (and similar wood waste) burning in stoves. The emission factors presented here provide an average for a typical solid biomass fraction.  
Different stoves are distinguished:

* Conventional stoves
* High-efficiency stoves
* Advanced / ecolabelled stoves and boilers

These 3 stove types are described in more detail in Section 2.2.1.

The split between conventional, high-efficiency and ecolabelled stoves should be made based on country specific information. The Guidebook does not contain specific information on a country basis for this split. Generally it is assumed that most stoves in Europe are still conventional, given the relatively long lifetime of stoves. In some European regions however, particularly in Germany and Scandinavian countries, a significant share of the stoves is likely similar to ecolabelled stoves with the associated emission factors. For instance in Denmark, new stoves have to meet stringent regulations. At European level, the Ecodesign Directive includes specific elements aimed to significantly particulate emissions from wood stoves, but this legislation will only be implemented in 2022.

If no information is available on the split between different types of stoves, it is good practice to assume all stoves are conventional stoves.

Emission factors for pellet boilers/stoves are provided in the section on “Single house boilers” in Table 3.44.

Table 3.40 Tier 2 emission factors for source category 1.A.4.b.i, conventional stoves burning wood and similar wood waste 3)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tier 2 emission factors | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood and similar wood waste | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Conventional stoves | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 50 | g/GJ | 30 | 150 | Pettersson et al. (2011) |
| CO | 4000 | g/GJ | 1000 | 10000 | Pettersson et al. (2011) and Goncalves et al. (2012) |
| NMVOC | 600 | g/GJ | 20 | 3000 | Pettersson et al. (2011) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996/2) |
| NH3 | 70 | g/GJ | 35 | 140 | Roe et al. (2004) |
| TSP (total particles) | 800 | g/GJ | 400 | 1600 | Alves et al. (2011) and Glasius et al. (2005) 1) |
| PM10 (total particles) | 760 | g/GJ | 380 | 1520 | Alves et al. (2011) and Glasius et al. (2005)  1) |
| PM2.5 (total particles) | 740 | g/GJ | 370 | 1480 | Alves et al. (2011) and Glasius et al. (2005)  1) |
| BC (based on total particles) | 10 | % of PM2.5 | 2 | 20 | Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989) |
| TSP (solid particles only) | 200 | g/GJ | 400 | 1600 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| PM10 (solid particles only) | 160 | g/GJ | 380 | 1520 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| PM2.5 (solid particles only) | 140 | g/GJ | 370 | 1480 | Denier van der Gon et al. (2015) applied on Alves et al. (2011) and Glasius et al. (2005) 4) |
| BC (based on solid particles only) | 53 | % of PM2.5 | 11 | 100 | Denier van der Gon et al. (2015) applied on Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989) 4) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| PCBs | 0.06 | g/GJ | 0.006 | 0.6 | Hedman et al. (2006) 2) |
| PCDD/F | 800 | ng I-TEQ/GJ | 20 | 5000 | Glasius et al. (2005); Hedman et al. (2006); Hübner et al. (2005) |
| Benzo(a)pyrene | 121 | mg/GJ | 12 | 1210 | Goncalves et al. (2012); Tissari et al. (2007);  Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011) |
| Benzo(b)fluoranthene | 111 | mg/GJ | 11 | 1110 |
| Benzo(k)fluoranthene | 42 | mg/GJ | 4 | 420 |
| Indeno(1,2,3-cd)pyrene | 71 | mg/GJ | 7 | 710 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
2. Assumed equal to conventional boilers.
3. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
4. Emission factors for solid particles are calculated from the total particulate EFs by applying the ratio of emission factors for solid / total particles reported in Denier van der Gon et al. (2015). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.41 Tier 2 emission factors for source category 1.A.4.b.i, high-efficiency stoves burning wood 6)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | High-efficiency stoves | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 80 | g/GJ | 30 | 150 | Pettersson et al. (2011) 1) |
| CO | 4000 | g/GJ | 500 | 10000 | Johansson et al. (2003) 2) |
| NMVOC | 350 | g/GJ | 100 | 2000 | Johansson et al. (2004) 2) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996b) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 3) |
| TSP (total particles) | 400 | g/GJ | 200 | 800 | Glasius et al. (2005) 4) 5) |
| PM10 (total particles) | 380 | g/GJ | 290 | 760 | Glasius et al. (2005) 4) 5) |
| PM2.5 (total particles) | 370 | g/GJ | 285 | 740 | Glasius et al. (2005) 4) 5) |
| BC (based on total particles) | 16 | % of PM2.5 | 5 | 30 | Kupiainen & Klimont (2007) 2) |
| TSP (solid particles only) | 170 | g/GJ | 85 | 340 | Denier van der Gon et al. (2015) applied on Glasius et al. (2005) 4) 5) 7) |
| PM10 (solid particles only) | 150 | g/GJ | 75 | 300 | Denier van der Gon et al. (2015) applied on Glasius et al. (2005) 4) 5) 7) |
| PM2.5 (solid particles only) | 140 | g/GJ | 70 | 280 | Denier van der Gon et al. (2015) applied on Glasius et al. (2005) 4) 5) 7) |
| BC (based on solid particles only) | 43 | % of PM2.5 | 13 | 79 | Denier van der Gon et al. (2015) applied on Kupiainen and Klimont ) 2) 7) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.03 | µg/GJ | 0.003 | 0.3 | Hedman et al. (2006) |
| PCDD/F | 250 | ng I-TEQ/GJ | 20 | 2600 | Hedman et al. (2006) |
| Benzo(a)pyrene | 121 | mg/GJ | 12 | 1210 | Goncalves et al. (2012); Tissari et al. (2007);  Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011) |
| Benzo(b)fluoranthene | 111 | mg/GJ | 11 | 1110 |
| Benzo(k)fluoranthene | 42 | mg/GJ | 4 | 420 |
| Indeno(1,2,3-cd)pyrene | 71 | mg/GJ | 7 | 710 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed equal to conventional stoves.
2. Assumed equal to conventional boilers.
3. Assumed low emitting.
4. Wood stoves < 3 years old.
5. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
6. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
7. Emission factors for solid particles are calculated from the total particulate EFs by assuming the PM2.5 solid particle EF is equal to those for conventional stoves (i.e. the emission reduction by using high-efficiency stoves is fully achieved in the condensable fraction). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.42 Tier 2 emission factors for source category 1.A.4.b.i, advanced / ecolabelled stoves and boilers burning wood 3)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Advanced / ecolabelled stoves and boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 95 | g/GJ | 50 | 150 | Pettersson et al. (2011) |
| CO | 2000 | g/GJ | 500 | 5000 | Johansson et al. (2003) |
| NMVOC | 250 | g/GJ | 20 | 500 | (2009 update of the Guidebook) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996/2) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 1) |
| TSP (total particles) | 100 | g/GJ | 20 | 250 | Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 2) |
| PM10 (total particles) | 95 | g/GJ | 19 | 238 | Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 2) |
| PM2.5 (total particles) | 93 | g/GJ | 19 | 233 | Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 2) |
| BC (based on total particles) | 28 | % of PM2.5 | 11 | 39 | Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) |
| TSP (solid particles only) | 54 | g/GJ | 10 | 125 | Denier van der Gon et al. (2015) applied on Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 4) |
| PM10 (solid particles only) | 49 | g/GJ | 10 | 115 | Denier van der Gon et al. (2015) applied on Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 4) |
| PM2.5 (solid particles only) | 47 | g/GJ | 10 | 110 | Denier van der Gon et al. (2015) applied on Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011) 4) |
| BC (based on solid particles only) | 55 | % of PM2.5 | 22 | 77 | Denier van der Gon et al. (2015) applied on Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011)4) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.007 | g/GJ | 0.0007 | 0.07 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed low emitting.
2. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
4. Emission factors for solid particles are calculated by assuming the condensable fraction is 50% based on Denier van der Gon et al. (2015) for pellet stoves. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

#### Single house boilers (<50 kWth)

This section provides default emission factors for single house boilers, defined as boilers with a thermal capacity below 50 kW. If a dinstiction between manual and automatic feed is made, it is good practice to apply the EFs for conventional boilers (Table 3.43) for manual feed single house boilers, and apply the EFs for pellet stoves (Table 3.44) for automatic feed single house boilers.

Table 3.43 Tier 2 emission factors for source category 1.A.4.b.i, conventional boilers < 50 kW burning wood and similar wood waste 6)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Tier 2 emission factors | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood and similar wood waste | | | | |
| **SNAP (if applicable)** | 020202 | Residential plants, combustion plants < 50 MW (boilers) | | | |
| **Technologies/Practices** | Conventional boilers < 50 kWth | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 80 | g/GJ | 30 | 150 | Pettersson et al. (2011) |
| CO | 4000 | g/GJ | 500 | 10000 | Johansson et al. (2003) 1) |
| NMVOC | 350 | g/GJ | 100 | 2000 | Johansson et al. (2004) 2) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (2003) |
| NH3 | 74 | g/GJ | 37 | 148 | Roe et al. (2004) |
| TSP (total particles) | 500 | g/GJ | 250 | 1000 | Winther (2008) 3) and Johansson et al. (2003) 4) |
| PM10 (total particles) | 480 | g/GJ | 240 | 960 | Winther (2008) 3) and Johansson et al. (2003)  4) |
| PM2.5 (total particles) | 470 | g/GJ | 235 | 940 | Winther (2008) 3) and Johansson et al. (2003)  4) |
| BC (based on total particles) | 16 | % of PM2.5 | 5 | 30 | Kupiainen & Klimont (2007) 5) |
| TSP (solid particles only) | 170 | g/GJ | 85 | 340 | Denier van der Gon et al. (2015) applied on Winther (2008) 3) and Johansson et al. (2003) 4) |
| PM10 (solid particles only) | 150 | g/GJ | 75 | 300 | Denier van der Gon et al. (2015) applied on Winther (2008) 3) and Johansson et al. (2003)  4) |
| PM2.5 (solid particles only) | 140 | g/GJ | 70 | 280 | Denier van der Gon et al. (2015) applied on Winther (2008) 3) and Johansson et al. (2003)  4) |
| BC (based on solid particles only) | 54 | % of PM2.5 | 17 | 100 | Denier van der Gon et al. (2015) applied on Kupiainen & Klimont (2007) 5) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| PCBs | 0.06 | µg/GJ | 0.006 | 0.6 | Hedman et al. (2006) |
| PCDD/F | 550 | I-Teq ng/GJ | 20 | 2600 | Hedman et al. (2006); Hübner et al. (2005) |
| Benzo(a)pyrene | 121 | mg/GJ | 12 | 1210 | Goncalves et al. (2012); Tissari et al. (2007);  Hedberg et al. (2002); Pettersson et al. (2011); Glasius et al. (2005); Paulrud et al. (2006); Johansson et al. (2003); Lamberg et al. (2011) |
| Benzo(b)fluoranthene | 111 | mg/GJ | 11 | 1110 |
| Benzo(k)fluoranthene | 42 | mg/GJ | 4 | 420 |
| Indeno(1,2,3-cd)pyrene | 71 | mg/GJ | 7 | 710 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers have not been included.
2. Assumed old boilers.
3. Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers. One outlier value for old boilers have not been included.
4. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
5. Based on the PM2.5 emission factor 475 g/GJ
6. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
7. Emission factors for solid particles are calculated from the total particulate EFs by applying the ratio of emission factors for solid / total particles reported in Denier van der Gon et al. (2015). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.44 Tier 2 emission factors for source category 1.A.4.b.i, pellet stoves and boilers burning wood pellets 1)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.b.i | Residential plants | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020205 | Residential - Other equipments (stoves, fireplaces, cooking,...) | | | |
| **Technologies/Practices** | Pellet stoves and boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 80 | g/GJ | 50 | 200 | Pettersson et al. (2011) |
| CO | 300 | g/GJ | 10 | 2500 | Schmidl et al. (2011) and Johansson et al. (2004) |
| NMVOC | 10 | g/GJ | 1 | 30 | Johansson et al. (2004) and Boman et al. (2011) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (1996/2) |
| NH3 | 12 | g/GJ | 6 | 24 | Roe et al. (2004) |
| TSP (total particles) | 62 | g/GJ | 31 | 124 | Denier van der Gon et al. (2015) |
| PM10 (total particles) | 60 | g/GJ | 30 | 120 | Denier van der Gon et al. (2015) |
| PM2.5 (total particles) | 60 | g/GJ | 30 | 120 | Denier van der Gon et al. (2015) |
| BC (based on total particles) | 15 | % of PM2.5 | 6 | 39 | Schmidl et al. (2011) |
| TSP (solid particles only) | 32 | g/GJ | 16 | 64 | Denier van der Gon et al. (2015) |
| PM10 (solid particles only) | 30 | g/GJ | 15 | 60 | Denier van der Gon et al. (2015) |
| PM2.5 (solid particles only) | 30 | g/GJ | 15 | 60 | Denier van der Gon et al. (2015) |
| BC (based on solid particles only) | 30 | % of PM2.5 | 12 | 78 | Denier van der Gon et al. (2015) applied on Schmidl et al. (2011) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.01 | g/GJ | 0.001 | 0.1 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.

#### Medium boilers (>50 kWth)

This section provides default emission factors for medium boilers, defined as boilers with a thermal capacity between 50 kW and 50 MW. To apply the emission factors, the fuel consumption needs to be split between 2 capacity ranges: 50 kWth – 1 MWth and 1 MWth – 50 MWth. If no information is available on the split between these two size ranges, it is good practice to assume all medium size boilers are in the size range 50 kWth – 1 MWth.

For the > 1 MWth size range, all boilers are assumed to be automatic feed and EFs are provided in . For the size range 50 kW – 1 MW, a split between manual feed (MB\_M) and automatic feed (MB\_A). Default split factors on a per country basis are available in Table 3.36 to Table 3.38. Emission factors for manual and automatic feed medium-sized boilers are available in Table 3.47 and Table 3.48, respectively.

If country specific information is used on the share of medium boilers and no split between manual and automatic feed is available, there is also an emission factor table with averaged EFs (Table 3.46). For emissions of PM and NMVOC, the emission factor suggested is the average of the manual and automatic boilers in this size range (50 kWth – 1 MWth) presented in Table 3.47 and Table 3.48.

Table 3.45 Tier 2 emission factors for non-residential sources, medium sized (>1 MWth to ≤ 50 MWth) boilers wood 4)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i | Commercial / institutional: stationary | | | |
| 1.A.4.c.i | Stationary | | | |
| 1.A.5.a | Other, stationary (including military) | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 20100 | Commercial and institutional plants | | | |
| 20300 | Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Wood combustion >1MW – Boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** | HCH | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 210 | g/GJ | 50 | 300 | US EPA (2003) |
| CO | 300 | g/GJ | 50 | 4000 | German test standard for 500 kW-1MW boilers; |
| Danish legislation (Luftvejledningen) |
| NMVOC | 12 | g/GJ | 5 | 300 | Johansson et al. (2004) 1) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (2003) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 2) |
| TSP (total particles) | 40 | g/GJ | 20 | 80 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 5) |
| PM10 (total particles) | 38 | g/GJ | 19 | 76 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 3) 5) |
| PM2.5 (total particles) | 37 | g/GJ | 18 | 74 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 3) 5) |
| BC (based on total particles) | 15 | % of PM2.5 | 6 | 39 | Schmidl et al. (2011) 4) |
| TSP (solid particles) | 36 | g/GJ | 18 | 72 | Johansson et al. (2004) |
| PM10 (solid particles) | 34 | g/GJ | 17 | 68 | Johansson et al. (2004) 3) |
| PM2.5 (solid particles) | 33 | g/GJ | 17 | 67 | Johansson et al. (2004) 3) |
| BC (based on solid particles) | 17 | % of PM2.5 | 7 | 44 | Denier van der Gon et al. (2015) applied on Schmidl et al. (2011) 4) 5) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.007 | g/GJ | 0.0007 | 0.07 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed equal to low emitting wood stoves
2. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3. Assumed equal to advanced/ecolabelled residential boilers
4. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
5. Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized automatic boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.46 Tier 2 emission factors for non-residential sources, medium sized (>50KWth to ≤ 1 MWth) boilers wood (in the absence of information on manual/automatic feed)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | | |
|  | Code | | Name | | | |
| **NFR source category** | 1.A.4.a.i | | Commercial / institutional: stationary | | | |
| 1.A.4.c.i | | Stationary | | | |
| 1.A.5.a | | Other, stationary (including military) | | | |
| **Fuel** | Wood | | | | | |
| **SNAP (if applicable)** | 20100 | | Commercial and institutional plants | | | |
| 20300 | | Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Wood combustion <1MW – Boilers | | | | | |
| **Region or regional conditions** | NA | | | | | |
| **Abatement technologies** | NA | | | | | |
| **Not applicable** |  | | | | | |
| **Not estimated** |  | | | | | |
| **Pollutant** | **Value** | **Unit** | | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 91 | g/GJ | | 20 | 120 | Lundgren et al. (2004) 1) |
| CO | 435 | g/GJ | | 50 | 4000 | EN 303 class 5 boilers, 150-300 Kw, German test standard for 500 kW-1MW boilers |
| NMVOC | 156 | g/GJ | | 5 | 400 | Aggregate of Table 3.47 and Table 3.48 |
| SOX | 11 | g/GJ | | 8 | 40 | US EPA (2003) |
| NH3 | 37 | g/GJ | | 18 | 74 | Roe et al. (2004) 2) |
| TSP (total particles) | 105 | g/GJ | | 41.5 | 166 | Aggregate of Table 3.47 and Table 3.48 |
| PM10 (total particles) | 100.5 | g/GJ | | 39.5 | 158 | Aggregate of Table 3.47 and Table 3.48 |
| PM2.5 (total particles) | 98.5 | g/GJ | | 38.5 | 154 | Aggregate of Table 3.47 and Table 3.48 |
| BC (based on total particles) | 26 | % of PM2.5 | | 8.5 | 39 | Aggregate of Table 3.47 and Table 3.48 |
| TSP (solid particles) | 93 | g/GJ | | 46.5 | 186 | Aggregate of Table 3.47 and Table 3.48 |
| PM10 (solid particles) | 88.5 | g/GJ | | 44 | 176.5 | Aggregate of Table 3.47 and Table 3.48 |
| PM2.5 (solid particles) | 86.5 | g/GJ | | 43.5 | 173 | Aggregate of Table 3.47 and Table 3.48 |
| BC (based on solid particles) | 29 | % of PM2.5 | | 9.5 | 44 | Aggregate of Table 3.47 and Table 3.48 |
| Pb | 27 | mg/GJ | | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.03 | g/GJ | | 0.006 | 0.3 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | | 2 | 8 |
| HCB | 5 | µg/GJ | | 0.1 | 30 | Syc et al. (2011) |

