Best Available Techniques (BAT) for Domestic Wood Heating

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Study carried out by the Flemish Knowledge Centre
for Best Available Techniques (VITO)
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https://emis.vito.be/nl/bbt/publicaties/bbtbref-en-andere-publicaties/huishoudelijke-houtverwarming

In case of doubt, please consult the original Dutch version.

INTRODUCTION

You are reading one of the BAT studies published by the BAT Knowledge Centre. This sector report covers the Best Available Techniques for domestic wood heating.

→ What are BAT studies?

The BAT studies are reports that describe the BAT for each sector. These sector reports are distributed digitally (http://www.emis.vito.be), both to government as well as companies.

→ What are BAT?

Environmentally-friendly techniques aim to reduce the environmental impact of companies. These can be techniques to reuse or recycle waste, remedy soil and groundwater, or to purify flue gases and waste water. They are very often preventive measures that prevent the emission of pollutants and reduce the use of energy, raw materials and consumables. When such techniques, compared to all other similar techniques, are the most effective ecologically and they are also affordable, we call them the Best Available Techniques (BAT).

→ What is the BAT Knowledge Centre?

The Flemish Institute for Technological Research (VITO) was commissioned by the Flemish Government in 1995 to set up a knowledge centre for Best Available Techniques (BAT). The BAT Knowledge Centre keeps an inventory of environmentally friendly techniques, evaluates the Best Available Techniques (BAT) per sector and formulates BAT recommendations to the Flemish Government and companies.
The BAT Knowledge Centre, together with its sister project EMIS (http://www.emis.vito.be), is financed by the Flemish Region. The knowledge centre is supervised by a steering committee chaired by the Territorial Development, Environmental Planning and Projects (GOP) division of the Department of Environment and Spatial Development,. The other entities involved in the policy area (various divisions of the Department of Environment and Spatial Development and the Flanders Environment Agency(VMM), the Flemish Public Waste Agency (OVAM), the Flemish Energy Agency (VEA), the Flemish Land Agency (VLM)) also sit on the steering committee.

→ Why are BAT studies useful?

The permit conditions imposed on companies and the ecology premium in force in Flanders are largely based on BAT. As such, the sectoral conditions laid down in VLAREM II often reflect the degree of environmental protection achievable with BAT. So defining BAT is not only useful for companies but also as a reference for public authorities in the context of their permitting policy. In certain cases, the Flemish Government also grants subsidies to companies when they invest in BAT.
The BAT Knowledge Centre develops BAT studies for an industry or group of similar activities. These studies describe the BAT and provide the necessary background information. This background information helps the licensing authority to become more acquainted with day-to-day business practice. Moreover, it shows companies the scientific basis for the environmental conditions in their permit.

The BAT studies also make recommendations to adapt permit conditions and ecology premium rules. Experience shows that the Flemish Government actually uses the recommendations on a regular basis for new environmental regulations. However, the recommendations are considered to be non-binding in the meantime.
Domestic wood combustion is not a classified activity in VLAREM, so no permit conditions apply. This does not alter the fact that it makes sense to determine BAT for this activity as well. Knowledge regarding BAT enables policy makers, manufacturers, installers, users and other stakeholders to take better substantiated measures to reduce the environmental impact of domestic wood heating.

→ **How was this study created?**

Every BAT study is the result of intensive research in the literature, visits to companies, collaboration with experts in the sector, surveys of manufacturers and suppliers, extensive contacts with company and environmental managers and civil servants, etc. The described BAT are a snapshot and not necessarily complete: not all BAT that are possible today and in the future are included in the study. A steering committee was set up with representatives from industry and government to provide scientific support for the study. This committee met three times to steer the content of the study (on 15/03/2019, 20/06/2019, 27/01/2020). The names of the committee members and the external experts who contributed to this study are listed in Appendix 1. The BAT Knowledge Centre has taken into account the comments of the members of the steering committee insofar as possible. However, this report is not a text of compromise. It reflects the techniques that the BAT Knowledge Centre currently considers to be up-to-date and the recommendations that meet those requirements.

READING GUIDE

In **Chapter 1** we explain the concept of Best Available Techniques (BAT) and their implementation in Flanders and then we outline the general framework of the present BAT study.
Chapter 2 describes the domestic wood heating activity and its main socio-economic and environmental-legal aspects.
Chapter 3 describes the wood combustion process and the fuels and appliances used, and we assess the environmental impact.
Chapter 4 gives an overview of the techniques that can be applied to improve environmental performance.
In **Chapter 5** we evaluate these environmentally-friendly techniques and select the BAT. We take into account the technical feasibility but also the environmental benefits and the economic feasibility (cost feasibility and effectiveness).
Chapter 6 deals with recommendations based on the BAT.
Finally, **Chapter 7** describes emerging techniques and includes recommendations for further research.

SUMMARY

The BAT Knowledge Centre, founded by the Flemish Government and hosted by VITO, is tasked with inventorying, processing and disseminating information on environmentally-friendly techniques. The knowledge centre must also advise the Flemish authorities on implementing Best Available Techniques (BAT). This report defines the BAT for domestic wood heating.

Emissions from domestic wood heating have a negative impact on air quality, especially during the heating season. This may have health effects, both for users and in the vicinity. It may also cause odour and smoke nuisance for local residents. To solve these problems, the Green Deal 'Domestic Wood Heating' was signed in Flanders in 2018 (https://omgeving.vlaanderen.be/green-deal-huishoudelijke-houtverwarming). The BAT study is being prepared as part of this Green Deal and more specifically within the framework of the following 2 actions:

- research into potential technological improvements for new appliances (action 1.2.2)
- research into the feasibility and potential of retrofitting old, polluting combustion appliances (action 1.1.2).

The study focuses in the first place on techniques (BAT) for the **design of new appliances**. Appliances are designed to comply with the applicable emission and energy efficiency requirements under standardised test conditions. However, environmental performance in real-life conditions of use (varying combustion conditions which are not always optimal) will be lower than the performance measured in labs under standardised test conditions. The BAT evaluation therefore also examines techniques that eliminate the influence of (incorrect) user behaviour as much as possible (automation) so that the performance in actual conditions deviates less from that under standardised test conditions. The BAT evaluation was carried out for different appliance types: wood stoves (logs), pellet stoves, mass stoves, wood-burning boilers (logs) and pellet boilers, also taking into account the intended application and the profile of the user (e.g. number of hours that the appliance is intended to be used, time/effort the user is willing to invest in good heating practice, maintenance, etc.). For an overview of the techniques that have been evaluated as BAT for each of these appliance types, please refer to Table 32. No techniques (BAT) are available for open fireplaces to optimise the combustion process and/or reduce emissions. This means that emissions are very high and energy efficiency is low. For this reason, the use of open fireplaces is not considered as BAT.

Possible **retrofitting of existing appliances** was also investigated. Two important retrofitting options are the installation of an ESP (electrostatic precipitator) and the installation of a catalyst. Both techniques can help to reduce emissions from existing appliances. Compared to the complete replacement of the existing appliance by a new, more efficient unit, these measures have benefits as well as disadvantages, as indicated in Table 34. This means that whether or not they are regarded as BAT depends on the situation and that the replacement by a new appliance must always be assessed.

In addition to measures for the design of new appliances and the retrofitting of old appliances, the study also focuses on measures for the **installation and use** of appliances, and for the **maintenance and service/inspection** of appliances and flue gas pipes. These measures are of great importance to reduce the environmental impact of domestic wood heating but are not investigated in so much detail in this study. They are the subject of other actions in the framework of the Green Deal 'Domestic Wood Heating'.

The BAT selection and advice was based on literature research and consultation with representatives of the federations, suppliers, specialists from the public administration and other experts. Formal consultations took place in a steering committee whose composition is given in Appendix 1.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BAT	Best Available Techniques
BC	Black Carbon (indicator for soot, measured using light absorption)
COC	Condensable Organic Compounds
CH	Central Heating
EC	Elemental Carbon (indicator for soot, measured using a thermal-optical method)
EF	Emission Factor
EKG	Energy, Climate and Green Economy division of the Department of Environment and Spatial Development
EN	European Norm
ESP	Electrostatic Precipitator (electrofilter)
FSC	Forest Stewardship Council
GOP	Territorial Development, Environmental Planning and Projects division of the Department of Environment and Spatial Development
HC	Hydrocarbons
IPPC	Integrated Pollution Prevention and Control
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne
NBN	(Standard of the Belgian) Bureau for Standardisation
NMVOC	Non-Methane Volatile Organic Compounds
OGC	Organic Gaseous Carbon
OVAM	Flemish Public Waste Agency
PAHs	Polycyclic Aromatic Hydrocarbons
PCDDF	Dioxins and furans
PEFC	Programme for the Endorsement of Forest Certification Schemes
PM	Particulate Matter
POA	Primary Organic Aerosols
ppm	Parts per million
SOA	Secondary Organic Aerosols
TSP	Total Suspended Particles
VEA	Flemish Energy Agency
cbc	Case-by-case
VLM	Flemish Land Agency
VMM	Flanders Environment Agency
VOC	Volatile Organic Compounds

LIST OF DEFINITIONS

Please note:
This table contains definitions as set out in the applicable regulations (= Source)[1].
Parts of definitions relating to aspects that do not fall under the concept of 'domestic wood heating' and therefore fall outside the scope of the BAT study have been put [between brackets].

Definitions of heating appliances in general	
Domestic wood heating	refers to heating appliances in which wood can be burnt for local or central indoor heating *Source: Green deal – Domestic wood heating*
Combustion appliance	technical appliance in which solid [,liquid or gaseous] fuel is burned to use the generated heat for space heating and optionally for the production of hot consumable water *Source: Combustion Appliances Order*
Heating appliance	freestanding stove, inset stove, boiler-stove, pellet appliance or boiler *Source: RD Heating Appliances 2010*
Definitions of appliances for local space heating	
Solid fuel local space heater	a space heating appliance that emits heat by direct heat transfer or by direct heat transfer in combination with heat transfer to a fluid, in order to achieve and maintain a certain level of human thermal comfort within an enclosed space in which the product is situated, possibly combined with a heat output to other spaces, and is equipped with one or more heat generators that convert solid fuels directly into heat *Source: Regulation (EU) 2015/ 1185* *Similar definition in Regulation (EU) 2015/1186*
Open fronted solid fuel local space heater	a solid fuel local space heater of which the fire bed and combustion gases are not sealed from the space in which the product is fitted and which is sealed to a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion *Source: Regulation (EU) 2015/ 1185* *Similar definition in Regulation (EU) 2015/1186*
Closed fronted solid fuel local space heater	a solid fuel local space heater of which the fire bed and combustion gases can be sealed from the space in which the product is fitted and which is sealed to a chimney or fireplace opening or that a flue duct for the evacuation of products of combustion *Source: Regulation (EU) 2015/ 1185* *Similar definition in Regulation (EU) 2015/1186*
Freestanding stove	domestic appliance fitted with a combustion chamber which, in its normal state, is completely closed with a stove door, which supplies heat by means of radiation and/or convection, in a continuous or

[1] Note that the definitions in the RD Heating Appliances 2010 refer to EN standards that have been updated or replaced (and sometimes the scope, etc. may have changed).
For example, the definition of 'boiler': "The power of the appliance is less than or equal to 300 kW. The appliance complies with the definitions, requirements, test methods and labelling of standard NBN EN 303-5 in its latest edition": In the '1999' version of standard NBN EN 303-5, the applicability was limited to boilers with a nominal heat output of up to 300 kW. The new standard NBN EN 303-5: 2012 goes to 500 kW.

	non-continuous manner, and which can supply hot water if it is fitted with a heat exchanger. The appliance complies with the definition, requirements, test methods and labelling of standard NBN EN 13240 in its latest edition *Source: RD Heating Appliances 2010*
Inset stove	domestic appliance that provides heat by means of radiation and/or convection, continuously or not, and designed to be placed in a recess, a space or in the combustion chamber of an open fireplace and that can provide hot water if it is fitted with a heat exchanger. The appliance complies with definitions, requirements, test methods and labelling of standard NBN EN 13229 in its latest edition *Source: RD Heating Appliances 2010*
Boiler-stove	domestic appliance that supplies hot water and provides heat by means of radiation and/or convection. "The power of the appliance is less than or equal to 50 kW. The appliance complies with the definitions, requirements, test methods and labelling of standard NBN EN 12809 in its latest edition *Source: RD Heating Appliances 2010*
Pellet appliance	domestic appliance that provides heat by means of radiation and/or convection, only using automatically fed pellets as fuel, and that can provide hot water if it is fitted with a heat exchanger. "The power of the appliance is less than or equal to 50 kW. The appliance complies with the definitions, requirements, test methods and labelling of standard NBN EN 14785 in its latest edition *Source: RD Heating Appliances 2010*
Slow heat release appliance	appliance that complies with the definitions, requirements, test methods and labelling of standard NBN EN 15250 in its latest edition *Source: RD Heating Appliances 2010*
Open fireplace	domestic appliance that provides heat by means of radiation and/or convection and is fitted with a combustion chamber that cannot be sealed. The appliance complies with the definition, requirements, test methods and labelling of standard NBN EN 13229 in its latest edition *Source: RD Heating Appliances 2010*
Definitions of appliances for central heating	
Central heating appliance	a combustion appliance with a central heating boiler and, optionally, a separate burner, in which the generated heat is distributed via a controlled and channelled transport system to multiple separate spaces where this heat is used to condition the indoor climate of the space in question and, optionally, to a unit for the production of hot consumable water *Source: Combustion Appliances Order*
Boiler	domestic appliance that only provides heat through a heat exchanger that uses water. The appliance can be supplied with solid fuel manually or automatically. "The power of the appliance is less than or equal to 300 kW. The appliance complies with the definitions, requirements, test methods and labelling of standard NBN EN 303-5 in its latest edition *Source: RD Heating Appliances 2010*

Solid fuel boiler	a device equipped with one or more solid fuel heat generators that provides heat to a water-based central heating system in order to reach and maintain at a desired level the indoor temperature of one or more enclosed spaces, with a heat loss to its surrounding environment of not more than 6 % of rated heat output *Source: Regulation (EU) 2015/1189* *Similar definition in (EU) 2015/1187*
Solid fuel heat generator	the part of a solid fuel boiler that generates the heat through the combustion of solid fuels *Source: Regulation (EU) 2015/ 1189 and 1187*
Water-based central heating system	a system using water as a heat transfer medium to distribute centrally generated heat to heat emitting devices for the heating of enclosed spaces within buildings, or parts thereof; [including block or district heating networks] *Source: Regulation (EU) 2015/ 1189 and 1187*
Definitions regarding installation of appliances	
Flue gas pipe	construction, intended for the evacuation of flue gases *Source: Combustion Appliances Order*
Heating room	the room in which the combustion device is located *Source: Combustion Appliances Order*
Heating appliance connected as type B (non-room-sealed heating appliance)	a combustion appliance connected to a flue gas pipe, whereby the combustion air is extracted from the heating room *Source: Combustion Appliances Order*
Heating appliance connected as type C (roomsealed heating appliance)	a combustion appliance whose combustion chamber is sealed from the heating room. The pipes for the supply of combustion air and the exhaust of flue gases and the end piece form an integral part of the appliance *Source: Combustion Appliances Order*
Definitions of fuels	
Recommended solid fuel	fuel of commercial quality that is specified in the operating instructions of the appliance and which enables the performance published with the tests which are carried out in accordance with standards NBN EN 14961, NBN EN 14785, NBN EN 13240, NBN EN 13229, NBN EN 12809 and NBN EN 303-5 According to these standards and as an example, solid fuels can be logs, wood pellets, coal, etc. *Source: RD Heating Appliances 2010*
Non-recommended solid fuel	fuel not intended by the manufacturer or his authorised representative established in the European Union or by the competent service, and whose use may impair the proper functioning of the appliance and cause emissions into the atmosphere of pollutants that are a hazard to health and the environment *Source: RD Heating Appliances 2010*
Wood pellets	renewable solid compacted fuel derived from crushed woody biomass, with or without organic binder, usually cylindrical in any length between 3.15 and 45 mm, with broken ends *Source: RD Wood pellets 2011*

Woody biomass	biomass originating from trees, bushes and shrubs, including log wood, chipped wood, compressed wood in the form of pellets, compressed wood in the form of briquettes, and sawdust *Source: Regulation (EU) 2015/1185* *Similar definition in Regulation (EU) 2015/ 1186, 1187 and 1189*
Preferred fuel	the single fuel for which is to be preferably used for the solid fuel local space heater according to the manufacturer's instructions *Source: Regulation (EU) 2015/1185* *Similar definition in Regulation (EU) 2015/ 1186, 1187 and 1189*
Other suitable fuel	a fuel, other than the preferred fuel, which can be used in the solid fuel local space heater according to the manufacturer's instructions and includes any fuel that is mentioned in the instruction manual for installers and end-users, on free access websites of manufacturers and suppliers, in technical or promotional material and in advertisements *Source: Regulation (EU) 2015/1185* *Similar definition in Regulation (EU) 2015/ 1186, 1187 and 1189*
Definitions of emissions	
Flue gases (or combustion products)	the gaseous emissions from a combustion appliance that result from combustion and which contain solid, liquid and gaseous emissions *Source: Combustion Appliances Order*
Particulate matter	particles of various shape, structure and density scattered in the gaseous phase of the flue gas; *Source: Regulation (EU) 2015/ 1185 and 1189*
Seasonal emissions	a) for automatically stoked solid fuel boilers, a weighted average of the emissions at rated heat output and the emissions at 30 % of the rated heat output, expressed in mg/m3; (b) for manually stoked solid fuel boilers that can be operated at 50 % of the rated heat output in continuous mode, a weighted average of the emissions at rated heat output and the emissions at 50 % of the rated heat output, expressed in mg/m3; (c) for manually stoked solid fuel boilers that cannot be operated at 50 % or less of the rated heat output in continuous mode, the emissions at rated heat output, expressed in mg/m3; (d) for solid fuel cogeneration boilers, the emissions at rated heat output, expressed in mg/m3 *Source: Regulation (EU) 2015/1189*
Definitions of energy efficiency	
Nominal power or nominal output (rated output or rated capacity)	the maximum heat output, expressed in kW, specified and guaranteed by the manufacturer for continuous use, whereby the useful efficiency indicated by the manufacturer is achieved *Source: Combustion Appliances Order*
Combustion efficiency	the combustion efficiency calculated according to Siegert's formula *Source: Combustion Appliances Order*
Direct heat output	the heat output of the product by radiation and convection of heat, as emitted by or from the product itself to air excluding the heat output of the product to a heat transfer fluid, expressed in kW *Source: Regulation (EU) 2015/ 1185 and 1186*

Indirect heating functionality	the product is capable of transferring part of the total heat output to a heat transfer fluid, for use as space heating or domestic hot water generation *Source: Regulation (EU) 2015/ 1185 and 1186*
Indirect heat output	the heat output of the product to a heat transfer fluid by the same heat generation process that provides the direct heat output of the product, expressed in kW *Source: Regulation (EU) 2015/1186*
Nominal heat output	the heat output of a solid fuel local space heater comprising both direct heat output and indirect heat output (where applicable), when operating at the setting for the maximum heat output that can be maintained over an extended period, as declared by the manufacturer, expressed in kW *Source: Regulation (EU) 2015/1185* *Similar definition in Regulation (EU) 2015/1186*
Nominal heat output	the declared heat output of a solid fuel boiler when providing heating of enclosed spaces with the preferred fuel, expressed in kW *Source: Regulation (EU) 2015/ 1189 and 1187*
Minimal heat output	the heat output of a solid fuel local space heater comprising both direct heat output and indirect heat output (where applicable), when operating at the setting for the lowest heat output, as declared by the manufacturer, expressed in kW *Source: Regulation (EU) 2015/1185* *Similar definition in Regulation (EU) 2015/1186*
Seasonal space heating energy efficiency	the ratio between the space heating demand for a designated heating season supplied by a solid fuel boiler and the annual energy consumption required to meet that demand, expressed in % *Source: Regulation (EU) 2015/1189*

CHAPTER 1. ABOUT THIS BAT STUDY

In this Chapter we first explain the Best Available Techniques (BAT) concept. Next, we outline the general framework of this Flemish BAT study. The objectives, contents, guidance, working method and other aspects of the BAT study are clarified.

1.1. Best Available Techniques in Flanders

1.1.1. Definition

The term "Best Available Techniques", abbreviated as BAT, is defined in VLAREM II , Article 1.1.2 as follows:
"the most effective and advanced stage in the development of activities and methods of operation, whereby the practical usefulness of special techniques for providing in principle the basis for emission limit values and other permit conditions is demonstrated, with the intention of preventing all emissions and impacts on the environment or where that is not practicable to generally reduce them;

- "techniques" means both the applied techniques and how the installation is designed, built, maintained, operated and decommissioned;
- "available" means that the techniques concerned are developed on a scale which allows implementation in an industrial context, under economically and technically viable conditions, regardless of whether these techniques are applied or produced on the territory of the Flemish Region, as long as they are reasonably accessible to the operator;
- "best" means the most effective for achieving a high general level of protection of the environment as a whole."

This definition is the starting point for the implementation of the BAT concept in the domestic wood heating sector in Flanders.

1.1.2. Best Available Techniques as a concept in the Flemish environmental policy

→ **Background of the concept**

Almost every human activity (e.g. housing construction, industrial activity, recreation, agriculture) affects the environment in one way or another. Often it is not possible to estimate how harmful the impact is. Due to this uncertainty, every activity is considered to have to be carried out with maximum care in order to burden the environment as little as possible. This is the so-called precautionary principle.

In its environmental policy for businesses, the Flemish Government has translated this precautionary principle into the requirement of applying the "Best Available Techniques". This requirement is included as such in the general rules of VLAREM II (Art. 4.1.2.1). Applying BAT means first and foremost that every operator should do everything that is technically and economically possible to avoid environmental damage. In addition, compliance with permit conditions is also deemed to conform with the obligation to apply BAT.

Within the Flemish environmental policy, the concept of BAT is mainly used as a basis for laying down permit conditions. Such conditions which are imposed on establishments in Flanders are based on two principles:

- the BAT are applied;
- the remaining environmental effects must not compromise the defined environmental quality objectives.

The European Industrial Emissions Directive (2010/75/EU) and its predecessor, the "IPPC" Directive (2008/1/EC), also require member states to support these two principles when defining permit conditions.

Domestic wood combustion is not a classified activity in VLAREM, so no permit conditions apply. This does not alter the fact that it makes sense to determine BAT for this activity as well. Knowledge regarding BAT enables policy makers, manufacturers, installers, users and other stakeholders to take better substantiated measures to reduce the environmental impact of domestic wood heating.

→ Implementing the concept

To substantiate the BAT concept, we need to clarify the general definition of VLAREM II in more detail. The BAT Knowledge Centre uses the following explanations for the three elements.

- "Best" means "best for the environment as a whole", whereby the impact of the technique under consideration on the various environmental compartments (air, water, soil, waste, etc.) is carefully assessed;
- "Available" means the fact that it is available on the market and reasonably priced. In other words, the techniques are no longer in an experimental stage but have effectively proven their value in practice. The cost price is deemed reasonable if it is feasible for an 'average' user and is not disproportionate to the environmental result achieved;
- "Techniques" are technologies and organisational measures. They concern technical adaptations, the use of less polluting raw materials, end-of-pipe measures, as well as good practices.

1.2. BAT STUDY FOR DOMESTIC WOOD HEATING

1.2.1. BACKGROUND OF THE STUDY

Domestic wood heating contributes to the renewable energy generation target, but is also the cause of a number of problems. Stoking wood gives rise to emissions of pollutants such as fine dust, BC, dioxins, PAHs and NMVOCs. Emissions are higher when older and polluting appliances are used, when stoking in incorrectly installed appliances or if the appliance is not used correctly, and when wood is not dry enough. Emissions from domestic wood heating have a negative impact on air quality, especially during the heating season, with possible health effects as a result, both for users and in the vicinity. This type of heating may also cause nuisance for local residents.

To solve these problems, the Green Deal – Domestic Wood Heating was signed in 2018 (https://omgeving.vlaanderen.be/green-deal-huishoudelijke-houtverwarming). The initiators of the Green Deal are the Department of Environment and Spatial Planning and the Federation for the technology industry, Agoria-CIV. Together with 21 other partners, they are committed to implementing 27 actions included in the Green Deal. The objective is to reduce emissions of fine dust, BC, dioxins, PAHs and NMVOCs from domestic wood heating by at least 50% by 2030.

This BAT study is being prepared as part of the Green Deal and more specifically within the framework of the following 2 actions:

- research into potential technological improvements for new appliances (action 1.2.2)
- research into the feasibility and potential of retrofitting old, polluting combustion appliances (action 1.1.2).

1.2.2. Targets and scope of the study

This BAT study includes a BAT analysis for domestic wood heating. The purpose of the study on domestic wood heating is to:

- identify measures that can be taken to prevent or reduce emissions and effects on the environment;
- select the BAT (Best Available Techniques) from the inventoried measures;
- formulate recommendations to policymakers, manufacturers, installers, users and other stakeholders based on the BAT.

The most important emissions within the scope of this study are emissions to air (fine dust, BC, CO, dioxins/PAHs, NMVOCs). Energy efficiency is also a point for attention.

As far as heating technologies are concerned, the study is limited to appliances intended for local or central indoor heating with wood, and specifically for residential applications (households). The various appliance types that fall within the scope of the study are listed in paragraph 2.1. Non-wood fuel appliances (e.g. gas or coal stoves, oil boilers, etc.) or wood appliances used for other applications than domestic wood heating (e.g. sauna stoves, cookers, ovens, outdoor heating, etc.) are outside the scope of the study.

The focus of the study is on techniques and good practices, not on policy measures. The switch to other heating technologies is also not within the scope of this study.

In addition to measures for the design of new appliances and the retrofitting of old appliances, the study also focuses on measures for the installation and use of appliances, and for the maintenance and service/inspection of appliances and flue gas pipes. However, this is discussed in less detail and will be the subject of other actions in the framework of the Green Deal – Domestic Wood Heating.

1.2.3. Content of the study

The starting point of the study on the Best Available Techniques for domestic wood heating is a socio-economic screening (chapter 2).

Chapter 3 describes the wood combustion process and the fuels and appliances used, and we assess the environmental impact.

Chapter 4 provides an inventory of environment-friendly techniques for domestic wood heating based on extensive research of the literature together with data obtained from federations, suppliers, specialists from the public administration and other experts. An assessment is subsequently made for each of these techniques in chapter 5, in respect of not only the overall environmental efficiency but also of the technical and economic feasibility. This in-depth assessment allows us to select the Best Available Techniques.

The BAT, in turn, form the basis for a number of suggestions for policymakers, manufacturers, installers, users and other stakeholders (Chapter 6). Chapter 7 further describes emerging techniques and includes recommendations for further research and technological development.

A large number of literature sources were consulted to prepare this BAT study. These can be found at the end of the report. In order to increase the readability of the report, it was decided not to overload the text itself with source references. Source references have only been included for very specific information obtained from a specific source.

CHAPTER 2. SOCIO-ECONOMIC & ENVIRONMENTAL-LEGAL POSITIONING OF THE SECTOR

In this chapter we will situate and examine the activity of domestic wood heating, both socio-economically and environmental-legally.

First we try to describe the activity and delineate the subject of study as precisely as possible. Next we discuss a number of relevant socio-economic aspects. In a third section we discuss the most important environmental-legal aspects in more detail.