1. Assumed equal to low emitting wood stoves
2. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3. Assumed equal to advanced/ecolabelled residential boilers
4. Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized manual boilers (there is very little difference between automatic and medium sized boilers concerning the solid and condensable fractions in total PM according to this paper). BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.47 Tier 2 emission factors for non-residential sources, manual boilers burning wood 4)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020100  020300 | Commercial and institutional plants  Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Wood combustion <1MW - Manual Boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 91 | g/GJ | 20 | 120 | Lundgren et al. (2004) 1) |
| CO | 570 | g/GJ | 50 | 4000 | EN 303 class 5 boilers, 150-300 Kw |
| NMVOC | 300 | g/GJ | 5 | 500 | Naturvårdsverket, Sweden |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (2003) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 1) |
| TSP (total particles) | 170 | g/GJ | 85 | 340 | Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden 5) |
| PM10 (total particles) | 163 | g/GJ | 81 | 326 | Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden 2) 5) |
| PM2.5 (total particles) | 160 | g/GJ | 80 | 320 | Denier van der Gon et al. (2015) applied on Naturvårdsverket, Sweden 2) 5) |
| BC (based on total particles) | 28 | % of PM2.5 | 11 | 39 | Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) 3) 5) |
| TSP (solid particles) | 150 | g/GJ | 75 | 300 | Naturvårdsverket, Swede |
| PM10 (solid particles) | 143 | g/GJ | 71 | 285 | Naturvårdsverket, Sweden 2) |
| PM2.5 (solid particles) | 140 | g/GJ | 70 | 279 | Naturvårdsverket, Sweden 2) |
| BC (based on solid particles) | 32 | % of PM2.5 | 13 | 45 | Denier van der Gon et al. (2015) applied on Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) 3) 5) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.06 | g/GJ | 0.006 | 0.6 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Assumed equal to low emitting wood stoves
2. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
3. Assumed equal to advanced/ecolabelled residential boilers
4. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
5. Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized manual boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

Table 3.48 Tier 2 emission factors for non-residential sources, automatic boilers burning wood 5)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Tier 2 emission factors** | | | | | |
|  | Code | Name | | | |
| **NFR source category** | 1.A.4.a.i 1.A.4.c.i 1.A.5.a | Commercial / institutional: stationary Agriculture / forestry / fishing: Stationary Other, stationary (including military) | | | |
| **Fuel** | Wood | | | | |
| **SNAP (if applicable)** | 020100  020300 | Commercial and institutional plants  Plants in agriculture, forestry and aquaculture | | | |
| **Technologies/Practices** | Wood combustion <1MW - Automatic Boilers | | | | |
| **Region or regional conditions** | NA | | | | |
| **Abatement technologies** | NA | | | | |
| **Not applicable** |  | | | | |
| **Not estimated** |  | | | | |
| **Pollutant** | **Value** | **Unit** | **95 % confidence interval** | | **Reference** |
| **Lower** | **Upper** |
| NOX | 91 | g/GJ | 20 | 120 | Lundgren et al. (2004) 1) |
| CO | 300 | g/GJ | 50 | 4000 | German test standard for 500 kW-1MW boilers;Danish legislation (Luftvejledningen) |
| NMVOC | 12 | g/GJ | 5 | 300 | Johansson et al. (2004) 1) |
| SOX | 11 | g/GJ | 8 | 40 | US EPA (2003) |
| NH3 | 37 | g/GJ | 18 | 74 | Roe et al. (2004) 2) |
| TSP (total particles) | 40 | g/GJ | 20 | 80 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 6) |
| PM10 (total particles) | 38 | g/GJ | 19 | 76 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 3) 6) |
| PM2.5 (total particles) | 37 | g/GJ | 18 | 74 | Denier van der Gon et al. (2015) applied on Johansson et al. (2004) 3) 6) |
| BC (based on total particles) | 15 | % of PM2.5 | 6 | 39 | Schmidl et al. (2011) 4) |
| TSP (solid particles) | 36 | g/GJ | 18 | 72 | Johansson et al. (2004) |
| PM10 (solid particles) | 34 | g/GJ | 17 | 68 | Johansson et al. (2004) 3) |
| PM2.5 (solid particles) | 33 | g/GJ | 17 | 67 | Johansson et al. (2004) 3) |
| BC (based on solid particles) | 17 | % of PM2.5 | 7 | 44 | Denier van der Gon et al. (2015) applied on Schmidl et al. (2011) 4) 6) |
| Pb | 27 | mg/GJ | 0.5 | 118 | Hedberg et al. (2002), Tissari et al. (2007) , Struschka et al. (2008), Lamberg et al. (2011) |
| Cd | 13 | mg/GJ | 0.5 | 87 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Hg | 0.56 | mg/GJ | 0.2 | 1 | Struschka et al. (2008) |
| As | 0.19 | mg/GJ | 0.05 | 12 | Struschka et al. (2008) |
| Cr | 23 | mg/GJ | 1 | 100 | Hedberg et al. (2002) , Struschka et al. (2008) |
| Cu | 6 | mg/GJ | 4 | 89 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| Ni | 2 | mg/GJ | 0.5 | 16 | Hedberg et al. (2002), Struschka et al. (2008), Lamberg et al. (2011) |
| Se | 0.5 | mg/GJ | 0.25 | 1.1 | Hedberg et al. (2002) |
| Zn | 512 | mg/GJ | 80 | 1300 | Hedberg et al. (2002), Tissari et al. (2007), Struschka et al. (2008), Lamberg et al. (2011) |
| PCB | 0.007 | g/GJ | 0.0007 | 0.07 | Hedman et al. (2006) |
| PCDD/F | 100 | ng I-TEQ/GJ | 30 | 500 | Hedman et al. (2006) |
| Benzo(a)pyrene | 10 | mg/GJ | 5 | 20 | Boman et al. (2011); Johansson et al. (2004) |
| Benzo(b)fluoranthene | 16 | mg/GJ | 8 | 32 |
| Benzo(k)fluoranthene | 5 | mg/GJ | 2 | 10 |
| Indeno(1,2,3-cd)pyrene | 4 | mg/GJ | 2 | 8 |
| HCB | 5 | µg/GJ | 0.1 | 30 | Syc et al. (2011) |

1. Data for modern boilers
2. Assumed equal to low emitting wood stoves
3. PM10 estimated as 95 % of TSP, PM2.5 estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
4. Assumed equal to residential pellet boilers
5. If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 19 MJ/kg for wood pellets.
6. Emission factors for total particles are calculated by taking the ratio between PM2.5 for total particles and for solid particles only based on Denier van der Gon et al. (2015) for medium-sized automatic boilers. BC, PM10 and TSP are calculated by assuming the condensable fraction only contains particles <2.5µm, and does not contain any BC.

### Activity data

#### General approach for collecting activity data

The Tier 2 approach for biomass relies on information on the fuel consumption of biomass for different appliance type and separately for wood and pellets. Ideally, data for pellet consumption and other biomass should be available from national data or statistics. However, if this information is not available, a first approximation suggested is to assume that the automatic single house boilers (SHB\_A) are using pellets, while all other appliance types use non-pellet solid biomass.

The first prerequisite is the total amount of biomass combustion. This data is commonly available from statistics, e.g. from national statistics, from Eurostat and from the energy balances of the International Energy Agency. It should be recognised that especially for solid biomass, these numbers may be uncertain. For example, 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 could be an underestimation. Consultation with the forestry experts and/or energy demand modelling is recommended to verify and/or adjust the energy consumption figures from statistics.However, some countries do include this aspect in their national statistics on energy consumption. Therefore, without any better information it is good practice to adopt the energy consumption figures available in national or international statistics.

The heating values (net and gross calorific values NCV and GCV) of wood is primarily dependent on the moisture and ash content. At 0% ash and water (“daf”) the NCV and GCV of fuel wood are about 19 and 20 MJ/kg, respectively. Ash is inert during combustion and an increase in ash content results in a proportional decrease in heating value. According to (FAO, 2015) ash contents in biomass fuels usually range from 0.5 to 10%, for fuel wood usually between 0.5 and 2% and for other herbaceous agricultural waste lying between 5 and 10% (e.g. straw = 6%). The NCV and GCV of fuel wood at water content W (H(W) in MJ/kg) can be calculated according to H(W) = (Hdm\*(100-W)-2.44\*W)/100, with Hdm being the heating value of the wood in dry (anhydrous) state (NCV or GCV in MJ/kg), W the wood water content (% water on wet basis) and 2.44 the evaporation heat of water at 25°C (MJ/kg). Note that water content is not the same as moisture content (humidity), the difference being that moisture content is expressed on a dry basis while water content is expressed on a wet basis.

Fuel wood water content may vary widely as used, primarily depending on species, drying time and climatic conditions during drying. Newly chopped fresh wood is made up half by water and half by wood substance. Once it has been dried in ambient air, the typical water content is reduced to 15-20% (FAO, 2015). If water content is unknown 20% may be assumed by default. When wood (waste) is processed into pellets the water content decreases to below 10% (e.g. 8%). The water content of oven-dry and torrefied wood may be even lower but the use of oven-dried and toffefied wood in small combustion appliances will likely be small, since this treatment is typically done to strengthen the wood and make it fit for use e.g. as building material. FAO (2015) estimates the following typical NCVs:

Table 3.38 Net Calorific Values for fuel woods with different moisture contentsnd 1% ash

|  |  |  |
| --- | --- | --- |
| **Type of solid biomass** | **Water content (%)** | **NCV (MJ/kg)** |
| Oven-dry wood | 5% | 18.5 |
| Pellets | 8% | 17.1 |
| Fuel wood (fully air dried) | 15 | 15.6 |
| Fuel wood (partially air dried) | 20% | 14.6 |
| Wood chips and surface dry wood | 30% | 12.4 |

In addition, advancement of inventory approach from Tier 1 to Tier 2 requires the further disaggregation of fuel use from national totals down into fuel use by specific technology types. Information on fuel use at this level of aggregation is expected to be more limited and would likely require additional surveying/research by the inventory agency to help derive the data needed for further disaggregation. If this information is available or can be collected, it is good practice to use this national data source. However, when this information is not available, this Tier 2 methodology provides default information to stratify the solid biomass consumption according to different appliance types on a per country basis.

More information on activity data is provided in Section 3.3.4 on non-biomass fuels.

#### Independent estimates of biomass consumption

As mentioned above, some statistical estimates of solid biomass consumption in especially the residential sector may be underestimating the actual use in households. Since wood combustion is a key source of especially particulate emissions, reliable activity data are of crucial importance.

For an independent estimate, several methods exist. Options are to use information on energy demand in space heating (see e.g. Table 3.34) and combine this with statistics on the total surface area (in m2) in the residential sector. However, it should be noted that a distinction needs to be made between the various fuel types that may be used for space heating (e.g. gas or electricity). Another option is to start from the total energy demand in the residential sector, express this in GJ/person and compare different countries.

The latter approach was used by Denier van der Gon et al. (2015), where total wood use for UNECE-Europe by country was estimated by starting from the specific residential wood use per person (GJ / capita), in this case adopted from the GAINS model. The data from the GAINS model show that higher wood consumption occurs in countries with higher wood availability, and based on combining population data with land cover for woodlands a relation between these was derived. Using this, for several countries corrections were introduced. Resulting wood consumption data for the year 2010 are shown in Table 3.49.

Table 3.49 Per capita wood consumption for 2010 estimated by Denier van der Gon et al. (2015)

|  |  |  |  |
| --- | --- | --- | --- |
| **Country** | **Per capita wood use (GJ)** | **Country** | **Per capita wood use (GJ)** |
| Albania | 2.5 | Hungary | 3.3 |
| Armenia | 2.5 | Ireland | 0.5 |
| Austria | 10.0 | Italy | 2.5 |
| Azerbaijan | 1.5 | Lithuania | 8.2 |
| Belgium | 2.4 | Luxembourg | 2.0 |
| Bulgaria | 4.1 | Latvia | 16.4 |
| Bosnia and Herzegovina | 8.2 | Moldova | 2.6 |
| Belarus | 2.6 | Macedonia (FYROM) | 6.2 |
| Switzerland | 2.3 | Malta | 0.8 |
| Cyprus | 0.8 | Netherlands | 1.1 |
| Czech Republic | 5.1 | Norway | 6.1 |
| Germany | 3.2 | Poland | 3.8 |
| Denmark | 8.0 | Portugal | 2.9 |
| Spain | 2.0 | Romania | 7.5 |
| Estonia | 14.0 | Russia | 4.1 |
| Finland | 13.1 | Slovakia | 4.6 |
| France | 5.8 | Slovenia | 9.5 |
| United Kingdom | 0.4 | Sweden | 4.7 |
| Georgia | 1.7 | Turkey | 2.6 |
| Greece | 2.3 | Ukraine | 3.0 |
| Croatia | 6.3 | Serbia, Montenegro  and Kosovo | 7.1 |

## Tier 3 emission modelling and use of facility data

Installation-specific emission estimation is not considered to be applicable for the activities detailed. However the Tier 3 methodology allows a modelling-based approach using more detailed appliance population data and applies more technology-specific emission factors — guidance on determining plant-specific emission factors is given in the Measurement Protocol. Relevant emission factors are also provided at Appendix A.

### Use of biomass fuels within small combustion plant (<50MWth)

The Tier 1 inventory approach to produce emission estimates for small combustion plant is based on quantities of fuel types consumed by the small combustion sector (<50MWth). Advancement to the Tier 2 inventory approach level provides the opportunity to refine estimates based on technology types which span both residential and commercial combustion; with technologies detailed in section 2.2 of this guidebook chapter. The further refinement and advancement to Tier 3 inventory approach should assess the impact on emissions that performance issues and age of fleet can have for the small combustion sector. This approach should not be based on an installation-specific emission estimate, but would be suited to proportional analysis of the total number of appliances in use.

Biomass based fuels will typically have greater variation than other fuel types used within the small combustion sector. This is due in part to the evolution and range of wood and biomass appliances that might be in use, but also due to the variation in the nature of the fuel itself which can have significant impacts on the resulting emissions.

In terms of performance for wood based small combustion plant, particularly within the residential sector, Morrin et al (2015), discuss the impacts of setting the equipment in use correctly. For stoves and boilers where the fuel mixture is too rich (ratio of fuel to oxygen favours fuel) combustion is more limited meaning that the carbon is retained in the monoxide form. Emissions for ‘rich’ operating conditions will increase the amount of carbon monoxide and particulate matter (as soot) generated, while NOX is reduced due to lack of available oxygen. In lean operating conditions (ratio of fuel to oxygen overly favours oxygen) the performance output of the stove/boiler is reduced, with emission outputs reducing the amount of CO and particulate matter generated but increasing NOX significantly.

Maintenance and correct setting of equipment in use are likely to have impacts on the quantity and nature of emissions generated from small combustion plant. The Morrin et al (2015) study conducted by the Ireland Environmental Protection Agency, included sampling and analysis of boiler equipment with laboratory trial conditions as well as field sampling for in-use equipment. Table 3.50 provides details of the results of this study for NOX in particular and highlighting the potential wider variation for wood pellet based fuels compared to fuel oil and gas equivalents.

The University of Aveiro in Portugal conducted studies as part of the AIRUSE (2014) project to assess the impact that different types of wood have on the resulting emissions to air. This takes into account the fact that different types of wood will vary in terms of oil content, quantity of carbon, and moisture which affect the combustion mechanics. It can also be assumed that the physical nature of the material (wood logs versus wood pellet) would have impact on how completely the wood burns and thus the resulting emissions.

Table 3.50 Sampling and analysis results for boilers within laboratory trials and in-use equipment. Data referenced from Irish EPA Research, Report 149: Improved Emissions Inventories for NOX and Particulate Matter from Transport and Small Scale Combustion Installations in Ireland’, 2015

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Appliance type** | **Fuel Type** | **Number of appliances sampled** | **Laboratory trials** | **Field survey of in-use equipment** | **NOX** | **Units** |
| Residential Boiler | Fuel Oil | 6 | √ |  | 42 | g/GJ |
| Residential Boiler | Fuel Oil | 23 |  | √ | 36.6 | g/GJ |
| Commercial Boiler[1] | Fuel Oil | 4 |  | √ | 32-36 | g/GJ |
| Residential Boiler | Gas | 4 | √ |  | 25.8 | g/GJ |
| Residential Boiler | Gas | 6 |  | √ | 48.3 | g/GJ |
| Commercial Boiler[1] | Gas | 5 |  | √ | 19 | g/GJ |
| Residential Boiler | Wood Pellet | 3 | √ |  | 44 – 57 | g/GJ |
| Residential Boiler | Wood Pellet | 2 |  | √ | 75 | g/GJ |
| Commercial Boiler[2] | Wood Pellet | 1 |  | √ | 81 | g/GJ |

1. Sampling based on appliances used to service offices and schools
2. Sampling based on one 400kw wood pellet boiler.

Table 3.51 and Table 3.52 provide the results of the AIRUSE project with sampling across a variety of different wood types for fireplaces, traditional stoves, and modern ecolabelled stoves. For Fireplaces this illustrated that CO ranged from 2762 – 6258 mg/MJ (equivalent to g/GJ) with black poplar producing the greatest emissions and pellets fuels producing 3151 mg/MJ. For PM2.5 the range is from 373 – 1135 mg/MJ with the greatest emissions coming from olive and pellet fuels producing 649 mg/MJ. Traditional stoves showed similar ranges with CO emissions from 2054 – 5362 mg/MJ with cork oak producing the highest emissions, and pellet based fuels producing 3400 mg/MJ. For PM2.5 emissions range from 150 – 721 mg/MJ with pyrenean oak producing the highest emissions, and pellet based fuels producing 384 mg/MJ.