2.1. Description , delineation and classification of the sector

2.1.1. Delineation of the domestic wood heating activity

The BAT study for domestic wood heating focuses on the combustion of wood in appliances for local or central indoor heating, and specifically for residential applications (households). Non-wood fuel appliances (e.g. gas or coal stoves, oil boilers, etc.) or wood appliances used for other applications than domestic wood heating (e.g. sauna stoves, cookers, ovens, outdoor heating, etc.) are outside the scope of the study.

2.1.2. Technical classification of the sector

Different approaches are possible for the classification of appliances. The correlation table (Excel file as Appendix 3 to this study) gives an overview of a number of classifications in use and the similarities between them. The listed classifications are those discussed in paragraph 2.3 according to the various regulations (EN standards, RD, ecodesign, Germany, Austria, Denmark and Energy labelling). The BAT study mainly uses the following classification:

- Open fireplace
- Inset stove or cassette
- Built-in stove
- Freestanding stove – non-slow heat release
- Mass stove
- Boiler

A detailed description of these appliance types is given in paragraph 3.3.

The various classifications are based on several criteria. The main criteria are described briefly below:

- Local heat output versus central heating
- Direct or indirect heat output
- Open or closed combustion chamber
- Installation method

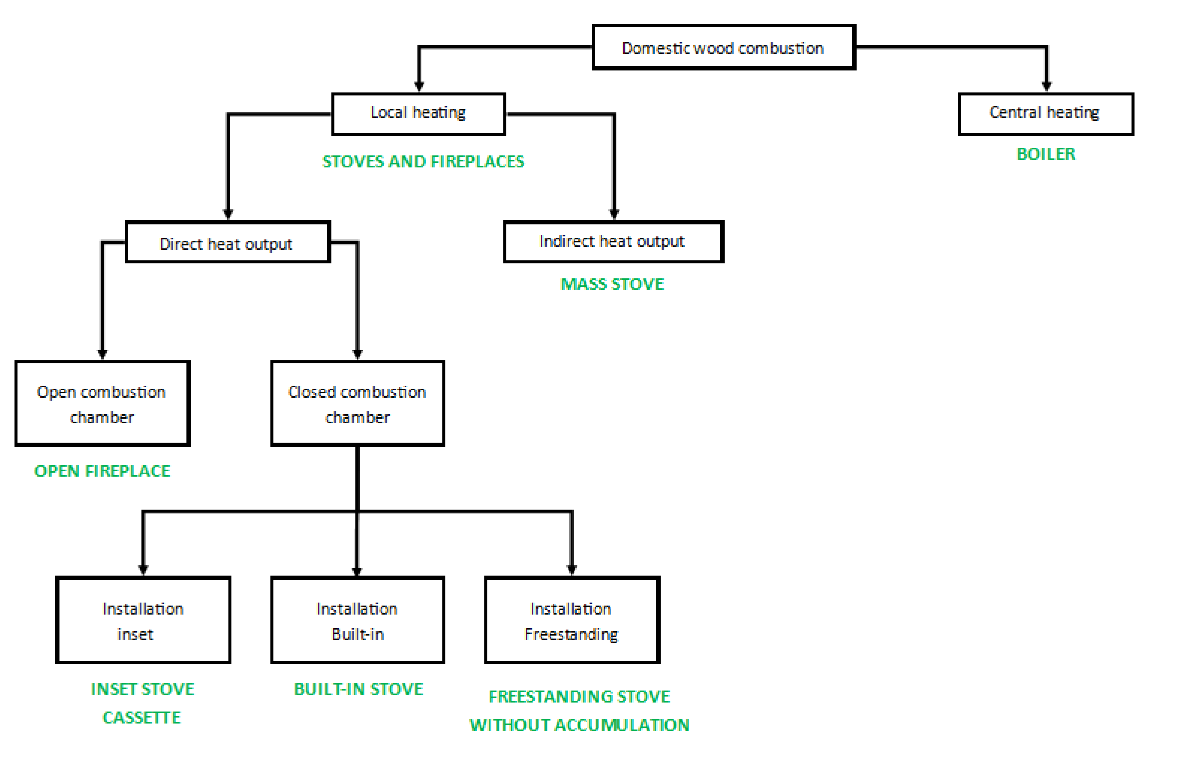

Figure 1: technical classification of domestic wood heating

A first distinction can be made on the basis of the **place of heat output**. If the heat is emitted to the space in which the appliance is located, this is referred to as **local space heating**. The term **central heating** applies if the heat is used to heat other rooms. The distinction between boilers and stoves/fireplaces is based entirely on this criterion: boilers are used for central heating, stoves/open fireplaces for local space heating (see also the List of Definitions in the beginning of the report).

In addition, a distinction is made between **direct and indirect** heat output where direct heat output is by convection or radiation and indirect heat output is with systems where the heat is temporarily stored in an intermediate medium. In boilers, the heat is transferred via a heat exchanger to an intermediate medium such as water or air in order to heat other rooms. Mass stoves temporarily store the heat in a solid intermediate medium such as stone to gradually release it into the room. With the other stoves and fireplaces, the heat is released directly (via convection and/or radiation) in the space. Some stoves also have the option of connecting to a central heating system in order to release heat in other spaces besides the local space heating.

Whether **or not** the **combustion chamber is closed** is the basic criterion for the distinction between an open fireplace and all other appliances for domestic wood heating. An open fireplace has an open front. In stoves and boilers, the combustion chamber is closed. An exception to this are the so-called lifting door fireplaces. These stoves with a (glass) door can be used in an open, semi-open or closed set-up and are an alternative to a real open fireplace.

The further distinction between different types of stoves is based on **the method of installation**. A freestanding stove is a freestanding appliance that is placed on the floor. An inset stove/cassette is integrated in an existing chimney opening or a chimney casing/wall. In the case of a built-in stove, the chimney is built around the appliance (mainly new construction or thorough renovation).

Within the various types of appliances, further distinctions can be made on the basis of the following criteria, among others:

- Type of fuel
- Fuel supply
- Continuous or non-continuous systems
- Airtightness: open or closed in relation to the living space
- Automation air supply
- Other classifications: age, application and capacity

For all appliance types, a distinction can be made according to the **type of recommended fuel** (logs, pellets, briquettes, wood chips). Only logs can be used in open fireplaces. For stoves and boilers, a distinction is made between the systems fired with pieces of wood (logs, briquettes and, in the case of a boiler, also wood chips) and the pellet-fired systems. There are also appliances on the market that are designed to fire both pellets and pieces of wood. These units are based on a pellet appliance with an extra grate for pieces of wood. The combustion chamber is optimised for pieces of wood, resulting in a limited efficiency loss for pellets.

Related to this is **whether the fuel is supplied automatically or not**. Pellet appliances always have an automatic fuel supply. They either have local storage in the appliance itself that needs to be refilled regularly (daily) or, in the case of boilers, can be connected to a larger silo. With appliances fired with pieces of wood, the fuel supply is generally manual; boilers with an automatic supply of pieces of wood do exist but are rare.

For wood-fired appliances without automatic supply, it is also important to distinguish between appliances suitable for **continuous use and non-continuous use**. Appliances for continuous use are able to burn for a relatively long time with a relatively high wood load (7 to 8 kg of wood). The combustion chamber is quite high or deep and air is controlled in such a way that the pile of wood burns away slowly.

The distinction between **closed and open in relation to the living space** is also very important. Appliances that are open in relation to the living space extract the air for combustion from the living space itself. This in turn requires that this space is also supplied with the necessary air from outside. Airtight appliances are sealed from the living space and are equipped with an air supply duct.

Within the various types of appliances, further distinctions can be made based on the applied **air supply automation** and required control systems. In general, the rule is that the more automation, the less influence the user has. Most appliances in use which are fired with pieces of wood are still mainly controlled manually. Certain manufacturers offer standard semi-automatic appliances in which a number of operations are performed mechanically (e.g. air supply at start-up). Gradually, these devices will evolve to become fully automatic systems that are controlled electronically. Pellet appliances are already fully automatic.

In addition to the classification based on the technical characteristics mentioned above, appliances can also be classified by other means, e.g. on the basis of capacity, application or age of the appliance. This last classification, in combination with the technical classification, is relevant when preparing emission inventories (see paragraph 3.4.4). Classifications based on application (main or auxiliary heating) or location of the heating system (rural or urban environment) are also relevant in this context, but they do not so much relate to the appliance itself as to how it is used. This also applies to the capacity that depends on the type of house (detached/terraced house, old/modern, etc.) as well as the space(s) to be heated. Most wood stoves have a capacity of 8 to 10 kW; less than 6 kW is not suitable for pieces of wood as it is technically too complex and the temperature is not high enough. Pellet stoves may have a lower capacity.

For more information about the criteria and the link with the different types of appliances, please refer to chapters 3 & 4.

2.2. Socio-economic positioning of the sector

2.2.1. Domestic wood heating in Flanders

For the figures on domestic wood consumption in Flanders we refer to the 'Energy Balance Flanders 1990-2017 (Jespers, Neven, Renders, Vingerhoets, & Pelgrims, 2019)'. Based on the available data sources, this report provides an overview of energy flows, production and consumption in Flanders in 2017 and charts the evolutions since 1990.

For 2017, domestic biomass consumption is estimated at 13.5 PJ. Total energy consumption in households in 2017 is estimated at 193.9 PJ. The relative contribution of biomass (wood) is therefore about 7%. The figure below shows the evolution of domestic energy consumption in the period 1990-2017 for wood and other energy sources. This shows a gradual increase in the share of wood in total domestic energy consumption.

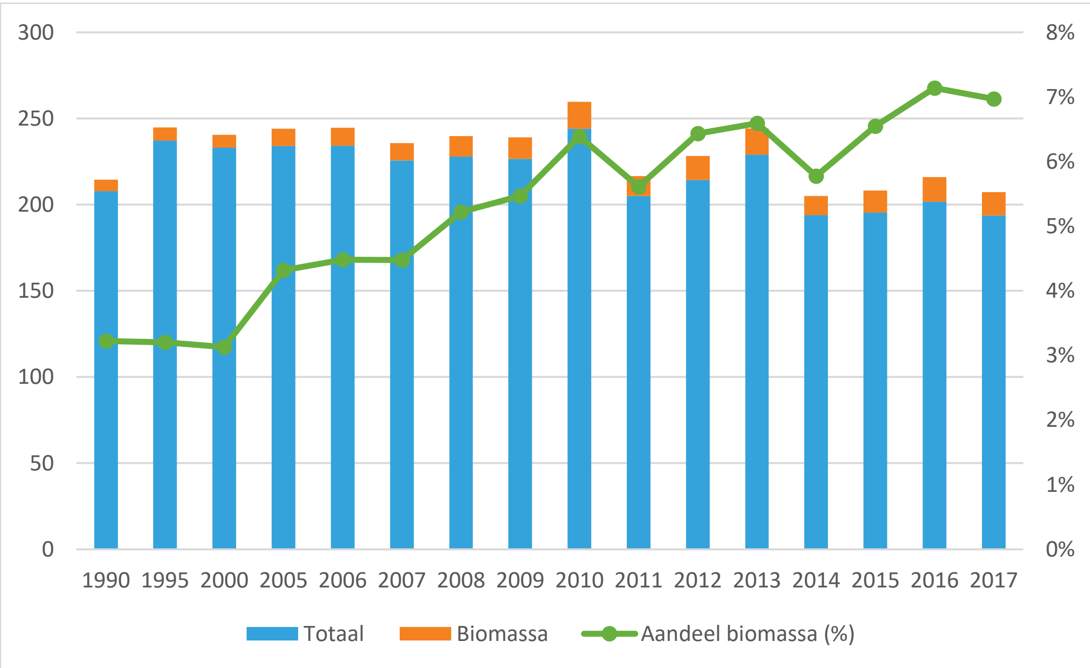

Figure2: Evolution of domestic energy consumption (the green line indicates the share of biomass) (Jespers, Neven, Renders, Vingerhoets, & Pelgrims, 2019)

It should be noted that the estimates of biomass consumption by households are to a large extent based on an energy survey (ECS survey) of households with data for the year 2010. This has resulted in a significant level of uncertainty. The annual update of the balance sheet takes into account changes in the level of urbanisation and degree-days in Flanders.

In 2019, the Flanders Environment Agency (VMM) (Veldeman Nele, 2019) commissioned an online survey on domestic wood heating with a sample of 596 effective wood-burning users, who together reported a total of 715 wood installations. According to the summary of the survey results, 21% of Flemish households use wood as a fuel. The use of wood is higher in rural areas. Wood is almost exclusively used as a fuel in houses. These are often older houses, owned by the occupant. Wood is mainly stoked as auxiliary heating, for the cosiness. A minority of 20% of wood-burning users said that they use wood as their main source of heating.

2.2.2. Inventory of appliances for domestic wood heating in Flanders

According to the online survey commissioned by VMM (Veldeman Nele, 2019), the total number of appliances in Flanders was estimated at 700,000. The distribution of installations by type and age, as reported by the respondents, is presented in Figure 3 and Figure 4.

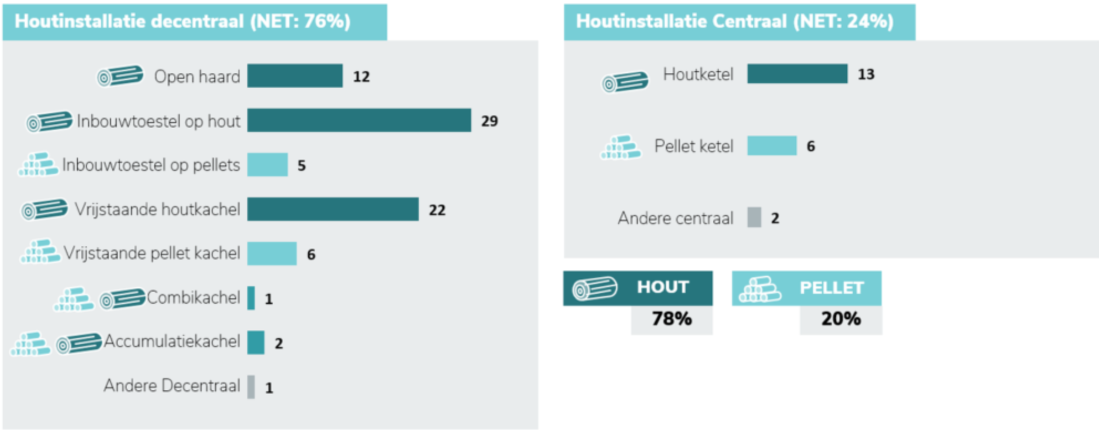

Figure 3: Distribution of installations by type, survey results (left figure concerns local heating, right figure concerns central heating (Veldeman Nele, 2019)

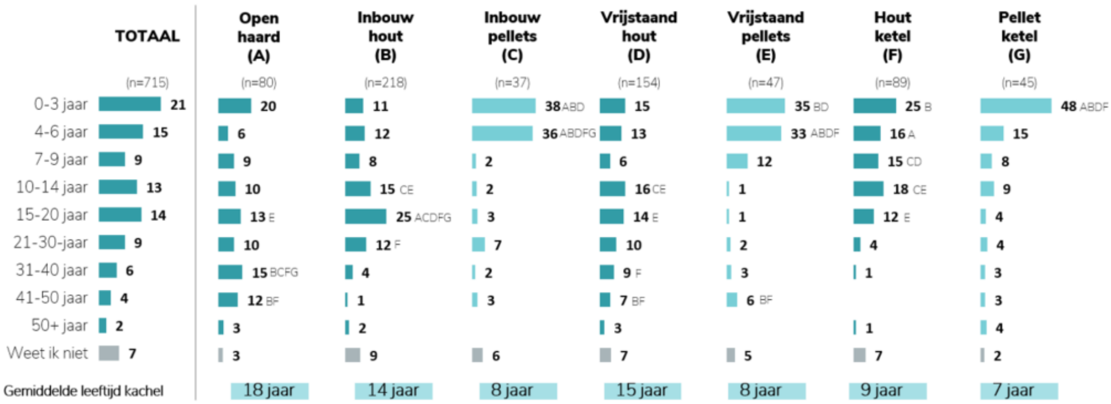

Figure 4: Distribution of installations by age, survey results (Veldeman Nele, 2019)

When analysing the data obtained from the survey (Veldeman Nele, 2019), the share of boilers in the Flemish total of domestic wood burning appliances was considered to be unrealistically high, especially as many boilers older than 20 years were also reported. Previous studies have shown that it is very difficult to find old (> 20 years) Flemish wood boilers. Therefore, it was assumed that there were errors in the survey results, for example because respondents specified the age for an existing fuel oil heating system (including central heating) or had a wood stove (decentralised) in mind instead of a wood-burning boiler.

2.2.3. THE STOVE AND BOILER MARKETS IN FLANDERS

→ **Socio-economic positioning of the sector**

The Flemish/Belgian sector of domestic wood heating (stoves/boilers) comprises different types of activities. A clearly defined NACE code does not exist for this sector and the companies active in this sector are classified in different NACE codes, so it is difficult to provide a comprehensive economic overview of the activities. A first group of companies produce and/or distribute appliances. A second group of companies are the installers who ultimately sell the appliances to the consumer and also take care of the installation. Direct sales of appliances through the 'do-it-yourself' stores also exists and this often involves imported stoves. Sales of wood and pellets is also an important part of this sector in addition to the activities related to appliances. Again, it is very difficult to obtain a good overview of the companies active in this sector and this is not described here. The companies active in this market are all SMEs.

Starting from the members of Agoria, who produce and/or import domestic wood heating appliances, an estimate was made of several economic data from the sector of stove builders, importers and distributors. This concerns 20 companies that had a total turnover of 235 million euros in 2018 with an added value of 45.5 million euros. In 2018, the sector employed around 600 FTEs. An estimate was also made of the sales figures of stoves in Belgium based on a survey of the members of Agoria. This shows that from 2013 to 2018, stove sales fell by as much as 37%, and this translated clearly into a decrease in added value and employment in the sector of -12% and -15.5% respectively between 2013 and 2018. Turnover includes both production for sales in Belgium and exports, while the stove sales survey focuses solely on the domestic market. The companies that produce appliances in Belgium also export appliances abroad, and this explains the difference between the very sharp drop in sales on the one hand and the slightly less sharp drop in turnover and employment on the other.
This decrease can be explained by several aspects. A first element is that the winters of 2014 and 2015 were quite mild, and this led to a traditional decline in sales. However, since 2016, winters have been colder again but this has not translated into a recovery of stove sales; on the contrary, a further decline in sales was measured. According to Agoria, this may be explained by the fact that heating advice communications at times of high fine dust concentrations started from 2016 onwards, and this may have discouraged consumers from replacing their old stove.

→ **Prices of appliances**

The prices of appliances may vary greatly depending on the capacity of the appliance and the degree of finishing, design and automation. An evolution towards lower capacity (and probably cheaper appliances in theory) can be expected in the future due to increasing insulation levels of dwellings. The cost of delivering and installing the appliance, including connection to the flue gas pipe, must also be taken into account in addition to the purchase price for the actual appliance. If no flue gas pipe is available or it is not suitable, additional costs must be taken into account to create or modify a flue gas pipe.

Table 1 gives the price ranges based on a survey of the different manufacturers/importers (see paragraph 4.8), whereby they were asked to describe their cheapest and most expensive models. These figures and the associated techniques and emissions show that in general there is no clear link between the technology used, the price of the appliance and the emissions levels. The reason for this is that stove prices also include a significant cost for the design which is often much higher than the extra cost for additional emission-reducing techniques.

Table 1: Price ranges for new appliances according to survey of manufacturers/importers, rounded off to 500 EUROS

Appliance type	Price range (EUROS)
Wood stove – inset stove/cassette	2,000 – 3,000
Wood stove – built-in stove	2,000 – 7,500
Wood stove – freestanding stove – non-slow heat release	500 – 5,000
Wood stove – mass stove	3,500 – 11,000
Pellet stove – freestanding stove – non-slow heat release	2,500 – 5,500
Pellet stove – mass stove	4,000 – 9,500
Pellet boiler	6,000 – 11,000

Some price ranges as found in the literature are given below. These are always cost prices for new appliances. Older appliances are offered at lower prices on the second-hand market.

Livios published an overview with indicative prices for stoves and fireplaces on its website (see Table 2 for these price ranges). For these indicative prices a selection was made from the latest edition of the 'Borderel van Eenheidsprijzen' (Statement of Unit Prices), compiled by Architecten & Ingenieursbureau Aspen. These figures are based on average prices for small-scale projects for houses and apartments. The prices include installation and connection to an existing chimney, without construction works, and exclusive of VAT.

Table 2: Price ranges for new appliances according to Livios, including installation, rounded off to 500 EUROS

Appliance type and capacity	Price range (EUROS)
Pellet stove – freestanding	2,500 – 5,000
Pellet stove – built-in	3,000 – 3,500
CH pellet stove	4,500 – 5,500
Wood stove – freestanding - cast iron	1,000 – 3,000
Wood stove – built-in - cast iron	2,000 – 3,000
Wood stove – built-in – with CH connection	3,000 – 6,000

The French agency Ademe also published typical price ranges for new appliances, excluding installation. These are given in Table 3.

Table 3: Price ranges for new appliances, excluding installation (Ademe, 2018)

Appliance type	Price range (EUROS)
Boiler with reverse combustion - pieces of wood	3,000 – 6,000
Boiler with hydro-accumulation tank - pieces of wood	6,000 – 14,000
Boiler – Wood chips	15,000 – 22,000
Automatic boiler – pellets	5,000 – 15,000
Condensing boiler – pellets	10,000 – 20,000
Inset or built-in stove	1,000 – 5,000
Stove - pieces of wood	1,000 – 5,000
Stove – pellets	1,600 – 6,000
Mass stove – pieces of wood	5,000 – 16,000

The agency Ademe gives following indicative prices for the installation:

- 250 to 1,500 euros for stoves, insert fireplaces and non-automatic boilers
- 2,000 to 3,000 euros for automatic boilers.

2.3. ENVIRONMENT-LEGAL POSITIONING OF THE SECTOR

The sections below outline the environment-legal framework of this BAT study. The focus is mainly on regulations in Flanders. In addition, national and European regulations are also discussed, as well as regulations in a number of European countries. In addition to regulations, environmental labels are also discussed.

To enable a better comparison of the requirements for appliances in different regulations and eco-labelling systems, two overview tables were drawn up in Excel. These have been included as appendixes to the BAT study.

- Appendix 3: Excel file 'correlation table': this compares the classification of types of appliances used in the various regulations and eco-labelling systems, and indicates which types correspond to each other in terms of content;
- Appendix 4: Excel file 'overview of standards': this contains an overview of the requirements from the various regulations and eco-labelling systems for different types of appliances and different parameters, and lets you (via the 'Pivot table' tab) generate different tables so you can compare them in different ways.

2.3.1. FLEMISH REGULATIONS

→ VLAREM II

VLAREM II (Order of the Flemish Government with the general and sectoral provisions on environmental hygiene) regulates the classification and environmental conditions for nuisance-causing establishments in the Flemish Region.

VLAREM II distinguishes between three classes of nuisance-causing establishments. Establishments or activities of the first class present the highest risks or nuisances. Establishments or activities of the third class present the lowest risks or nuisances. The class to which an establishment belongs depends on the items listed in Appendix 1 to VLAREM II 'Classification list'. Combustion installations with a nominal thermal input < 300 kW are **not classified** in VLAREM. This means that the combustion of pure wood fuels (including wood from forest maintenance, wood pellets, etc.) in domestic appliances is allowed and that VLAREM does not impose any environmental conditions (except for the conditions in part 6 – see below).

The **incineration of waste**, including wood waste, is classified under VLAREM (Section 2.3.4 'Storage and incineration or co-incineration'). This means that for this activity an integrated environmental permit must be applied for, and that the relevant environmental conditions must be complied with. In practice, this is not a realistic option for domestic applications, which means that incineration of waste in domestic wood heating appliances can be considered prohibited by definition. VLAREM provides an exception to this for 'the incineration of untreated wood waste with water content not exceeding 20%, excluding sawdust, curls, shavings, dust and chips, in appliances for heating living and working spaces, in heaters used to enjoy the decorative function of the flame ('decorative' heaters) and in similar appliances with a maximum nominal thermal capacity of 300 kW'. This activity does not fall under heading 2.3.4 and is therefore non-classified (= allowed). This is subject to VLAREMA conditions (see below).

Section 6 of VLAREM II sets out environmental conditions for non-classified establishments. Chapter 6.6 contains environmental conditions for non-classified establishments for heating of buildings. It states the following:

Article 6.6.0.1
The provisions of the Order of the Flemish Government of 8 December 2006 on the maintenance and inspection of central burners for the heating of buildings or the production of hot consumption water apply to central burners other than those stated in section 43 of the classification list, which are mainly used to heat buildings and, optionally, to produce hot consumption water.

Part 6 of VLAREM II does not contain any conditions for local space heating appliances (stoves and fireplaces).

For more information:
- Link to the most recent version of VLAREM II: https://navigator.emis.vito.be/mijn-navigator?woId=263&woLang=nl

→ VLAREMA (Order of the Flemish Government of 17 February 2012)

The VLAREMA is an implementation order of the Materials Decree. It contains more detailed rules on (special) wastes, raw materials, selective collection, transport, the obligation to keep records and extended manufacturer responsibility. Article 4.5.2 of VLAREMA imposes a **ban on** the incineration or use as fuel of certain waste streams, including wood waste. This ban applies, inter alia, to wastes collected separately for recycling and to wastes which, because of their nature, quantity or homogeneity, can be re-used or recycled in accordance with the most appropriate and available techniques, whether or not after pre-treatment or further sorting.

- Link to the most recent version of VLAREMA: https://navigator.emis.vito.be/mijn-navigator?woId=43991&woLang=nl

→ **Combustion Appliances Order (Order of the Flemish Government of 8 December 2006)**

The Order of the Flemish Government of 8 December 2006 on the maintenance and inspection of **central heating appliances** for the heating of buildings or for the production of hot consumption water, in short the Combustion Appliances Order, has been applicable in the Flemish Region since 1 June 2007. The order has already been amended several times. These regulations contain provisions relating to the inspection prior to the first use, maintenance and the heating audit for central heating appliances.

According to the Combustion Appliances Order, a central heating appliance is a heating appliance that distributes the generated heat via a transport system to several separate spaces where this heat is used to condition the interior climate of the room in question. Such a combustion appliance may optionally be equipped with a facility for the production of sanitary hot water (Article 2, 9°). A stove does not fall under this definition and is therefore not subject to the Combustion Appliances Order.

For central heating appliances fired with solid fuels, including wood, the **requirements** set out in the Combustion Appliances Order are summarised in Table 4.

Table 4: Obligations imposed by the Combustion Appliances Order on owners and users of central heating appliances using solid fuels (including wood)

What	Inspection before first use	Maintenance [2]	Heating audit
Mandatory for	Owner (landlord)	User (tenant)	Owner (landlord)
Capacity	All	All	From 20 kW
When	New central heating appliance[1]	Annually	Together with the first maintenance service after the appliance has reached the age of 5 years and thereafter 5-yearly
To be carried out by:	Skilled professional or certified technician	Skilled professional or certified technician[3]	Certified heating audit technician
Documentation	Inspection report and combustion certificate	Cleaning and combustion certificate	Heating audit report

[1] A new central heating appliance is an appliance that:

a. is used for the first time;
b. is fitted with a new boiler or burner;
c. has been refurbished (e.g. replacement of the connection piece with the flue gas pipe);
d. has been moved.