The results presented in Table 3.51 and Table 3.52 illustrate potential emissions can be broad with maximum emission values more than double the minimum values. In developing emission estimates to Tier 3 level to account for the broad range in variation for emissions generated by wood fuel based appliances in the small combustion sector a set of practical steps need to be taken to assess the available activity data and the fleet of appliances in use.

Firstly there is a requirement to better understand the type of wood fuels used within a reporting nation. This information may be available in part from trade associations representing wood/woodpellet sales. However this will only provide commercially aquired wood stocks. As a second stage use of public surveys to better understand the type and age of appliance, maintenance patterns and frequency of wood use from non-commerical sources can be used to corroborate and develop further nationally held data.

These stages will provide such information as should be needed to help typify the existing in-use fleet of appliances on the market. This should include proportional (percentage) breakdown of the typical types of wood (oak, spruce, pine, etc) and nature of equipment in use (age, well maintained vs poorly maintained). This information should then further be used to help guide in selection of appropriate emission factors for different categories of appliance.

Table 3.51 Emission Factors from traditional appliances (fireplace versus wood stove) – reprinted from AIRUSE ‘Emission profiles for biomass burning’ March 2014 (units as mg/MJ)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **EF [mg.MJ-1]** | | | | | | | | | | | | | | |
|  |  |  | CO2 | | CO | | PM2.5 | | PM10 | | OC | | EC | |
| **Ref Fuel** | | **av. std.** | | **av. std.** | | **av. std.** | | **av. std.** | | **av. std.** | | **av. std.** | |
| **Fireplace** | [1] | Maritime pine | 93784 | 7135 | 2762.16 | 372.43 | 372.97 | 194.59 |  |  | 156.76 | 70.27 | 33.51 | 26.49 |
| Golden wattle | 91730 | 3714 | 3340.54 | 204.86 | 421.62 | 335.14 |  |  | 189.19 | 167.57 | 18.38 | 14.05 |
| Holm oak | 90541 | 7946 | 3340.54 | 441.62 | 702.70 | 448.65 |  |  | 389.19 | 216.22 | 16.22 | 5.95 |
| Eucalypt | 85676 | 3930 | 4264.86 | 397.30 | 648.65 | 410.81 |  |  | 275.68 | 210.81 | 19.46 | 19.46 |
| Olive | 94216 | 10432 | 4378.38 | 433.51 | 1135.14 | 540.54 |  |  | 491.89 | 308.11 | 21.08 | 8.65 |
| Cork oak | 89838 | 16595 | 4261.62 | 1183.78 | 972.97 | 540.54 |  |  | 540.54 | 281.08 | 36.76 | 21.62 |
| Portugese oak | 88703 | 2200 | 4243.24 | 951.35 | 756.76 | 524.32 |  |  | 329.73 | 183.78 | 17.30 | 10.81 |
| Briquettes/Pellets | 91405 | 2946 | 3151.35 | 913.35 | 648.65 | 416.22 |  |  | 318.92 | 227.03 | 15.68 | 13.51 |
| [2] | European beech | 94545 | 4966 | 4021.15 | 361.96 | 311.89 | 68.11 |  |  | 210.81 | 49.73 | 23.24 | 12.43 |
| Pyrenean oak | 87466 | 4482 | 4651.15 | 761.31 | 675.68 | 220.54 |  |  | 487.57 | 163.78 | 32.43 | 4.86 |
| Black poplar | 95406 | 9667 | 6258.36 | 634.20 | 757.30 | 275.14 |  |  | 568.11 | 182.16 | 42.70 | 10.27 |
| [3] | Maritime pine |  |  | 3243.24 | 486.49 | 0.00 | 0.00 | 722.42 | 235.96 | 431.88 | 150.08 | 81.86 | 41.46 |
| Eucalypt |  |  | 4540.54 | 156.76 | 0.00 | 0.00 | 1093.70 | 154.10 | 630.05 | 90.17 | 20.88 | 2.12 |
| Cork oak |  |  | 4702.70 | 551.35 | 0.00 | 0.00 | 744.86 | 154.13 | 450.14 | 103.50 | 32.45 | 8.17 |
| **Woodstove** | [1] | Maritime pine | 90270 | 13568 | 3086.49 | 1027.03 | 281.08 | 232.43 |  |  | 135.14 | 135.14 | 32.97 | 23.24 |
| Golden wattle | 85622 | 22324 | 5216.22 | 1297.30 | 427.03 | 232.43 |  |  | 221.62 | 143.24 | 15.68 | 9.73 |
| Holm oak | 88216 | 17027 | 3443.24 | 1005.41 | 313.51 | 210.81 |  |  | 162.16 | 113.51 | 12.43 | 5.41 |
| Eucalypt | 83676 | 14000 | 3654.05 | 772.97 | 540.54 | 362.16 |  |  | 281.08 | 216.22 | 20.00 | 16.22 |
| Olive | 93243 | 17297 | 3508.11 | 848.65 | 470.27 | 243.24 |  |  | 248.65 | 118.92 | 24.86 | 12.97 |
| Cork oak | 86703 | 22378 | 5362.16 | 1664.86 | 448.65 | 329.73 |  |  | 259.46 | 183.78 | 22.70 | 17.84 |
| Portugese oak | 85027 | 10811 | 4643.24 | 691.89 | 702.70 | 448.65 |  |  | 335.14 | 248.65 | 17.30 | 8.11 |
| Briquettes/Pellets | 88432 | 14108 | 3400.00 | 854.05 | 383.78 | 259.46 |  |  | 200.00 | 162.16 | 9.73 | 6.49 |
| [2] | European beech | 94484 | 3176 | 2966.25 | 209.70 | 149.73 | 39.46 |  |  | 86.49 | 27.03 | 23.24 | 7.03 |
| Pyrenean oak | 76477 | 7369 | 5166.89 | 419.34 | 721.08 | 203.78 |  |  | 494.05 | 144.86 | 48.65 | 10.81 |
| Black poplar | 101586 | 1544 | 4544.21 | 262.23 | 236.76 | 75.68 |  |  | 154.59 | 59.46 | 47.57 | 2.70 |
| [3] | Maritime pine |  |  | 2054.05 | 43.24 |  |  | 256.09 | 127.43 | 107.00 | 32.15 | 89.80 | 60.59 |
| Eucalypt |  |  | 2540.54 | 227.03 |  |  | 411.50 | 132.78 | 224.35 | 73.05 | 32.28 | 11.85 |
| Cork oak |  |  | 2918.92 | 508.11 |  |  | 300.73 | 155.00 | 160.53 | 99.00 | 26.80 | 1.55 |
| [4] | Maritime pine | 87756 | 1639 | 3357.38 | 672.80 |  |  | 351.19 | 85.80 | 165.18 | 112.34 | 101.61 | 38.35 |
| European beech | 88298 | 7781 | 2569.00 | 473.58 |  |  | 338.19 | 3.33 | 142.95 | 6.30 | 67.29 | 11.90 |

1. GONÇALVES, C.; ALVES, C.; PIO, C. - Inventory of fine particulate organic compound emissions from residential wood combustion in Portugal. Atmospheric Environment. 50 (2012) 297–306. doi: 10.1016/j.atmosenv.2011.12.013.
2. MARTINS, V. I. F. - Emissões de carbono particulado durante a queima doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2012
3. DUARTE, M. A. C. - Emissões de compostos carbonosos pela queima doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2011
4. Vicente, E. A. D. - Medidas para mitigar as emissões da combustão doméstica de biomassa. [S.l.]: Universidade de Aveiro, 2013

Table 3.52 Emission Factors from Modern Ecolabelled stoves – reprinted from AIRUSE ‘Emission profiles for biomass burning’ March 2014

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | | **EF [mg.MJ-1]** | | | | | | | | | |
|  | |  | CO2 | | CO | | PM10 | | OC | | EC | |
| **Fuel** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** |
| **Eco-labelled woodstove** | [5] | Maritime pine | 88649 | 525 | 1485.95 | 144.86 | 60.54 | 13.51 | 15.68 | 6.49 | 23.78 | 12.97 |
| Golden wattle | 89730 | 3819 | 2505.95 | 120.54 | 65.95 | 10.27 | 12.97 | 5.41 | 15.68 | 5.41 |
| Eucalyptus | 85405 | 461 | 2188.11 | 484.86 | 111.89 | 45.95 | 35.68 | 16.76 | 14.59 | 10.27 |
| Cork oak | 88541 | 525 | 3489.73 | 346.49 | 156.22 | 48.65 | 67.03 | 13.51 | 17.84 | 9.73 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **EF [mg.MJ-1]** | | | | | | | **%PM10** | | | | **EF [mg.MJ-1]** | | | |
|  | |  | CO2 | | CO | | PM10 | | OC | | EC | | OC | | EC | |
| **Fuel** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** | **av.** | **std.** |
|  | **[6]** | Briquettes |  |  | 939.33 |  | 72.77 |  | 37.60 |  | 33.10 |  | 27.36 |  | 24.09 |  |
| **Eco-labelled** | Beech |  |  | 1680.96 |  | 89.28 |  | 37.00 |  | 35.60 |  | 33.04 |  | 31.79 |  |
| **woodstove** | Oak |  |  | 1813.66 |  | 71.86 |  | 29.80 |  | 22.20 |  | 21.41 |  | 15.95 |  |
| Spruce |  |  | 1339.82 |  | 79.55 |  | 32.90 |  | 28.30 |  | 26.17 |  | 22.51 |  |

1. FERNANDES, A. P. et al. - Emission factors from residential combustion appliances burning Portuguese biomass fuels. Journal of environmental monitoring: JEM. 13:11 (2011) 3196–206. doi: 10.1039/c1em10500k.
2. SCHMIDL, C. et al. - Particulate and gaseous emissions from manually and automatically fired small scale combustion systems. Atmospheric Environment. ISSN 13522310. 45:39 (2011) 7443–7454. doi: 10.1016/j.atmosenv.2011.05.006.

# Data quality

## Completeness

The potential for self-supply or other unrecorded fuel supply needs to be considered.

## Avoiding double counting with other sectors

In cases where it is possible to split the emissions, it is good practice to do so. However, care must be taken that the emissions are not double counted.

## Verification

### Best Available Technique emission factors

The size of combustion appliance will generally fall below the threshold where guidance on BAT emission levels applies.

However, many countries apply emission controls on appliances in the size range considered and selected emission limit values are provided in the following sections. Details of the methodology applied to calculate emission factors from emission limits are provided in Appendix B.

### Fuel sulphur content

For processes without SO2 abatement, the sulphur content of the fuel provides a means to calculate the SO2 emission factor.

EFSO2 = [S] x 2 x 1000

100 x CV

where:

* EFSO2 is the SO2 emission factor g.GJ-1,
* [S] is the percent sulphur (w/w),
* CV is the net/inferior calorific value GJ.kg-1,
* 2 is the ratio of the RMM of SO2 to Sulphur.

This equation can be extended to include a factor for retention of SO2 in ash.

Liquid fuels in the EC are subject to sulphur limits (EC SCOLF, 1999/2005) as summarised in Table 4.1. The SO2 emission factors in Table 4.1 have been calculated assuming 100 % conversion of fuel sulphur and applying UK net calorific values for fuel oils (DUKES, 2007).

Table 4.1 Sulphur emission factors from oil sulphur limits

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fuel oil** | **Implementation date** | **Maximum sulphur content** | **SO2 emission factor, g.GJ-1** | **Comment** |
| Heavy fuel oil | 1.1.2003 | 1 % | 485 | Assumes net CV of 41.2 GJ.tonne-1 |
| Gas oil | Pre 1.1.2008 | 0.2 % | 92 | Assumes net CV of |
|  | Post 1.1.2008 | 0.1 % | 46 | 43.4 GJ.tonne-1 |

### Residential and small (< 500 kW output) non residential solid fuel boilers

EN303 pt5 is a harmonised EN Standard covering solid fuel central heating hot water boilers up to 500kW output which incorporates emission ‘classes’ for CO, OGC (volatile organic compounds) and filterable PM. The emission factors associated with the emission concentrations are provided in Table 4.2 and are calculated based on stoichiometric specific flue gas volume of 253 m3/GJ net fuel input for biomass and 258 m3/GJ net fuel input for bituminous coal (see Stewart R, 2012 and Appendix B).

Many countries operate type-approval schemes for residential coal and biomass appliances which apply TSP emission limits on solid fuel appliances and these can be developed into emission factors. Ecolabelling schemes for gas appliances may include labelling for NOX emissions.

Table 4.2 EN303 Pt 5 emission classes as emission factors

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Fuel** | **Fuel** | **Appliance** | **Emission concentration, mg m-3 at STP (0 ºC, 101.3 kPa), dry and 10 % O2** | | | | | | | | |
| **feed** | **type** | **output** | **CO** | | | **‘OGC’ (VOC)** | | | **PM** | | |
| **type** |  | **kW** | **Class 3** | **Class 4** | **Class 5** | **Class 3** | **Class 4** | **Class 5** | **Class 3** | **Class 4** | **Class 5** |
| Manual | biogenic | ≤50 | 5 000 | 1 200 | 700 | 150 | 50 | 30 | 150 | 75 | 60 |
|  |  | >50≤150 | 2 500 |  |  | 100 |  |  | 150 |  |  |
|  |  | >150≤500 | 1 200 |  |  | 100 |  |  | 150 |  |  |
|  | fossil | ≤50 | 5 000 |  |  | 150 |  |  | 125 |  |  |
|  |  | >50≤150 | 2 500 |  |  | 100 |  |  | 125 |  |  |
|  |  | >150≤500 | 1 200 |  |  | 100 |  |  | 125 |  |  |
| Automatic | biogenic | ≤50 | 3 000 | 1 000 | 500 | 100 | 30 | 20 | 150 | 60 | 40 |
|  |  | >50≤150 | 2 500 |  |  | 80 |  |  | 150 |  |  |
|  |  | >150≤500 | 1 200 |  |  | 80 |  |  | 150 |  |  |
|  | fossil | ≤50 | 3 000 |  |  | 100 |  |  | 125 |  |  |
|  |  | >50≤150 | 2 500 |  |  | 80 |  |  | 125 |  |  |
|  |  | >150≤500 | 1 200 |  |  | 80 |  |  | 125 |  |  |
|  |  |  | Emission factors, g.GJ-1 (net thermal input) | | | | | | | | |
| Manual | biogenic | ≤50 | 2 426 | 582 | 340 | 73 | 24 | 15 | 73 | 36 | 29 |
|  |  | >50≤150 | 1 213 |  |  | 49 |  |  | 73 |  |  |
|  |  | >150≤500 | 582 |  |  | 49 |  |  | 73 |  |  |
|  | fossil | ≤50 | 2 470 | 593 | 346 | 73 | 25 | 15 | 61 | 37 | 30 |
|  |  | >50≤150 | 1 235 |  |  | 49 |  |  | 61 |  |  |
|  |  | >150≤500 | 593 |  |  | 49 |  |  | 61 |  |  |
| Automatic | biogenic | ≤50 | 1 455 | 485 | 243 | 49 | 15 | 10 | 73 | 29 | 19 |
|  |  | >50≤150 | 1 213 |  |  | 39 |  |  | 73 |  |  |
|  |  | >150≤500 | 582 |  |  | 39 |  |  | 73 |  |  |
|  | fossil | ≤50 | 1 482 | 593 | 346 | 49 | 15 | 10 | 61 | 30 | 20 |
|  |  | >50≤150 | 1 235 |  |  | 39 |  |  | 61 |  |  |
|  |  | >150≤500 | 593 |  |  | 39 |  |  | 61 |  |  |

Notes:  
PM is filterable PM.  
OGC expressed as Carbon

### Ecodesign regulations for small combustion installations

In the EU, several Regulations define minimum requirements (including air emissions) under the Ecodesign Directive. The Directive provides a framework for setting minimum requirements which are given legal force through implementing Regulations.

Implementing reulations have been produced for :

* Space heaters and combination heaters (central heating boilers ≤ 400 kW output gas, oil, electric) and small cogeneration units ≤ 50 kW electrical output;
* Water heaters (≤ 400 kW output gas, oil, electric);
* Solid fuel central heating boilers (≤ 500 kW output, biomass or mineral fuels) and small cogeneration units ≤ 50 kW electrical output;
* Domestic local space heaters ≤ 50 kW output (gas, liquid, electric);
* Commercial local space heaters ≤ 120 kW output (gas, liquid, electric); and
* Solid fuel local space heaters ≤ 50 kW output.

Details of emission limit values are provided at Appendix C, note that whilst emission limit values reflect current controls in some countries, the minimum requirements defined in the Regulations come into effect in the period 2018-2022 (implementation dates are set in the Regulations).

### Proposed Medium Combustion Plant directive

The EU Clean Air Policy Package (December 2013) included a proposal for a Medium Combustion Plant (MCP) directive setting minimum requirements for 1-50 MWth combustion plant. The negotiated emission limit values which will apply to new MCP from 2018 and all existing MCP from 2025 for 5-50 MWth and 2030 for 1-5 MWth are summarised at Appendix C.

### Selected national emission limits for small combustion installations

Many countries apply emission controls to combustion appliances smaller than 50 MWth and a summary of selected countries’ pollutant limit values is provided as emission factors below; further details (and countries) are provided at Appendix C.