[2] Maintenance of a central heating appliance that uses solid fuel consists of checking the general operating state and safety of the central heating unit, cleaning and checking the flue gas pipe, and cleaning the internal parts which come into contact with the flue gases.

[3] Cleaning and checking the flue gas pipe should always be carried out by a chimney sweep. This must be done prior to the service visit.

The correct and safe state of operation is checked during the initial commissioning inspection and maintenance service checks.

Safe state of operation relates to the safety aspects for users, or all aspects that may harm the health of users (e.g. CO formation and consequently ventilation, fire safety, etc.). A solid fuel central heating appliance is deemed to be in a safe state of operation if the following conditions are met:

- there is sufficient draught in the flue gas pipe so that the flue gases are discharged easily, in accordance with the code of good practice
- The heating room is ventilated sufficiently and there is a sufficient supply of combustion air according to the code of good practice (i.e. the manual of the appliance).

The correct state of operation relates to the technical combustion part of the inspection or maintenance service. A solid fuel appliance shall be in the correct state of operation if it complies with the condition that it emits harmful and polluting smoke only rarely and for short periods of time.

For more information:

- Most recent version of the Combustion Appliances Order: https://navigator.emis.vito.be/mijn-navigator?woId=29139&woLang=nl
- Information from the Department of Environment and Spatial Development for technicians: https://omgeving.vlaanderen.be/informatie-voor-erkende-technici-centrale-verwarming
- Information from the Department of Environment and Spatial Development for owners and users:
  https://omgeving.vlaanderen.be/veilig-verwarmen
- Standards NBN B 61-001/002 containing requirements for the design of combustion compartments

→ VLAREL (Order of the Flemish Government of 19 November 2010)

The regulations on recognitions can be found in the Order of the Flemish Government of 19 November 2010 establishing the Flemish regulation on environmental recognitions, abbreviated as VLAREL. The VLAREL has been applicable since 1 January 2011 and has been amended several times since then. The regulation includes provisions relating to the procedure and conditions for obtaining recognition, the compulsory five-yearly refresher training, payment of the fee and notifications of changes in identification data. Article 6 of the VLAREL lists the different categories of recognitions. In the context of this BAT study, the category 2c '**certified heating audit technician** as mentioned in article 6 of the order regarding the maintenance and inspection of central heating appliances' is important (art. 6, 2° VLAREL).

For more information:

- Link to the most recent version of the VLAREL: https://navigator.emis.vito.be/mijn-navigator?woId=38542&woLang=nl
- Information from the Department of Environment and Spatial Development about recognitions:
  www.omgevingvlaanderen.be/erkenningen

→ Energy Order (Order of the Flemish Government of 19 November 2010)

The Energy Order (Order on general provisions of the energy policy) is part of the energy performance regulation. Title VIII of the Energy Order deals with the 'Recognition of energy experts, reporters, training and examination institutions and the certification of contractors and installers'. Article 8.5.1 of Title VIII lists the categories of works for which a **certificate of competence** may be introduced on a voluntary basis in order to guarantee the quality of contractors and installers. For the purpose of this study, categories 4 (installation of a biomass stove for decentralised heating, up to a maximum thermal capacity of 100 kW) and 5 (installation of a biomass boiler for the production of domestic hot water or heating, up to a maximum thermal capacity of 100 kW) are relevant.

For more information:

- Link to the most recent version of the Energy Order: https://navigator.emis.vito.be/mijn-navigator?woId=59734&woLang=nl

2.3.2. Federal regulations

→ Royal Decree on heating appliances (Royal Decree of 12 October 2010)

The requirements for domestic solid fuel heating appliances (e.g. pieces of wood, wood pellets, coal, etc.) are stipulated in the Royal Decree regulating the minimum requirements for efficiency and emission levels of pollutants for solid fuel heating appliances, in short the RD on heating appliances. Stoves and boilers that do not comply with the conditions of this Royal Decree may not be put on the market in Belgium[2].

Annex I and Annex II to the Royal Decree set out the **minimum efficiency requirements and maximum emission levels**. These have gradually become more strict: Phase I started at the end of 2011, Phase II applied from the end of 2013 and Phase III started on 24 November 2016. The requirements depend on the type of appliance. A distinction is made between freestanding stoves, inset stoves, slow heat release appliances, pellet appliances, open fireplaces, boilers and boiler-stove combinations (for definitions of appliance types, see list of definitions). The requirements for Phase III are summarised in Table 5. All requirements apply at rated capacity. The emissions are expressed at a reference oxygen content of 13% for stoves and at 10% for boilers.

Table 5: Phase III requirements for solid fuel heating appliances from the Royal Decree on heating appliances

Appliance and relevant standard	Minimum efficiency levels		Maximum value of CO emissions		Maximum value of particulate emissions(2)	
	continuous	non-continuous	continuous	non-continuous	continuous	non-continuous
Freestanding stove NBN EN 13240	≥ 65 %	≥ 75 %	≤ 0.8 %	≤ 0.1 %	≤ 150 mg/Nm³	≤ 40 mg/Nm³
Inset stove NBN EN 13229	≥ 65 %	≥ 75 %	≤ 0.8 %	≤ 0.1 %	≤ 150 mg/Nm³	≤ 40 mg/Nm³
Slow heat release appliance fired with solid fuel NBN EN 15250	≥ 75 %		≤ 0.1 %		≤ 40 mg/Nm³	
Pellet appliance NBN EN 14785	≥ 85 %		≤ 0.02 %		≤ 30 mg/Nm³	

[2] 'To be put on the market' is defined in the Product Standards Act as: 'to introduce, import or possess with a view to selling or making available to third parties, to offer for sale, selling, offer for rent, to rent, or grant for valuable consideration or free of charge'. Whether the second-hand market also falls within this definition is a matter of discussion.

Boiler-stove NBN EN 12809	≥ 75 %	≤ 0.1 %	≤ 150 mg/Nm³
Boiler NBN EN 303-5	≥ 75 %	≤ 1.5 g/Nm³	≤ 100 mg/Nm³
Open fireplace(1) NBN EN 13229	≥ 65 %	≤ 0.8 %	≤ 300 mg/Nm³

(1) These are only open fireplaces that are designed as 'appliance'. Open masonry fireplaces or similar do not fall within the scope of the Royal Decree according to Art. 3.
(2) measured according to TS 15883 (European Technical Specification for 'Residential solid fuel burning appliances - Emission test methods): The requirements are set in line with the 'heated filter' method. The emission levels are not achievable using the 'flow dilution tunnel' method. The gravimetric method is used for boilers, with exclusion of particulate matter formed by gaseous organic compounds when flue gases come into contact with the ambient air. See paragraph 3.4.1 for more information on the measuring methods used.

In order to be put on the market, solid fuel heating appliances must have a '**declaration of conformity**' stating that the appliance complies with the statutory emission and efficiency requirements laid down in the Royal Decree. The declaration is drawn up by the manufacturer or his authorised representative based in the European Union for each type or model of appliance and this declaration must be included in the technical manual for the appliance. The declaration also contains the following information:

- The name of the manufacturer or his authorised representative based in the European Union
- The commercial brand of the appliance
- The type or model
- The reference of the inspection report, the name of the laboratory that prepared the report and the reference of the standard used
- The capacity or range of capacities (in kW)
- The level of efficiency (measured in a lab test)
- The emission of CO (measured in a lab test)
- Particle emissions (measured in a lab test)
- Information on the recommended solid fuel
- Information on the non-recommended solid fuel

The list of solid fuel appliances declared by the manufacturer to be in conformity with phase III of the Royal Decree can be consulted on the website of the FPS Public Health, Food Chain Safety and Environment. The declaration of conformity for each appliance can also be consulted here. Market checks are carried out by the FPS Environment.

For more information:

- Link to the RD on Heating Appliances:
  http://www.emis.vito.be/node/21650
- Link to the list of appliances on the website of the FPS Public Health, Food Chain Safety and Environment:
  https://www.health.belgium.be/nl/e-services/lijst-van-verwarmingstoestellen

→ Royal Decree on Wood Pellets (Royal Decree of 5 April 2011)

The Royal Decree laying down the requirements that wood pellets must meet in order to be used as fuel for non-industrial heating appliances regulates the quality of wood pellets.

Article 5 of the decree stipulates product standards for wood pellets. It concerns conditions on the origin of the wood used to produce the pellets (chemically untreated wood, from sustainable forest management) and technical requirements (inter alia humidity, ash content, calorific value, dimensions, etc., chemical composition).

In order to be put on the market, pellets for solid fuels must have a '**Label of certified quality**' declaring that the pellets comply with the requirements of the Royal Decree, inter alia:

- origin of the wood: wood used for the production of pellets must contain chemically untreated wood and come from sustainable forest management operations such as those bearing the FSC and PEFC labels. Other labels can be used as long as they respect the same sustainable forest management objectives as the FSC and PEFC labels
- they must have a moisture content of less than 10 percent and an ash content of less than 1.5 percent
- the calorific value must be at least 16.3 MJ/kg and the density at least 600 kg/m^3.

Finally, various compositional conditions are imposed, such as the levels of sulphur, nitrogen, chlorine, arsenic, cadmium, lead, etc.

The FPS Public Health, Food Chain Safety and Environment is responsible for monitoring the quality of pellets.

For more information:

- Link to the most recent version of the RD on Wood Pellets: https://navigator.emis.vito.be/mijn-navigator?woId=38921&woLang=nl

2.3.3. European Regulations

→ CE marking

Many products which are manufactured, traded or imported in the European Economic Area (EEA) must bear a CE marking. This label (see Figure 5) shows that a product complies with all applicable European safety, health and environmental requirements that require CE marking. The CE marking was imposed in 1993 through the CE Marking Directive (Directive 93/68/EEC), which amended a series of existing product-specific directives (which provided for an old EC marking). Since the publication of the CE Marking Directive, many product-specific directives have been renewed or newly created and the obligation for CE marking is often directly included in these new directives. As a result, the CE marking directive itself has lost its importance. For construction products, the CE marking obligation is regulated by the Construction Products Regulation.

Figure 5: CE marking label

For domestic wood heating appliances, the CE marking is linked to the standards with requirements and test methods (see paragraph 2.3.5):

- NBN EN 13229: Inset fireplaces and open fireplaces (replaced by NBN EN 16510-1 from 2018)
- NBN EN 13240: Freestanding stoves (replaced by NBN EN 16510-1 in 2018)
- NBN EN 12809: Boiler-stoves (replaced by NBN EN 16510-1 from 2018)

- NBN EN 14785: Pellet appliances
- NBN EN 15250: Slow heat release appliances
- NBN EN 303-5: Boilers

For more information:
- information from the federal government about the CE marking: https://www.belgium.be/nl/economie/handel_en_consumptie/producten_en_diensten/non_food-producten/ce-label

→ **Energy labelling**

New appliances of certain groups are required to have an energy label in Europe. This energy label shows the category to which the appliance belongs, ranging from most (A++ label) to least energy-efficient (G label).

For domestic wood heating appliances, the conditions for labelling are laid down in the following European regulations:
- Regulation (EU) 2015/1186 of 24 April 2015 applicable to **local space heating appliances**
- Regulation (EU) 2015/1187 of 27 April 2015 applicable to **solid fuel boilers** and packages consisting of a solid fuel boiler, supplementary heating appliances, temperature controllers and solar energy installations

The energy efficiency class of a local space heating appliance is determined on the basis of the energy efficiency index, as indicated in Table 6. The energy efficiency index is calculated in accordance with Annex XIII to Regulation (EU) 2015/1186 and Annex IX to Regulation (EU) 2015/1187. The calculations are based on the seasonal space heating energy efficiency with a positive correction for the use of biomass as well as various other positive and negative corrections, e.g. indoor heating comfort controls, additional electricity consumption, and the energy consumption of a permanent pilot flame.

Table 6: Energy efficiency classes for local space heating appliances (Regulation (EU) 2015/1186) and for solid fuel boilers (Regulation (EU) 2015/1187)

Energy efficiency class	Energy efficiency index (EEI) according to regulation (EU) 2015/1186	Energy efficiency index (EEI) according to regulation (EU) 2015/1187
A+++		EEI ≥ 150
A++	EEI ≥ 130	125 ≤ EEI < 150
A+	107 ≤ EEI < 130	98 ≤ EEI < 125
A	88 ≤ EEI < 107	90 ≤ EEI < 98
B	82 ≤ EEI < 88	82 ≤ EEI < 90
C	77 ≤ EEI < 82	75 ≤ EEI < 82
D	72 ≤ EEI < 77	36 ≤ EEI < 75
E	62 ≤ EEI < 72	34 ≤ EEI < 36
F	42 ≤ EEI < 62	30 ≤ EEI < 34
G	EEI < 42	EEI < 30

The layout of the labels is displayed in Figure 6.

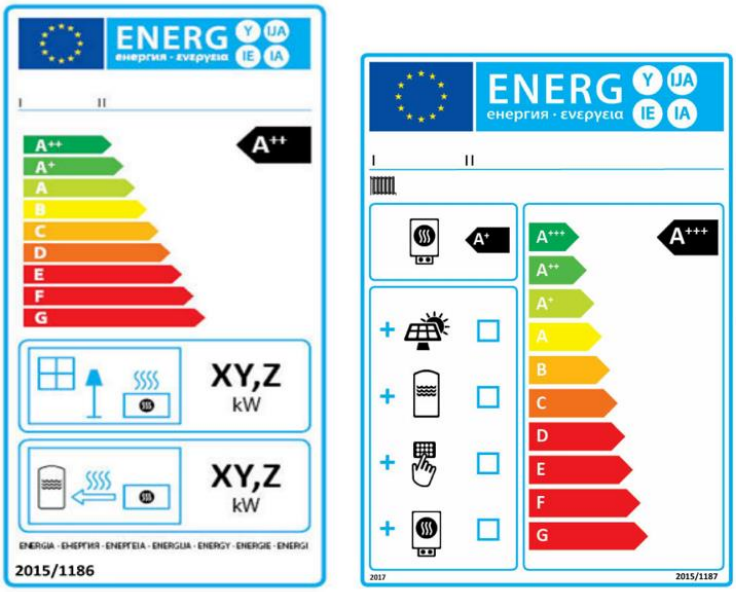

Figure 6: Energy labels according to EU 2015/1186 (stoves, left) and EU 2015/1187 (boilers, right)

The supplier must provide further technical information upon request, as set out in Annexes V to the regulations, to the authorities of the Member States and to the Commission.

For more information:
- Delegated regulation (EU) 2015/1186: http://www.emis.vito.be/node/34342
- Delegated regulation (EU) 2015/1187: http://www.emis.vito.be/node/34343

→ **Ecodesign directive**

The Ecodesign Directive (2009/125/EC) is a framework directive for establishing Ecodesign requirements (through European legislation) for energy-related equipment (ErP). In implementation hereof, product requirements have been drawn up for new wood stoves and biomass-fired boilers. These are included in the following regulations:
- Regulation (EU) 2015/1185 of 24 April 2015 applicable to **solid fuel local space heating appliances**
- Regulation (EU) 2015/1189 of 28 April 2015 applicable to **solid fuel boilers**

Regulation (EU) 2015/1185 sets requirements on ecological design for the placing on the market and putting into service of solid fuel local space heating appliances with a maximum nominal heat output of 50 kW. Regulation (EU) 2015/1189 does the same for solid fuel boilers with a maximum nominal heat output of 500 kW. These regulations contain **requirements for energy efficiency and emissions,** to be determined in accordance with the methods laid down in the annex to the regulations.

The energy efficiency and emission requirements of both regulations are summarised in Table 7. The emission requirements are expressed at standard conditions (273K, 1013 mbar). The emission requirements for stoves (EU 2015/1185) refer to emissions at nominal heat output, for boilers (EU

2015/1189) they refer to seasonal emissions (see list of definitions). The reference oxygen content is 13% for stoves (EU 2015/1185) and 10% for boilers (EU 2015/1189).

Table 7: Ecological design requirements for domestic wood heating appliances[(1)]

	Seasonal energy efficiency	Dust	OGC	CO	NOx
Appliances with open front (EU) 2015/1185 (from 1/1/2022)	30 %	50 mg/m³ *or* 6 g/kg dry matter[(2)]	120 mg/m³	2000 mg/m³	200 mg/m³
Appliances with closed front – solid fuel other than wood pellets (EU) 2015/1185 (from 1/1/2022)	65 %	40 mg/m³ *or* 5 or 2.4 g/kg dry matter[(2)]	120 mg/m³	1500 mg/m³	200 mg/m³
Appliances with closed front – wood pellets as fuel (EU) 2015/1185 (from 1/1/2022)	79 %	20 mg/m³ *or* 2.5 g/kg or 1.2 g/kg (dry matter) [(2)]	60 mg/m³	300 mg/m³	200 mg/m³
Solid fuel boilers with nominal heat output of max. 20 kW and automatically fired (EU) 2015/1189 (from 01/01/2020)	75%	40 mg/Nm³	20 mg/Nm³	500 mg/Nm³	200 mg/Nm³
Solid fuel boilers with nominal heat output of max. 20 kW and manually fired (EU) 2015/1189 (from 01/01/2020)	75%	60 mg/Nm³	30 mg/Nm³	700 mg/Nm³	200 mg/Nm³
Solid fuel boilers with nominal heat output > 20 kW and automatically fired (EU) 2015/1189 (from 01/01/2020)	77 %	40 mg/Nm³	20 mg/Nm³	500 mg/Nm³	200 mg/Nm³
Solid fuel boilers with nominal heat output > 20 kW and manually fired (EU) 2015/1189 (from 01/01/2020)	77 %	60 mg/Nm³	30 mg/Nm³	700 mg/Nm³	200 mg/Nm³

[(1)]Where the regulations distinguish between biomass and fossil fuels, the value for biomass has been included in the table.

[(2)]depending on the measurement method used: values in mg/Nm³ when using the 'heated filter' method (measurement in the flue gas pipe), values in g/kg when using one of the two 'flow dilution tunnel' methods (see paragraph 3.4.1 for more information on the measurement methods used)

In addition, the necessary product information about the appliances must also be provided, as specified in annexes to the regulations.

Annex V to the Regulation gives **indicative benchmarks for best-performing** solid fuel local space heating **appliances** available on the market when the Regulation entered into force. These benchmarks are summarised in Table 8. The performances are expressed at standard conditions (273K, 1013 mbar). The performances for stoves (EU 2015/1185) refer to emissions at nominal heat output, for boilers (EU 2015/1189) they refer to seasonal emissions (see list of definitions). The reference oxygen content is 13% for stoves (EU 2015/1185) and 10% for boilers (EU 2015/1189).

Table 8: Indicative benchmarks for best performing domestic wood heating appliances

	Seasonal energy efficiency	Dust	OGC	CO	NOx
Appliances with open front (EU) 2015/1185	47 %	20 mg/m³	30 mg/m³	500 mg/m³	50 mg/m³
Appliances with closed front – solid fuel other than wood pellets (EU) 2015/1185	86 %	20 mg/m³	30 mg/m³	500 mg/m³	50 mg/m³
Appliances with closed front – wood pellets as fuel (EU) 2015/1185	94 %	10 mg/m³	10 mg/m³	250 mg/m³	50 mg/m³
Solid fuel boiler (EU) 2015/1189	96 % for cogeneration boilers 90% for boilers with flue gas condenser 84% for other boilers	2 mg/m³	1 mg/m³	6 mg/m³	97 mg/m³

An important note regarding the indicative benchmarks is that when the regulations entered into force there was no appliance on the market that met all the requirements at the same time. However, there were several appliances on the market that met one or more of these requirements. The Regulations give examples of 'good combinations' of performances achieved by existing appliances. These are summarised in Table 9. The performances are expressed at nominal heat output and standard conditions (273K, 1013 mbar). The reference oxygen content is 13% for stoves (EU 2015/1185) and 10% for boilers (EU 2015/1189).

Table 9: Examples of existing appliances with 'good combinations'

	Seasonal energy efficiency	Dust	OGC	CO	NOx
Appliances with closed front – solid fuel other than wood pellets(1) (EU) 2015/1185	83 %	33 mg/m³	69 mg/m³	1125 mg/m³	115 mg/m³

Appliances with closed front – wood pellets as fuel (EU) 2015/1185	91 %	22 mg/m³	6 mg/m³	312 mg/m³	121 mg/m³
Solid fuel boiler[1] (EU) 2015/1189	81%	7 mg/m³	2 mg/m³	6 mg/m³	120 mg/m³

[1]The nature of the fuel in the example appliance is not specified in the regulations. So it is not clear whether it is about a wood appliance or an appliance using other solid fuel.

For more information:

- Regulation (EU) 2015/1185: http://www.emis.vito.be/node/34341
- Regulation (EU) 2015/1189: http://www.emis.vito.be/node/34345

2.3.4. FOREIGN REGULATIONS

This section briefly summarises the regulations that apply in some European countries with regard to domestic wood heating.

→ Denmark

In Denmark, new legislation on wood stoves and boilers entered into force on 26 January 2018. This replaces older legislation from 2008.

The emission requirements for wood stoves are as follows:

- Dust: 4 g/kg (measurement with flow dilution tunnel) – 30 mg/Nm³ at 13% O_2 (measured directly in the flue gas pipe)
- OGC: 120 mg C/Nm³ at 13% O_2

The emission requirements for manually fired wood boilers are as follows:

- Dust: 60 mg/Nm³ at 10% O_2
- CO: 700 mg/Nm³ at 10% O_2
- OGC: 30 mg/Nm³ at 10% O_2

The emission requirements for automatically fired wood boilers are as follows:

- Dust: 40 mg/Nm³ at 10% O_2
- CO: 500 mg/Nm³ at 10% O_2
- OGC: 20 mg/Nm³ at 10% O_2

Wood stoves and boilers may only be installed if they meet these emission requirements. To demonstrate that the emission requirements have been met, appliances are subject to a (type) inspection and a certificate is issued. The person who has the appliance installed must have the test certificate checked and signed by a skilled chimney sweep at his own expense. Conditions are also imposed with regard to the chimney height.

The regulation provides for the necessary enforcement possibilities (e.g. fines) and the possibility for municipalities to draw up additional regulations for specific zones if necessary.

For more information:

- Statutory Order regarding regulation of air pollution from solid fuel combustion establishments under 1 MW https://eng.mst.dk/media/189839/bek-regulering-af-luftforurening-fra-fyringsanlaeg-2018_eng_.pdf

→ **Germany**

In Germany the 'Verordnung über kleine und mittlere Feuerungsanlagen (1. BImSchV) applies to appliances for domestic wood heating. This regulation was updated in 2010.

New installations must comply with the emission and energy efficiency requirements shown in Table 10. These conditions were progressively tightened: a first phase applied to appliances put into service from 22/03/2010 (phase 1), a second (stricter) phase to appliances put into service after 31/12/2014 or 31/12/2016 (phase 2). The emission requirements are expressed at nominal heat output. The reference oxygen content is 13%. For further clarification about the name of the appliance types, see the 'Correlation table' appended as Appendix 3 to the BAT study.

Table 10: Emission requirements and energy efficiency requirements from the 1. BImSchV

Type	**Phase 1: Appliances from 22/03/2010**		**Phase 2: Appliances after 31/12/2014(1)**		**Energy efficiency**
	CO (g/m³)	Dust (g/m³)	CO (g/m³)	Dust (g/m³)	%
Raumheizer mit Flachfeuerung	2.0	0.075	1.25	0.04	73
Raumheizer mit Füllfeuerung	2.5	0.075	1.25	0.04	70
Speichereinzelfeuerstätten	2.0	0.075	1.25	0.04	75
Kamineinsätze (geschlossene Betriebsweise)	2.0	0.075	1.25	0.04	75
Kachelofeneinsätze mit Flachfeuerung	2.0	0.075	1.25	0.04	80
Kachelofeneinsätze mit Füllfeuerung	2.5	0.075	1.25	0.04	80
Pelletöfen ohne Wassertasche	0.4	0.05	0.25	0.03	85
Pelletöfen mit Wassertasche	0.4	0.03	0.25	0.02	90
Boilers – untreated firewood (≥ 4 - 500 kW)	1.0	0.10	0.40	0.02	
Boilers – wood pellets (≥ 4 - 500 kW)	0.8	0.06	0.40	0.02	

(1)for firewood boilers: after 31/12/2016

For stoves it must be demonstrated by means of a lab test for each type of appliance that these emission requirements and energy efficiencies are met. This is attested by a certificate of conformity. Consumers should ensure that they receive a certificate of conformity at the time of purchase and should keep it available for the chimney sweep.

For central heating boilers, the inspection takes place on-site (= during use). 2-yearly measurements are to be made by the chimney sweep for this purpose.

For appliances older than 22/03/2010, a transitional arrangement has been worked out with various transition periods (until 2015 for the oldest appliances, until 2025 for appliances from shortly before 2010). After these transitional periods, they will also be subject to emission requirements. However, these are less stringent than the emission requirements for new appliances:

- After the transitional period, existing stoves must meet emission requirements of 4 g/m³ for CO and 0.15 g/m³ for dust. This must be demonstrated by a type approval report from the manufacturer (if available) or by an on-site emission measurement. If the stove does not comply with the emission requirements, the appliance must be taken out of service (replaced) or fitted with a filter (electrostatic precipitator). Exceptions are foreseen, among others for stoves that are the sole heating source in a dwelling and for 'historical' stoves (built before 1950).
- Existing boilers must comply with the phase 1 emission requirements as shown in Table 10 after the transitional period.

The 1. BImSchV further stipulates that the moisture content of the wood may not exceed 25% (with the exception of wood fired in installations designed for fuels with a higher moisture content, e.g. wood chips). This must also be checked by the chimney sweep.

Open fireplaces are allowed, according to the 1. BImSchV, to be used only occasionally. Only untreated pieces of wood or wood briquettes may be burned in these fireplaces.

There is an important role for the chimney sweep in the 1. BImSchV:

- For boilers, he carries out on-site measurements every two years to check compliance with the emission requirements.
- For stoves, he checks the proper functioning and technical condition of the appliance twice every 7 years. This is also the case when a new appliance is put into use or when the appliance changes ownership.
- He measures the moisture content of the stored wood.
- He gives advice to the owner on how to fire the appliance optimally, if an existing stove has to be taken out of service or fitted with an electrostatic precipitator, and how to store the wood in such a way that it dries sufficiently.

For more information:

- 1. BImSchV
  http://www.gesetze-im-internet.de/bimschv_1_2010/inhalts_bersicht.html
- Explanation of 1. BImSchV
  https://www.umweltbundesamt.de/sites/default/files/medien/publikation/long/3776.pdf

→ **Austria**

In Austria, the 'Vereinbarung gemäß Art. 15a B-VG über das Inverkehrbringen von Kleinfeuerungen und die Überprüfung Seite 1 von 2 von Feuerungsanlagen und Blockheizkraftwerken' from 2011 applies. These regulations impose emission requirements for new appliances. A distinction is made here between manually and automatically fired appliances (see Table 11). The emission requirements apply at nominal load, and for CO and OGC also at partial load (lowest specified capacity range limit). However, exceptions to the emission requirements at partial load are possible (on certain conditions, e.g. compulsory mentioning in the documentation that comes with the appliance).