Table 4.3 Selected national emission limits as emission factors for coal-fired boilers

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Country | Size | Ref. | Emission concentrations, mg.m-3 at STP (0ºC, 101.3 kPa) dry at reference O2 content | | | | | | | |
|  |  | O2 | NOX |  | SO2 |  | PM |  | CO | VOC |
|  |  | % | Low | High | Low | High | Low | High |  |  |
| France | 20–50 MW | 6 | 450 | 650 | 850 | 2 000 | 50 | 100 | 200 | 110 |
| France | < 4 MW | 6 | 550 | 825 | 2 000 |  | 150 |  |  |  |
| France | 4–10 MW | 6 | 550 | 825 | 2 000 |  | 100 |  |  |  |
| France | > 10 MW | 6 | 550 | 825 | 2 000 |  | 100 |  |  |  |
| Finland | 1–50 MW | 6 | 275 | 550 | 1 100 | 1 100 | 55 | 140 |  |  |
| Germany | < 2.5 MW | 7 | 300 | 500 | 350 | 1 300 | 50 |  | 150 |  |
| Germany | < 5 MW | 7 | 300 | 500 | 350 | 1 300 | 50 |  | 150 |  |
| Germany | > 5 MW | 7 | 300 | 500 | 350 | 1 300 | 20 |  | 150 |  |
| Germany | > 10 MW | 7 | 300 | 400 | 350 | 1 300 | 20 |  | 150 |  |
|  |  |  | Emission factor, g.GJ-1 (net basis) | | | | | | | |
| France | 20–50 MW |  | 163 | 235 | 308 | 725 | 18 | 36 | 72 | 40 |
| France | < 4 MW |  | 199 | 299 | 725 |  | 54 |  |  |  |
| France | 4–10 MW |  | 199 | 299 | 725 |  | 36 |  |  |  |
| France | > 10 MW |  | 199 | 299 | 725 |  | 36 |  |  |  |
| Finland | 1–50 MW |  | 100 | 199 | 398 | 398 | 20 | 51 |  |  |
| Germany | < 2.5 MW |  | 116 | 194 | 136 | 505 | 19 |  | 58 |  |
| Germany | < 5 MW |  | 116 | 194 | 136 | 505 | 19 |  | 58 |  |
| Germany | > 5 MW |  | 116 | 194 | 136 | 505 | 8 |  | 58 |  |
| Germany | > 10 MW |  | 116 | 155 | 136 | 505 | 8 |  | 58 |  |

Table 4.4 Selected national emission limits as emission factors for wood-fired boilers

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Country | Size | Ref. | Emission concentrations, mg.m-3 at STP (0ºC, 101.3 kPa) dry at reference O2 content | | | | | | | |
|  |  | O2 | NOX |  | SO2 |  | PM |  | CO | VOC |
|  |  | % | Low | High | Low | High | Low | High |  |  |
| France | 20–50 MWth | 11 | 400 | 650 | 200 | 2000 | 50 | 100 | 200 | 110 |
| France | < 4 MW | 11 | 500 | 750 | 200 |  | 150 |  |  |  |
| France | 4–10 MW | 11 | 500 | 750 | 200 |  | 100 |  |  |  |
| France | > 10 MW | 11 | 500 | 750 | 200 |  | 100 |  |  |  |
| Finland | 1–5 MW | 6 | 250 | 500 |  |  | 250 | 375 |  |  |
| Finland | 5–10 MW | 6 | 250 | 500 |  |  | 125 | 250 |  |  |
| Finland | 10–50 MW | 6 | 250 | 500 |  |  | 50 | 125 |  |  |
| Germany | < 2.5 MW | 11 | 250 |  | 350 |  | 100 |  |  | 10 |
| Germany | < 5 MW | 11 | 250 |  | 350 |  | 50 |  |  | 10 |
| Germany | > 5 MW | 11 | 250 |  | 350 |  | 20 |  |  | 10 |
|  |  |  | Emission factor, g.GJ-1 (net basis) | | | | | | | |
| France | 20–50 MWth |  | 232 | 377 | 116 | 1161 | 29 | 58 | 116 | 64 |
| France | < 4 MW |  | 290 | 435 | 116 |  | 87 |  |  |  |
| France | 4–10 MW |  | 290 | 435 | 116 |  | 58 |  |  |  |
| France | > 10 MW |  | 290 | 435 | 116 |  | 58 |  |  |  |
| Finland | 1–5 MW |  | 96 | 193 |  |  | 96 | 145 |  |  |
| Finland | 5–10 MW |  | 96 | 193 |  |  | 48 | 96 |  |  |
| Finland | 10–50 MW |  | 96 | 193 |  |  | 19 | 48 |  |  |
| Germany | < 2.5 MW |  | 145 |  | 203 |  | 58 |  |  | 6 |
| Germany | < 5 MW |  | 145 |  | 203 |  | 29 |  |  | 6 |
| Germany | > 5 MW |  | 145 |  | 203 |  | 12 |  |  | 6 |

Table 4.5 Selected national emission limits as emission factors for oil-fired boilers

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Country | Size | Ref. | Emission concentrations, mg.m-3 at STP (0ºC, 101.3 kPa) dry at reference O2 content | | | | | | | |
|  |  | O2 | NOX |  | SO2 |  | PM |  | CO | VOC |
|  |  | % | Low | High | Low | High | Low | High |  |  |
| France | 20–50 MWth | 3 | 450 | 650 | 850 | 1 700 | 50 | 100 | 100 | 110 |
| France | < 4 MW | 3 | 550 | 825 | 1 700 |  | 150 |  |  |  |
| France | 4–10 MW | 3 | 550 | 825 | 1 700 |  | 100 |  |  |  |
| France | > 10 MW | 3 | 500 | 750 | 1 700 |  | 100 |  |  |  |
| Finland | 1–15 MW | 3 | 800 | 900 | 1 700 |  | 50 | 200 |  |  |
| Finland | 15–50 MW | 3 | 500 | 670 | 1 700 |  | 50 | 140 |  |  |
| Germany | HWB | 3 | 180 | 350 |  |  | 50 |  | 80 |  |
| Germany | LPS | 3 | 200 | 350 |  |  | 50 |  | 80 |  |
| Germany | HPS | 3 | 250 | 350 |  |  | 50 |  | 80 |  |
|  |  |  | Emission factor, g.GJ-1 (net basis) | | | | | | | |
| France | 20–50 MWth | 3 | 127 | 184 | 241 | 481 | 14 | 28 | 28 | 31 |
| France | < 4 MW |  | 156 | 233 | 481 |  | 42 |  |  |  |
| France | 4–10 MW |  | 156 | 233 | 481 |  | 28 |  |  |  |
| France | > 10 MW | 3 | 141 | 212 | 481 |  | 28 |  |  |  |
| Finland | 1–15 MW | 3 | 226 | 255 | 481 |  | 14 | 57 |  |  |
| Finland | 15–50 MW | 3 | 141 | 190 | 481 |  | 14 | 40 |  |  |
| Germany | HWB | 3 | 51 | 99 |  |  | 14 |  | 23 |  |
| Germany | LPS | 3 | 57 | 99 |  |  | 14 |  | 23 |  |
| Germany | HPS | 3 | 71 | 99 |  |  | 14 |  | 23 |  |

Table 4.6 Selected national emission limits as emission factors for gas-fired boilers

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Country | Size | Ref. | Emission concentrations, mg.m-3 at STP (0ºC, 101.3 kPa) dry at reference O2 content | | | | | | | |
|  |  | O2 | NOX |  | SO2 |  | PM |  | CO | VOC |
|  |  | % | Low | High | Low | High | Low | High |  |  |
| France | 20–50 MWth | 3 | 120 | 350 | 35 |  | 5 |  | 100 | 110 |
| France | < 10 MW | 3 | 150 | 225 | 35 |  | 5 |  |  |  |
| France | > 10 MW | 3 | 100 | 150 | 35 |  | 5 |  |  |  |
| Finland | 1–15 MW | 3 | 340 | 400 |  |  |  |  |  |  |
| Finland | 15–50 MW | 3 | 170 | 300 |  |  |  |  |  |  |
| Germany | HWB | 3 | 100 |  | 10 |  | 5 |  | 50 |  |
| Germany | LPS | 3 | 110 |  | 10 |  | 5 |  | 50 |  |
| Germany | HPS | 3 | 150 |  | 10 |  | 5 |  | 50 |  |
|  |  |  | Emission factor, g.GJ-1 (net basis) | | | | | | | |
| France | 20–50 MWth |  | 34 | 99 | 10 |  | 1 |  | 28 | 31 |
| France | < 10 MW |  | 42 | 64 | 10 |  | 1 |  |  |  |
| France | > 10 MW |  | 28 | 42 | 10 |  | 1 |  |  |  |
| Finland | 1–15 MW |  | 96 | 113 |  |  |  |  |  |  |
| Finland | 15–50 MW |  | 48 | 85 |  |  |  |  |  |  |
| Germany | HWB |  | 28 |  | 3 |  | 1 |  | 14 |  |
| Germany | LPS |  | 31 |  | 3 |  | 1 |  | 14 |  |
| Germany | HPS |  | 42 |  | 3 |  | 1 |  | 14 |  |

## Developing a consistent time series and recalculation

The emissions of non-CO2 emissions from fuel combustion change with time as equipment and facilities are upgraded or replaced by less-polluting energy technology. The mix of technology used with each fuel will change with time and this has implications for the choice of emission factor at Tier 1 and Tier 2.

## Uncertainty assessment

### Emission factor uncertainties

There is uncertainty in the aggregated emission factors used to estimate emissions. The number of sources, range of use, sizes, fuel quality (particularly solid fuels and biomass) and technologies in the residential sector will impact on the uncertainty to be expected from the application of an ‘Aggregate’ emission factor.

### Activity data uncertainties

The activity data for residential fuel use may be subject to uncertainty from issues of self-supply, waste disposal or ‘unofficial’ fuel sources.

## Inventory quality assurance/quality control QA/QC

No specific issues

## Mapping

No specific issues

## Reporting and documentation

No specific issues

# Glossary

|  |  |
| --- | --- |
| Automatic feed boiler: | boiler with fully automated fuel supply |
| 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 17 435 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 draught |
| CHP: | combined heat and power production |
| Coke: | refers to the solid residue obtained from hard coal (NAPFUE 107) or brown coal (NAPFUE 108) by processing at high temperature in the absence of air |
| Efficiency: | is the ratio of produced 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: | coal of a gross caloric value > 17 435 kJ/kg on ash-free but moisture basis, i.e. steam coal (NAPFUE 102, GHV> 23 865 kJ/kg), sub-bituminous coal (NAPFUE 103, 17 435 kJ/kg < GHV<23 865 kJ/kg) and anthracite |
| Liquid fuels: | refers to kerosene (NAPFUE 206), gas oil (gas/diesel oil (NAPFUE 204), residual oil, residual fuel oil (NAPFUE 203) & other liquid fuels (NAPFUE 225) |
| Manual feed boiler: | boiler with periodical manual fuel supply |
| Patent fuels: | 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) |
| 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 |

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# Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection’s expert panel on combustion and industry. Please refer to the TFEIP website ([www.tfeip-secretariat.org/](http://www.tfeip-secretariat.org/)) for the contact details of the current expert panel leaders.

Appendix A Technology-specific emission factors

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

Table A 1 Emission factors for small coal combustion installations

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | mg/GJ | |
| SO2 | NOX | CO | NMVOC 1) | VOC 1) | PAH | BaP |
| Domestic open fire | n.d | n.d | n.d. | 141) | 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.*

Notes:

1. No information about NMVOC and VOC standard reference — usual CH4 or C3H8 are used.
2. Original data in g/kg;.
3. Original data in g/kg; for recalculation Hu 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 A 2 Emission factors for combustion of manufactured solid fuels

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | Mg/GJ | |
| SO2 | NOX | 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) | 1 125 2); 1 193 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).* Notes:

1. No information about NMVOC and VOC standard reference — usually CH4 or C3H8 are used.
2. Original data in g/kg.
3. 10 kW open fire, smokeless coal brands.
4. Stoves, charcoal and char briquettes, 12.5 kW roomheater, coke and manuf. briq.
5. UNECE TFEIP: Dutch fig. for coke use.
6. UNECE TFEIP: Sweden, pellet boilers, 1.8–2 MW.
7. As THC.
8. 8) UNECE TFEIP: Sweden, briquette boilers 1.8–2 MW; n.d.- no data.

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Types of appliances | Efficiency  % | Assortment of fuel | Emissions factor of pollutants | | | | | | |
| CO  G/GJ | SO2a)  g/GJ | NOX  G/GJ | TSP  g/GJ | 16 PAH  g/GJ | Ba)P  mg/GJ | VOC (C3) 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 | 2 500–11 000 | 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 | 300–1 000 | 50–90 | 400–650 | 500–1 100 |
| Standard boiler | 50–67 | 1 800–7 000 | 200–800 | 50–150 | 150–500 | 30–90 | 600–900 | 400–1 200 |
| Advanced boiler | 76–82 | Assortment coal, | 200–1 500 | 200–800 | 150–200 | 50–100 | 0.2–0.6 | 2–30 | 60–120 |

*Source: Kubica, 2003/1.*

Note:

a) Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors are for sulphur content between 0.5 % and 1.0 % with oxidation efficiency of sulphur about 90 %.

Table A 4 Range of emissions from small coal 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 | SO2a)  g/GJ | NOX  G/GJ | TSP  g/GJ | 16 PAH  g/GJ | B a)P  mg/GJ | VOC (C3)  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 mm c) | 120–800 | 130–350 | 150–300 | 30–60 | 0.1–0.7 | 1–20 | 1–50 |

*Source: Kubica, 2003/1.*

Notes:

a) Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors are for sulphur content between 0.5 % and 1.0 % with oxidation efficiency of sulphur about 90 %.

b) Manually fuelled.

c) For capacity above 50 kW, grain size 5–30 mm.

Table A 5 Emission value of coal combustion in stoves 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 | 3 939 | 2 994 | 48 | 793 | 3 271 | 2 360 |
| SO2 | g/GJ | 361.6 | 282.8 | 347.8 | 131.5 | 253.0 | 211.0 |
| NOX as NO2 | g/GJ | 190.3 | 162.3 | 172.9 | 160.0 | 81.2 | 104.0 |
| VOCs (C3) | 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 | 26 688 | 29 676 | 87.2 | 0.2 | 39 500 | 3 2800 |
| 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.*

Note:

n.d. — no data.

Table A 6 Emission factors for advanced coal-fire small boilers (< 1 MW) 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 | ≤ 2 000 | ≤ 1 000 | |
| Nitrogen dioxide; NOX as NO2 | ≤ 150 | ≤ 200 | |
| Sulphur dioxide; SO21) | ≤ 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).*

Notes:

1) Emission factor of sulphur dioxide strongly depends on sulphur content of fuel; these emission factors were established for sulphur content of < 0.6 %.

2) TOC is the sum of organic pollutants both in the gaseous phase and as organic solvent soluble particles except C1–C5 (Kubica 2003/1).

Table A 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 |
| SO2 | g/GJ | 464 | 353 | 379 | 311 | 290 | 251 | 490 | 557 |
| NOX as NO2 | g/GJ | 269 | 232 | 109 | 96 | 150 | 155 | 137 | 141 |
| VOCs (C3) | 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.*

Note:

n.d. — no data.

Table A 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 | 62–6 250 | < 6.2 |
| Particles, after cyclone; g/GJ | 94–312 | 31–94 |

*Source: van Loo, 2002.*

Notes

1. 1) Original data in mg/m3o at 11 % O2, for recalculation Hu of 16 GJ/t and 10m3/kg of flue gases were assumed.
2. 2) No information about CxHy standard reference — usually CH4 or C3H8 are used.

Table A 9 Emission factors for pellet burners in Sweden

| Type of the burners | TSP  (g/GJ) | CO2  (%) | O2  (%) | THC 1)  (g/GJ) | NOX  (g/GJ) | Effect (kW) |
| --- | --- | --- | --- | --- | --- | --- |
| Pellet burner (continuous operation) | | | | | | |
| Nominal effect | 22 | 9.5 | 11.1 | 3 | 73 | 10.7 |
| 6 kW capacity | 4 | 6.0 | 14.6 | 78 | 70 | 6.2 |
| 6 kW generated power\* | 28 | 4.8 | 15.8 | 31 | 68 | 6.2 |
| 3 kW 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 |
| 6 kW generated power | 64 | 9.1 | 11.3 | 60 | 64 | 6.1 |
| 6 kW generated power+ | - | 10.6 | 9.7 | 41 | 174 | 6.3 |
| 3 kW generated power | 15 | 8.6 | 11.9 | 10 | 67 | 3.1 |

*Source: Bostrom, 2002.*

Notes:

1. No information about THC standard reference — usual CH4 or C3H8 are used.
2. \*High ventilation, + wood with high ash content.

Table A 10 Emission factors for wood boilers in Sweden

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Type of the burners | TSP  (g/GJ) | CO2  (%) | O2  (%) | THC 1)  (g/GJ) | CO (g/GJ) | NOX (g/GJ) |
| Water cooled boiler | | | | | | |
| Intermittent log burning | 89 | 6.8 | 13.4 | 1 111 | 4 774 | 71 |
| Water cooled boiler | | | | | | |
| Operation using accumulator | 103 | 8.3 | 11.8 | 1 500 | 5 879 | 67 |
| Intermittent log burning | n.d. | 5.6 | 13.4 | 4 729 | 16 267 | 28 |
| Cold-start | 2 243 | 6.9 | 14.6 | 2 958 | 8 193 | 64 |

*Source: Bostrom; (2002).*

Note:

1. No information about THC standard reference — usual CH4 or C3H8 are used.
2. n.d. — no data.

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Techniques | NOX  (g/GJ) | CO  (g/GJ) | VOCa)  (g/GJ) | THC as CH4  (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 | 1 846 | n.d. | 67 | 122 | 4 040 |
| Stoker burners | 98 | 457 | n.d. | 4 | 59 | 9 |
| Wood boilers | 101 | 4 975 | n.d. | 1 330 | n.d. | 30 |
| Modern wood-stoves | 58 | 1 730 | n.d. | 200 | 98 | 26 |
| Traditional wood-stoves | 29 | 6 956 | 671 | 1 750 | 1 921 | 3 445 |
| Fireplaces | n.d. | 6 716 | 520 | n.d. | 6 053 | 105 |

*Source: van Loo, (2002).*

Notes

1. No information about VOC standard reference — usual CH4 or C3H8 are used.

2. n.d. — no data.

Table A 12 Arithmetic Aggregates of emission values from biomass combustion in small-scale applications

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Techniques | Load  (kW) | Excess air ratio | CO  (g/GJ) | CxHya)  (g/GJ) | Part. TSP  (g/GJ) | NOX  (g/GJ) | Temp. (oC) | Efficiency (%) |
| Wood — stoves | 9.33 | 2.43 | 3 116 | 363 | 81 | 74 | 307 | 70 |
| Fire place inserts | 14.07 | 2.87 | 2 702 | 303 | 41 | 96 | 283 | 74 |
| Heat storing stoves | 13.31 | 2.53 | 1 723 | 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.*

Notes:

1. Original date in mg/m3o at 13 % O2, for recalculation Hu of 16 GJ/t and 10m3/kg of flue gases were assumed.
2. a) No information about CxHy standard reference — usual CH4 or C3H8 are used.
3. n.d. — no data.

Table A 13 Emissions from small industrial wood-chip combustion applications in the Netherlands (g/GJ)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Type of operation | Combustion principle | Draught control | Capacity kW | CO | CxHy a) | NOX | TSP | Efficiency  ( %) |
| Manual | Horizontal grate | Natural uncontrolled | 36 | 1 494 | 78 | 97 | 13 | 85 |
| Forced uncontrolled | 34.6 | 2 156 | 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.*

Notes:

1. Original date in mg/m3o at 11 % O2, for recalculation Hu of 16 GJ/t and 10 m3/kg of flue gases were assumed.
2. a) No information about CxHy standard reference — usual CH4 or C3H8 are used.
3. n.d. — no data.

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

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Techniques | Capacity (kW) | SO2  (g/GJ) | CO  (g/GJ) | VOC as C3  (g/GJ) | TSP  (g/GJ) | NOX  (g/GJ) | 16 PAH g/GJ | Efficiency (%) |
| Wood — log, stoves | 5.7 | 9.8 | 6 290 | 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 |
| Gas fire, pre-oven | 20.0 | 21.0 | 1 226 | 6.8 | 15.6 | 78.9 | 480 | 83.9 |

*Source: Kubica, et al., 2002/2.*

Table A 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 | 2 230 | 4 172 | 1 757 | 2 403 | 427 | 1 484 |
| SO2 | g/GJ | 127.1 | 66.5 | 15.9 | 4.8 | 74.6 | 151.0 |
| NOX (as NO2) | g/GJ | 105.3 | 76.1 | 41.6 | 31.7 | 110.1 | 405.0 |
| VOC (as C3) | 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 |
| TOC1) | g/GJ | 59.4 | 39.4 | 98.6 | 176.0 | 18.1 | 39.0 |
| 16 PAHs acc EPA | Mg/GJ | 9 489 | 3 381 | 9 100 | 9 716 | 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 A 16 Emission factors for 1.75 MW and 2 MW boilers in Sweden

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Fuel | Effect (%) | O2  (%) | CO  (g/GJ) | THC  (g/GJ) a) | CH4  (g/GJ) | TSP  (g/GJ) | NOX  (g/GJ) | NH3  (g/GJ) |
| Pellets | 20 | 4 | 7 400 | 500 | 400 | 43 | 17 | 6 |
| Pellets | 50 | 7 | 1 600 | 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 | 3 900 | 48 | 31 | 51 | 25 | 2 |

*Source: Bostrom C-A, UN-ECE TFEIP (2002).*

Note:

a) No information about CxHy standard reference — usual CH4 or C3H8 are used.

Table A 17 Emission factors for biomass small combustion installations

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | mg/GJ | |
| SO2 | NOX | CO | NMVOC 1) | VOC 1) | PAH | BaP |
| Domestic open fire | n.d | n.d | 4 000 | n.d | 90–800 | 13 937; 10 062;  7 9371 2) | n.d |
| Domestic closed stoves | 3) n.d. | 29 | 7 000 | 1 750 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.*

Notes:

1. 1) No information about NMVOC and VOC standard reference — usual CH4 or C3H8 are used.
2. 2) Original data in g/kg for recalculation Hu of 16 GJ/t was assumed and PAH that is ∑16 PAH.
3. 3) Traditional wood stove.
4. 4) Modern wood stove.
5. 5) THC as CH4.
6. 6) Wood boilers.
7. 7) Wood chips boilers 1.8–2 MW.
8. 8) Wood, charcoal, 120 kW boiler, benchmark.
9. 9) Wood, charcoal, 120 kW, improved boiler.
10. n.d. — no data.

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

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pollutant | Fuel | | | | |
| Natural gas | Oil | LPG | Petroleum | Coal |
| VOC1) | 6.3 | 15 | 2 | 10 | 60 |
| SO2 | 0.22 | 87 | 0.22 | 4.6 | 420 |
| N2O | 0.1 | 0.6 | 0.1 | 0.6 | 1.5 |
| NOX (as NO2) | 57.5 | 50 | 40 | 50 | 75 |
| CO | 15.8 | 60 | 10 | 10 | 1 500 |
| CO2 | 55 920 | 73 000 | 66 000 | 73 000 | 103 000 |
| TSP | 0.3 | 5 | 10 | 2 | 200 |
| PM10 | 0.3 | 4.5 | 2 | 1.8 | 120 |
| Particles >PM10 | - | 0.5 | - | 0.2 | 80 |

*Source: Heslinga D., 2002.*

Note:

1) No information about VOC standard reference — usual CH4 or C3H8 are used.

Table A 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 C3) 1) | 8.9 | 7.8 | 6.2 | 0.6 | 5 | 4.2 | 10 | 2.1 |
| SO2 1) | - | - | - | - | 110 | 112 | 140 | 120.3 |
| NOX (as NO2) 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 |
| SO2 2) | n.d. | - | - | - | 115–145 Aggregate 130 | - | - | - |
| NOX (as NO2) 2) | 17–22 Aggregate 20 | - | - | - | 35–55 Aggregate 40 | - | - | - |
| CO 2) | 7–12  Aggregate 9 | - | - | - | 10–12 Aggregate 11 | - | - | - |

*Source: 1) Kubica et al., 1999; 2) Kubica et al., 2005/2 The measurements were done in the field.*

Note:

n.d. — no data.

Table A 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 NO2) | 64 | 30 | 29 | 38 | 23 | 66 | 63 |
| CO | 3.1 | 0.0 | 0.0 | 3.6 | 0.4 | 0.0 | 1.4 |
| SO2 | 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 A 21 Emission factors for gas-fired small combustion installations

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | mg/GJ | |
| SO2 | NOX | CO | NMVOC 1) | VOC 1) | PAH | BaP |
| Open fire | 0.5 | 50 | 20 | 6 | n.d. | n.d | n.d. |
| Closed 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.*

Notes:.

* 1. No information about VOC standard reference — usual CH4 or C3H8 are used. Original data in mg/t for recalculation Hu of 35 GJ/t was assumed.
  2. mg/1000xm3.
  3. n.d. — no data.

Table A 22 Emission factors for LPG small combustion installations

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | mg/GJ | |
| SO2 | NOX | CO | NMVOC 1) | VOC 1) | PAH | BaP |
| Open fire | None | | | | | | |
| Closed 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.*

Notes

1. 1) No information about VOC standard reference — usual CH4 or C3H8 are used. Original data in g/kg for recalculation Hu of 42 GJ/t was assumed.
2. n.d. — no data.

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | |
| g/GJ | | | | | mg/GJ | |
| SO2 | 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.*

Notes:

1. No information about VOC standard reference — usual CH4 or C3H8 are used.
2. Original data in g/kg t for recalculation Hu of 42 GJ/t was assumed.
3. n.d. — no data.

Table A 24 Emission factors for fuel oil small combustion installations

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants | | | | | | | |
| g/GJ | | | | | | Mg/GJ | |
| SO2 | 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).*

Notes:

1) No information about VOC standard reference — usual CH4 or C3H8 are used.

2) Original data in g/Mt for recalculation Hu 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 A 25 Emission of pollutants for gaseous, liquid and coal fuels for small combustion installations in Italy

| Installation | | Pollutants | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| g/GJ | | | | | | |
| SO2 | NOX | CO | VOC1) | 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 |
| Aggregate | 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 |
| Aggregate | 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 |
| Aggregate | 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 |
| Aggregate | 650 | 150 | 2 000 | 200 | 150 | 140 | 70 |

*Source: Caserini S. 2004.*

Note:

1) No information about VOC standard reference — usual CH4 or C3H8 are used.

Table A 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 | | | | |
| SO2 | NOX as NO2 | CO | CO2 | TSP |
| Households | 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 A 27 Emission factors of CO, NOX and SO2 for advanced combustion techniques of coal and biomass

| Source | Installation/fuel | Pollutants (g/GJ) | | |
| --- | --- | --- | --- | --- |
| SO2 | NOX  (as NO2) | 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 % and 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 25 kW  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 500 kW  100 % and 33 % of capacity | n.d. | 123; n.d. | 16; 126 |
| BLT, 2004/1 | Wood chips, boiler 20 kW  100 % and 33 % of capacity | n.d. | 44; n.d. | 17; 108 |
| BLT, 2004/2 | Wood log and briq., boiler 50 kW  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. | 4 010 |
| Hübner et al.,20051 2) | Boiler < 50 kW; 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. | 2 100 |
| Stove; beach wood logs | n.d. | n.d. | 2 100–4 700 |
| Stove; wood | n.d. | n.d. | 1 500 |
| 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., 20011) | Pellet boilers with fixed grates with moving scrapes 1.75–2.5 MW | n.d. | 30–50 | 20–100 |
| Houck et al., 20001) | 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; Aggregate 33 | 52–100; Aggregate 88 |
| Pellet stove 4.8 kW (low load 2.3 kW) | n.d. | 29–33; Aggregate 31 | 243–383; Aggregate 299 |
| Natural-draft wood stove, 9 kW; birch pine spruce | n.d. | 37–71; Aggregate 50 | 1 200–7 700; Aggregate 3 800 |
| Pellet stove, 4–9.5 kW; pine and spruce (high load) | n.d. | 57–65; Aggregate 61 | 110–170; Aggregate 140 |
| Pellet stove, 4- 9,5 kW; pine and spruce (low load 30 %) | n.d. | 52–57; Aggregate 54 | 320–810; Aggregate 580 |
| Kubica, 2004/2 | Pellet boilers |  |  |  |
| Kubica at al., 2005/4 | Automatic-fuelled coal boilers - stocker; pea coal (qualified size) | 120–450; Aggregate 260 | 96–260;  Aggregate 190 | 90–850  Aggregate 280 |
| Automatic-fuelled coal boilers;  fine coal (qualified coal size) | 355–600  Aggregate 420 | 70–200  Aggregate 145 | 60–800  Aggregate 450 |
| Kubica K.; 2004/1 | Conventional stove 5 kW | 253 | 81 | 2 272 |
| 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 technique; 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 0.3–0.6 MW | 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 | 2 403 |
| Boiler, bottom feed, wood briquettes | n.d. | 42 | 1 757 |
| Automatic-fuelled boiler — stocker 30 kW, pellets | n.d. | 200 | 200 |
| Automatic-fuelled boiler, wood chips | n.d. | 150 | 880 |
| Kubica at al., 2005/23) | Automatic-fuelled coal boiler — stocker, ≤ 25 kW (120 pieces);  pea coal | n.d. | 67–207; Aggregate 161 | 104–320; Aggregate 150 |
| Automatic-fuelled coal boiler,  ≤ 35 kW (68 pieces); fine coal, | 155–496  Aggregate 252 | 64–208; Aggregate 122 | 119–435; Aggregate 232 |
|  |  |  |  |  |

Notes:

1. 1) Original factors in g/kg of fuels, for recalculation Hu 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. 2) Capacity of all boilers < 50 kW and all stove < 10 kW.
3. 3) A measurement was done in the field.
4. n.d. — no data.

Table A 28 Wood burning appliance emission factors in British Columbia (Gulland, 2003)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Installation | Pollutants1) | | | | | | |
| g/GJ | | | | | | |
| SO2 | 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 |
| Conventional 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 |

Note:

1) Original factors in kg/tonne of fuels, for recalculation Hu of 16 GJ/t for wood was assumed.

Table A 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, 20011) | Small furnaces | n.d. | 110 | 270 |
| Domestic boiler | n.d. | 90 | 150 |
| CEPMEIP, 20021) | 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., 20001) | 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., 19981) | Residential heating | n.d. | n.d. | 153±50 % |
| Single family house boiler, stoves | n.d. | n.d. | 94±54 % |
| Winiwarter et al, 20011) | Residential plants | 75 | 85 | 94 |
| Domestic stoves, fireplaces | 122 | 138 | 153 |
| UBA, 1999a1) | Domestic furnaces, hard coal | n.d. | n.d. | 250 |
| Domestic furnaces, brown coal | n.d. | n.d. | 350 |
| EPA, 1998a1) | 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, 19961) | 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 5 kW | n.d. | n.d. | 523 |
| Kubica, 2004/2 | Chamber boiler, top feed; fine coal | n.d. | n.d. | 50–200 |
| 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 0.3–0.6 MW | 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., 2005/23) | Automatic-fuelled coal boiler — stocker, 25 kW (120 pieces) | n.d. | n.d. | 54–133  Aggregate 78 |
| Automatic-fuelled coal boiler, fine coal, 25 and 35 kW (68 pieces) | n.d. | n.d. | 70–380 Aggregate 187 |
| Kubica et al., 2005/3 | Hard coal; stoves and boilers < 1 MW | 25-100  Aggregate 65 | 25-1050  aver.270 | 30-1,200  Aggregate 360 |
| Hard coal; boilers > 1 MW < 50 MW | 70-122  Aggregate 70 | 90-250  Aggregate 110 | 25-735  Aggregate 140 |
| Brown coal  Residential/commercial/institutional/ | 140 | 260 | 350 |
| Coke  Residential/commercial/institutional/ | 30 -80  Aggregate 80 | 96-108  Aggregate 90 | 14-133  Aggregate 110 |
| Krucki A. et al., 20062) | 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., 20052) | Open fire place | n.d. | 1 200 | n.d. |

Notes:

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 A 30 Particulate matter size fractions reported in the literature for coal combustion (per cent of TSP emissions)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Source | Installation type | PM2.5 | PM10 | TSP |
| UBA, 1999a1) | Domestic furnaces, hard coal | n.d. | 90 % | 100 % |
| EPA, 1998a1) | 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 % |

Notes:

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

Table A 31 Particulate matter emission factors reported in the literature for wood burning (g/GJ)

| Source | Installation type | PM2.5 | PM10 | TSP |
| --- | --- | --- | --- | --- |
| BUWAL, 20011) | 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, 20001) | Domestic furnaces | n.d. | n.d. | 200–500 |
| Dreiseidler, 19991) | Domestic furnaces | n.d. | n.d. | 200 |
| Baumbach, 19991) | Domestic furnaces | n.d. | n.d. | 50–100 |
| Pfeiffer et al., 20001) | Residential and domestic | n.d. | n.d. | 41–65 |
| CEPMEIP, 20021) | ‘High emissions’ | 270 | 285 | 300 |
| ‘Low emissions’ | 135 | 143 | 150 |
| Winiwarter et al, 20011) | Residential plants | 72 | 81 | 90 |
| Domestic stoves, fireplaces | 118 | 133 | 148 |
| NUTEK, 19971) | 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, 19871) | 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., 19981) | Residential heating | n.d. | n.d. | 148±46 % |
| Single family house boiler, stoves | n.d. | n.d. | 90±26% |
| Zhang et al., 20001) | Firewood in China | n.d. | n.d. | 760–1 080 |
| Houck and Tiegs, 1998/13) | 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, national 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 |
| Hobson M. et al, 2003 | UNECE TFEIP, Sweden, wood chips boilers 1.8–2 MW | n.d. | n.d. | 51 |
| Open fire < 5 kW, hardwood2) | n.d. | 494 | n.d. |
| Domestic open fire: hundreds of source 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, 1998a4) | Boilers, bark | n.d. | n.d. | 2 266 |
| Lammi et al., 19934) | 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 25 kW | 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 briquettes, boiler 7.7–26 kW | n.d. | n.d. | 4 |
| BLT, 1999 | Wood chips, boiler 500 kW | n.d. | n.d. | 28 |
| BLT, 2004/1 | Wood chips, boiler 20 kW | n.d. | n.d. | 8 |
| BLT, 2004/2 | Wood log and briquettes, boiler 50 kW | n.d. | n.d. | 16 |
| BLT, 2000/2 | Wood briquettes, 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., 20002) | Fireplaces | As PM2.5. | n.d. | 180–560; Aggregate 380 |
| Woodstove | n.d. | n.d. | 140–450; Aggregate 270 |
| Lee et al., 20052) | 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., 20022) | Fireplaces; hardwood — yellow poplar | n.d. | n.d. | 425 ± 50 |
| Fireplaces; hardwood — white ash | n.d. | n.d. | 206 ± 19 |
| 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.; 20012) | 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  Aggregate 240 |
| Pellet burner boilers 10–15 kW, horizontal feeding of the fuel; sawdust, logging residues and bark | n.d. | n.d. | 57-157  Aggregate 95 |
| Pellet burner boilers 10–15 kW, underfeeding of the fuel; sawdust, logging residues and bark | n.d. | n.d. | 64-192  Aggregate 140 |
| Broderick et al. 20052) | 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. | Aggregate 590 |
| All factory-built fireplaces with open door, cordwood | n.d. | n.d. | Aggregate 840 |
| Gaegauf et al., 2001 | Wood room heaters | 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 room heaters | n.d. | n.d. | 54 ± 3 |
| 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., 20017) | Pellet boilers with fixed grates with moving scrapes 1.75–2.5 MW | n.d. | n.d. | 35–40 |
| Nussbaumer, 20012) | 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 boiler5) | n.d. | n.d. | 68 |
| Wood residues, boiler5) | n.d. | n.d. | 70 |
| Urban waste wood, boiler6) | n.d. | n.d. | 1.5 |
| Houck et al., 20002) | 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., 20052) | Conventional stove woodstove | 890 | n.d. | n.d. |
| Catalytic certified woodstove | 430 | n.d. | n.d. |
| Non-catalytic 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  Aggregate 15 |
| Pellet stove 4.8 kW (low load 2.3 kW) | n.d. | n.d. | 32–81  Aggregate 51 |
| Natural-draft wood stove, 9 kW; birch pine spruce | n.d. | n.d. | 37–350  Aggregate 160 |
| Pellet stove, 4–9,5 kW; pine and spruce (high load) | n.d. | n.d. | 15–17; Aggregate 16 |
| Pellet stove, 4–9,5 kW; pine and spruce (low load 30 %) | n.d. | n.d. | 21–43  Aggregate 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 5 kW | 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 |
| Kubica et al., 2005/3 | Residential/commercial/institutional/ | 9–698  Aggregate 450 | 10–713  Aggregate 490 | 17–4 000  Aggregate 520 |
| Boilers > 1MW < 50 MW | 9–170  Aggregate 80 | 60–214  Aggregate 80 | 20–500  Aggregate 100 |
| Hedberg et al., 20022) | Commercial soapstone stove, birch logs | 6–163  Aggregate 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. | 87–2 200 |
| 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 | 908) | n.d. | 100 |
| Sauna | 1908) | n.d. | 200 |
| Pellets burner | 708) | n.d. | n.d. |
| Pellets burner | 258) | n.d. | 35 |
| Wood chips/pellets boiler 30–50 kW | 158) | n.d. | 20 |
| Wood chips boiler 30–50 kW | 108) | n.d. | 20 |
| Pellets boiler 30–50 kW | 108) | n.d. | 15 |
| Wood chips/pellets stoker6) 50–500 kW | 208) | n.d. | 40 |
| Wood chips stoker 30–500 kW6) | 308) | n.d. | 50 |
| Pellets stoker 50–500 kW6) | 108) | n.d. | 20 |
| Wood chips grate boiler 5–20 MW | 20–556) |  |  |
| Wood chips Fluidized bed 20–100 MW | 2–207) |  |  |
| Wood chips grate boiler 20–100 MW7) | 3–10 |  |  |
| Wood chips grate boiler 10 MW6) | 38) | 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. | 200–5 500 |
| 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 | 366,8) | n.d. |  |
| Moving grate 1.5 MW saw dust, Medium load | 286,8) | n.d. |  |
| Moving grate 1.5 MW saw dust, high load | 256,8) | n.d. | n.d. |
| Moving grate 1.5 MW pellets, low load | 206,8) | n.d. | n.d. |
| Moving grate 1.5 MW pellets, medium load | 196,8) | n.d. | n.d. |
| Moving grate 1 MW forest residue, medium load | 6766,8) | n.d. | n.d. |
| Moving grate 1 MW forest residue, high load | 576,8) | n.d. | n.d. |
| Strand. et al, 2004 | Moving grate 6 MW forest residue, high load | 436,8) | n.d. | n.d. |
| Moving grate 12 MW forest residue, high load | 776,8) | n.d. | n.d. |
| Moving grate 0.9 MW pellets, low load | 106,8) | n.d. | n.d. |