Table 11: Emission requirements for wood-fired appliances < 50 kW from the document Vereinbarung Art 15a B VG - Inverkehrbringen von Kleinfeuerungen

	Emission requirements (mg/MJ[(1)]) until 31/12/2014				**Emission requirements (mg/MJ[(1)]) from 1/1/2015 onwards**			
	CO	NOx	OGC	Dust	CO	NOx	OGC	Dust
Wood stove - fired manually	1100	150	80	60	1100	150	50	35
Pellet stove - fired automatically	500[(2)]	150	30	50	500	100	30	25
Wood boiler - fired manually	500	150	50	50	500	100	30	30
Pellet boiler - fired automatically	250[(2)]	150	30	40	250	100	20	20

[(1)]expressed in relation to the net energy content of the fuel
[(2)]the requirement may be exceeded by 50% at 30% partial load of the nominal heat output

It must be demonstrated by means of a lab test for each type of appliance that these emission requirements are met. This is attested by a certificate of conformity. The suppliers are obliged to hand over a copy of the test report to the buyer. For individually built mass stoves, it is not possible to subject each unit to a type test. A calculation program is available for this purpose. The result of the calculation replaces the type test for these stoves.

The regulation also provides for periodic checks on the proper and safe operation of the installation. However, these conditions are laid down at Länder level.

The chimney sweep also has an important role to play in Austria. He gives advice on the installation of a new stove (suitability of the flue gas pipe, dimensioning of the stove, air supply, wood storage, etc.).

For more information:

- Vereinbarung Art 15a B VG - Inverkehrbringen von Kleinfeuerungen'
  https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=LrSbg&Gesetzesnummer=20000826
- Information about the regulation
  http://www.richtigheizen.at/ms/richtigheizen_at/recht/

→ **The Netherlands**

For wood stoves used by private individuals in the Netherlands only the CE type approval applies, whereby the manufacturer can declare that his product complies with European safety and/or health guidelines. The Dutch manufacturers and specialist dealers belonging to the NHK (Foundation for Dutch Fireplaces and Stove Industry) generally use the German standard (see above) as a minimum performance requirement (Feringa, van der Wal, de Vogel, & Coenrady, 2019).
In January 2019, State Secretary Van Veldhoven announced his intention to bring forward the implementation of the Ecodesign Regulation in the Netherlands to 1 January 2020. However, at the

time of writing this BAT study, the early implementation of the Ecodesign Regulation is still under discussion and an effective date for early implementation is not yet known.

2.3.5. STANDARDS WITH REQUIREMENTS AND TESTING METHODS

Standards have been developed for different types of domestic wood heating appliances that contain technical requirements that the appliances must comply with, as well as test protocols to determine the emissions and energy efficiency of the appliances (see also paragraph 3.4.1). These standards are used when appliances are tested by labs to demonstrate conformity with European or national standards or labels. The standards themselves do not impose any emission requirements, they only determine the measurement protocols. The various regulations on the environmental performance of domestic wood heating appliances (see above), refer to EN (or national) standards for the method of measurement.

The most important standards are:

- EN 13240 for freestanding stoves
- EN 13229 for inset appliances and open fireplaces
- EN 14785 for wood pellet stoves
- EN 15250 for slow heat release stoves (mass stoves)
- EN 12809 for boiler-stoves up to 50 kW
- EN 303-5 for central heating boilers up to 500 kW

In 2018, part 1 of the **new standard EN 16510** 'Domestic combustion appliances for solid fuels - Part 1: General requirements and testing methods' was published.
It replaces standards EN 13240 for freestanding stoves, EN 13229 for inset appliances and open fireplaces, and EN 12809 for boiler-stoves up to 50 kW. The new standard describes the test methods and the measurement methods for CO, NOx, OGC and dust in a more detailed manner than the existing standards but without contradicting them. (Source: http://rrf-online.eu/en/publication-of-en-16510-1-as-a-non-harmonized-standard/)

The new standard will be extended with additional parts for specific types of appliances in the future:

- Part 2-1: Room heaters;
- Part 2-2: Inset appliances including open fires;
- Part 2-3: Cookers;
- Part 2-4: Independent boilers – Nominal heat output up to 50 kW;
- Part 2-5: Slow heat release appliances;
- Part 2-6: Appliances fired by wood pellets.

Source: https://www.nen.nl/NEN-Shop/Bouwnieuwsberichten/Norm-voor-huishoudelijke-verbrandingstoestellen-voor-vaste-brandstoffen-gepubliceerd.htm

The current technical specification for the measurement methods (TS15883) will no longer apply once the series of standards EN 16510 are in force. The measurement methods will then be integrated in EN16510-1 (personal communications sector). Emissions are measured at nominal heat output and, if appropriate, at partial load according to the EN standards. **Sampling during the start-up period, when emissions are often higher, is not covered in the EN standards.** For boilers, EU standards refer to seasonal emissions (see list of definitions).

In addition to the above-mentioned standards for different types of appliances, there are also standards for various aspects of the installation of appliances, among others:

- NBN EN 12831-1: Energy performance of buildings – method for calculation of the design heat load – part 1: space heating load, and associated ANB (national annex)
- NBN B61-001 and 002:2019: Heating systems in buildings - Heating units design - Total rated capacity greater than or equal to 70 kW and less than 70kW. These standards, although applicable to central boilers, are, in the absence of a specific standard for stoves and fireplaces, generally used as a benchmark for stoves and fireplaces. Manufacturers' guidelines are usually also based on this standard
- The technical report CEN/TR 16798-4:2017, which is a background document to NBN EN 16798-3:2017, contains recommendations for the minimum distance between an air supply inlet on the one hand and an air exhaust outlet (ventilation, etc.) or flue gas outlet of a heater on the other hand. These recommendations are based on the 'dilution factor' concept and represent an interesting approach, although they do not provide an absolute guarantee for the absence of nuisance complaints.
- NBN EN 15287-1: 2010: Chimneys - Design, installation and commissioning of chimneys - Part 1: Chimneys for non-roomsealed heating appliances. This standard contains provisions on the design, the installation criteria for chimney systems, the construction of made-to-measure chimneys, and the relining of existing chimneys.
- NBN EN 15287-2: 2008: Chimneys - Design, installation and commissioning of chimneys - Part 2: Chimneys for roomsealed heating appliances. This standard contains provisions for the design, installation and labelling criteria for chimney systems, the connection of flue gas ducts and air supply ducts for space heating applications
- NBN EN 13384-1: Chimneys - Thermal and dynamic flow calculation methods - Part 1: Chimneys for a single heating appliance
- NBN EN 13384-1: Chimneys - Thermal and dynamic flow calculation methods - Part 1: Single chimneys for multiple heating appliances
- NBN S 01-400-1:2008: Acoustic criteria for residential buildings

2.3.6. ENVIRONMENTAL LABELS

The purpose of environmental labels is to help consumers make an environmentally conscious choice. They can be awarded to certain products (including services) if these products meet predefined sustainability criteria. These criteria are drawn up by an independent body and may cover the whole life cycle of the product. Manufacturers can submit an application for their products on a voluntary basis. If they meet the criteria, they can claim the label.

This section discusses a number of environmental labels for wood stoves and boilers. Environmental labels also exist for wood fuels (pellets). These are mentioned where relevant but not further discussed.

→ European Ecolabel

The European Ecolabel (see Figure 7) is an environmental label of the European Union for non-food products and services and was introduced in 1992.

Figure 7: European Ecolabel

In 2014, criteria were published for the award of the European Ecolabel for water-based heating appliances (2014/314/EU - Commission Decision of 28 May 2014 on establishing the criteria for the award of the EU Ecolabel for water-based heaters). These apply, among others, to heating appliances with a solid fuel boiler, i.e. wood-fired boilers for domestic heating.

No Ecolabel criteria have been developed for wood stoves and for wood fuels.

The emission and energy efficiency criteria for wood-fired boilers are summarised in Table 12. The emission values are expressed at 10% O_2 and for seasonal emissions (see list of definitions).

Table 12: Criteria for energy efficiency and seasonal emissions for the European Ecolabel

Appliance	CO (mg/Nm^3)	NOx (mg/Nm^3)	OGC (mg/Nm^3)	Dust (mg/Nm^3)	Energy efficiency (%)
Solid biomass-fired boiler - automatically fired	175	150	7	20	79%
Solid biomass-fired boiler - manually fired	250	150	7	20	79%

In addition, a series of criteria must also be met regarding
- Emission requirements for greenhouse gases
- The materials used
- Sustainable product design
- Installation instructions and user information.

For more information:
- General information about the European Ecolabel:
  https://www.ecolabel.be/nl
  http://ec.europa.eu/environment/ecolabel/index_en.htm
- Commission Decision of 28 May 2014 on establishing the criteria for the award of the EU Ecolabel for water-based heaters (2014/314/EU):
  https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX%3A32014D0314

→ **Der Blauer Engel (Germany)**

Der Blauer Engel is a German label (see Figure 8), founded in 1978 by the German government.

Figure 8: Label of Der Blauer Engel

In 2016 (renewed) criteria were published for:

- wood pellet stoves (UZ 111, valid until 31/12/2020)
- wood pellet boilers and wood chip boilers (UZ 112, valid until 31/12/2020).

In 2020 criteria were published for:

- wood stoves (UZ 212, valid until 31/12/2023)

There are also criteria for wood pellets (DE-UZ 153).

The emissions and energy efficiency criteria for stoves and boilers are summarised in Table 13. The emissions are expressed at a reference oxygen content of 13%. The appliances are tested at the rated capacity as well as at partial load.

Table 13: Criteria for energy efficiency and emissions for Der Blauer Engel

Appliance	**CO (mg/Nm³)**	**NOx (mg/Nm³)**	**OGC (mg/Nm³)**	**Dust (mg/Nm³)**	**Energy efficiency (%)**
Wood stoves (UZ 212)	500	180	70	15(1)	75
Wood pellet stoves (UZ 111)	160 (rated capacity) 250 (partial load)	150 (rated capacity) 200 (partial load)	8 (rated capacity) 13 (partial load)	15	90
Wood pellet boilers (UZ 112)	150	150	5	15	90
Wood chip boilers (UZ 112)	e165	150	5	15	90

(1) In addition to the requirement for the mass concentration (in mg/Nm³), there is also a requirement for the number of dust particles. This is 5 x 10^6 /cm³ and applies from 1/1/2022.
The effect of a dust filter, if present, may be taken into account to meet both requirements. The dust filter itself must have an efficiency of at least 75% for the mass concentration and at least 90% for the number of particles. The concentration before the downstream dust filter must not exceed 40 mg/Nm³.

The criteria for partial load do not apply for boilers if they are equipped with a buffer tank and the boiler will consequently only operate at nominal load.

The following conditions, among others, apply to wood stoves. The appliance must be airtight, combustion is monitored, and it is not possible for the user to adjust the air supply manually (this is usually achieved by automatic control).

In addition, a number of criteria such as the following must also be met:
- electricity consumption (in use and standby)
- the corresponding installation and operating instructions
- the associated services (e.g. maintenance contracts, technical training for installers and salespeople, advice, availability of spare parts, etc.)
- fuel quality (inform users about the appropriate fuels)
- the environmentally-friendly design (e.g. recyclability).

No one made an offer for any of the three categories in March 2020 (https://www.blauer-engel.de/sites/default/files/vergabekriterien_ubersicht_branchen_eng_2020_0_1.pdf).

For more information:
- General information about the Der Blauer Engel label
  https://www.blauer-engel.de
- Criteria for Wood Stoves (UZ 212)
  https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20212_202001_en_criteria.pdf
- Criteria for Wood Pellet Stoves (UZ111)
  https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20111-201602-en%20Criteria.pdf
- Criteria for Wood Pellet Stoves and Wood Chip Boilers (UZ 112)
  https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20112-201602-en%20Criteria.pdf

→ **The Nordic Swan (Sweden, Norway, Denmark and Finland)**

The Nordic Swan (see Figure 9) was established in 1989 by the Nordic Council of Ministers as an eco-labelling scheme for Sweden, Norway, Denmark and Finland.

Figure 9: Label of the Nordic Swan

In 2014 (renewed) criteria were published for:
- stoves (pellet stoves, tiled stoves, wood stoves, fireplaces and inset appliances, valid until 30/06/2022)
- solid biofuel boilers (pellet boilers, wood boilers, wood chip boilers, valid until 31/03/2021)

There are also criteria for solid fuels (including briquettes, firewood, pellets and wood chips).

The emissions and energy efficiency criteria for wood stoves and boilers are summarised in Table 14. The emissions are measured at nominal load and expressed at a reference oxygen content of 13% for stoves and 10% for boilers. The standards also apply for automatically fired boilers at partial load (except for dust with boilers ≤ 20 kW).

Table 14: Criteria for energy efficiency and emissions for the Nordic Swan

Appliance	CO (mg/Nm^3)	OGC (mg/Nm^3)	Dust [(1)]	NOx (mg/Nm^3)	Energy efficiency (%)
Manually fired stove or inset stove for non-continuous use	1250	100	2 g/kg fuel (average for max. 4 loads) 5 g/kg fuel (for each load)		76
Manually fired slow heat release appliances	1250	100	50 mg/m^3		83
Pellet stove with automatic feed	200	10	15 mg/m^3		87
Manually fired boiler	350	15	40 mg/m^3	200	87 + log(output)
Automatically fired boiler	250	10	30/40 mg/m^3	200	88 + log(output)

[(1)] requirements in g/kg measured using the 'flow dilution tunnel' method, requirements in mg/m^3 directly in the hot flue gas. See paragraph 3.4.1 for more information on the measuring methods used.

In addition, a series of criteria must also be met regarding
- the production process (e.g. materials used).
- the electricity consumption (at rated capacity)
- customer information (installation instructions, operating and maintenance instructions)
- information for distributors and installers (required skills, dimensioning, spare parts)
- the associated services (e.g. maintenance contracts, technical training for installers and salespeople, advice, availability of spare parts, etc.)

No information was found about the number of stoves or boilers with the Nordic Swan label.

For more information:
- General information about The Nordic Swan
  https://www.nordic-ecolabel.org/
- Criteria for stoves
  https://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=078
- Criteria for solid biofuel boilers
  https://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=060

→ **Umweltzeichen 37 (Austria)**

Umweltzeichen 37 is an environmental label that was established in Austria in 1990 by the Federal Ministry of the Environment.

Figure10: Umweltzeichen 37 label

In 2017 (updated) criteria were published for wood-fired heating systems (UZ 37).

There are also criteria for biomass based fuels (UZ 38).

The emissions and energy efficiency criteria for wood stoves and wood boilers are summarised in Table 15. Emissions are measured at the rated capacity unless stated otherwise.

Table 15: Criteria for energy efficiency and emissions for Umweltzeichen 37

Appliance	CO (mg/MJ)	NOx (mg/MJ)	C_{org} (mg/MJ)	Dust (mg/MJ)	Energy efficiency (%)
Stove - fired manually	650 (rated capacity) - (part load)	120	45	30	80
Stove - fired automatically	115 (rated capacity) 230 (partial load)	100	5 (rated capacity) 9 (partial load)	15	90
Boiler - fired manually	180 (rated capacity) 500 (partial load)	100	15	20	71.3 + 7.7 log (output)
Boiler - fired automatically - pellets	45 (rated capacity) 100 (partial load)	100	3 (rated capacity) 3 (partial load)	15	90
Boiler - fired automatically - chips	120 (rated capacity)	100	4 (rated capacity)	25	90

	200 (partial load)		6 (partial load)		

The criteria for partial load are not mandatory for boilers if they are equipped with a buffer tank and the boiler will consequently only operate at nominal load.

In addition, a series of criteria must also be met regarding
- heat loss by radiation for boilers
- electricity consumption
- fire safety
- buffer storage information
- materials used
- production process
- packaging
- the associated services (e.g. maintenance contracts, technical training for installers and salespeople, advice, availability of spare parts, etc.)
- information relating to that installation
- maintenance.

In April 2019, 50 manufacturers (mainly Austrian but also some German, Swiss and Italian) were allowed to use the Umweltzeichen 37 label for one or more of their appliances.

For more information:
- General information about the Umweltzeichen 37 label
  https://www.umweltzeichen.at/en/home/start
- Criteria for wood-fired heating systems (UZ 37)
  https://www.umweltzeichen.at/file/Guideline/UZ%2037/Long/Uz37_R6.0a_wood_fired_heating_systems_2017.pdf

→ **Flamme Verte (France)**

The Flamme Verte label was launched in 2000 by the manufacturers of domestic wood heating appliances with the support of the French agency ADEME (Agence de l' Environnement et de la Maîtrise de l'Energie). Originally a star system (similar to hotels and restaurants) was used, awarding appliances 1, 2 or 3 stars on the basis of 3 criteria: energy efficiency, CO emissions and dust emissions. OGC emissions were added later as a 4th criterion. The system has systematically become more stringent over the years because, on the one hand, lower classes were no longer allowed to carry the label and, on the other hand, higher classes were created. In 2019, only appliances with 6 or 7 stars may carry the label, and from 1 January 2020 only appliances with 7 stars (see Figure 11).

Figure 11: The Flamme Verte 7-star label

The emissions and energy efficiency criteria for wood stoves and wood boilers are summarised in Table 16. The emissions are expressed at a reference oxygen content of 13% for stoves and 10% for boilers.

Table 16: Criteria for energy efficiency and emissions for the Flamme Verte label

Appliance	**CO (mg/Nm³)**	**NOx (mg/Nm³)**	**C_{org} (mg/Nm³)**	**Dust (mg/Nm³)**	**Energy efficiency (%)**
Stove - pieces of wood	0.15 % (6★) 0.12 % (7★)			50 (6★) 40 (7★)	75
Stove – pellets	0.03 % (6★) 0.02 % (7★)			40 (6★) 30 (7★)	86
Boiler - fired manually	600 (6★) 500 (7★)		30	40 (6★) 30 (7★)	87
Boiler - fired automatically	450 (6★) 300 (7★)		20	30 (6★) 20 (7★)	87

Criteria for OGC for stoves and criteria for NOx were planned to be added in 2019.

Appliances of more than 100 brands carry the Flamme Verte label. When purchasing an appliance with the Flamme Verte label, the buyer is eligible for financial compensation from the government.

For more information:

- General information about the Flamme Verte label
  https://www.flammeverte.org/
- Criteria for 6 and 7 stars
  https://www.flammeverte.org/decouvrir-flamme-verte/comprendre-etiquette

CHAPTER 3. PROCESS DESCRIPTION AND ENVIRONMENTAL ASPECTS

In this chapter we describe the typical process for domestic wood heating as well as the associated environmental impact. We also give a general idea of the operation of the different appliance types. This information provides the background for describing in chapter 4 the environmentally-friendly techniques that can be used to reduce the environmental impact.

In practice, the details of the various appliances in use differ from stove manufacturer to stove manufacturer. Not all possible variants of the different appliances are described in this chapter. The actual implementation can also be more complex than described here.

It is in no way the intention of this chapter to make a statement on whether or not certain techniques are BAT. The fact that an appliance type is or is not mentioned in this chapter does not in any way mean that this appliance type complies or does not comply with BAT.

3.1. General aspects and emissions from wood combustion

3.1.1. The wood combustion process

Wood combustion is a complex process in which wood gas reacts with oxygen from the combustion air to release heat. A rough distinction can be made within this process between 3 sub-phases, each of which contains a complex set of processes and reactions:

- Drying phase = evaporation of free water
- Gasification phase = gasification and combustion of volatile components
- Burn-out phase = charcoal combustion

These 3 processes are not strictly consecutive but can take place simultaneously at different places in a heating appliance.

→ **Drying phase**

In the drying phase, the wood heats up and the moisture present evaporates.

Moist wood → Dry wood + water vapour

The evaporation of water requires energy. The more moist the wood, the more water will evaporate and the more energy is needed for the drying phase. This will lower the temperature of the flue gases and has an adverse effect on the energy yield of the combustion process and on emissions (see paragraph 3.1.4).

→ **Gasification phase**

When the dry wood heats up further, the gasification phase starts**.** A combination of pyrolysis reactions and evaporation subsequently releases volatile components from the wood. The chemical composition of the released gases depends on the nature of the wood and the process conditions (e.g. temperature). A considerable part of the wood (approx. 80%) is converted into volatile components. The volatile components then burn while releasing heat and light (flames). CO_2 and water are formed during this process at complete combustion. The solid phase remaining at the end of this process is charcoal which consists of C and inorganic compounds, including salts and metal oxides.

Dry wood → Charcoal (C) + Volatile components (CH)

Volatile components (CH) + O_2 → CO_2 + H_2O

→ **Burn-out phase**

The remaining charcoal then burns up further in the burn-out phase. CO_2 is formed during this process at complete combustion. During the burn-out phase, the charcoal still glows but no flames are visible because no further volatile components are released. At the end of the process, an ash residue remains.

C (charcoal) + O_2 → CO_2 + ash residue

3.1.2. EMISSION FORMATION IN WOOD COMBUSTION

Emissions from wood combustion can be divided into 3 groups:

- Primary emissions from incomplete combustion
- Primary emissions from inorganic components in the wood
- Secondary particles (aerosols) formed by condensation and/or chemical reactions in the atmosphere.

A detailed overview of the reactions involved in emission formation is presented in Figure 12.

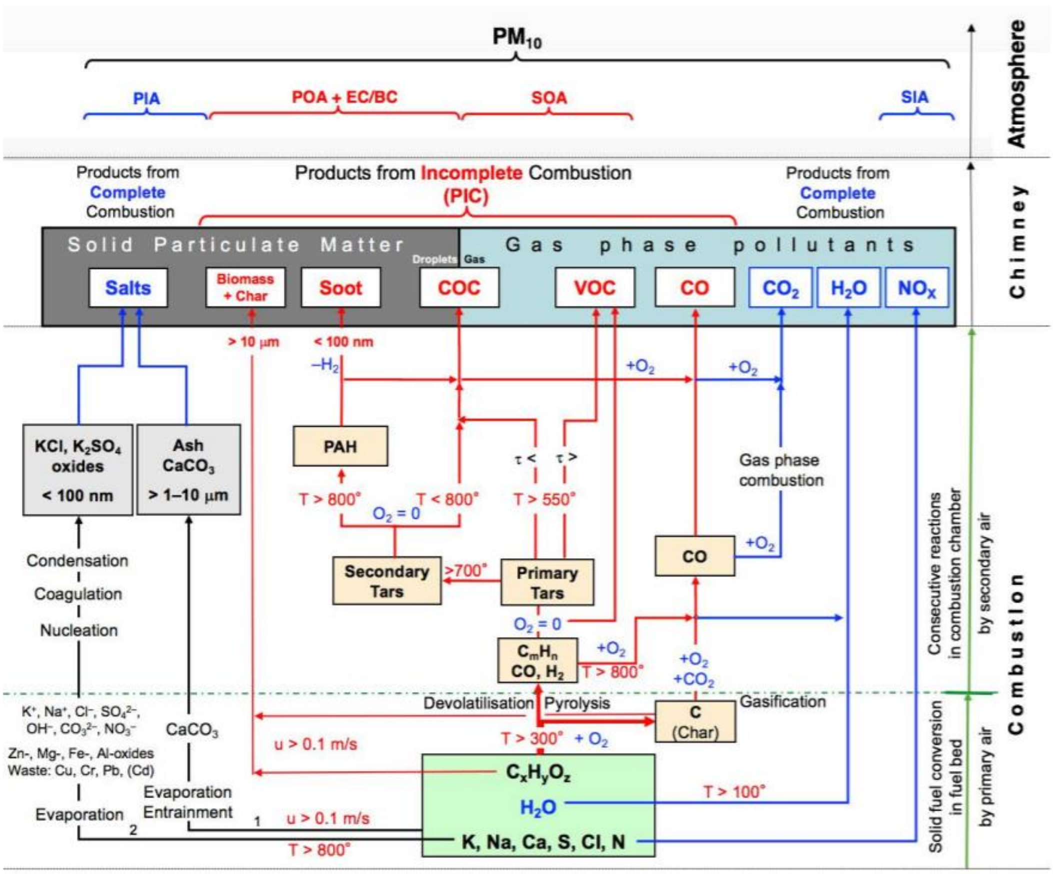

Figure 12: Formation of emissions from biomass combustion (Nussbaumer, 2017)

→ **Emissions from incomplete combustion**

In the case of complete combustion, the carbon in the wood is completely converted into CO_2. In practice, however, a combustion process is never entirely complete, and a fraction of the C is not converted into CO_2 but into products of incomplete combustion. These products can be subdivided into the following components:

- Soot: fine dust particles consisting of C, possibly contaminated with e.g. PAHs and metals for example, depending on the measurement method determined as elemental carbon (EC) or black carbon (BC)
- Condensable organic compounds (COC): organic components which are present in the flue gases in a gaseous state but which, when cooled, condense on solid particles or as droplets
- Volatile organic compounds (VOCs), including benzene, phenols, aldehydes, PAHs[3] (in particular benzo(a)pyrene): organic compounds present in the flue gases in a gaseous state and which remain gaseous even after cooling
- CO: carbon monoxide
- Dioxins and furans: If the residence time is too long between +/- 180 and 500 °C, dioxins may be formed by *de novo* synthesis. This requires not only carbon, hydrogen, oxygen and chlorine but also catalytically active metals (e.g. Cu, Fe or Cd), which are present on the ash particles.
- Wood dust: small particles of unburned wood

→ **Emissions due to the presence of inorganic components in the wood**

In addition to products from incomplete combustion, wood combustion also produces emissions due to the presence of inorganic components in the wood. The most important emissions are:

- Salts (KCl, K_2SO_4, $CaCO_3$, CaO, etc.): The presence of minerals in the wood leads to the presence of salts in the fine particles. In case of incomplete combustion, these salts only account for a limited proportion of the total particulate matter emission because it consists mainly of soot. As combustion becomes more complete, the proportion of soot in the fine particles decreases and the proportion of salts increases.
- (Heavy) metals: The presence of (heavy) metals in the wood may lead to emissions of (heavy) metals (such as Cd, Cr, Zn), usually bound to the fine particles.
- NO_x: Nitrogen in the wood leads to the formation of NOx (so-called fuel NOx). In addition, NO_x can also be formed from N_2 which is present in the combustion air (so-called thermal NO_x).

→ **Aerosols formed by cooling of the flue gases**

As the flue gases cool down in the flue gas pipe, certain condensable organic compounds (COC) will condense and form **aerosols**. These contribute to total dust emissions. Inorganic compounds (e.g. metals) can also condense.

COC are not always included in the reported emission data. This is because the usual measurement methods measure dust in the flue gases when they are still hot. Alternative measurement methods exist whereby the condensable fraction is determined in part (see paragraph 3.4.1 for more information on the measurement methods used).

[3] Heavier PAHs condense on dust (soot) particles; lighter PAHs such as benzo(a)pyrene remain gaseous.

→ **Secondary aerosols, formed in the atmosphere,**

The released primary emissions will give rise to secondary aerosols (dust particles) in the atmosphere as a result of the conversion of gaseous and vaporous hydrocarbons (VOCs) and CO into secondary organic aerosols (SOA). The formation of secondary particles is partly influenced by environmental factors (e.g. atmospheric conditions, such as wind, temperature, etc., and the presence of precursors of other origin).

Research indicates that the formation of secondary organic aerosols in the atmosphere is very intense, and takes place within a relatively short time scale (hours) (Tiitta, Leskinen, Hao, Yli-Pirila, & Kortelainen, 2016). This means that the formation of secondary aerosols contributes significantly to the impact of domestic wood heating on air quality. These components are not included in the reported emission data.

3.1.3. CONDITIONS FOR COMPLETE COMBUSTION

In order to increase energy efficiency and reduce emissions, it is important that a combustion process is as complete as possible. Three conditions must be met for this (the 3 Ts):

- Temperature
- Turbulence (to avoid local oxygen deficiencies)
- Time (residence time)

These are all influenced by the design and installation of the appliance but also by the quality of the wood used and the heating behaviour of the user (see paragraph 3.1.4). If optimal conditions are not reached for the 3 Ts, combustion will be incomplete and emissions will increase.

→ **Temperature**

Combustion reactions are faster and more complete at higher combustion temperatures than at lower temperatures. The combustion temperature is also influenced by the design of the combustion chamber (materials used, insulation, etc.) and by the temperature of the combustion air (pre-heating of the combustion air can increase the combustion temperature). In order to achieve a high combustion temperature, it is also important that heat losses from the combustion chamber are limited.

→ **Turbulence**

Adequate mixing of the released gases with sufficient air (oxygen) is important to achieve complete combustion. First and foremost, sufficient air must be introduced to avoid an overall oxygen deficiency. Even with sufficient air supply, local oxygen deficiencies may occur if there is insufficient mixing (turbulence) with the gases to be burned. Turbulence can be increased by introducing sufficient secondary (and possibly tertiary) air and by ensuring sufficient draught (natural or forced, e.g. with a flue gas fan) to guarantee sufficient negative pressure in the combustion chamber and an adequate supply of oxygen. A good stacking of the logs, with sufficient free space between the logs for good air circulation, is also important in this respect.

→ **Time**

In order to achieve complete combustion, the released gases must remain for a sufficient period of time in the zone where combustion takes place and secondary air is introduced.

3.1.4. FACTORS AFFECTING COMBUSTION QUALITY AND EMISSIONS

The factors that influence combustion quality and therefore emissions can be broadly divided into 5 groups:

- Appliance design
- Quality (moisture content, composition, dimensions, etc.) of the wood fuel used
- Installation of the appliance
- Behaviour of the user
- Maintenance of the appliance and flue gas pipe

In addition to these factors, weather conditions also play an important role in the impact of domestic wood heating on air quality. For example, windless weather and temperature inversion will impede the dispersion of dust emissions, resulting in a negative impact on air quality.

→ Appliance design

The appliance design largely determines the combustion conditions (temperature, turbulence, time – see paragraph 3.1.3) and therefore also the emissions and energy efficiency. For more information about appliance design and emission control measures, see paragraphs 4.1 and 4.2.

For appliances for continuous use (see paragraph 2.1.2), the emissions during the actual combustion phase are similar to those for other systems. However, in the case of continuous appliances, the last phase without flame (smouldering) is maintained as long as possible and this has a negative influence on the emissions. Consequently, continuous systems are much more complex in terms of controlling emissions.

→ Quality of the wood fuel used

The quality (moisture content, chemical composition, hardness, dimensions, proportion of bark, etc.) of the wood fuel used can also have a significant influence on the quality of combustion and therefore on emissions, including odour. Each type of appliance is basically designed to burn a certain quality of wood. Pellet stoves or pellet boilers, for example, are designed for wood pellets with a specific technical quality, e.g. ENplus A1. Appliances fired with pieces of wood are often optimised for logs with certain dimensions. The process will not be optimal if wood of a different quality is used and emissions will increase.

The **moisture content** of the wood is a particularly important parameter for wood stoves. The optimal moisture content for pieces of wood is between 10% and 20%. If the wood is too wet, the drying phase takes too long, combustion is difficult to start and the temperature remains too low, resulting in lower energy yield and higher emissions. In addition, the water vapour takes up a very large volume in the combustion chamber. This displaces combustion air so that insufficient oxygen is available for proper combustion. However, wood that is too dry is not good either because the sudden release of a large quantity of gases may lead to oxygen deficiency and soot formation. In other words, there is an optimal moisture content. Pellets carrying the ENplus certificate have a maximum humidity of 10%.

The **chemical composition of** the wood is also important. As mentioned earlier, the presence of inorganic components in the wood results in emissions of fine particles. These types of emissions determine the total dust emissions especially under good combustion conditions (e.g. in pellet stoves or boilers). Research on pellets from 42 different suppliers, all of which met the ENplus A1 standard, showed that the type of pellets can influence the emissions of fine particles by a factor of 5. The amount of inorganic components may also vary for logs. For example, dust emissions may be higher when burning wood with a lot of bark (e.g. branch wood) than when burning wood without bark. If combustion conditions are not ideal, the influence of the chemical composition on emissions is generally less decisive because emissions from incomplete combustion will be relatively more important. Wood with resin (e.g. pine and spruce) produces more soot and will therefore contaminate the flue gas pipe faster and increase the risk of chimney fires.

The **dimensions and shape** (length and thickness) of the fuel also determine combustion conditions. Small pieces of wood have a larger surface/volume ratio and therefore burn faster than larger pieces of wood. Using pieces of wood that are too long leaves insufficient space between the walls of the combustion chamber and the logs and this has an adverse effect. The optimal size of logs (length and thickness) varies from appliance to appliance, depending on the design of the appliance, and usually amounts to a maximum of 25-30 cm. For an average stove, the thickness of a block of wood should be between 6 and 12 cm (circumference approx. 20-30 cm). For lighting the stoves, it is important that the combustion process is started quickly and this requires smaller pieces of wood. Pellets with the ENplus certificate have a diameter of 6 mm (+/- 1) and a length between 3.15 and 40 mm.

→ Installation of the appliance

How an appliance is installed affects its performance. For example, an appliance with a capacity that is too high for the space in which it is placed will not be able to operate under optimal conditions, for example because users will tend to limit the air supply to reduce heat production. The design of the flue gas pipe (e.g. sufficiently long, double-walled) is also important to guarantee sufficient draught, to avoid condensation of the gases in the flue gas pipe and to emit the flue gases high enough.

→ Behaviour of the user

The user's behaviour is also important: the method for lighting, supplementary feeding, and the air supply control are examples of factors that may have a major influence on combustion quality and therefore on emissions. The more an appliance is automated instead of being manually fed and controlled, the lower the user's influence.

→ Maintenance of appliances and flue gas pipes

Finally, maintenance is also important to maintain the optimal operation of an appliance. This not only concerns the maintenance of the appliance but also of the flue gas pipe.

3.2. THE FUELS USED

Wood fuels suitable for domestic wood heating can be divided into logs, briquettes and pellets. The use of wood chips (shreds) for domestic applications is very limited.

Logs can come from different tree species. Types of wood that are available as firewood include:

- ash wood
- birch wood

- oak
- alder wood
- hornbeam
- fruit tree wood

Blocks of resinous coniferous wood are not recommended as the main fuel for a wood stove because the resin can contaminate the stove and the flue gas pipe.

Logs offered through the official sales channels are often pre-dried and cut to size. Firewood offered through informal channels, e.g. private forest owners, may come in a variety of qualities and often still needs to be cleaved to size and dried by the buyer.

Wood briquettes are made of pressed wood shavings and wood fibres and can be used as an alternative to logs. They can be made from coniferous wood as well as deciduous wood. They do not contain glues or other chemical additives. They have the advantage over logs that they do not need to be dried, and thanks to their design they require less storage space (stackable logs). They are denser and drier than natural logs and therefore have a higher energy content.

Wood pellets are compressed grains of sawdust or wood waste and usually made from coniferous wood. They are intended for use in special pellet stoves or pellet boilers. Like briquettes, pellets contain no chemical additives and have a low moisture content. They can be delivered in bags or bulk and can be poured as a liquid, which is an advantage in view of automatic feeding of combustion installations. Pellets marketed in Belgium must comply with the conditions laid down in the Royal Decree on wood pellets (see paragraph 2.3.2). Furthermore, pellet certification systems exist with specifications regarding raw materials, physical and chemical properties, energy content, and so on. The 2 most common certification systems in Flanders are DINplus and ENplus (A1 or A2).

For all wood fuels, besides the quality characteristics (which influence the combustion quality), the origin of the wood is also an important criterion in terms of **sustainability**. In terms of CO_2 neutrality, it is important that the wood originates from sustainably managed forests with at least a balance between growth and felling. The FSC or PEFC labels that may be present on pellets, for example, guarantee sustainable wood harvesting. In addition to its use as a fuel, wood also has other, higher-value applications (e.g. production of furniture, chipboard, etc.). For firewood or the production of briquettes or pellets, wood residue streams that are not suitable for higher-value applications are preferably used.

3.3. Appliances in use

The appliances in use can be subdivided into the following types (see also paragraph 2.1.2):

- Open fireplace
- Inset stove and inset cassette
- Built-in stove
- Freestanding stove – non-slow heat release
- Mass stove
- Boiler

The general operating principles of the appliances are briefly described below. Hybrid versions are also available in addition to the appliances described below. Hybrid appliances can burn both wood and pellets or they are appliances with both direct and indirect heat output (see also paragraph

2.1.2). These combinations with a CH connection generally produce higher efficiencies than their counterparts without a CH connection.

Chapter 4 (paragraph 4.1) discusses in more detail the specific measures that can be implemented in appliances with a view to improving combustion quality, reducing emissions and increasing energy efficiency.

3.3.1. Open Fireplaces

Traditional open fireplaces consist of a masonry combustion chamber in a recess that is directly connected to the flue gas pipe. The combustion chamber is open at the front and cannot be closed. There is the possibility to place a fireplace door so that the fireplace can be closed with a glass window. The fire is always visible. The generated heat is emitted by radiation.

Open fireplaces are used to burn pieces of wood.

Open fireplaces have a low efficiency and are mainly installed for their aesthetic effect. The capacity of a fireplace is between 5 and 15 kW (European Commission DG TREN, 2009). As a result of uncontrolled combustion, at which a lot of air is sucked out from the living room, more air often disappears than air can be heated. At cold outside temperatures, the efficiency can even become - negative because the cold outside air which is sucked in cools the interior more than the released combustion heat warms up the room. Even when the open fireplace is not in use and in the absence of a properly closing chimney flap, warm air will escape continuously via the open fireplace.

High wood consumption and uncontrolled combustion produce high levels of emissions. Furthermore, the wood smoke often has a low temperature and a low flow velocity at the end of the flue gas pipe, so that the smoke will generally not rise to dilute in the atmosphere but descend along the flue gas pipe.

Installing a fireplace door increases the efficiency but hinders the supply of air, which may affect good combustion, resulting in higher emissions.

In the case of open fireplaces, none of the conditions for effective combustion (temperature, turbulence and time) are met. Due to the large supply of air, the heat losses in the combustion chamber are high and the released gases are discharged quickly, so that there is little mixing of these gases with the air in the combustion zone and the residence time is rather short.

3.3.2. Inset stove or cassette

An inset stove or cassette (Figure 13) is an appliance that is built into an existing chimney opening (open fireplace) or a chimney casing/wall and is meant for local heat emission. An inset stove or cassette always has a door that close the combustion chamber and has a controlled air supply. This combines the visual advantages of an open fireplace with the technical properties of a stove. Modern inset stoves/cassettes have the following characteristics to optimise the combustion process: staged air supply, presence of flame baffle plate, presence of insulation in the combustion chamber, etc. These techniques contribute to the Three T's (temperature, turbulence and time) which have a positive influence on the combustion process. The closed combustion chamber, for example, ensures a higher temperature and heat retention during the combustion process; the presence of a flame baffle plate and the staged air supply increase the turbulence and the time that the generated gases reside in the combustion zone. A more detailed description of all possible measures to optimise the combustion process is given in paragraph 4.1.

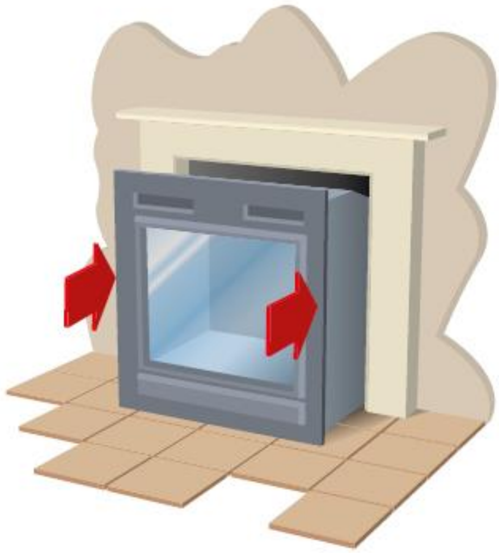

Figure 13: Inset stove (Ademe, 2018)

Due to the better combustion, inset stoves/cassettes for wood have a higher efficiency and lower emissions than open fireplaces. The capacity of an inset stove with wood is between 5 and 10 kW (European Commission DG TREN, 2009); the efficiency according to Ademe (Ademe, 2018) for old models (more than 10 years) is between 30% and 60%, and for modern appliances between 65% and 85%.
Heat transfer occurs via radiant heat and convection heat. The radiant heat can only be emitted through the glass. Most of the heat transfer is by means of convection heat which requires additional air ducts and a fan. From a technical point of view it is also possible to connect an indirect heat emission to this, but in practice it is not applied because the space is limited and this indirect heat emission requires extra space, e.g. overheating protection, cold water supply, safety techniques for a central heating system, etc.

Besides inset stoves/cassettes for burning wood, there are also models for burning pellets. However, the use of an inset stove/cassette for pellets in an existing opening also has several major disadvantages due to the less optimal conditions as a result of the limited space:

- Small buffer storage: the system can only be supplied with a limited quantity of pellets, so the pellets have to be replenished more often
- Lower efficiency compared to built-in or freestanding pellet stoves
- In general a lower output (7-9 kW) compared to built-in or freestanding pellet stoves.

The existing chimney is often too large, so that the draft in the chimney can have a negative effect on the combustion process. This can be solved by placing a stainless steel pipe with the correct diameter in the existing chimney (see paragraph 4.5.2).

3.3.3. BUILT-IN STOVE

Built-in stoves are technically (air supply, heat transfer, etc.) and visually (only front is visible) similar to inset stoves or cassettes. An important difference is that in case of a built-in stove the chimney is built around the appliance (mainly new construction or thorough renovation) as opposed to an inset stove or cassette that is placed in an existing opening (see Figure 14). Built-in stoves therefore are

less restricted in terms of the space they can use to improve optimal operation and increase efficiency. For example, the space above the combustion chamber can be used for post-combustion and extra heat release. The extra space enables a combination with a central heating connection.
Built-in stoves can also be fitted with a lifting door so the appliance can be operated with a closed or open door to create the effect of an open fireplace. The difficulty with these appliances is that when the door is closed they should be able to operate airtight. Airtightness with lifting doors is not easy but it is possible with a complex door. Modern lifting doors, for example, have a spring system that presses the door against the frame when it is closed but otherwise allows the door to move freely along the frame without wear on the seal. The airtightness of these systems differs little from that of a swinging door or hinged door where airtightness is also required but technically easier to achieve.

Figure 14: Built-in stove (Ademe, 2018)

Built-in stoves are typically new build appliances where the heat is naturally radiated to the mantelpiece/wall. This is in contrast to inset stoves/cassettes which are often placed as retrofit in an existing mantelpiece or open fireplace. Inset stoves/cassettes can be removed without any major breaking works.

Built-in stoves with pellets usually stand on a metal frame (easier for maintenance) and are equipped with a large buffer tank and sufficient space for the engines. This allows an efficiency of more than 80% and a capacity of up to 15kW.

3.3.4. FREESTANDING STOVE – NON-SLOW HEAT RELEASE

Free standing stoves are floor mounted appliances for local heat output. They are made of cast iron or steel and have a closed combustion chamber, a refractory lining and generally also a glass window for aesthetic effect. A distinction is made between firewood-fired stoves (wood stoves, fired with pieces of wood) and pellet-fired stoves (pellet stoves). Models are also available that are suitable for pellets as well as pieces of wood. These models are based on a pellet stove but have an additional grate for pieces of wood, and the combustion chamber is also optimised for pieces of wood. The advantage of these systems is that they offer the comfort of pellets (automatic control) but also the fire view/cosiness of wood-burning appliances. For example, one can start with pellets and continue firing with wood. As there is no standard yet for these combination appliances, they must be tested for both. In the past, combination wood/coal stoves were also on the market, but these are less and less common nowadays.

Wood-burning appliances are usually filled manually with pieces of wood or briquettes. Heat transfer to the environment is mainly via radiation. Because they are freestanding appliances, the heat can easily dissipate and therefore usually have a higher efficiency than built-in or inset stoves. According to the Ademe agency (Ademe, 2018), the efficiency is 40% to 60% for older stoves (over 10 years) and 70% to 85% for modern high-efficiency stoves.
There is a wide range of different types of stoves, on the one hand based on aesthetic preferences and on the other hand based on technical aspects such as air supply, fuel supply, combustion process control, etc.

In most models, combustion is controlled via the supply of primary and secondary combustion air. As such, a distinction is made between 3 types:

- Stoves with upward draught: the combustion air is added to the fuel from below and the resulting flue gases are evacuated upwards for secondary combustion above the first combustion zone. The principle is shown in Figure 15:

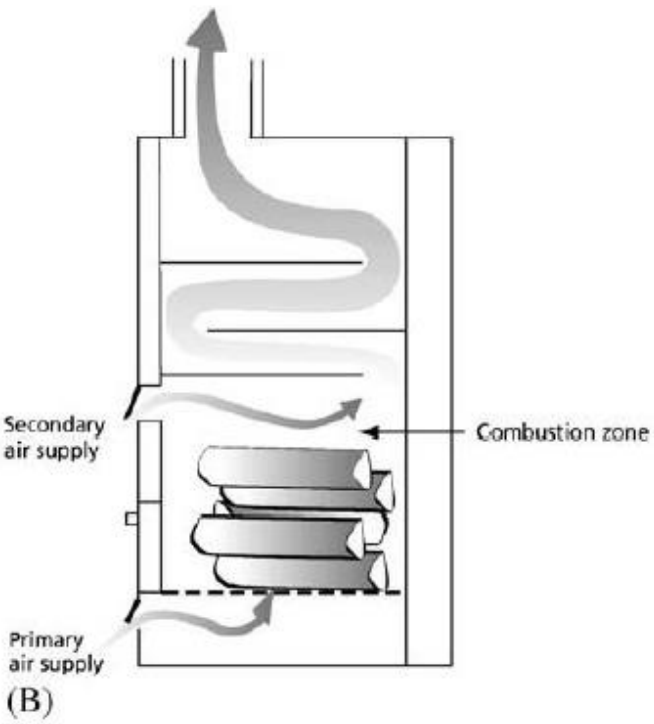

Figure 15: Principle of upward draught (European Commission DG TREN, 2009)

- Stoves with downward draught: here the primary air is supplied along the top of the combustion chamber and secondary air is supplied at the bottom of the combustion zone. The principle is shown in Figure 16: The flames are not visible with these systems.

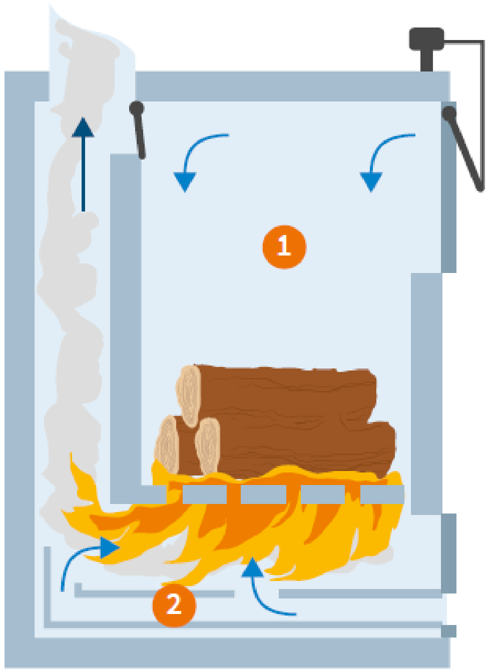

Figure 16: Principle of downward draught (Ademe, 2018)

- Stoves with lateral draught: here the secondary combustion occurs along the side, and the flue gases are brought to the side for secondary combustion.

Intermediate variations are also possible. The air supply can be controlled manually or automatically.

Older stoves have few or no control options for optimising the combustion process. The primary and secondary combustion air is also not separated. Modern stoves have a separate/second combustion chamber and contain many additional technical options to optimise the combustion process. The latest models of 'advanced stoves' also have the possibility to control most of these measures automatically, whether or not in combination with measurements. More information about these measures can be found in paragraph 4.1.

A distinction is also made between continuous and non-continuous combustion. The difference is based on the interval needed to refill and the ability to get the fire started again from sleep mode. Continuous systems must restart without sparks after 10 to 12 hours of slow combustion. This is possible by burning with a very low air supply so the fire can smoulder for a long time. However, this results in very high emissions because it has a significant negative impact on the combustion parameters of temperature and turbulence. Continuous systems are used relatively little in Flanders.

Pellet-fired stoves are suitable for continuous use, they are thermostatically controlled and can be programmed. Pellet stoves are automatic systems that do not require user intervention. The start-up of a pellet stove consists of supplying pellets from the storage buffer in the fire basket where the pellets are automatically ignited by means of a glow plug and supply of fresh air. Next, the quantity of pellets and the air supply are regulated automatically, depending on the required power. With this automation, a distinction is made between pellet appliances where the pellets are fed in at a constant speed and appliances where the speed of feed is based on the fire image (measurements). Depending on the type of automation, a correct ratio of air and fuel can be obtained in the combustion chamber, which contributes to high combustion efficiency and low emissions. Pellets also have low humidity and low ash formation, which also contributes to a better combustion process. The pellets are fed from above. The heat is mainly emitted by convection, in contrast to most wood stoves where the heat is mainly emitted by radiant heat. In case of pellet stoves, the heat is released to the ambient air via a heat exchanger, which may be blown into the living room using a fan (convection). The smoke is blown outside using a flue fan. Pellet stoves have an efficiency of at least 85% according to Ademe (Ademe, 2018) .

Some stoves and fireplaces combine direct and indirect heat emission. If water is used as an intermediate medium to heat other rooms, the system is referred to as boiler stoves/hearths or central heating stoves/hearths. Stoves that are equipped with ducts to distribute warm air over different rooms are called stoves with ducting. In the regulations, all these systems are always considered as appliances for local space heating.

3.3.5. MASS STOVE

Mass stoves are usually made of ceramic materials such as soapstone, tiles and/or clay, which store the heat and then gradually release it to the environment in the form of radiant heat. Moreover, the flue gases travel a much longer distance than in ordinary wood stoves which means that the absorption of residual heat from the flue gases is much better. This then helps to reduce the occurrence of smothering of the combustion compared to ordinary stoves where a lot of heat quickly disappears through the flue gas pipe. A possible disadvantage is that there are more horizontal ducts so that more soot is deposited if the appliance is not used correctly (e.g. wet wood as fuel) and this may adversely affect operation and reduce efficiency. However, when used properly, the soot deposit in a mass stove is lower than in an ordinary wood stove due to the higher combustion temperatures and good combustion in general. Maintenance is therefore highly dependent on the correct use and good heating practice. Also, a mass stove will often still be warm from the previous day when the fire is relighted, which means that the start-up temperature will soon be 100°C higher, which greatly reduces emissions when relighting the fire.
As heat is mainly released by means of radiation, this is usually experienced as very pleasant. Because the same comfort can be experienced with radiant heat at lower air temperatures, less heat will be lost through ventilation (provided the whole space can be radiated).
When used properly, the wood is burned at a high temperature, making the wood burning 'cleaner' than with ordinary stoves. Together with the fact that there is also little heat loss due to the choice of material, high efficiencies of 80 to 90% can be achieved according to Ademe (Ademe, 2018).

The disadvantage of mass stoves is that they are generally quite large and heavy and much more expensive than an ordinary wood stove.
Many of the measures applied to wood stoves and/or pellet stoves for optimising combustion can also be applied here.

3.3.6. BOILER

In a boiler, the heat is transferred to an intermediate medium such as water or air. The hot water or hot air is then used to heat other spaces via radiators or underfloor heating and possibly for domestic hot water. A distinction based on fuel can be made within the context of this study between boilers running on wood, pellets, and wood chips. However, the use of wood chips for domestic applications is very limited.

In a boiler, the varying heat demand can also be met by placing a heat buffer between the combustion installation and the release circuit. The heat buffer is sometimes also used to keep the boiler at a minimum temperature.

In the case of wood-fired boilers, a distinction is made between manual and automatic filling installations. Automatic filling allows better control of the combustion process as both the fuel and air supply can be controlled. This results in high efficiencies (up to 90% (Ademe, 2018)) and lower emissions.
Wood-fired boilers are available from 10 kW (European Commission DG TREN, 2009).

Pellet-fired boilers are always filled and controlled automatically. Smaller installations have a built-in storage space for fuel that is refilled manually every 1 to 2 days. Larger installations are connected to a storage silo with a fuel transfer system (see Figure 17). The storage capacity of a silo as shown in Figure 17 varies from 450 kg to 12 tons; larger volumes are possible in metal. Optimal combustion quality and high efficiency (85% to 95%) are achieved through full automation with computer-controlled regulation of the O2 and CO concentrations (Ademe, 2018)). Dust filters can be integrated or may be offered as a separate option.
Application of the principle of a condensing boiler increases the efficiency of these pellet-fired boilers to 105% (Ademe, 2018).

Figure 17: Pellet boiler with storage in silo

Wood-chip boilers generally have a higher capacity (usually higher than for domestic applications) and a higher investment cost compared to pellet boilers. Pellets have advantages over wood chips logistically in terms of manageability, storage and supply, and in terms of fuel quality. Wood chips are usually not uniformly shaped and often have a fluctuating moisture content which has a negative impact on emissions. In addition, wood chips have relatively high dust emissions if no filters are used. With a capacity from 100 or 200 kW and sufficient full-load hours, it can be more interesting from an economic point of view to choose wood chips instead of pellets. The higher investment cost for the boiler installation and fuel supply is offset by a lower fuel price. As the boiler increases in size, the quality of the wood chips also becomes less important.

3.4. ENVIRONMENTAL ASPECTS

A general discussion of the wood combustion process, the formation of emissions, and the influencing factors was given in paragraph 3.1. More quantitative information on emission levels, energy efficiencies, emission factors, and the overall environmental impact of domestic wood heating follows in paragraphs below. First of all, however, we look at how emissions and energy efficiency are measured and reported.

3.4.1. MEASURING AND REPORTING EMISSIONS AND ENERGY EFFICIENCY

When interpreting figures on emissions and energy efficiency of domestic wood heating, a number of factors influencing the measurement results must be taken into account, in particular the test conditions and the sampling and measurement methods used. Attention should also be paid to the units and reference conditions at which emissions are expressed.

→ **Test conditions used**

The combustion conditions in the appliance at the time of measurement have a highly significant influence on emissions and energy efficiency. Examples are the quality/moisture content of the wood fuel, the phase of the combustion process, working at rated capacity versus at partial load, and so on. The influence of these factors on emissions and energy efficiency is discussed in paragraph 3.1.4.