Notes:

1. As quoted in Klimont et al*.*, 2002.
2. Original factors in lb/ton or in g/kg for recalculation Hu 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. 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.
9. n.d. — no data.

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Appendix B Calculation of emission factors from emission concentrations

**B.1 Standardisation of emission concentrations from combustion activities**

Annual emissions, emission rates and emission limit values are generally expressed in terms of pollutant mass (for example tonnes.year-1, kg.hr-1, mg.m-3). Note that a mass concentration is meaningless unless the volume conditions are defined — typically for a combustion process the conditions will be a dry volume, at STP (0 °C, 101.3 kPa) and normalised to a reference oxygen concentration. Consumption of fuel requires a minimum theoretical (stoichiometric) quantity of air. In practise, more air than the stoichiometric quantity is required to achieve combustion. The oxygen content in exhaust gases from a combustion appliance is indicative of the amount of excess air and air ingress in the combustion system. Normalisation to a reference oxygen content allows comparison between technologies as it removes a diluting (or concentrating) effect of different levels of excess air/air ingress on the pollutant concentration.

Common oxygen concentrations for emission normalisation are:

* oil- or gas-fired boilers — 3 % O2
* solid-fuel boilers — 6, 7  % O2
* wood-fired boilers — 6, 7, 10, 11 or 13 % O2
* incineration — 11 % O2
* gas turbines — 15 % O2
* stationary engines — 5, 15  % O2
* dryers — 17 % O2.

Other normalisation oxygen concentrations are used including 0 % O2 which is commonly used in the testing of residential gas appliances. Concentrations can also be normalised using carbon dioxide (although this is much less common).

Usually emission concentration data will be provided as mass concentrations at a specified oxygen content. However, where emission data are provided in other forms, the following equations may help the user manipulate the date into a more useful form.

Some pollutants are measured and reported on a wet basis and may require standardisation to the dry condition.

[X]d = [X]w . 100

(100-[H2O])

where:

* [X]w is the measured concentration for a wet flue gas (ppm, mg.m-3, %v/v),
* [X]d is the measured concentration for a dry flue gas (same units as the dry concentration),
* [H2O] is the flue gas moisture content as % v/v on a wet basis.

Many pollutants are measured as volume (molar) concentrations. Conversion to a mass concentration assumes ideal gas behaviour and is detailed below:

[X]m = [X]d . MW

22.4

where:

* [X]d is the measured concentration in ppm (parts per million) by volume for a dry flue gas,
* [X]m is the measured concentration in mg.m-3 by volume for a dry flue gas,
* MW is the relative molecular mass of the pollutant (for example 64 for SO2),
* 22.4 is the volume occupied by 1 kgmole of an ideal gas at 0°C, 101.3 kPa (m3).

Note that NOX emission concentrations and emission factors are defined in terms of NO2. Hence, the relative molecular mass used for NOX is 46. VOC emission concentrations are often defined in terms of carbon. Hence, the relative molecular mass used for VOC is 12, but this will often be modified further for the calibration gas applied (for example MW for concentrations measured as propane C3H8 ‘equivalents’ would 3 x 12 - 36).

Normalisation to a reference O2 concentration is given by:

[X]ref = [X]m . (20.9-[ O2]ref)

(20.9-[O2]m)

where :

* [X]ref is the standardised concentration of the pollutant at the reference O2 content,
* [x]m is the measured concentration in mg.m-3 for a dry flue gas,
* [O2]m is the measured O2 concentration in % on a dry basis,
* [O2]ref is the reference O2 concentration in % on a dry basis (for example 3, 6 or 15 %).

This calculation is appropriate where pollutant and O2 concentrations are measured on a dry basis.

**B.2 Calculation of emission factors**

An emission factor relates the release of a pollutant to a process activity. For combustion processes, emission factors are commonly described as the mass of pollutant released per unit of fuel burned.

An emission factor can be calculated in several ways; the approach adopted uses the standardised pollutant emission concentrations and the specific theoretical (stoichiometric) volume of flue gas for the relevant fuel. This approach avoids measurement of exhaust gas flow and fuel flows which can have a high uncertainty and may not be practical at many combustion plant.

The approach requires knowledge of the fuel used, the pollutant concentration and the oxygen concentration.

Fuel analysis, where available, allows calculation of the specific flue gas volume from the elemental analysis. However, the US Environmental Protection Agency Method 19 provides flue gas volume for common fuels. For other fuels (for example derived gases, landfill gas, unrefined natural gas or waste-derived fuels) fuel analysis is advised to minimise uncertainty.

**Fuel analysis route:** the fuel analysis and combustion calculations are used to determine the stoichiometric air requirement and dry flue gas volume per volume or mass of fuel. Note that is important to understand the analysis reporting conditions, particularly for solid fuels. The calculations assume ideal gas behaviour. A dry flue gas volume is calculated for the reference O2 concentration used to normalise the pollutant emission concentration. A pollutant emission factor (EF) can hence be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content.

Generally, the flue gas volumes generated from combustion of fuel can be calculated in accordance with the following equations.

CXHY + (X+(Y/4)O2 = X CO2 + (Y/2) H2O

Note that some of the oxygen may be sourced from the fuel. For combustion in air, each cubic metre of oxygen is associated with (79.1/20.9) cubic metres of nitrogen.

The dry flue gas volume at stoichiometric conditions (DFGVSC) per unit mass of fuel (or volume for gaseous fuels) can be calculated and hence the dry flue gas volume at the normalised condition (DFGVref) for the required reference oxygen content:

DFGVref = DFGVSC . (20.9/(20.9-[O2ref]))

A pollutant emission factor (EF) can hence be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content. For example, at 15 % oxygen:

EF = [X]15% . DFGV15

Emission factors are reported in several ways and these are generally recalculated using physical or other properties of the fuel.

For example, a thermal emission factor (as used in the Guidebook) can be derived by dividing the emission factor calculated above by the calorific value of the fuel. For the Guidebook, this is the net (inferior) CV.

EFthermal = EF

CV

where:

* EFthermal is the thermal emission factor expressed in units to suit the user (for example g GJ-1),
* CV is the net calorific value of the fuel in appropriate units to suit the units of the emission factor.

**USEPA Method 19:** the USEPA provides stoichiometric dry flue gas volume for fuel oil. The USEPA data can be found in USEPA Method 19 (US Code of Federal Regulations, Title 40 Part 60, Appendix A). The USEPA ‘F-factor’ data are presented as the volume of dry flue gas at 20 °C associated with the gross thermal input of the fuel. These USEPA conditions are not consistent with the Guidebook or emission reporting practise in Europe and consequently some manipulation of the data is required. Calculations assume an ideal gas.

The USEPA method can be obtained here [www.epa.gov/ttn/emc/methods/method19.html](http://www.epa.gov/ttn/emc/methods/method19.html) and the F-factors are provided below.



The Fd factors are used — these represent the dry stoichiometric flue gas volume per unit of energy input. The Fw and Fc factors represent the wet flue gas volume and CO2 volumes respectively.

The USEPA dry flue gas volume at stoichiometric conditions are first recalculated to provide the flue gas volume (DFGVref) for the required oxygen content at STP and for the net energy input.

Fd’ = Fd . (273/293). ((CVgross)/CVnet))

where :

* Fd’ is the stoichiometric dry flue gas volume at STP per unit of net energy input – m3.J-1,
* Fd is the USEPA factor (20 °C and gross energy input),
* 273/293 volume correction — ratio of temperatures in Kelvin.

Note that it is the ratio between the fuels’ gross and net calorific values that is needed. Indicative ratios are provided below based on UK data (DUKES 2007).

Table B1 Gross and net fuel calorific ratios

|  |  |
| --- | --- |
| **Fuel** | **Ratio** |
|  |  |
| Power stn coal | 1.05 |
| Industrial coal | 1.05 |
| Wood | 1.08 |
| HFO | 1.05 |
| Gas oil | 1.05 |
| Natural gas | 1.11 |

The dry flue gas volume at the normalised oxygen content can then be calculated:

Fdref = Fd’ . (20.9/(20.9-[O2ref]))

A pollutant emission factor (EFthermal) can then be calculated by multiplying the standardised pollutant concentration by the dry flue gas volume at the same reference oxygen content. For example at 15 % oxygen:

EFthermal = [X]15% . Fd15%

Emission factors are reported in several ways and these are generally recalculated using physical or other properties of the fuel.

For example, a mass emission factor can be derived by multiplying the thermal emission factor calculated above by the net calorific value of the fuel.

EF = EFthermal . CV

where:

* EFthermal is the thermal emission factor expressed in units to suit the user (for example g GJ-1),
* CV is the net calorific value of the fuel in appropriate units to suit the units of the emission factor.

Example figures for correlation of emission concentrations to emission factors from USEPA Method 19 F factors are provided in Figures B1 and B2 below.

Figure B1 Emission factors — selected fuels and standardised concentrations up to 1 000 mg.m-3



Figure B2 Emission factors — selected fuels and standardised concentrations up to 200 mg.m-3



Appendix C Emission factors associated with emission limit values in selected countries

Table C1.1 Ecodesign NOx emission limits for boilers ≤400kW output, water heaters and LSH (gas and liquid fuel)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Type** | **Fuel :** | **ELV mg/kWh gross input** | | **ELV, g/GJ net input** | |
|  | **Gaseous** | **Liquid** | **Gaseous** | **Liquid** |
| Boilers | Boilers | 56 | 120 | 17 | 35 |
| Heat pump/Cogen | External combustion | 70 | 120 | 22 | 35 |
| Heat pump/cogen | Internal combustion | 240 | 420 | 74 | 123 |
| Water htrs | Water htrs | 54 | 120 | 17 | 35 |
| Heat pump | External combustion | 70 | 120 | 22 | 35 |
| Heat pump | Internal combustion | 240 | 420 | 74 | 123 |
| LSH | Domestic | 130 | 130 | 40 | 38 |
| LSH | Commercia; | 240 | 240 | 74 | 70 |

Emission limits drawn from EC Regulations 2015/1188, 2013/813 and 2013/814. Conversion from gross to net heat input based on conversions provided in Appendix B.

Table C1.2 Ecodesign emission limits for solid fuel boilers ≤500kW output

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Type** | **Fuel** | **mg/m3 at 10% O2 dry and STP (0°C, 101.3 kPa)** | | | | **g/GJ net heat input** | | | |
|  |  | PM | CO | OGC | NOX | PM | CO | OGC | NOX |
| Manual | Biomass | 40 | 500 | 20 | 200 | 19.4 | 243 | 9.7 | 97.0 |
| Auto |  | 60 | 700 | 30 | 200 | 29.1 | 340 | 14.6 | 97.0 |
| Manual | fossil | 40 | 500 | 20 | 350 | 19.8 | 247 | 9.9 | 173 |
| Auto |  | 60 | 700 | 30 | 350 | 29.6 | 346 | 14.8 | 173 |

PM emission limits based on filterable material only. All limits drawn from EC Regulation 2015/1189. Conversion from concentrations and emission factors assume a stoichiometric specific flue gas volume of 253 m3/GJ net fuel input for biomass and 258 m3/GJ net fuel input for bituminous coal (see AEA Technology 2012 and Appendix B).

Table C1.3 Ecodesign emission limits for solid fuel LSH

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Type** | **Fuel** | **g/kg (dry matter)** | | **mg/m3 at 13% O2 dry and STP (0°C, 101.3 kPa)** | | | | **g/GJ net heat input** | | | | | |
|  |  | **PM(iii)** | **PM(ii)** | **PM(i)** | **CO** | **OGC** | **NOX** | **PM(iii)** | **PM(ii)** | **PM(i)** | **CO** | **OGC** | **NOX** |
| open | Biomass | - | 6 | 50 | 2000 | 120 | 200 | - | 347 | 33.5 | 1339 | 80.3 | 134 |
| closed |  | 2.4 | 5 | 40 | 1500 | 120 | 200 | 139 | 289 | 26.8 | 1004 | 80.3 | 134 |
| pellet |  | 1.2 | 2.5 | 20 | 300 | 60 | 200 | 69 | 145 | 13.4 | 201 | 40.2 | 134 |
| cooker |  | 2.4 | 5 | 40 | 1500 | 120 | 200 | 139 | 289 | 26.8 | 1004 | 80.3 | 134 |
| open | fossil | - | 6 | 50 | 2000 | 120 | 300 | - | 178 | 34.1 | 1363 | 81.8 | 204 |
| closed |  | 5 | 5 | 40 | 1500 | 120 | 300 | 149 | 149 | 27.3 | 1022 | 81.8 | 204 |
| cooker |  | 5 | 5 | 40 | 1500 | 120 | 300 | 149 | 149 | 27.3 | 1022 | 81.8 | 204 |

PM emission limits based on different methods applied in EU. All limits drawn from EC Regulation 2015/1185. Conversion from concentrations and emission factors assume a stoichiometric specific flue gas volume of 253 m3/GJ net fuel input for biomass and 258 m3/GJ net fuel input for bituminous coal (see AEA Technology 2012 and Appendix B and, calorific values of 17.3 GJ/tonne (dry biomass) and 33.6 GJ/tonne (dry bituminous coal).

Table C2.1 Proposed Medium Compbustion Plant Directive emission limit values

Existing, new, small/large/engines/GTs

Table C3.1 Selected national emission limit values for small coal-fired combustion installations



Notes:

1. All combustion unit sizes are MWth (thermal input).
2. Range of concentrations (NOX, SO2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.

Table C3.2 Selected national emission limit values for small coal-fired combustion installations



Notes:

All combustion unit sizes are MWth (thermal input).

Range of concentrations (NOX, SO2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.

Table C3.3 Selected national emission limit values for small oil-fired combustion installations



Notes

All combustion unit sizes are MWth (thermal input).

Range of concentrations (NOX, SO2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.

Note that for SO2, the ELV for unabated combustion units is determined by fuel sulphur content and Directive 1999/32/EC on sulphur content of certain liquid fuels (1 % for heavy fuel oil and 0.2 % for gas oil until 1.1.2008 when the gas oil sulphur limit will be 0.1 %).

Germany distinguishes NOX emissions by application; HWB — hot water boiler, LPS — steam boiler supplying steam at temperature up to 210 ºC and up to 1.8 Mpa, HPS — boilers supplying steam at temperature greater than 210 ºC or pressure over 1.8 Mpa.

,

Table C3.4 Selected national emission limit values for small gas-fired combustion installations



Notes:

1. All combustion unit sizes are MWth (thermal input).
2. Range of concentrations (NOX, SO2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission levels rather than ELVs.
3. Germany distinguishes NOX emissions by application; HWB — hot water boiler, LPS — steam boiler supplying steam at temperature up to 210 ºC and up to 1.8 Mpa, HPS — boilers supplying steam at temperature greater than 210 ºC or pressure over 1.8 Mpa.

Table C3.5 Selected national emission limit values for engines and gas turbines



Notes:

1. All combustion unit sizes are MWth (thermal input).
2. Range of concentrations (NOX, SO2 and PM) generally corresponds to ELVs for new and existing combustion plant. Some countries apply BAT achievable emission level ranges rather than ELVs.
3. Note that for SO2, the ELV for unabated combustion units is determined by fuel sulphur content and Directive 1999/32/EC on sulphur content of certain liquid fuels (1 % for heavy fuel oil and 0.2 % for gas oil until 1.1.2008 when the gas oil sulphur limit will be 0.1 %).