Different test protocols are used to determine emissions and energy efficiency of domestic wood heating appliances:

- Measurements in labs according to standardised test procedures
- Measurements in labs with customised test protocols, e.g. to simulate practical situations
- On-site measurements in real-life conditions

Measurements in labs according to European or national standardised test procedures are carried out to demonstrate conformity with standards or labels (see paragraph 2.3.5). Emissions are measured at nominal heat output and, where appropriate, at partial load. **Sampling during the start-up period, when emissions are often higher, is not covered**. Also, a prescribed quality of fuel is used during the test and an appliance that is positioned correctly and with the correct settings (e.g. fixed negative pressure, preheated appliance, presence of an optimal glowing carbon bed, and quantity and size of the fuel adjusted to the thermal capacity). When designing new appliances, manufacturers focus on the standards to be respected so that appliances are designed, as it were, to perform well under the test conditions specified in the standards.

Because real-life conditions can differ considerably from those in the protocols of European or national standards, other test protocols are used for research into the actual emissions from domestic wood heating. These can be lab measurements under simulated real-life conditions, where for example the full cycle is simulated, including measurements at partial load, as well as actual 'field measurements' for appliances installed and used in households. Such measurements are not intended or suitable for checking conformity with European standards or labels. However, the results of these measurements are more suitable for establishing emission factors to estimate the total and actual emissions from domestic wood combustion than the measurements according to European or national standards. But they also may underestimate the actual emissions from domestic wood heating because they do not take into account incorrect heating practices which will always occur in practice.

→ **Measurement methods for dust**

For dust, the measurement method requires special attention. As described in paragraph 3.1.2, particle emissions from domestic wood combustion consist partly of COC (condensable organic compounds). These are formed when the flue gases in the flue gas pipe cool down, causing the condensable organic compounds present in the gases to condense. In the test protocols, sampling traditionally takes place in the hot flue gases and the dust is measured by means of a heated filter (= 'heated filter' method). In this case, the COC fraction is not or only to a limited extent measured too. Alternative methods have been developed in which dust is measured after cooling with the intention of also measuring COC (methods 'using natural draught, full flow dilution tunnel and filter at ambient temperature' or 'using a fixed draught of 12 Pa, full flow dilution tunnel and filter at ambient temperature or electrostatic precipitator'. Also with these methods, the temperature at the measurement will still be higher than a typical outdoor temperature in the winter, making it likely that a part of the COC will still not be measured. In the Ecodesign standards for stoves (EU/2015/1185) there is a choice between 3 methods for the measurement of fine particles (PM) from stoves. Depending on the chosen method other Ecodesign standards apply (see Table 7). The Ecodesign standards for boilers (EU/2015/1189) require that all particulate matter formed by gaseous organic compounds when flue gases come into contact with ambient air must be excluded from dust measurements.

In (Schön & Hartmann, 2018) the influence of various variations in measurement methods on the measured dust values was investigated. It was found that at high COC concentrations (typically related to poor combustion conditions) the measured dust values increase as the filtration temperature is lower, and that a non-homogeneous and non-constant filtration temperature, together with a number of other factors, creates a high level of uncertainty on the measured values from the measurement method with a heated filter, especially at high COC concentrations. On the other hand, the use of a flow dilution tunnel introduces many other uncertainties; as a result of which the use of this method according to (Schön & Hartmann, 2018) is not recommended for type approval of appliances, but may be useful for scientific studies into particle size and distribution and for determining emission factors. Further research to harmonise and standardise measurement methods for dust is ongoing. A method has been developed in this respect within the framework of the European EN-PME-TEST research project (Fraboulet, 2016) that is being evaluated for validation by CEN TC295 'Residential solid fuel burning appliances'.

→ **Units**

Emissions from domestic wood heating are expressed in different units, using either the quantity/energy content of the wood used or the flue gas volume as a reference. Some examples of units in use are:

- units related to flue gas volume:
    - mg/Nm³
    - ppm
    - vol%
- units related to energy input:
    - g/kg dry wood
    - g/GJ
- units related to the heat produced:
    - g/GJ

Units related to flue gas volume are used in standards and labels for setting emission requirements that appliances must comply with. Units related to energy input are mainly used to establish emission factors for emission inventories, to estimate the contribution of domestic wood heating to emissions.

The European guidebook for establishing national emission inventories contains calculation rules for converting between the two types of measured values (European Environment Agency, 2019). For wood, a stoichiometric flue gas volume of 253 m^3/GJ energy input and an energy content of 17.3 GJ/t (for dry wood) are assumed. In addition, a correction must be made for the reference oxygen content at which the emission concentration is expressed. The formula for converting an emission value (E) expressed in mg/Nm^3 to an emission factor (EF) in g/GJ is:

$$EF\ (g/GJ) = E\ (mg/Nm^3) \times 253/1000 \times (20.9/(20.9 - \%O_2Ref))$$

At a reference oxygen content of 13% (stoves) the following applies:

$$EF\ (g/GJ) = E\ (mg/Nm^3) \times 0.66933$$

At a reference oxygen content of 10% (boilers) the following applies:

$$EF\ (g/GJ) = E\ (mg/Nm^3) \times 0.48511$$

→ **Reference conditions**

When figures are given for emissions or energy efficiency, it should in principle always be clear what the corresponding reference conditions are.

In addition to the test protocols and measurement methods used (see above), the regime (nominal or partial load), and the reference oxygen content, moisture content, pressure and temperature are also important.

If the regime is not specified, the figures are usually (in the case of testing according to European or national standards) at nominal heat output. If figures are reported at partial load, this is usually explicitly stated. Seasonal emissions or energy efficiencies are also used, which are weighted averages of measured values at nominal heat output and at partial load.

When emissions from combustion processes are expressed in relation to the flue gas volume (e.g. in mg/Nm^3), this is done at a reference oxygen content, so that a correction is made for the dilution effects due to excess air. The European standards use a reference oxygen content of 13% for stoves and 10% for boilers. Furthermore, emissions are converted to standard conditions of moisture content (dry gas), pressure (1013 mbar) and temperature (273K). Most emission figures related to flue gas volume are expressed under these reference conditions.

It is also important when emissions are expressed in relation to energy input (e.g. in mg/MJ or mg/kg) that the precise reference is clearly specified (e.g. kg dry matter versus kg firewood).

3.4.2. ENVIRONMENTAL PERFORMANCE OF NEW APPLIANCES ACCORDING TO STANDARDISED TEST PROCEDURES

In order to demonstrate conformity with standards or labels, new appliances made available on the market are tested according to standardised test procedures (see paragraph 2.3.5). The test results are mentioned on the declaration of conformity accompanying the appliance.

The list of heating appliances with a declaration of conformity with the RD heating appliances (RD of 12 October 2010 - see paragraph 2.3.2) can be found via this link on the website of the FPS Public Health, Food Chain Safety and Environment: https://www.health.belgium.be/nl/e-services/lijst-van-verwarmingstoestellen. For each of the appliances, the declaration of conformity, containing the data from the type test (efficiency, CO and PM emissions), can be downloaded from the website.

In April 2019, a total of 4,756 appliances on renewable solid fuels were on the list, of which:

- 25 open fireplaces (NBN EN 13229B)
- 76 slow heat release appliances (NBN EN 15250)
- 67 boiler-stoves < 50 kW (NBN EN 12809)
- 500 boilers < 400 kW (NBN EN 303-5)
- 945 inset stoves (NBN EN 13229)
- 1,677 freestanding stoves (NBN EN 13240)
- 1,466 pellet appliances (NBN EN 14785)

1,627 of the 4,756 appliances are manufactured in Belgium.

As part of the BAT study, a survey was launched among manufacturers and importers in order to obtain a better picture of the technologies used with regard to better combustion and the reduction of emissions and the environmental performance of these techniques. For the appliances for which the questionnaire was completed, the environmental performances are summarised in paragraph 4.8.

3.4.3. EMISSIONS IN REAL-LIFE CONDITIONS VERSUS EMISSIONS ACCORDING TO STANDARDISED TEST PROCEDURES

The available information on emissions under real-life conditions is relatively limited. The discussion below is based on 4 studies conducted in recent years on emissions from domestic wood heating under real-life conditions, and their comparison with emissions measured under lab conditions according to standardised test procedures:

- a comprehensive review of the scientific literature on emissions from modern wood heating appliances under real-life conditions (Tytgat, Walpot, Cools, & Lenaerts, 2017)
- the European research project BeReal in which a measurement protocol was developed and measurements were carried out on various types of appliances, both in labs under standardised test conditions and in labs under simulated real-life conditions and on appliances installed and used in households (Reichert, et al., Final Report: Definition of suitable measurement methods and advanced type testing procedure for real life conditions, 2016)
- a study by the French institute INERIS on behalf of ADEME in which a number of recent appliances were measured by means of a test set-up with simulation of real-life conditions (Ademe - Ineris, 2016)
- a study for the Nordic Council of Ministers in which measurements were carried out on old and new appliances under various conditions, with a view to determining emission factors (Kindbom, et al., 2017).

→ **Bibliographic research (Tytgat, Walpot, Cools, & Lenaerts, 2017)**

Table 17 gives an overview of the emission data in mg/MJ found in the literature study (VMM-UA, 2017) for various types of domestic wood heating appliances. It concerns a combination of data obtained from lab tests using standardised test procedures (LAB), data obtained from measurements in labs under simulated real life conditions (PSEUDO), and data from real life measurements in people's homes (REAL).

Table 17: Overview of emission figures from various literature sources for different types of appliances (based on (Tytgat, Walpot, Cools, & Lenaerts, 2017))

Appliance type	Number of studies	Type of test	PM (mg/MJ)	CO (mg/MJ)	OGC (mg/MJ)	PAH (mg/MJ)	NOx (mg/MJ)
Closed fireplace	1	all	152-219	3949-5030	/	0.014	105-104
	0	LAB	/	/	/	/	/
	1	PSEUDO	152-219	3949-5030	/	0.014	105-104
	0	REAL	/	/	/	/	/
Traditional wood stove	10	all	38-955	110-7200	4561-8786	0.0325-220	35-66
	7	LAB	38-955	1100-7200	/	0.0325-220	35-66
	2	PSEUDO	55.5-225	2086-2355	4561-8786	0.122-0.008786	/
	1	REAL	48-189	/	/	/	/
Tiled stove	6	all	16-833	703-10611	24-2500	0.081-14.10	72-83
	2	LAB	16-833	703-10611	24-2500	/	72-83
	1	PSEUDO	28-31.3	1008-1207	52.4-69.2	0.081-0.099	/
	3	REAL	89-633	/	/	1.44-14.10	/
High efficiency stove	5	all	15-176	100-7829	94.2-95.5	0.0003-340	99-182
	2	LAB	15-114	100-770	/	1.65-340	/
	2	PSEUDO	46.1-176	1036-7829	94.2-95.5	0.152-0.466	99-182
	1	REAL	67-122	/	/	0.0003-0.0006	/
Advanced stove	1	all	9.7-68.05	731-824	18.2-26.3	/	/
	1	LAB	9.7-68.05	731-824	18.2-26.3	/	/
	0	PSEUDO	/	/	/	/	/
	0	REAL	/	/	/	/	/
Modern pellet stove	6	all	16-139	73-413	10	0.000077-0.5	32-165
	4	LAB	16-102	413	10	0.000077-0.5	165
	2	PSEUDO	31-139	73-192	/	0.0015	32-90
	0	REAL	/		/	/	
	1	all	98.6-106.1	8969-12632	651-1144	3.39-18.85	/

Traditional boiler	0	LAB	/	/	/	/	/
	1	PSEUDO	98.6-106.1	8969-12632	651-1144	3.39-18.85	/
	0	REAL	/	/	/	/	/
Advanced boiler	3	all	6.0-45.8	7-793.1	0.76-78.7	0.00012-0.105	50.2-168
	2	LAB	6.0-17.6	7-455	0.76-4.66	0.00012	50.2-168
	1	PSEUDO	9.7-45.8	45.4-793.1	1.7-78.7	0.006-0.105	/
	0	REAL	/	/	/	/	/
Wood/pellet boiler	4	all	11-116	12-547	1-2	0.00003-0.00015	59-127
	2	LAB	11-65	12-485	1-2	0.00003-0.00015	59-127
	2	PSEUDO	30-116	197-547	/	0.00006	61-95
	0	REAL	/	/	/	/	/

Some conclusions drawn from the analysis (VMM-UA, 2017):

- In general, the reported emission values (see Table 17) show a very large variability. Differences in the type and age of the tested appliances and in the test procedures and conditions used play an important role in this. The interpretation of the data is hampered by the fact that not all parameters/appliance types have been described and examined in all studies. The figures should therefore be compared with caution, and the available data are insufficient to determine the influence of all relevant variables (e.g. wood species used) on emissions.
- PM emissions from more recent stoves, with the latest technology, are generally lower than those from older stoves (see Figure 18). It should be noted that most emissions were measured in labs, either according to standardised measurement procedures (LAB) or under simulated real-life conditions (PSEUDO). Limited or no data on performance in real-life conditions (REAL) are available (see Table 17) for the latest appliance types in particular.
- High efficiency stoves perform better in terms of PM and CO emissions compared to traditional stoves, but NOx and PAHs emissions sometimes seem higher. Less data are available for advanced stoves, but emissions are generally even lower than those from high-efficiency stoves.
- The emissions for the various parameters are significantly higher when tested with smothered air supply. This has been determined for traditional stoves (factor 2), tiled stoves and high efficiency stoves and modern pellet stoves.

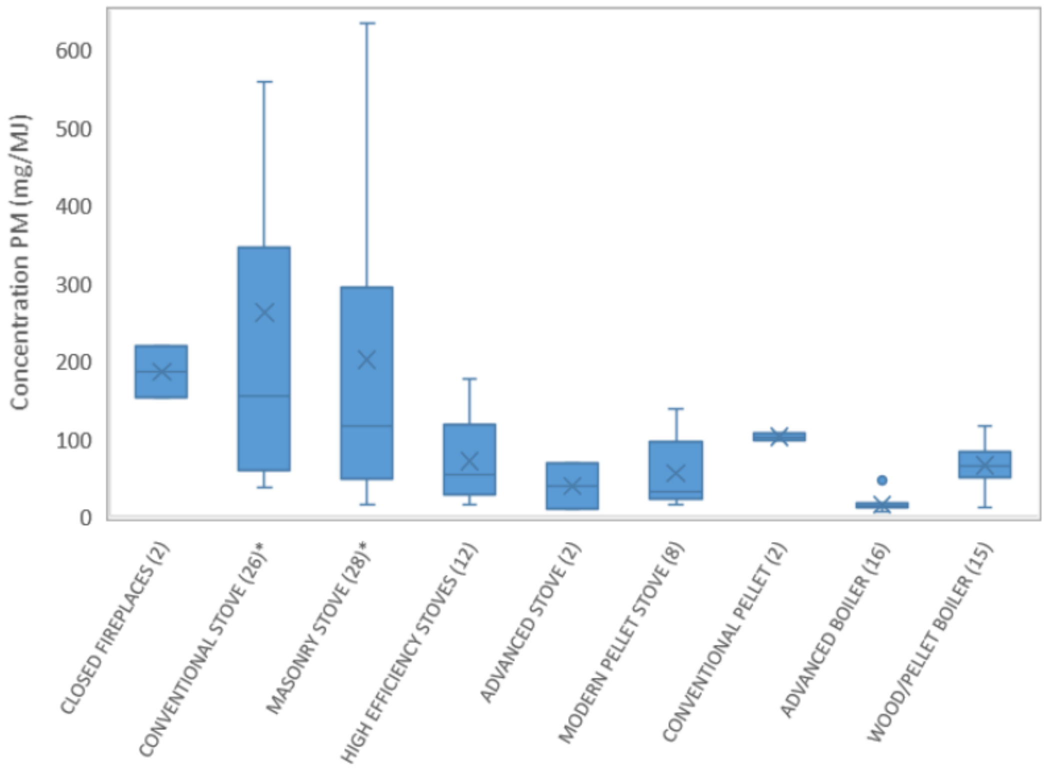

*Figure 18: Boxplot overview of PM emission figures (numbers in brackets) from various literature sources for different types of appliances; categories marked with * contain outliers above 1000 mg/MJ (Tytgat, Walpot, Cools, & Lenaerts, 2017)*

→ **European BeReal[4] research project**

In the BeReal project measurement protocols (BeReal test procedure) were developed to perform emission measurements in labs under conditions that simulate actual practice. The intention was to approximate real-life conditions as closely as possible (excluding real incorrect use). As part of the project also measurements were carried out in real-life conditions. For this purpose, 13 wood stoves and 4 pellet stoves were installed at real users. These were appliances produced in the years 2013-2015, with or without automatic air control. After the appliance had been in use for at least one month, measurements were carried out over 3 consecutive days. On the 1st day the user was asked to use the appliance as he was used to; on the 2nd day he was asked to follow a number of written guidelines (for wood stoves) or to use a standard pellet quality (for pellet stoves); on the 3rd day he received personal advice from a project employee to follow the conditions of the BeReal test procedure as much as possible. The results of the real-life measurements were then compared with the measurement results obtained in the lab for the same appliances, for both the results obtained with the use of the standardised test procedures and with the use of the procedure developed in the project (BeReal procedure). The average measurement results are given in *Table 18* for wood stoves and in *Table 19* for pellet stoves. It should be noted that the variability of the measurement data was quite high. For the measurement of PM, the BeReal method uses a method with a heated filter (= *excluding* condensable).

[4] (Reichert, et al., Deliverable D3.3 Final Report: Definition of Suitable Measurement Metods and Advanced Type Testing Procedure for Real Life Conditions, 2016)
(Rönnback, Henrik, Jespersen, & Jensen, 2016)
(Jespersen, Jensen, Rönnbäck, Persson, & Wöhler, 2016)

Table 18: Average measurements for 13 wood stoves according to the BeReal project

	According to standardised test procedure, as stated on the official documents accompanying the appliance	According to standardised test conditions, results by project partners	According to BeReal method (real-life conditions simulated in the lab)	Real-life measurements at real users - Day 1	Real-life measurements at real users - Day 2	Real-life measurements at real users - Day 3
CO ($mg/Nm^3@13\%O_2$)	848	1877	2891	3443	3211	3099
PM ($mg/Nm^3@13\%O_2$)	21	58	74	76	74	84
OGC ($mg/Nm^3@13\%O_2$)	58	130	245	310	279	297
Efficiency (%)	81	70	70	65	65	65

Table 19: Average measurements for 4 pellet stoves according to the BeReal project

	According to standardised test procedure, as stated on the official documents accompanying the appliance	According to standardised test conditions, results by project partners	According to BeReal method (real-life conditions simulated in the lab)	Real-life measurements at real users - Day 1	Real-life measurements at real users - Day 2	Real-life measurements at real users - Day 3
CO ($mg/Nm^3@13\%O_2$)	107	166	428	455	269	394
PM ($mg/Nm^3@13\%O_2$)	19	40	56	72	48	49
OGC ($mg/Nm^3@13\%O_2$)	3	3	9	31	5	8
Efficiency (%)	91	87	88	85	86	86

The following conclusions were drawn based on the measurements:

- The emissions according to the standardised test methods are considerably lower (typically factor 3) than the emissions according to the BeReal procedure (simulated real-life conditions), and this for all studied parameters (CO, OGC as PM). The emissions according to the BeReal procedure and the emissions measured at real users were roughly in the same order of magnitude.
- The emissions according to the standardised test methods as stated on the official documents accompanying the appliances were lower than the emissions measured by the project partners under the standardised test conditions. No explanation for this was found in the report. However, the method used by the project partners deviated from the standard method because the sampling for the analysis took place further away from the stove (= in already partially cooled flue gases).
- The energy efficiency determined according to the standardised test methods was higher than that determined according to the BeReal procedure (simulated real-life conditions) and with real users.
- Comparing the results for real users on day 1 and day 2, a slight improvement is observed on day 2 compared to day 1, which for wood stoves is attributed to the improved user behaviour (applying the guidelines) and for pellet stoves to the quality of the fuel. The results on day 3 differ the least from the results obtained when using the BeReal procedure.

→ **Study commissioned by the Nordic Council of Ministers (Kindbom, et al., 2017)**

With a view to improving the emission factors used in emission inventories, measurements were carried out in this study on various stoves and boilers, on the one hand according to European and Norwegian standardised test methods, and on the other hand in customised tests using moister wood and at partial load to estimate the influence of user behaviour on emissions. The following conclusions were drawn on the basis of the study (see also *Figure 19* and *Figure 20*):

- Emissions from traditional wood boilers are a factor of 5 to 10 higher (depending on the parameter) than those from modern wood boilers, pellet boilers or wood chip boilers. The emission levels are comparable for these latter 3 categories.
- For boilers, heating at partial load instead of at full load increases emission levels by a factor of 2 to 6 (sometimes higher) depending on the parameter and the technology.
- The use of wet fuels increases emissions from boilers by a factor of 1.5 to 2.
- For stoves, the differences between different technologies were less pronounced than for boilers. The highest emission levels were measured with tiled stoves, followed by older stove types (1.5 to 2 times higher than with modern wood stoves). Pellet stoves have the lowest emission levels for all parameters
- Heating at partial load instead of at full load in stoves increases emission levels by a factor of 1.5 to 3.5.
- Modern stoves were found to be sensitive to the moisture content of the wood, with emission levels increasing by a factor of 5 to 8 for PM and OC. For older stoves and tiled stoves, on the other hand, the emissions were little affected by the moisture content of the wood used. The higher impact with modern stoves is attributed to the more limited capacity of the air system in these appliances.
- For both stoves and boilers, the emissions of elemental carbon (EC) are relatively unaffected by partial load combustion or by the moisture content of the wood compared to other parameters. EC emissions also did not show a good correlation with PM emissions.

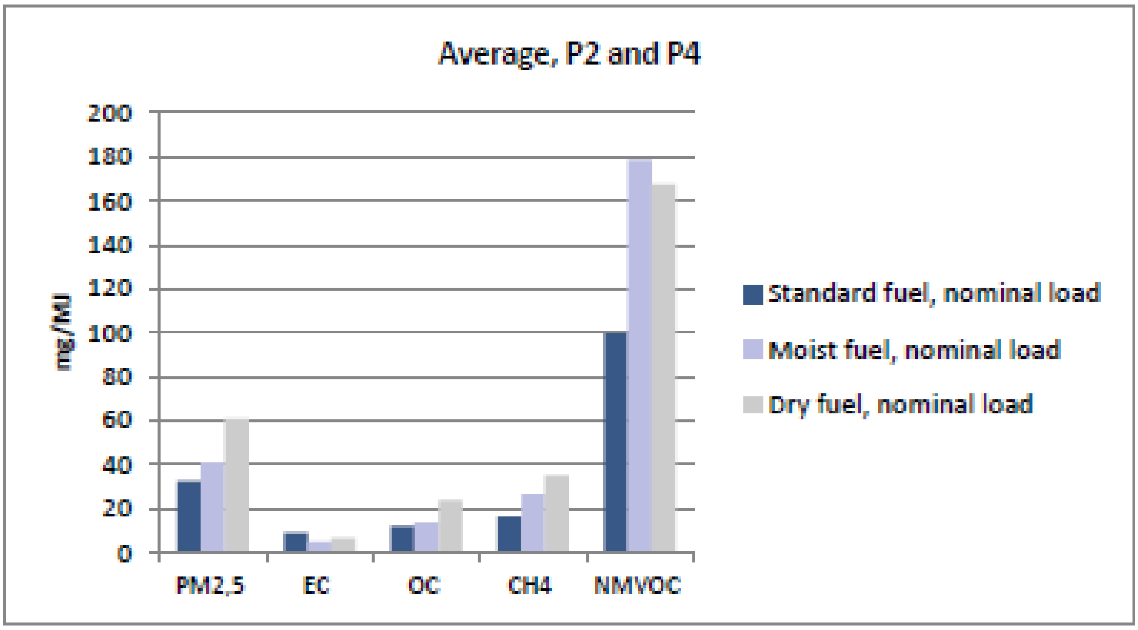

Figure 19: Average measured values when tested on 2 modern boilers fired with pieces of wood (Kindbom, et al., 2017)

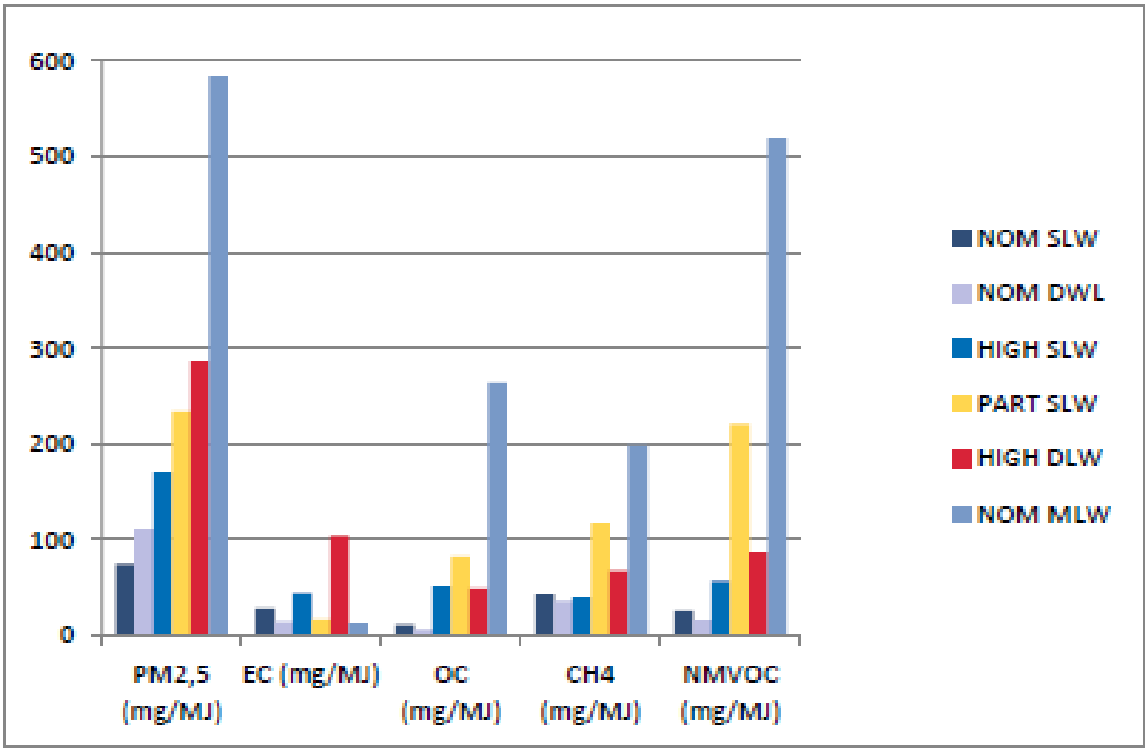

Figure 20: Average measured values when tested on 2 modern wood stoves (Kindbom, et al., 2017) *(NOM = nominal load, HIGH = high load, PART = partial load, SLW = standard log wood, DLW = dry log wood, MLW = moist log wood)*

→ **Research by INERIS on behalf of ADEME (Ademe - Ineris, 2016)**

In France, several appliances were tested under different conditions using an INERIS test bench, with the aim of simulating real-life conditions. Two stoves and two (closed/inset) fireplaces were tested which were considered to be representative for appliances that were available on the French market at that time. The results of the measurements are summarised in *Table 20*.

Table 20: Overview of average measurement results (Ademe - Ineris, 2016)

Parameter		CO	CO_2	NO_x	VOC	CH_4	PM (solids)	PM (solids + conden-sables)	PAHs	Benzo(a) pyrene	BC
Unit		**g/GJ**	**kg/GJ**	**g/GJ**	**g/GJ**	**g/GJ**	**g/GJ**	**g/GJ**	**mg/GJ**	**mg/GJ**	**g/GJ**
Appliance	Fireplace	3575	93	56	638	194	102	282	440	42	13
	Fireplace	3384	92	55	711	249	161	484	463	35	12
	Stove	3374	91	53	821	185	139	426	341	29	18
	Stove	4067	91	54	926	266	166	476	880	96	12
Number of logs	1-2	3679	91	56	794	222	154	440	457	40	15
	2-4	3521	92	53	754	225	130	394	605	61	13
Load	Nominal	2944	93	60	547	192	101	271	685	64	17
	Partial load	4256	90	49	1002	255	183	563	377	37	10
Wood species	Beech	2856	91	59	576	190	80	226	795	78	12
	Oak	5016	91	57	1136	335	216	671	306	29	8
	Spruce	2928	92	48	610	145	130	353	492	44	21
Lighting procedure	Cold	4078	91	55	944	247	164	473	577	57	17
	Warm	3122	92	54	604	199	121	361	485	44	10
Average		3600	92	54	774	223	142	417	531	51	14
Min		1448	85	33	151	51	13	94	116	8	1
Max		8183	95	69	2287	598	500	1355	2845	313	43

The following conclusions were drawn from these figures:

- The type of wood has a statistically significant influence on emissions. In particular when burning oak, higher emissions of CO, VOC, CH_4 and PM were observed. This is explained by a possible lack of oxygen during combustion (shortage of primary combustion air). This effect is probably more pronounced when the appliance is more airtight. The reverse effect was found for PAHs, benzo(a)pyrene and EBC (lower emissions for oak).
- Heating at partial load instead of at full load increases emission levels of CO, VOC, CH_4 and PM. A reverse influence was also found here for PAHs, benzo(a)pyrene and EBC (lower emissions at partial load).
- The fire-lighting procedure also has a major impact on emissions, with higher emissions for all parameters at lighting the fire cold than at lighting the fire warm.
- The influence of the other variables (type of appliance, number of logs) is of minor importance compared to the above parameters.

A comparison of the emission values for PM (solids) and PM (solids + condensables) shows that the values including condensables are a factor 2.7 to 7.2 higher than the values without condensable fraction. This is in line with the conclusions of other comparative studies in the literature, where a factor of 2.5 to 10 can be found (European Environment Agency, 2019).

→ **Conclusion**

However, environmental performance in real-life conditions, under varying and not always optimal combustion conditions, can deviate significantly from the environmental performance measured in labs when using the standardised test procedures under optimal conditions. The items for which the test procedures deviate from the real-life conditions include:

- Lighting and extinguishing the fire are rarely included
- Burning at partial load usually not included
- The condensable fraction of dust is usually not measured
- Ideal negative pressure
- Ideal fuel quality (moisture content, no bark, etc.)
- Ideal types of wood (e.g. no resinous coniferous logs)
- Ideal fuel dimensions
- Ideal fuel quantity
- Ideal installation
- Ideal adjustment and use (e.g. control of air supply)
- Pre-heated appliance

The number of measurements under real-life conditions (in people's homes) is very limited. Relatively more data is available on environmental performance measured in labs under conditions that simulate actual user's practice. From this it is clear that user behaviour (in particular the type of wood used, the use of moist wood, burning at partial load and the procedure for lighting the fire) can lead to significantly higher emissions. However, due to the lack of unambiguous and precise information on average or typical user behaviour (e.g. type of wood used, moisture content of the wood, procedure for lightning the fire, etc., and the combination of these individual aspects), a relatively large uncertainty remains with regard to the environmental performance under real-life conditions.

3.4.4. EMISSION FACTORS USED FOR EMISSION INVENTORIES

Emission inventories are prepared based on emission factors for various activities and processes, including domestic wood heating. Table 21 gives an overview of the emission factors from the European guidebook to prepare national emission inventories (European Environment Agency, 2019). Table 22 gives the values used by the Flanders Environment Agency VMM for preparing the Flemish emission inventory.

Table 21: Emission factors for domestic wood heating (European Environment Agency, 2019)

		General	Open fireplace	Stove - conventional	Stove - high efficiency	Stove- advanced	Boiler - conventional	Pellet stove and boiler
NOx	g/GJ	50	50	50	80	95	80	80
CO	g/GJ	4000	4000	4000	4000	2000	4000	300
NMVOC	g/GJ	600	600	600	350	250	350	10
SOx	g/GJ	11	11	11	11	11	11	11
NH_3	g/GJ	70	74	70	37	37	74	12
TSP (including condensables)	g/GJ	800	880	800	400	100	500	62
PM_{10} (including condensables)	g/GJ	760	840	760	380	95	480	60
$PM_{2.5}$ (including condensables)	g/GJ	740	820	740	370	93	470	60
BC	% of $PM_{2.5}$	10	7	10	16	28	16	15
TSP (excluding condensables)	g/GJ		270	200	170	54	170	32
PM_{10} (excluding condensables)	g/GJ		260	160	150	49	150	30
$PM_{2.5}$ (excluding condensables)	g/GJ		240	140	140	47	140	30
BC	% of $PM_{2.5}$		24	53	43	55	54	30
PCDD/F	ng I-TEQ/GJ	800	800	800	250	100	550	100
B(a)P	mg/GJ	121	121	121	121	10	121	10

Table 22: Emission factors for domestic wood heating used by the Flanders Environment Agency VMM for preparing the air emission inventory

		NOx (tonne/ PJ)	CO (tonne/ PJ)	NMVOC (tonne/ PJ)	SOx (tonne/ PJ)	NH_3 (tonne/ PJ)	Dust (tonne/ PJ)	PM_{10} (tonne/ PJ)	$PM_{2.5}$ (tonne/ PJ)	ElC (tonne/ PJ)	PCDD-F (g/PJ)	B(a)P (kg/PJ)
Wood fuels other than pellets												
Cassette/ stove	<2000	50	4000	600	11	70	800	760	740	74.00	0.8	121
	2000-2013	80	2000	350	11	37	400	380	370	59.20	0.1	10
	2014-2016	95	2000	250	11	37	100	95	93	26.04	0.1	10
	>=2017	95	1676	250	11	37	54	52	52	14.56	0.1	10
Boiler	<2000	80	4000	350	11	74	500	480	470	75.20	0.55	121
	2000-2013	80	4000	350	11	74	170	163	160	44.80	0.55	121
	2014-2016	80	4000	350	11	74	170	163	160	44.80	0.55	121
	>=2017	80	4000	350	11	74	40	38	37	5.55	0.55	121
Open fireplace	<2000	50	4000	600	11	74	880	840	820	57.40	0.8	121
	2000-2013	50	4000	600	11	74	880	840	820	57.40	0.8	121
	2014-2016	50	4000	600	11	74	880	840	820	57.40	0.8	121
	>=2017	50	4000	600	11	74	880	840	820	57.40	0.8	121
Soapstone/ tiled stove	<2000	80	2000	350	11	37	400	380	370	59.20	0.1	10
	2000-2013	80	2000	350	11	37	400	380	370	59.20	0.1	10
	2014-2016	95	2000	250	11	37	100	95	93	26.04	0.1	10
	>=2017	95	1676	250	11	37	54	52	52	14.56	0.1	10
Wood pellets												
Cassette/ stove	<2000	50	4000	600	11	70	62	60	60	9	0.8	121
	2000-2013	80	300	10	11	12	62	60	60	9	0.1	10
	2014-2016	80	300	10	11	12	62	60	60	9	0.1	10
	>=2017	80	300	10	11	12	62	60	60	9	0.1	10
Boiler	<2000	80	300	10	11	12	62	60	60	9	0.1	10

	2000-2013	80	300	10	11	12	62	60	60	9	0.1	10
	2014-2016	80	300	10	11	12	62	60	60	9	0.1	10
	>=2017	80	300	10	11	12	62	60	60	9	0.1	10
Open fireplace	<2000	50	4000	600	11	74	880	840	820	57.40	0.8	121
	2000-2013	50	300	600	11	74	880	840	820	57.40	0.8	121
	2014-2016	50	300	600	11	74	880	840	820	57.40	0.8	121
	>=2017	50	300	600	11	74	880	840	820	57.40	0.8	121
Soapstone/ tiled stove	<2000	80	300	10	11	12	62	60	60	9	0.1	10
	2000-2013	80	300	10	11	12	62	60	60	9	0.1	10
	2014-2016	80	300	10	11	12	62	60	60	9	0.1	10
	>=2017	80	300	10	11	12	62	60	60	9	0.1	10

A comparison of the emission factors of VMM and those of EMEP shows that the emission factors of VMM are largely based on those of EMEP. The main similarities and differences are summarised in Table 23. For dust, the VMM emission factors correspond to the EMEP emission factors including condensables.

Table 23: Comparison of emission factors VMM-EMEP

Appliance type VMM	Age	Emission factors according to EMEP type	Exceptions
Wood fuels other than pellets			
Cassette/ stove	< 2000	stove - conventional	
	2000-2013	stove- high efficiency	CO, PCDD and B(a)P: stove - advanced
	2014-2016	stove - advanced	
	>= 2017	stove - advanced	dust and CO: own (lower) values
Boiler	< 2000	boiler - conventional	
	2000-2013	boiler - conventional	dust: own (lower) values
	2014-2016	boiler - conventional	dust: own (lower) values
	>= 2017	boiler - conventional	dust: own (lower) values
Open fireplace	< 2000	open fireplace	
	2000-2013	open fireplace	
	2014-2016	open fireplace	
	>= 2017	open fireplace	
Soapstone/ tiled stove	< 2000	stove- high efficiency	CO, PCDD and B(a)P: stove - advanced
	2000-2013	stove - high efficiency	CO, PCDD and B(a)P: stove - advanced
	2014-2016	stove - advanced	
	>= 2017	stove - advanced	dust and CO: own (lower) values
Pellets			
Cassette/ stove	< 2000	stove - conventional	
	2000-2013	pellet stove and boiler	
	2014-2016	pellet stove and boiler	
	>= 2017	pellet stove and boiler	
Boiler	< 2000	pellet stove and boiler	
	2000-2013	pellet stove and boiler	
	2014-2016	pellet stove and boiler	
	>= 2017	pellet stove and boiler	
Open fireplace	< 2000	open fireplace	
	2000-2013	open fireplace	
	2014-2016	open fireplace	
	>= 2017	open fireplace	
Soapstone/ tiled stove	< 2000	pellet stove and boiler	
	2000-2013	pellet stove and boiler	
	2014-2016	pellet stove and boiler	
	>= 2017	pellet stove and boiler	

3.4.5. Global impact of domestic wood heating

→ Impact of domestic wood heating on emissions, air quality, health and nuisance

VMM makes an annual estimate of the emissions to air from various sources. For domestic wood heating, the estimate is based on current knowledge of emission factors, wood consumption and the composition of the domestic wood heating appliances in use. According to these emission figures, wood heating makes a significant contribution to air pollution in Flanders, with a contribution of (VMM, 2019)
- 28% for PM10
- 44% for PM2.5
- 66% for benzo(a)pyrene
- 22% for dioxins.

Based on measurements commissioned by VMM, it was estimated that about 1/3 of the fine dust (PM_{10}) in the ambient air in Dessel in winter came from domestic wood heating (Van Poppel, et al., 2016).

These emissions have a negative impact on air quality, especially during the heating season, and cause health effects. Successive human biomonitoring campaigns (2002-2006, 2007-2011 and 2012-2015), carried out by the Support Centre for Environment and Health, show that there is increased exposure to contaminants in the body when burning wood (both indoors and outdoors).

In addition, the Flemish Government's nuisance surveys show that there is an increasing nuisance caused by smoke from the flue gas pipe (including smoke from wood heating): the percentage of people who reported experiencing nuisance (in answer to the question 'If you think of the past 12 months, to what extent have you been hindered or not hindered in and around your home by smoke from chimneys?') rose from 4.3% in 2003 to 5.9% in 2007, 7.4% in 2012 and 10.4% in 2017 (Departement Omgeving, 2018).

→ Wood as a renewable energy source – link with global warming

CO_2 emissions from wood burning is the result of the combustion of carbon that was previously absorbed from the atmosphere and stored in wood, so no net CO_2 is released into the atmosphere. For this reason, wood is considered to be a renewable and CO_2-neutral fuel according to the applicable European rules. Within this context, domestic wood heating contributes to achieving the European objectives of generating 13% of Flemish energy consumption from renewable energy sources by 2020. Wood is also eligible to help meet the minimum share of renewable energy required by EPB for buildings.

The climate neutrality of wood as a fuel is currently the subject of much debate. A lawsuit is currently pending against the EU regarding this principle.

On the one hand, CO_2-neutrality presupposes that the wood originates from sustainable forestry, with a balance between felling and growth, so that the CO_2 that is released during wood combustion is returned to trees. If more wood is felled or wood is felled faster than new wood grows, this results in a decrease in the carbon sequestered in forests, which in the medium term and counting from the time of planting results in a net increase of CO_2 into the atmosphere. In that case, the emissions cannot be regarded as climate-neutral.

On the other hand, wood can also be used for other purposes in addition to heating, for example as a raw material (e.g. building materials). In these applications, the CO_2 is stored longer in products, increasing the carbon sequestered in the economy, and reducing the CO_2 in the atmosphere. Striving for applications with highest possible value is a starting point in environmental policy and can be used as an argument to consider CO_2 emissions from wood heating not necessarily as CO_2- neutral (De Bruyn, van der Veen, & Korteland, 2019). However, this view is not generally shared. There is also an unknown amount of wood that cannot (at present) be used for other applications because it is not collected centrally to be used for an application with higher value (e.g. from garden maintenance, maintenance of small private forests) or because, due to its quality, it cannot be used for other applications (e.g. branch wood).

Finally, domestic wood heating contributes significantly (38%) to black carbon (BC) emissions. BC has warming properties by absorption of light and heat but also indirect cooling properties. In net terms, it contributes to global warming. In contrast to CO_2, BC has a limited life span in the atmosphere (a few weeks).

CHAPTER 4. AVAILABLE ENVIRONMENTALLY-FRIENDLY TECHNIQUES

In this chapter we describe the various measures that can be implemented in domestic wood heating systems in order to prevent or reduce environmental nuisance. These include measures for the design of new appliances, measures for the installation, use and maintenance of appliances, and measures for retrofitting old, polluting appliances. In the discussion about environmentally-friendly techniques, each of the following points are discussed :

- description of the technique;
- applicability of the technique;
- environmental benefits of the technique;
- financial aspects of the technique.

The information in this chapter forms the basis on which the BAT evaluation will be carried out in Chapter 5. It is therefore not the intention to already make statements in chapter 4 about whether or not certain techniques are considered BAT. In other words, the fact that a technique is discussed in this chapter does not necessarily mean that this technique is BAT.

Regarding the discussion on the measures, we first discuss the measures applicable to the design of new appliances. Paragraph 4.1 lists the primary measures that can be applied in a new appliance. Primary measures are measures to prevent the formation of emissions and/or to increase energy efficiency. Next, secondary measures are discussed (paragraph 4.2). Secondary measures are measures to reduce end-of-pipe emissions.

Paragraphs 4.3 and 4.4 then discuss the primary and secondary measures available for retrofitting existing appliances.

Finally, the measures relating to the installation of the appliances (paragraph 4.5), the use of the appliances (paragraph 4.6) and the maintenance of the appliances and the flue gas pipe (paragraph 4.7) are discussed.

4.1. Design of new appliances – Primary measures

Various techniques can be used to improve combustion quality when designing an appliance for domestic wood heating. The measures consist of optimising the combustion chamber and the air supply.

These technologies are always aimed at optimising the Three T’s, i.e. a sufficiently high temperature in the combustion chamber, sufficient turbulence of the air flows, and a sufficiently long residence time in the combustion zones concerned, with the aim of creating an optimal combustion and as a result reducing the emissions.

The temperature is influenced, among other things, by the material used, the presence of insulation, the shape and size of the combustion chamber and the presence or absence of a glass window. The main factors influencing turbulence are air supply and sufficient draught as well as the size and shape of the combustion chamber. Air supply and the distribution of air in the combustion chamber in relation to the size of the combustion chamber largely determine the residence time. Each of the measures influencing one or more T’s is discussed in the paragraphs below.

4.1.1. Flame baffle plate

→ Description

A flame baffle plate, sometimes also called a brake plate, is used to improve the combustion process. This plate ensures that the flue gases do not end up directly in the chimney so that a better heat transfer can take place. Due to the resulting thrust, the unburned gases are additionally - in a secondary step - post-combusted. This further increases efficiency. A flame baffle plate therefore has a positive influence on the Three T's: a reduction of heat losses (= increase of temperature), an increase of turbulence and of residence time. Additional advantages of this flame baffle plate are:

- prevent the flames from entering the flue gas pipe, which may reduce the risk of a chimney fire
- prevent the materials above the flame baffle plate from being exposed to flames with higher temperatures
- deposit of (coarse) dust in the space behind the flame baffle plate which reduces dust emissions at the chimney outlet.

A flame baffle plate can be made of refractory materials, e.g. cast iron, refractory bricks, steel, Chamotte, etc. and can easily be replaced if necessary.
If the appliance has a second combustion chamber, the flame baffle plate leads the hot gases from the first combustion chamber to the second combustion chamber.

A flame baffle plate can also be made of flue gas-permeable foam ceramic, which also has a filtering effect and is therefore also called a filter. This also improves combustion due to the enormous heat reflection and reduces fine dust emissions.

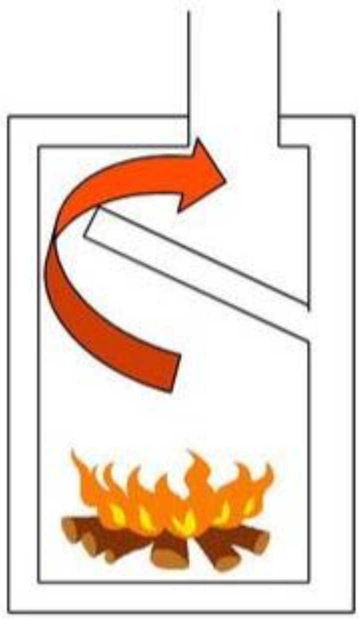

Figure21: The flame baffle plate in the stove ensures that hot gases are not released directly up the flue gas pipe (Van Walsem Kachelspecialist, 2019)

→ Applicability

No technical restrictions are known. A flame baffle plate is already standard in wood-fired stoves and inset/built-in stoves.

→ Environmental benefit

The presence of a flame baffle plate ensures better combustion, reducing emissions and increasing energy efficiency.

→ Financial aspects

A flame baffle plate costs less than 100 euros. The price of a flue gas-permeable filter made of foam ceramic is more than 100 euros.

4.1.2. GRATE IN THE COMBUSTION CHAMBER

→ Description

If a grate is present in the combustion chamber, the fuel is burned on the grate. A grate in the combustion chamber ensures that ashes fall through the grate and are collected in an ash pan which can then be easily emptied (see Figure 22). However, burning on a grate also has disadvantages:

- A lot of incompletely burned particles also fall through the grate; these particles still have an energetic value and their removal to the ash pan reduces efficiency.
- An excess supply of primary combustion air through the grate cools the fire and blows up combustion gases, which may then burn incompletely, resulting in increased emissions.

Pellet appliances use a grate as standard, as the ash bed obstructs the supply of air from below. In the case of wood stoves, systems with a grate as well as systems that fire the wood on bricks in the ashes are used; the choice of system depends mainly on the overall combustion concept of the appliance. There is also an intermediate version in which the grate can be closed.
For boilers, a distinction can be made between:

- 'staged grate' technology whereby the fuel moves on the grate through different temperature zones to be successively dried, gasified and finally to be burned completely.
- Rotating grate: due to the continuous movement, ash is continuously excessively sieved, so that combustion always occurs on a small quantity of ash.

However, ash residue is limited if combustion is good.

Figure 22: Example of a grate in the combustion chamber of an open fireplace (Werkspot, 2010)

→ Applicability

No technical restrictions are known. The use of an ash pan is possible but complex for airtight systems.
With wood stoves and built-in/inset stoves, depending on the overall combustion concept, firing on a grate or firing on bricks is the most appropriate. For boilers or pellet appliances, a grate is used as standard.

→ Environmental benefit

The removal of ash improves combustion which reduces emissions. On the other hand, an excess supply of primary combustion air through the grate increases emissions. In some cases, a stone bottom with a bed of ashes acts as a small insulation layer and facilitates the start-up phase for wood stoves and results in better combustion and lower emissions.

→ Financial aspects

The additional cost for using a grate is low.

4.1.3. INSULATION OF THE COMBUSTION CHAMBER(S)

→ Description

Insulation keeps the heat in the combustion chamber so that the temperature in the combustion chamber remains high and good combustion conditions are maintained. Insulation material is material that is refractory, in other words resistant to high temperatures.
There are different types of insulation materials, including refractory insulation cloth, refractory bricks (e.g. Chamotte), refractory plates (e.g. Vermiculite, see also Figure 23), etc.
Refractory bricks or plates are used especially in stoves to protect the steel or cast iron exterior. In addition, they also absorb heat and release it as radiant heat, until some time after the combustion process has already ended.

The size and type of the glass window also plays an important role in terms of insulation because windows may cause significant heat losses; see paragraph 4.1.5.

Figure 23: Insulation of a wood stove with refractory ceramic lining (Stokertje, 2019)

→ Applicability

No technical restrictions are known. Insulation of the combustion chamber is already applied as a standard.

→ Environmental benefit

The use of refractory insulation material has a positive influence on maintaining high temperatures in the combustion process, making it more optimal and reducing emissions. This also has a positive effect on energy efficiency.

→ Financial aspects

No financial data are known. However, the use of heat-resistant insulation material requires an additional investment for the material in question.

4.1.4. Use of heat-reflective material in the combustion chamber

→ Description

Heat-reflective material aims to produce and maintain an optimal temperature in the combustion chamber as quickly as possible. An example of heat-reflective material is vermiculite.

→ Applicability

No technical restrictions are known.

The use of material that reflects too much heat is not recommended, for example, for stoves with a glass front where the temperature of the glass becomes too high and the glass breaks. A correct combination of vermiculite and cast iron is recommended. Currently it is mainly used in pellet stoves and to a lesser extent in wood stoves or pellet boilers. It is not used in mass stoves.

→ **Environmental benefit**

Increasing the temperature during the start-up phase reduces emissions during this phase because the temperatures necessary for optimal combustion are reached more quickly. After the start-up phase, heat-reflecting material contributes to maintaining the temperature in the combustion chamber, which has a positive effect on emissions and efficiency. The disadvantage of vermiculite is that it is very fragile.

→ **Financial aspects**

No financial data are known. However, the use of heat-reflective material requires an additional investment for the material in question.

4.1.5. Small glass window with double, triple or coated glass.

→ **Description**

The glass window is in the first place for the aesthetically pleasing effect but also makes it possible to see/control when fuel needs to be topped up or if the fire is not working correctly (soot deposit on the glass window). The disadvantage is that heat loss in the combustion chamber is greater with a glass window. Heat loss through the glass window can be reduced by limiting the quantity and size of the glass area and by choosing glass with better insulation and consequently low heat loss (e.g. double glazed, triple glazed, coated glass). Double glazing is already used to a limited extent but requires an additional financial investment as the construction is more complex and the glass more expensive, as cleaning requires that the glass parts can be easily dismantled. Triple glazing is currently only used for cookers.
The sealing of the glass is also very important to guarantee the airtightness of the appliance.

→ **Applicability**

No technical restrictions are known. For pellet stoves, a limitation of the glass surface is standard practice. Wood-fired appliances more often have a higher aesthetic value, which makes the glass part of great importance. Boilers do not have a glass window.

→ **Environmental benefit**

If heat loss is too high, combustion conditions are no longer optimal, resulting in increased emissions. Choosing a suitable glass window can contribute to a reduction of heat loss in the combustion chamber and consequently to a reduction of emissions. Double glazing, for example, can raise the combustion temperature by 150°C, which has a significant effect on emissions. Also, in the start-up phase, the optimal temperature will be reached much faster as there is considerable less heat loss.

→ Financial aspects

No financial data are known. However, the use of double glazing requires an additional investment for the glass itself as well as for the more complex construction involved.

4.1.6. Shape of the combustion chamber

→ Description

The shape of the combustion chamber also plays an important role in achieving optimal combustion. The following aspects must be taken into account for the design:

- A combustion chamber that is sufficiently high and narrow is preferred so the oxygen from the combustion air can easily reach and oxidise the flammable components in the wood gas.
- Sufficient turbulence
- The lining of the combustion chamber must be as homogeneous as possible, without sudden change of direction or cross-section, and without 'dead zones' (where there is a poor mix of oxygen and flue gases).
- Combustion gases must always be returned to increase residence time.
- Good heat output after the second combustion chamber (see paragraph 4.17) so that the flue gases can cool down sufficiently and heat is released to the space. Forced ventilation can contribute to this.

A sufficiently high combustion chamber is important for optimal combustion, in particular for achieving an optimal residence time and turbulence of the flue gases in the combustion chamber. Mass stoves, pellet appliances and boilers are based on this technique and often have a combustion chamber with a height of more than 1 metre.

→ Applicability

With inset stoves/cassettes, a vertical combustion chamber is often not possible due to the limited space available. With built-in stoves and wood stoves, where the visual aspect plays an important role, it is less used.

→ Environmental benefit

A vertical combustion chamber improves the combustion process with corresponding increases in efficiency and lower emissions.

→ Financial aspects

No financial data are known regarding a possible additional cost for a vertical combustion chamber.

4.1.7. PRESENCE OF A SECOND COMBUSTION CHAMBER OR COMBUSTION ZONE/DUCT FOR POST-COMBUSTION

→ **Description**

The presence of a second combustion chamber or combustion zone/duct for post-combustion ensures better combustion of the unburned particles in the flue gases because it affects time and turbulence positively for achieving optimal secondary combustion.
Both systems have an additional injection of secondary combustion air. If it is located under the flame baffle plate, it is referred to as a second combustion zone. If it is located above the flame baffle plate, it is referred to as second combustion chamber.
The second combustion zone can make use of the high temperature in the combustion chamber. However, this also has disadvantages, such as too much turbulence which means the flue gases sometimes pass through the combustion zone too quickly. The location for the supply of secondary combustion air is very important: if too low, the supplied air acts as combustion air; if too high, the effect is smaller because the residence time after mixing with the pyrolysis gases at high temperature is shorter.
A separate combustion chamber has been developed for optimal post-combustion conditions, but cooling of the flue gases makes it more difficult to maintain combustion.
There are also innovations in the field of a horizontal combustion chamber in which the gases are led sideways while the ascending gases are led into an enclosed combustion chamber on the side.