Appendix D 2013 update of methodologies for Small combustion (1A4)

A review of the emissions factors for small combustion was performed in 2013. Details of this can be found in Appendix D of the 2013 EMEP/EEA air polliutant emission inventory guidebook chapter for small combustion (1A4).

Appendix E Black carbon methodology for Small combustion (1A4)

Nielsen, O.-K., Plejdrup, M.S. & Nielsen, M. (2012)

This appendix covers a review of the available data for BC emissions from small combustion. Furthermore, separate discussion papers are dedicated to a review of the GB 2009 emission factors (EFs) and to discuss different methods for allocating fuel consumption data to different technologies as well as bottom-up methods for estimating fuel consumption for small combustion installations.

**Residential plants**

The 2009 EMEP/EEA Guidebook (GB) contained four Tier 1 EF tables and a larger number of Tier 2 EF tables as presented in the table below. In the 2009 version, there was no match between the technological descriptions in section 2.2 and the EFs provided in section 3 of the chapter.

List of EF tables for residential plants in the GB chapter on small combustion.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** |
| Table 3-3 | 1 | Coal | Residential |  |
| Table 3-4 | 1 | Natural gas | Residential |  |
| Table 3-5 | 1 | Other liquid fuels | Residential |  |
| Table 3-6 | 1 | Biomass | Residential |  |
| Table 3-12 | 2 | Solid fuels | Residential | Fireplaces |
| Table 3-13 | 2 | Gaseous fuels | Residential | Fireplaces |
| Table 3-14 | 2 | Wood | Residential | Fireplaces |
| Table 3-15 | 2 | Solid fuels | Residential | Stoves |
| Table 3-16 | 2 | Solid fuels | Residential | Boilers < 50 kW |
| Table 3-17 | 2 | Wood | Residential | Stoves |
| Table 3-18 | 2 | Wood | Residential | Boilers < 50 kW |
| Table 3-19 | 2 | Natural gas | Residential | Boilers < 50 kW |
| Table 3-20 | 2 | Liquid fuels | Residential | Stoves |
| Table 3-21 | 2 | Liquid fuels | Residential | Boilers < 50 kW |
| Table 3-22 | 2 | Coal | Residential | Advanced stoves |
| Table 3-23 | 2 | Wood | Residential | High-efficiency stoves |
| Table 3-24 | 2 | Wood | Residential | Advanced/ecolabelled stoves |
| Table 3-25 | 2 | Wood | Residential | Pellet stoves |

***Biomass combustion***

Emission factors are included in one Tier 1 emission factor table and 6 Tier 2 emission factor tables in the 2009 GB. As mentioned above the technology description in chapter 2.2 does not match the Tier 2 emission factor tables. Suggested new technology names and the link to the technology description in chapter 2.2 are shown below. The emission factor table for advanced fireplaces will be deleted and replaced by an emission factor table for high-efficiency stoves.

List of EF tables for residential plants in the GB chapter on small combustion.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** | **New technology name** | **Chapter 2.2 technology name** |
| Table 3-6 | 1 | Biomass | Residential |  | - | - |
| Table 3-14 | 2 | Wood | Residential | Fireplaces | Open fireplaces | Open and partly closed fireplace |
| Table 3-17 | 2 | Wood | Residential | Stoves | Conventional stoves | Closed fireplace, conventional traditional stoves, domestic cooking |
| Table 3-18 | 2 | Wood | Residential | Boilers < 50 kW | Conventional boilers < 50 kW | Conventional biomass boilers |
| Table 3-24 | 2 | Wood | Residential | Advanced stoves | Advanced/ecolabelled stoves and boilers | Advanced combustion stoves, masonry heat accumulating stoves[[1]](#footnote-1), catalytic combustor stoves, advanced combustion boilers |
| Table 3-25 | 2 | Wood | Residential | Pellet stoves | Pellet stoves and boilers | Modern pellet stoves, automatic wood boilers (pellets / chips) |

BC and OC fractions of PM depend of both technology, wood type and PM emission level. For open fireplaces the OC fraction is high whereas a more complete combustion in advanced stoves results in a lower OC fraction.

It has not been possible to distinguish between elemental carbon and black carbon. Most references state data for elemental carbon.

In most recent European literature PM and BC measurement data are based on dilution sampling and BC fractions related to PM2.5.

***Residential wood combustion (Tier 1)***

The revised emission factor for PM2.5 is 740 g/GJ (370-1480). The Tier 1 emission factor for PM2.5 follows the emission factor for conventional stoves. The BC fraction for stoves (10 %) will be applied.

***Fireplaces***

The revised emission factor for PM2.5 from fireplaces is 820 (410-1640) g/GJ.

The BC fraction 7 % of PM2.5 that is an Aggregate of the listed references will be applied. The Aggregate OC fraction is 43 %.

List of BC references for open fireplaces.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reference** | **Country** | **Plant** | **PM [g/GJ]** | **EC or BC** | **OC** |
| Alves et al. 2011 | Portugal | Brick open fireplace, wood logs | PM2.5: 550-1122 | 4.7 % (2.2-7.5 %) | 43.2-53 % |
| Alves et al. 2011 | Portugal | Brick open fireplace, briquettes | PM2.5: 850 | 5.4 % | 47.7 % |
| Goncalves et al. 2011 | Portugal | Brick open fireplace | PM2.5: 47-1611 | 1.1[[2]](#footnote-2)-17 % | 20-48 % |
| Fernandes et al. 2011 | Portugal | Brick open fireplace, wood logs | PM2.5: 700  (374-1026) | 2-12 % | - |
| Fernandes et al. 2011 | Portugal | Brick open fireplace, briquettes | PM2.5: 692 | 2,98 % | 45 % |
| Fine et al. 2002 | USA | Open fireplace, hardwood | PM2.5: 183-378 | 1.2-6.4 % | 74.2-84.9 % |
| Fine et al. 2002 | USA | Open fireplace, softwood | PM2.5: 89-206 | 14.2-17.9 % | ~100 % |
| Bølling et al., 2009 | - | Open fireplace | PM2.5: 160-910 |  |  |
| Kupiainen & Klimont 2004 (IIASA) | - | Open fireplace | - | 10 % | 50 % |

***Conventional stoves***

The revised emission factor and interval for PM2.5 from conventional stoves is 740 (370-1480) g/GJ..

The BC fraction 10 % of PM2.5 that is an Aggregate of the listed references will be applied. Some of the BC fractions are however based on TSP. The Aggregate OC fraction is 45 %[[3]](#footnote-3).

List of BC references for conventional stoves.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reference** | **Country** | **Plant** | **PM [g/GJ]** | **EC or BC** | **OC** |
| Alves et al. 2011 | Portugal | Cast iron woodstove, split logs | PM2.5: 557  (344-906) | 1.9 - 7.7 % | 45.6 - 53.6 % |
| Alves et al. 2011 | Portugal | Cast iron woodstove, briquettes | 233 | 3,9 % | 47.1 % |
| Goncalves et al. 2011 | Portugal | Cast iron woodstove, wood logs and briquetts | PM2.5: 92 - 1433 | 0.82 - 9.3 % | 30- 50 % |
| Fernandes et al. 2011 | Portugal | Cast iron woodstove, wood logs | PM2.5: 447  (278-617) | 3-12 % | - |
| Fernandes et al. 2011 | Portugal | Cast iron woodstove, briquettes | PM2.5: 396 | 3.62 % | 40.27 % |
| Bølling et al. 2009 | - | Conventional wood stoves | 50-2100 | -[[4]](#footnote-4) | - |
| US EPA (SPECIATE), 2002 (IIASA) | USA | Stoves, woodlogs, hardwood | - | 14 % of TSP | 42 % of TSP |
| US EPA (SPECIATE), 2002 (IIASA) | USA | Stoves, woodlogs, softwood | - | 20 % of TSP | 39 % of TSP |
| Rau, 1989 (IIASA) |  | Stoves, woodlogs, hardwood | - | 5-16 % of TSP | 14-57 % of TSP |
| Rau, 1989 (IIASA) |  | Stoves, woodlogs, softwood | - | 5-38 % of TSP | 20-51 % of TSP |

***Conventional boilers < 50 kW***

The revised emission factor level and interval for PM2.5 from conventional boilers is 470 (235-945) g/GJ.

BC emission factors have been reported by Kupiainen & Klimont (2007). Based on the default PM2.5 emission factor 475 g/GJ the BC fraction 16 % have been estimated.

List of BC references for conventional boilers.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reference** | **Country** | **Plant** | **PM [g/GJ]** | **EC or BC** | **OC** |
| Bølling et al. 2009 | - | Conventional wood boilers and masonry heaters | PM2.5: 50-2000 | 10 %-35 % of TC |  |
| Kupiainen & Klimont 2007 | - | Boilers < 50 kWth | - | 75 mg/MJ1) |  |
| Johansson et al. 2004 |  | Old-type boilers | TSP: 87-2200 g/GJ | - |  |

1. Corresponding to 16 % of the default emission factor 475 g/GJ

***High-efficiency stoves***

The plant category is new. The emission factor for PM2.5 is 370 (285-740) g/GJ. The same BC fraction as for conventional boilers will be applied.

***Advanced/ecolabelled stoves and boilers***

The revisedemission factor level and interval for PM2.5 from advanced/ecolabelled stoves and boilers is 93 (19-233) g/GJ.

The category includes the chimney type stove[[5]](#footnote-5).

The BC fraction 28 % of PM2.5 that is an Aggregate of the listed references will be applied. The Aggregate OC fraction is 31 %.

List of BC references for advanced / ecolabelled stoves and boilers.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reference** | **Country** | **Plant** | **PM [g/GJ]** | **EC or BC** | **OC** |
| Goncalves et al. 2010 | Portugal | Chimney type (tiled stove) | PM10: 62-161 | 11.3-37.1 % | 19.7-42.8 % |
| Fernandes et al. 2011 | Portugal | Chimney type (tiled stove) | PM10: 101 (50-152) | 11-37 % |  |
| Schmidl et al. 2011 | Austria | Chimney type (tiled stove) 6.5 kW | PM10: 54-78 | 24.2-38.7 % | 26.8-38.8 % |
| Schmidl et al. 2011 | Austria | Advanced tiled stove 6kW | PM10: 58-66 | 29.8-37.6 % | 22.2-35.6 % |

***Pellet stoves and boilers***

The revised emission factor level for PM2.5 from pellet stoves is 29 (9-47) g/GJ.

The BC fraction 15 % of PM10 referring to Schmidl et al. (2011) will be applied. The Aggregate OC fraction is 13 %.

List of BC references for pellet stoves and boilers.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Reference** | **Country** | **Plant** | **PM** | **EC or BC** | **OC** |
| Schmidl et al. 2011 | Austria | Automatically fed pellet stove, 6 kW | PM10: 2-7 g/GJ | 13.7-15.87 % | 4.7-5.3 %,  22 % in the start-up phase |
| Schmidl et al. 2011 | Austria | Automatically fed boiler 40 kW moving grate | PM10: 6-26 g/GJ | 0.2-45.2 % | 2-38.2 % |
| Bølling et al. 2009 | ? | Pellet stoves and boilers | PM2.5: 10-50 g/GJ | 6 % | - |
| Verma et al., 2011 | Belgium | Five different pellet boilers (15-35 kW) | 1-11 g/GJ[[6]](#footnote-6) | 0-38.8 % | - |
| Sippula et al., 2007 | Finland | Pellet boiler | PM1: 58 g/GJ | 1.5 % | 6.6 % |

***Overview of BC emission factors for residential wood combustion***

The list below gives an overview of the BC fractions for residential wood combustion and the resulting BC emission factor if the default emission factor for PM2.5 is applied. The resulting BC emission factors are compared to the emission factor intervals from Kupiainen & Klimont (2007).

List of EF tables for residential plants in the GB chapter on small combustion.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **New technology name** | **PM2.5** | **BC fraction** | **BC [g/GJ]** | **Kupiainen & Klimont 2007** |
| Table 3-6 | 1 | Biomass | Residential | - | 740[[7]](#footnote-7) | 10% | 74 | 0.83-105 |
| Table 3-14 | 2 | Wood | Residential | Open fireplaces | 820 | 7% | 57 | 75-100 |
| Table 3-17 | 2 | Wood | Residential | Conventional stoves | 740 | 10% | 74 | 75-105 |
| Table 3-18 | 2 | Wood | Residential | Conventional boilers < 50 kW | 470 | 16 % | 75[[8]](#footnote-8) | 75 |
| Table 3-23 | 2 | Wood | Residential | High-efficiency stoves | 370 | 16 % | 59 | 56-79 |
| Table 3-24 | 2 | Wood | Residential | Advanced/ecolabelled stoves and boilers | 93 | 28% | 26 | 56-79 |
| Table 3-25 | 2 | Wood | Residential | Pellet stoves and boilers | 29 | 15% | 4 | 0.83 |

An overview of BC and OC fractions is shown below. In general, the BC fraction increases with improved combustion technology. However, the fraction for pellet stoves and boilers is lower than for advanced / ecolabelled stoves and boilers. The OC fraction decrease with improved combustion technology.

List of BC and OC fractions for residential wood combustion.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **New technology name** | **PM2.5** | **BC fraction** | **OC fraction** |  |
| Table 3-6 | 1 | Biomass | Residential | - | 740 | 10% | - |  |
| Table 3-14 | 2 | Wood | Residential | Open fireplaces | 820 | 7% | 43% |  |
| Table 3-17 | 2 | Wood | Residential | Conventional stoves | 740 | 10% | 45% |  |
| Table 3-18 | 2 | Wood | Residential | Conventional boilers < 50 kW | 470 | 16 % | - |  |
| Table 3-23 | 2 | Wood | Residential | High-efficiency stoves | 370[[9]](#footnote-9) | 16 % | - |  |
| Table 3-24 | 2 | Wood | Residential | Advanced/ecolabelled stoves and boilers | 93 | 28% | 31% |  |
| Table 3-25 | 2 | Wood | Residential | Pellet stoves and boilers | 29 | 15% | 13% |  |

***Solid fuel combustion***

There are five EF tables in the 2009 GB for solid fuels in residential plants. One of the EF tables is for Tier 1, while the remaining four tables is Tier 2 EF tables for fireplaces, stoves, small boilers and advanced stoves.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** |
| Table 3-3 | 1 | Coal | Residential |  |
| Table 3-12 | 2 | Solid fuels | Residential | Fireplaces |
| Table 3-15 | 2 | Solid fuels | Residential | Stoves |
| Table 3-16 | 2 | Solid fuels | Residential | Boilers < 50 kW |
| Table 3-22 | 2 | Coal | Residential | Advanced stoves |

Some data are available for BC emission shares from small scale coal combustion. However, it has not been possible to find specific data for all technologies. Most data are available for stoves, with no data being available for advanced stoves and small boilers (< 50 kW).

**Engelbrecht et al. (2002)** reports source profiles for residential coal combustion in South Africa. Engelbrecht et al. (2002) presents data for stoves and braziers (assumed comparable to fireplaces) for bituminous coal and for low smoke fuels. The data reported are shown in the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Stove** | **Fireplace** | **Stove** | **Stove** |
| **% of PM2.5** | **Bituminous coal** | **Bituminous coal** | **Low-smoke coal** | **Low-smoke coal** |
| EC | 9.5167 | 9.839 | 18.9857 | 6.8002 |
| OC | 70.8 | 78.268 | 56.3225 | 73.6005 |

Very similar results are obtained for stoves and fireplaces combusting bituminous coal. The EC shares of PM2.5 for the low-smoke coal are differing slightly more, but are still comparable to the data for bituminous coal.

Pinto et al. (1998) reports EC and OC shares of PM2.5 from residential combustion of lignite in hand-fired stoves. The analysis was done for particles collected during the smouldering phase as well as during the active phase. The data are included in the table below.

|  |  |  |
| --- | --- | --- |
| **% of PM2.5** | **Residential coal combustion, smouldering** | **Residential coal combustion, active** |
| EC | 6.2 | 10 |
| OC | 68 | 62 |

Watson et al. (2001) presents data for a composite of two stoves and two fireplaces. The reported EC share of PM2.5 is 26.08 % and the OC share is reported as 69.49 %. The four datasets are not included in the original reference but is included in the SPECIATE database. The four single datasets are shown in the table below.

|  |  |  |
| --- | --- | --- |
| **% of PM2.5** | **EC** | **OC** |
| Stove burning coal from Trapper Mine. | 6.7953 | 65.4335 |
| Stove burning coal from Trapper Mine. | 33.2055 | 45.4365 |
| Fireplace and stove burning coal from Seneca Mine. | 21.2664 | 75.9568 |
| Fireplace and stove burning coal from Seneca Mine. | 43.0381 | 91.1323 |

Bond et al. (2004) reports EC fractions of 0.5 to 0.6 for residential coal combustion in stoves based on unpublished data. It has not been possible to find any later publication where these measurement data have been described in more detail.

Zhang et al. (2012) reports EC and OC shares of PM2.5 based on five measurements in China. The EC share is reported as 6.4 % ± 2.3 %-point. The OC share is reported as 48.7 % ± 19.1 %-point.

In the table below is a summary of the available data concerning EC.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Technology** | **Engelbrecht et al., 2002** | **Engelbrecht et al., 2002** | **Pinto et al., 1998** | **Watson et al., 2001** | **Bond et al., 2004** | **Zhang et al., 2012** |
|  | **% of PM2.5** | **% of PM2.5** | **% of PM2.5** | **% of PM2.5** |  | **% of PM2.5** |
| Fireplaces | 9.839 |  |  |  |  |  |
| Stoves | 9.5167 | 18.9857; 6.8002 | 2; 6.2 | 26.08 | 50 | 6.4 |

The data reported by Watson et al. (2001) and Bond et al. (2004) seem like outliers compared to the remaining datasets. One of the measurements by Watson et al. (2004) (6.8 %) was close to the other data sources but the remaining three data points differed significantly. The data for low-smoke fuels from Engelbrecht et al. (2002), the data by Pinto et al. (1998) and the data from Zhang et al. (2012) is thought to be the best data set for stoves. The value for low-smoke fuel (AFC) reported by Engelbrect et al. (2002) of 6.8 % is in close agreement with the percentage of 6.4 reported by Zhang et al. (2012). Pinto et al. (1998) reports a share of 6.2 % for the smoldering phase and only 2 % for the active phase. Considering these datasets and noting that the other available data are higher, it is recommended that data from Zhang et al., (2012) are used as BC share for coal stoves. For fireplaces the share reported by Engelbrecht et al. (2002) is the only source and is therefore included. No information has been found in the literature neither for advanced coal stoves nor for small coal boilers. Since there is no information available to suggest that the composition of particles for these technologies are different than for coal stoves, it is recommended to use Zhang et al. (2012) as the reference for the BC EF.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** | **BC share of PM2.5** | **Reference** |
| Table 3-3 | 1 | Coal | Residential |  | 6.4 | Zhang et al., 2012 |
| Table 3-12 | 2 | Solid fuels | Residential | Fireplaces | 9.839 | Engelbrecht et al., 2002 |
| Table 3-15 | 2 | Solid fuels | Residential | Stoves | 6.4 | Zhang et al., 2012 |
| Table 3-16 | 2 | Solid fuels | Residential | Boilers < 50 kW | 6.4 | Zhang et al., 2012 |
| Table 3-22 | 2 | Coal | Residential | Advanced stoves | 6.4 | Zhang et al., 2012 |

***Other fuel combustion***

The 2009 guidebook includes seven tables for residential combustion of gaseous and liquid fuels. Two of the tables cover Tier 1 for natural gas and liquid fuels, respectively. The three Tier 2 tables for gaseous fuels cover fireplaces, stoves and boiler, while the two tables for liquid fuels cover stoves and boilers. The technology for table 3-13 is changed from fireplaces to cooking appliances, as the use of gaseous fuels in fireplaces to be of limited relevance.

A literature study has been carried out and a short description of the most important references is given in the following;

Hildemann et al, 1991: Presents EFs for natural gas combustion in home appliances based on measurements of emissions from a residential natural gas fired space heater and a water heater;

EC = 6.7 % of PM2.5OC = 84.9 % of PM2.5

Muhlbaier, 1981: Present EFs for residential gas fired appliances, based on measurements for three furnaces and one hot water heater;

EC = 4 % of PM2.5

OC = 8 % of PM2.5

Reff et al, 2009: In order to make an inventory of PM2.5 trace elements in the United States, Reff et al has set up a list of 84 source categories based on CSSs from NEI and profiles from SPECIATE. SPECIATE profile #92156 gives Reff et al as reference, and according to the notes in SPECIATE the EFs are based on the EFs given in Hildemann et al. Reff et al (supp. Info.) has scaled OC down as the sum of species > 100 % of PM2.5 in the original reference because Hildemann et al did not correct for artifacts. The following EFs are presented in the article for residential natural gas combustion;

EC = 6.7 % of PM2.5OC = 84.9 % of PM2.5

Bond et al, 2004: together with a global BC inventory EFs for BC and OC applicable for small combustion appliances are presented;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Kerosene,**  **residential** | **LPG\*,**  **residential** | **Natural gas,**  **All** | **Heavy fuel oil,**  **All** |
| Ratio to | PM1 | PM1 | PM1 | PM1 |
| BC, % | 13 | 13 | 6 | 8 |
| OC, % | 10 | 10 | 50 | 3 |

\*Bond et al assumes the same EFs as for kerosene

A summary of EC and OC emission factors from the reviewed literature is given in the table below.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Hildemann et al., 1991** | **Muhlbaier, 1981** | **Battye and Boyer** | **Reff et al., 2009** | **Bond et al, 2004** | **Bond et al, 2004** | **SPECIATE 4.3** |
| **Source** | residential | residential | residential | Residential | Residential | Residential | Residential |
| **Technology** |  | Furnaces and water heater |  |  |  |  | oil boiler |
| **Fuel** | natural gas | Natural gas | natural gas | natural gas | LPG | Kerosene | distillate oil |
| **Ratio to** | PM2.5 | PM2.5 | PM2.5 | PM2.5 | **PM1\*\*\*** | **PM1\*\*\*** | PM2.5 |
| **BC, %** | 6.7 | 4 | 6.7 | 6.7 | **13** | **13** | 3.898 |
| **OC, %** | 84.9\* | 8 |  | 49.0\*\* | **10** | **10** | 1.765 |
| **Note** |  |  | high estimate = 15 |  |  |  | EFs not found in the reference (Hays et al, 2008) |

\*Also refered in Chow et al., 2011  
\*\*Down-scaled values from Hildemann et al  
\*\*\* Bond et al, 2004 reference mention that PM1 make up 100 % of TSP

Hildemann et al, 1991, Reff et al. 2009 and Muhlbaier, 1981 are assumed to be the best sources for BC and OC EFs for residential appliances. The remaining references seem to use the EFs by Hildemann et al. An Aggregate of the EFs from Hildemann et al and Muhlbaier are **proposed for residential natural gas combustion** (for OC an Aggregate of Muhlbaier and Reff et al are proposed as the EFOC in Reff et al are a scaled value based on Hildemann et al.).

The most appropriate reference to emission factors for LPG and kerosene combustion in residential stoves are Bond et al, 2004. For liquid fuel combustion in residential boilers only one emission factor has been observed, and the EF has not been found in the original reference (Hays et al, 2008) but only in SPECIATE 4.3. Still, this EF is proposed for application in the guidebook.

**The following table resumes the proposed EFs for the guidebook:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** | **BC** | **OC** | **Reference** |
| Table 3-4 | 1 | Natural gas | Residential |  | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-5 | 1 | Other liquid fuels | Residential |  | 3.898 | 1.765 | SPECIATE 4.3 |
| Table 3-13 | 2 | Gaseous fuels | Residential | Fireplaces | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-19 | 2 | Natural gas | Residential | Boilers < 50 kW | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-20 | 2 | Liquid fuels | Residential | Stoves | 13 | 10 | Bond et al, 2004 |
| Table 3-21 | 2 | Liquid fuels | Residential | Boilers < 50 kW | 3.898 | 1.765 | SPECIATE 4.3 |

**Other small combustion plants**

Other small combustion plants refer to plants typically in the commercial/institutional sector but the EFs are generally applicable to plants smaller than 50 MW. The chapter contains Tier 1 EFs for the main fuel groups and Tier 2 EFs for different technologies for coal, wood, natural gas and oil. The list of GB 2009 EF tables is presented in the table below.

List of EF tables for non-residential combustion in the GB chapter on small combustion.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** |
| Table 3-7 | 1 | Coal | Non-residential |  |
| Table 3-8 | 1 | Gaseous fuels | Non-residential |  |
| Table 3-9 | 1 | Liquid fuels | Non-residential |  |
| Table 3-10 | 1 | Biomass | Non-residential |  |
| Table 3-26 | 2 | Coal | Non-residential | Boilers 50 kW to 1 MW |
| Table 3-27 | 2 | Coal | Non-residential | Boilers 1-50 MW |
| Table 3-28 | 2 | Coal | Non-residential | Manual boilers < 1 MW |
| Table 3-29 | 2 | Coal | Non-residential | Automatic boilers < 1MW |
| Table 3-30 | 2 | Liquid fuels | Non-residential | Boilers 50 kW to 1MW |
| Table 3-31 | 2 | Liquid fuels | Non-rediential | Boilers 1MW to 50MW |
| Table 3-32 | 2 | Wood | Non-residential | Boilers 50 kW to 1MW |
| Table 3-33 | 2 | Wood | Non-residential | Boilers 1MW to 50MW |
| Table 3-34 | 2 | Wood | Non-residential | Manual boilers < 1 MW |
| Table 3-35 | 2 | Wood | Non-residential | Automatic boilers < 1MW |
| Table 3-36 | 2 | Natural gas | Non-residential | Boiler 50 kW to 1 MW |
| Table 3-37 | 2 | Natural gas | Non-residential | Boiler 50 kW to 1 MW |
| Table 3-38 | 2 | Natural gas | Non-residential | Gas turbines |
| Table 3-39 | 2 | Gas oil | Non-residential | Gas turbines |
| Table 3-40 | 2 | Gaseous fuels | Non-residential | Gas engines |
| Table 3-41 | 2 | Gas oil | Non-residential | Gas engines |

***Biomass combustion***

Three emission factor tables are relevant for biomass combustion in non-residential plants.

The PM2.5 emission factor for non-residential combustion of biomass is 140 g/GJ. The BC fraction for advanced/ecolabelled boilers will be applied.

The PM2.5 emission factor for non-residential manual boilers combusting wood is 140 g/GJ. For automatic boilers the emission factor is 33 g/GJ. For manual boilers the BC fraction for advanced/ecolabelled residential stoves and boilers will be applied. For automatic boilers the BC fraction for residential pellet boilers will be applied.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** | **PM2.5 [g/GJ]** | **BC fraction** | **BC [g/GJ]** | **Kupiainen & Klimont (2007)** |
| Table 3-10 | 1 | Biomass | Non-residential |  | 140 | 28 % | 39 | - |
| Table 3-32 | 2 | Wood | Non-residential | Boilers 50kW to 1MW | 86.5\* | 21.5 %\* | 19\* | - |
| Table 3-33 | 2 | Wood | Non-residential | Boilers 1MW to 50 MW | 33\* | 15 %\* | 5\* | - |
| Table 3-34 | 2 | Wood | Non-residential | Manual boilers < 1 MW | 140 | 28 % | 39 | 35 |
| Table 3-35 | 2 | Wood | Non-residential | Automatic boilers < 1MW | 33 | 15 % | 5 | - |

\*Values for Tables 3-32 and 3-33 are based on the aggregated data for manual and automatic boilers <1MW and assumptions about technology type and performance for >1MW technologies.

***Solid fuel combustion***

There are five EF tables in the 2009 GB for solid fuels in small-scale non-residential plants. One of the EF tables is for Tier 1, while the remaining four tables are Tier 2 EF tables for boilers.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Tier | Fuel | Sector | Technology |
| Table 3-7 | 1 | Coal | Non-residential |  |
| Table 3-26 | 2 | Coal | Non-residential | Boilers 50 kW to 1 MW |
| Table 3-27 | 2 | Coal | Non-residential | Boilers 1-50 MW |
| Table 3-28 | 2 | Coal | Non-residential | Manual boilers < 1 MW |
| Table 3-29 | 2 | Coal | Non-residential | Automatic boilers < 1MW |

It is not clear from the 2009 GB, what is the distinction between EF table 3-27 and either table 3-29 or 3-30. Table 3-27 should presumably be the same as either 3-29 or 3-30.

It has not been possible to find in the literature detailed EC (or BC) measurements on this level of detail regarding the combustion technology. Therefore, the same BC share is used for small boilers (< 1 MW) as the one for domestic boilers, while medium sized boilers are assumed to have the same share as large boilers (see chapter 1A1).

***Other fuel combustion***

The 2009 guidebook includes eight tables for non-residential combustion of gaseous and liquid fuels. Two of the tables cover Tier 1 for gaseous fuels and liquid fuels, respectively. The Tier 2 tables cover natural gas combustion in boilers 50kW-1MW and 1MW-50MW, natural gas and liquid fuel combustion in turbines and in engines.

A literature study has been carried out and a short description of the most important references is given in the following text;

Mugica et al, 2008: Include emission factors for a smaller industrial LP gas steam boiler (1 m3 capacity);

EC = 5.353 % of PM2.5 (± 0.35)

OC = 71.32 % of PM2.5 (± 5.04)

England et al, 2007: Present data from eight gas-fired units, here among a dual-fuel institutional boiler and a diesel powered electricity generator. The profile presented by England et al for gas-fired boilers include EFs for BC and OC;

BC = 13 %  
OC = 61 %

Bond et al, 2004: together with a global BC inventory EFs for BC and OC applicable for small combustion appliances are presented;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Kerosene,**  **residential** | **LPG\*,**  **residential** | **Natural gas,**  **All** | **Heavy fuel oil,**  **All** |
| **Ratio to** | **PM1** | **PM1** | **PM1** | **PM1** |
| BC, % | 13 | 13 | 6 | 8 |
| OC, % | 10 | 10 | 50 | 3 |

\*Bond et al assumes the same EFs as for kerosene

Mazzera et al, 2001: Measurements from McMurdo station, Antarctica, for e.g. diesel-fueled heating appliances for space heating are used as basis for the presented EFs for EC and OC;

|  |  |  |
| --- | --- | --- |
|  | **Diesel, non-residential** | **Diesel, non-residential**  **Recalculated\*** |
| **Ratio to** | **PM10** | **PM2.5** |
| BC, % | 4.4916; 7.3929 | 5.85; 9.63 |
| OC, % | 54.3207; 72.0403 | 70.78; 93.87 |

\*recalculated according to the current size distribution for PM in the guidebook (TSP = 27.5 g/GJ, PM10 = 21.5 g/GJ, PM2.5 = 16.5 g/GJ)

Battye et al, 2002: It is not clear which sources the EFs are based on, but they are included here as they refer to combustion in commercial appliances;

|  |  |  |
| --- | --- | --- |
|  | **Petroleum,**  **commercial** | **Natural gas**  **commercial** |
| **Ratio to** | **PM2.5** | **PM2.5** |
| BC, % | 7.4 | 6.7 |

Cooper et al, 1987:Presents a number of PM species profiles for combustion. The profile for oil boiler, Cubatao, T<15 are assumed applicable for small non-residential appliances;

BC = 8.69 % of PM2.5OC = 8.96 % of PM2.5

A summary of EC and OC emission factors from the reviewed literature is given in the tables below.

**Gaseous fuels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Reference** | **Battye and Boyer** | **Bond et al, 2004** | **England et al, 2007** |
| **Source** | commercial | All | All |
| **Technology** |  |  | Boiler |
| **Fuel** | natural gas | natural gas | Gaseous fuels |
| **Ratio to** | PM2.5 | PM1\* | PM10 |
| **BC, %** | 6.7 | 6 | 13 |
| **OC, %** |  | 50 | 61 |
| **Note** | high estimate = 15 |  |  |

\* Bond et al, 2004 reference mention that PM1 make up 100 % of TSP

**Liquid fuels**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **SPECIATE 4.3** | **Battye and Boyer** | **Mugica et al, 2008** | **Cooper et al, 1987** | **Bond et al, 2004** | **Mazzera et al, 2001** | **Mazzera et al, 2001** |
| **Source** | Commercial and institutional | Commercial |  |  | All | Non-residential | Non-residential |
| **Technology** | boilers |  | boiler | boiler |  | (Air heating) | Steam-heating boiler |
| **Fuel** | residual oil | Petroleum | LPG | Oil | Heavy fuel oil | Diesel | Diesel |
| **Ratio to** | PM2.5 | PM2.5 | PM2.5 | PM2.5 | PM1\* | PM2.5\*\* | PM2.5\*\* |
| **BC, %** | 2.42 | 7.4 | 5.353 | 8.69 | 8 | 5.85\*\* | 9.63\*\* |
| **OC, %** | 7.8 |  | 71.32 | 8.96 | 3 | 70.78\*\* | 93.87\*\* |
| **Note** | Aggregate of 8 samples from schools, hospitals, apartments, and industrial boilers  EFs not found in the reference (Watson, 1979) | high estimate = 13 | Smaller industrial boiler | included in SPECIATE (13504\*) | From SPECIATE 3.1 |  |  |

\* Bond et al, 2004 reference mention that PM1 make up 100 % of TSP  
\*\* Recalculated shares according to the current size distribution in the guidebook

The guidebook only includes Tier 1 emission factors for liquid fuel combustion in small appliances. None of the seven BC emission factors stand out as more applicable than the others. Therefore it is proposed to apply the Aggregate of the seven EF values to the guidebook. The OC emission factors show more variation than the BC emissions factors and further investigation might be useful to find the most appropriate emission factor. Here the Aggregate of the six EFs is given with the corresponding BC EF.

The following EFs have been included for combustion of liquid and gaseous fuels in small appliances. For combustion in non-residential turbines and engines EFs proposed for turbines and engines in sector 1A1 have been applied:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Tier** | **Fuel** | **Sector** | **Technology** | **BC** | **OC** | **Reference** |
| Table 3-8 | 1 | Gaseous fuels | Non-residential |  | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-9 | 1 | Liquid fuels | Non-residential |  | 6 | 36 | See text |
| Table 3-30 | 2 | Fuel oil | Non-residential | Boiler 50 kW to 1MW | No estimate | No estimate | - |
| Table 3-31 | 2 | Fuel oil | Non-residential | Boiler 1 MW to 50 MW | No estimate | No estimate | - |
| Table 3-36 | 2 | Natural gas | Non-residential | Boiler 50 kW to 1 MW | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-37 | 2 | Natural gas | Non-residential | Boiler 1 MW to 50 MW | 5.35 | 28.5 | Hildemann et al, 1991; Muhlbaier, 1981 |
| Table 3-38 | 2 | Natural gas | Non-residential | Gas turbines | 2.5 |  | **\*** |
| Table 3-39 | 2 | Gas oil | Non-residential | Gas turbines | 2.5 |  | **\*** |
| Table 3-40 | 2 | Gaseous fuels | Non-residential | Gas engines | 2.5 |  | **\*** |
| Table 3-41 | 2 | Gas oil | Non-residential | Gas engines | 2.5 |  | **\*** |

\* Aggregate of EFs from England et al. (2004), Wien et al. (2004) and US EPA (2011). For further description, please refer to “Discussion paper – BC methodologies for Energy Industries (1A1)”.

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1. This technology can be included in the category Energy efficient stoves instead dependent on the most common technology applied for masonry heat accumulating stoves in the country. [↑](#footnote-ref-1)
2. Briquettes [↑](#footnote-ref-2)
3. Not including Fine et al. (2002) [↑](#footnote-ref-3)
4. EC data only related to TC [↑](#footnote-ref-4)
5. The chimney type stove are iron stoves with chamotte lining (Schmidl et al. 2011). [↑](#footnote-ref-5)
6. Not diluted [↑](#footnote-ref-6)
7. Not estimated yet. Assumed that the emission factor for conventional stoves will be applied. [↑](#footnote-ref-7)
8. Refers to Kupiainen & Klimont (2007) [↑](#footnote-ref-8)
9. Not estimated yet [↑](#footnote-ref-9)