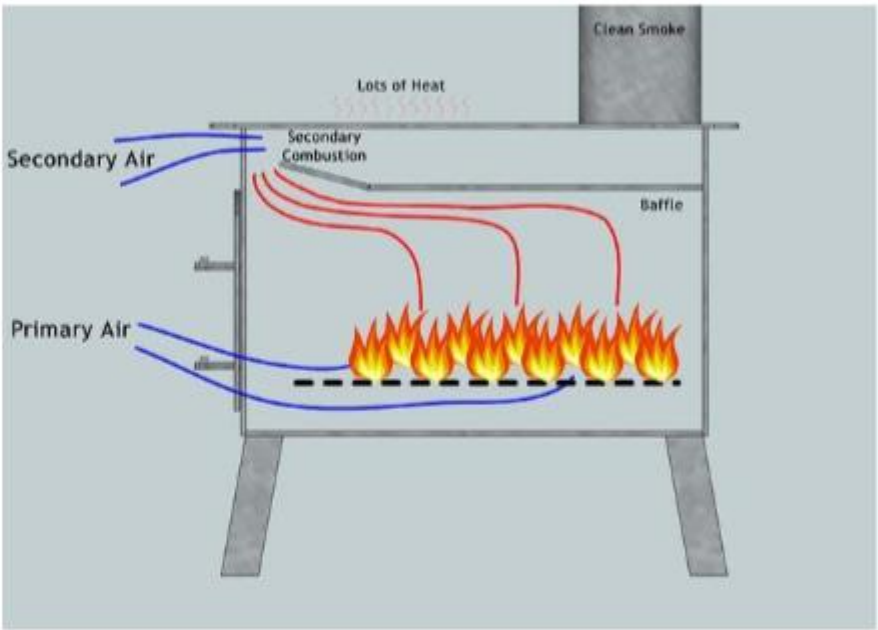

Figure 24: Schematic representation of a secondary combustion zone in a stove (Plomp, 2017)

→ **Applicability**

No technical restrictions are known. A second combustion chamber or combustion zone is already applied as a standard. A second combustion zone is currently the most common system.

→ Environmental benefit

Improved secondary combustion results in an increase in efficiency and a decrease in emissions. A secondary combustion chamber where a sufficiently high temperature can be maintained has a better emission reduction compared to a second zone. However, if the temperature in the second combustion chamber is not high enough, the reduction is much smaller.
Appliances with a downward draught always have a second combustion chamber and should therefore also have lower emissions. However, these appliances are more complex and more expensive, do not have visible flames and are therefore not so popular.

→ Financial aspects

No data are known about the extra cost for a post-combustion zone or an additional combustion chamber.

4.1.8. STAGED AIR SUPPLY

→ Description

Different phases can be distinguished in the combustion process (see paragraph 3.1.1). Optimal combustion can only be achieved if each of these phases proceeds optimally. For example, it is important to complete the start-up phase as quickly as possible and switch to the nominal phase. Phases of smouldering should always be avoided as much as possible. Since each phase has different requirements in terms of air supply, a distinction is made between the possible presence of different types of air supply: primary, secondary, tertiary air supply, and the air supply to keep the glass window clean:

- The primary air supply provides the supply of oxygen when lighting the stove and serves to gasify the fuel and burn the charcoal. Once the fire is burning, the primary air supply can be shut off/restricted. Primary air can be supplied through specially provided openings, by opening the ventilation grilles or by leaving the door ajar.
- The secondary air supply takes place in the upper zone of the combustion chamber or in a separate additional combustion chamber, where the secondary combustion takes place (see paragraph 4.1.7). It provides mixing and turbulence of the pyrolysis gases with the aim of better oxidation/post-combustion of unburned particles and products of incomplete combustion in the flue gases. Secondary air can also be supplied through several narrowed openings that further increase turbulence.
- Tertiary air supply: this term is sometimes used for the air supply to a separate post-combustion chamber but has the same function as the secondary air supply, i.e. extra turbulence during oxidation of the unburned particles in the flue gases to achieve better post-combustion and correspondingly a higher efficiency and lower emissions.
- In addition, modern stoves also have an air supply to keep the glass window clean (glass cleaning air), this air streams along the window and thus limits the amount of soot that settles on the glass window. The air then serves as primary or secondary combustion air.

A minimum requirement for staged air supply according to *the Guidelines for Low Emission and High Efficiency Stove Concepts of ERA-NET Bioenergy project "Woodstoves 2020"* (July 2017) is primary air in combination with air supply to keep the glass window clean with both streams controlled separately. The air supply can be controlled manually or automatically (see paragraph 4.1.9). In the case of manual control, a distinction can be made between controlling each air supply separately or a system with mono-control (see paragraph 4.1.9) where the proportions of the different air supply types are mechanically determined per regime by the manufacturer, often by means of a rotary disc. The secondary air must be preheated. This can be achieved by designing the air ducts accordingly (see paragraph 4.1.12). Primary air, on the other hand, must not be preheated in order to avoid rapid combustion.

In well-insulated and airtight houses, there may be insufficient supply of air from the space to be heated. It is therefore better and more efficient to use an airtight appliance and to supply the combustion air directly from outside (see paragraph 4.5.3).

→ Applicability

Most stoves have a primary and a secondary air supply.

→ Environmental benefit

A staged air supply optimizes the combustion process which results in an increased efficiency and reduced emissions (in particular CO and fine particles).

→ Financial aspects

The additional cost for the extra air supply ducts is 100 to 200 euros.

4.1.9. AIR SUPPLY CONTROL –MONO-CONTROL OF AIR SUPPLY

→ Description

The proportion of the different types of air supply are mechanically fixed per regime by the manufacturer by means of, for example, a rotary disc operated manually by the user. A distinction is made between start-up, nominal with control according to capacity, and burn-out regime. It is important that the position of the control is clearly indicated on the controller.

→ Applicability

The technique is used for appliances fired with pieces of wood. Mono-control is standard for the appliances in the survey.

→ Environmental benefit

Proper control of the air supply optimizes the combustion process, resulting in increased efficiency and reduced emissions.

→ Financial aspects

The extra cost for a mono-control is limited.

4.1.10. AIR SUPPLY CONTROL – AUTOMATIC CONTROL OF AIR SUPPLY AND AIR CIRCULATION

→ Description

A traditional wood stove is often equipped with a staged air supply (see paragraph 4.1.8). Manual operation of opening and/or closing the air supply can have a major impact on the combustion process:

- Primary air supply:
    - Too much primary air supply already causes partial oxidation of the pyrolysis gases resulting in too many unburned gases.
    - Too little primary air supply has a smouldering effect instead of combustion and this has a negative impact on efficiency and emissions.
- Secondary air supply:
    - Too much secondary air supply lowers the combustion temperature, making combustion conditions less favourable and increasing emissions.
    - Too little secondary air supply results in incomplete oxidation and in turn higher emissions.

This also applies to systems that use a manually controlled electric flue gas fan for the air supply. The impact of the user still remains high in this scenario.

The mono-control system (see paragraph 4.1.8) limits the influence of the user, but here too it is still the user who decides which regime is chosen.

Automatic systems ensure an optimal supply of primary, secondary, tertiary and/or glass cleaning air, whereby valves and/or a flue gas fan are controlled thermo-mechanically or electronically on the basis of measurements in order to optimise combustion conditions throughout the entire process. The general rule is that an increase in automation leads to a decrease in human errors. The lower the influence of the user, the lower the emissions due to incorrect use, and the better the correspondence between real life and lab measurements.

The system requires robust sensors, electricity and must be suitable for several types of fuel quality and load factors.
The following systems are available and can also be combined:

- Temperature control: measures the temperature of the flue gas in the combustion chamber; this is a less expensive sensor which is still sufficiently robust and therefore a suitable choice for control in stoves.
- Gas sensors: for measuring oxygen (λ sensor), carbon dioxide, carbon monoxide, or hydrogen in the flue gases. These are best suited for achieving high efficiency and low emissions.
    - Oxygen sensors are reliable and durable with good accuracy and low cross-sensitivity.
    - Carbon monoxide sensors usually detect all unburned components (CO and H_2 together). These sensors are also suitable but are more expensive than the oxygen sensors.

    - Combinations of oxygen and carbon monoxide sensors provide the highest efficiency and lowest emissions but are still expensive to purchase.
- Pressure sensors/Excess air sensor
- Flame detection sensor
- Open door detection sensor
- ...

The use of a temperature control or gas sensor for the control is mainly a choice of the manufacturer; both systems are equivalent and complementary.

→ Applicability

No technical restrictions are known. However, it is important that manual control remains possible in case there is no power or one of the sensors does not work.
For pellet-fired appliances, the automatic control of the air supply is already applied as a standard, mainly on the basis of a flue gas temperature control. A flame temperature control is optionally used to control the fuel supply. Automatic control is not used so often for wood-fired appliances. The reason for this is that the simple appliances require little knowledge and are easy to use and maintain. More complex appliances "scare off", while these appliances are easy to use and therefore also offer extra comfort in terms of use. An additional benefit of good control is that these systems also work well at partial load.

→ Environmental benefit

Proper regulation of the air supply ensures the correct temperature and air flow during the combustion process, resulting in increased efficiency and reduced emissions (in particular CO and fine particles). In addition, the ease of use increases and the factor incorrect use is reduced. Automatic control systems ensure that combustion processes in real-life are closer to those in lab conditions and therefore form the basis for low emissions.
By measuring the temperature in the combustion chamber and in the supply, it is possible to obtain a shorter phase for ignition, more stable oxygen concentrations in flue gases during combustion and post-combustion as well as a lower oxygen supply and sufficiently high temperatures in the combustion chambers. Measuring oxygen or other gases, additionally or as an alternative, also increases the efficiency of the combustion process which, in combination with temperature measurement, results in even higher efficiency and lower emissions.
The influence of the fuel used (e.g. too moist wood) cannot be compensated. However, the measurement of oxygen in combination with the measurement of the combustion temperature can be used to inform the user that the fuel is of poor quality. When the user adds more wood and the system supplies extra air without resulting in a temperature increase and while the oxygen present in the flue gases is maintained, fuel of poor quality is the only possible cause. Without oxygen measurements, a malfunction in the air supply due to poor draught, for example, can also be the cause.
Automatic regulation of the air supply also has a positive influence on wood consumption, which can be lower than with manual regulation.
Additional electricity is required to control the entire system. For the temperature sensor this is limited to 3 watts; an oxygen sensor always needs to be warmed up and therefore has a higher energy consumption.

→ Financial aspects

Automatic control comes with an additional cost compared to a standard combustion system. Considering the price/quality ratio, the temperature sensor is the most suitable for private installations. The combination of a sensor for O_2 and CO is expensive and therefore only rarely used. The combination of a temperature sensor with an oxygen sensor is more common. The additional cost for this automatic control system comes down to 500 to 800 euros. The more automatic control, the higher the extra cost. Suppliers say that the payback period for automatic control is approximately 4 to 5 years. If these sensors are used on a larger scale, the extra cost can decrease considerably.

4.1.11. AIRTIGHT DESIGN OF THE APPLIANCE

→ Description

An airtight appliance has a closed combustion chamber that is hermetically sealed from the living space. Airtight appliances allow a controlled air supply, which has a positive effect on the quality of combustion and efficiency (for example, by avoiding too much excess air). An airtight design of the appliance also reduces the risk of flue gases penetrating into the living area.
Supply of air from the living space, in the case of a non-airtight appliance, requires sufficient ventilation of the living space. Air can enter old non-airtight houses through all kinds of cracks and crevices. However, in modern and airtight houses with mechanical exhaust ventilation and/or extractor hoods in the (connected) kitchen, the negative pressure created by these appliances can, in the case of non-airtight combustion appliances, be stronger than the chimney draught, causing the combustion appliance to receive insufficient combustion air, which results in poor combustion. Flue gases may also be sucked into the living room. In airtight houses it is therefore essential to use airtight appliances that extract the combustion air directly from outside. In the case of appliances that use air supply control, it is also essential that the appliance is airtight, otherwise the functioning will be undone due to possible leaks in the system.
There are currently no standards for airtightness, but these could be included in future European quality requirements.

→ Applicability

An airtight version of the appliances is generally applicable. It is already a requirement for airtight houses.

→ Environmental benefit

Airtight appliances have better air supply control which results in better combustion and consequently lower emissions and higher efficiency. In addition, airtight appliances ensure that no flue gases can enter the living space and this reduces health risks (CO poisoning).

→ Financial aspects

The extra seals for an airtight design have a low additional cost.

4.1.12. PREHEATING SECONDARY SUPPLY AIR COMBUSTION

→ Description

Secondary combustion air can be preheated either by running the air control duct through the combustion chamber up to the outlet or by using a double-walled flue gas pipe. The flue gases are discharged via the central duct and give off heat to the outer duct that is used for the (external) air supply, so that it is preheated. Systems where the air is drawn in through a double-walled flue gas pipe are only possible with very airtight units and under well-defined conditions. A double-walled flue gas pipe is seldom used with stoves fired with pieces of wood. Here it is only applicable with a 3-fold system consisting of a flue gas pipe, insulation and air supply. A flue gas fan (see paragraph 4.5.6) is usually used for pellet appliances, combination appliances and wood-fired boilers to guarantee the negative pressure in the firebox.
Primary air should not be preheated in order to avoid too fast combustion.

→ Applicability

The technique is generally applicable.

→ Environmental benefit

By pre-heating the secondary combustion air, a decrease in combustion temperature can be avoided. Maintaining the combustion temperature results in optimal combustion and a corresponding reduction in emissions.
Excessive cooling of the flue gas temperature must also be avoided as this has a negative influence on the natural draught and on the combustion conditions (condensation in the chimney). Installing a flue gas fan can solve this problem.

→ Financial aspects

No financial data are known.

4.1.13. FLUE GAS HEAT RECOVERY SYSTEM

→ Description

Some heat also happens to disappear together with the flue gases. Recovering this heat from the flue gases increases the overall efficiency of the system. Some of the methods used to recover heat are:

- Double-walled flue gas pipe: see paragraph 4.1.12
- Condenser unit (only for boilers): condenses the flue gases and recovers the released heat with a heat exchanger and then uses this heat to warm up water in a boiler. This can be integrated or a separate unit. The presence of an additional heat exchanger for condensing volatile substances can also further reduce emissions. However, wood smoke also contains potentially acidifying components including nitrogen, sulphur and chlorine compounds.

When the wood smoke condenses in combination with condensed water vapour, acids are formed in the condensate, which at very low pH levels can affect the metals.
Lowering the temperature in the flue gas pipe may also result in poor draught, resulting in poor combustion. A flue gas fan (see paragraph 4.5.6) can be used to optimise the draught in the flue gas pipe.

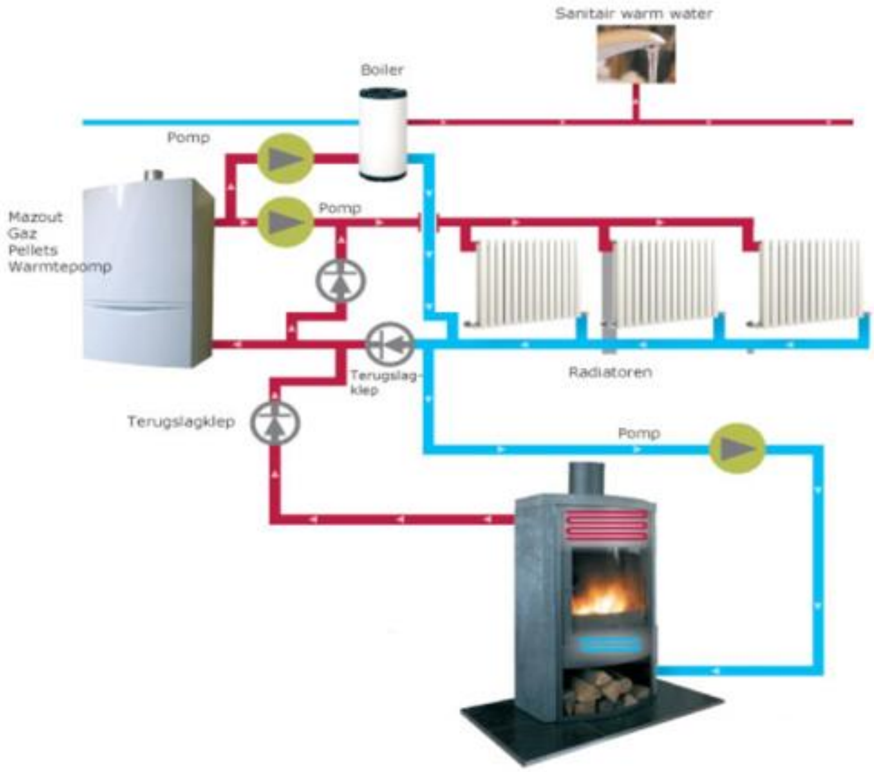

Figure 25: Example of connecting the hot flue gases to the central heating (return pipe in blue is optional) (DDG, 2019)

→ Applicability

- Double-walled flue gas pipe: this is used to a limited extent with stoves.
- Condenser unit: flue gas fan required: this is standard in boilers.

→ Environmental benefit

Efficiency can be increased by 12 % with heat recovery based on the condensation of the flue gases. In addition, this may also reduce emissions of particulate matter and VOCs to a limited extent.
A heat exchanger can increase the efficiency from 8 to 28% and also reduce fine particles and VOCs considerably.

→ Financial aspects

Additional costs depend on the method used. An extra heat exchanger involves an extra material cost.

4.1.14. Offering appliances with different capacity classes and ranges

→ Description

Emission measurements (see paragraph 3.4.3) show that emissions at partial load are significantly higher than at nominal load of the appliance. An appliance must have sufficient capacity and range to meet the heat demand even on the coldest days of the year. In practice, however, most days of the year will require a lower output than that required for the cold days. This means that heating is often at partial load. In order to avoid using appliances at a partial load that is too low, it is important to use an appliance that is tailored to the heat demand (see paragraph 4.6). The right capacity or the amount of produced heat is also determined by the size of the combustion chamber. If the combustion chamber is too large, more heat is generated than necessary. Often, the fuel or air supply is then reduced in order to reduce the size of the fire, but this means that the optimal combustion conditions are no longer met and emissions increase (see chapter 3 - emissions in practice).

Manufacturers can remedy this by offering appliances with different capacity classes and ranges on the one hand, and by designing appliances that also achieve sufficient efficiency at partial loads on the other hand. As such, customers have the opportunity to choose the right appliance for their application. The capacity of standard appliances sold in Germany and Austria is 6 kW, while in Flanders it is still 8-10 kW. In theory, 4 kW is sufficient for an average living room. This suggests that Flemish stoves often operate at too low a partial load, resulting in higher emissions.

The dealer/installer plays an important role in advising the user to choose the correct appliance.

Mass stoves are less likely to be fired at partial load for long periods as they are designed to operate at nominal load for a short period and at relatively high temperatures and where the heat is stored and gradually released without the need for additional firing in between.
Pellet stoves, in turn, are modular so that combustion is always more optimal.
In a boiler, the fluctuating heat demand can be met by placing a heat buffer between the combustion installation and the release circuit in order to optimise the continuity of the combustion process and operation at nominal load.

→ Applicability

There are no known technical restrictions for offering appliances with different capacities, although, if the combustion chamber is too small it becomes more difficult to adapt the design in such a way that optimal combustion is ensured.
However, determining the right capacity is not easy as this depends on several factors, such as the space to be heated, the weather conditions, the user, etc. Regulating the capacity could be a solution, but this may also increase the risk of smothering the fire.
In the case of stoves used to enjoy the decorative function of the flame (‘decorative’ stoves), the capacity may be lower as the heat demand is largely supplied by another heater. However, the visual aspect is especially important with these appliances and appliances with a large fire view are often chosen. These appliances may have a higher capacity than needed.

In terms of appliance casings, users are sometimes wrongly advised to buy a model with a capacity greater than necessary to avoid prolonged heating at high temperatures that may deform the steel or cause the cast iron to crack.

→ Environmental benefit

Appliances can be increasingly fired at nominal load by avoiding over-dimensioning, resulting in better combustion and consequently lower emissions. However, the capacity must be sufficient to provide sufficient heat at very low outdoor temperatures. In practice, a much lower capacity is usually required and appliances are often fired at partial load. Therefore it is very important that the appliance also functions properly at partial load in order to limit the increase in emissions.

→ Financial aspects

Choosing an appliance with the correct capacity does not have a relevant impact on the purchase price. The purchase of an extra buffer tank for boilers does imply an extra cost.

4.1.15. AUTOMATIC FUEL FEEDING

→ Description

Fuel can be fed manually or automatically. Automatic feed always tries to add the right amount of fuel at the right time to maintain optimal combustion conditions. Automatic fuel feeding is mainly used for pellets. However, an additional distinction must be made between automatic pellet feed with regulation and without regulation. Systems without regulation add the pellets at a constant speed, typically with an Archimedes screw. However, pellets can vary in thickness, length and density, so that at a constant adjusted speed the pellet stove sometimes receives too much or sometimes too little fuel, resulting in poor combustion. In systems with regulation, the speed of this screw is adjusted according to the flame pattern so that optimal combustion is always achieved regardless of the thickness, length and density of the pellets.
With regard to storage, a distinction is made between internal storage, which has to be replenished manually on a daily basis, and external storage in a tank or silo that requires an additional transportation system.
Automatic fuel feeding is also possible when burning pieces of wood but this requires a fully adapted design.
In addition, there is a possibility, for example, to use signalling when refilling is needed. This is often applied in wood boilers fired with pieces of wood or wood chips.

Figure 26: Pellet stove with automatic pellet feeding from an internal storage tank (Omniconfort, 2019)

→ **Applicability**

Automatic fuel feeding is applied as standard in pellet fired appliances. This is also possible with wood-fired boilers, but the system is only used sporadically. When used in wood-fired boilers, It is important that the logs have the same size.

→ **Environmental benefit**

Automatic fuel supply ensures that the right amount of fuel is always present and that fuel is added at the right time for an optimal combustion process. This results in a reduction of emissions and an increase in efficiency.

→ **Financial aspects**

No financial data are known.

4.1.16. ADVANCED COMBUSTION PROCESS CONTROL BASED ON ROOM TEMPERATURE AND WEATHER CONDITIONS

→ **Description**

Advanced control of the combustion process in automatic boilers or pellet appliances means there is additional control of the capacity and of the fuel/air supply ratio based on room temperature and weather conditions.. Measurements are used to control either the supply of fuel or the storage of heat via an intermediate medium such as mass, water or PCM (Phase Change Material). The advantage of heat storage is that the unit can always operate at the rated capacity. However, storage in PCM is difficult to control.

→ Applicability

No technical restrictions are known. However, it is only used sporadically because of the extra investment cost. Furthermore, automatic process control is used rarely for appliances fired with pieces of wood.

→ Environmental benefit

The advantage is mainly in terms of ease of use and less in terms of the impact on efficiency/yield and emissions. It is possible that there is an influence on global energy demand because less wood is needed as people do not heat more than they need.

→ Financial aspects

Such systems are about 10% more expensive than installations without this process control. In the case of storage via an intermediate medium, the extra cost of the intermediate medium, casing and pumps must also be taken into account.

4.2. Design of new appliances – Secondary measures

4.2.1. Catalyst

→ Description

Most of the undesirable or potentially unhealthy and/or environmentally harmful compounds in wood smoke are the result of incomplete combustion (see paragraph 3.1.2). A catalyst reduces the temperature for combustion of the compounds in wood smoke significantly so that the products resulting from incomplete combustion are further oxidised (burned). The catalyst therefore ensures a 'cleaner' combustion.

When hot gases pass through the catalyst, reactions similar to combustion occur, but without flames. The aim is to transform as many pollutants as possible into carbon dioxide and water. In the case of a wood stove or boiler, the catalyst also releases heat through oxidation of the smoke, improving combustion efficiency while reducing emissions. (White Beam, 2015)

The basic structure of solid catalysts can consist of metals (most common is iron alloy) or ceramics (e.g. aluminium oxide, zirconium oxide). The active metals responsible for the catalytic reaction are usually precious metals such as platinum (Pt), rhodium (Rh), and/or palladium (Pd) with the following main characteristics (*Figure 27*):

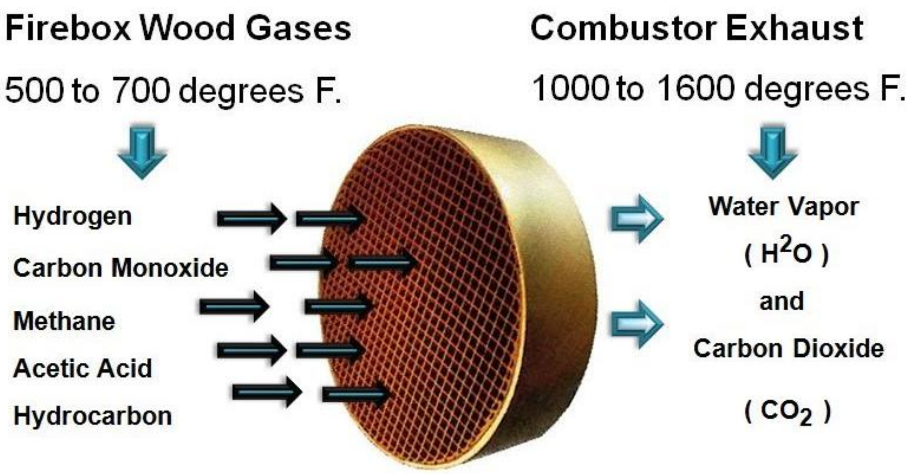

Figure 27: Operation of a catalyst and transformation of pollutants (Cork, 2013)

The following activities of the metals can be observed:

Rh > Pd > Pt --> oxidation of CO

Pt > Rh > Pd --> oxidation of VOCs

Rh > Pd > Pt --> reduction of NO

If the flue gases can reach very high temperatures, non-precious metals such as nickel (Ni), copper (Cu), and magnesium (Mg) can achieve similar conversion rates. (Mack R. , et al., 2017))

Distributors of **ceramic catalysts** for wood burning include Bullerjan (Chimcat type), mainly active in Europe; and Firecat (e.g. the Combustor ACI-68C or Combustor ACI-2C), mainly active in the US. Distributors of **metal catalysts** include Condar (SteelCat type), mainly active in the US; and Ecolink (PALCAT and ABCAT type), mainly active in Europe and Flanders.

→ **Applicability**

Catalysts mainly serve to further reduce emissions of a properly installed and functioning stove that is used correctly. Optimal combustion as a starting point will also contribute to slower degradation and longer life of the catalyst.

<u>Temperature limits and bypass:</u>

The reactions that the catalyst (see also *Figure 27*) promotes are temperature-dependent. When the flue gas temperature exceeds a certain threshold, the catalyst is activated and becomes warmer than the flue gas entering it. This is known as the activation or *light-off* temperature and usually occurs between 250°C to 300°C for CO reduction, while the reduction of hydrocarbons usually starts at 150°C for cyclic compounds. When the flue gas is below the *light-off temperature*, the catalyst will not have an oxidising effect. Various factors contribute to efficient combustion and will ensure a sufficiently high combustion temperature above the *light-off* temperature.

For **ceramic catalysts**, too low a temperature is disadvantageous because some oils and tar in the combustion gas (e.g. creosote) will be deposited onto the catalyst, which will significantly increase the cleaning frequency of the catalyst. That is why most combustion appliances with integrated catalyst are equipped with a bypass linked to a thermometer. At flue gas temperatures lower than *light-off*, the bypass valve is in an open position and the flue gases will circulate directly to the flue gas pipe without passing through the catalyst. At flue gas temperatures higher than *light-off*, the bypass valve closes and the catalyst is activated (see also Figure 28) (White Beam, 2015). A **metal catalyst** suffers less from this problem because the high conductivity of the metal structure inside triggers a self-cleaning process that burns the aromatic compounds from tar. Installing a bypass connected to a thermometer is therefore not necessary for this version, and a manual bypass option is often sufficient.

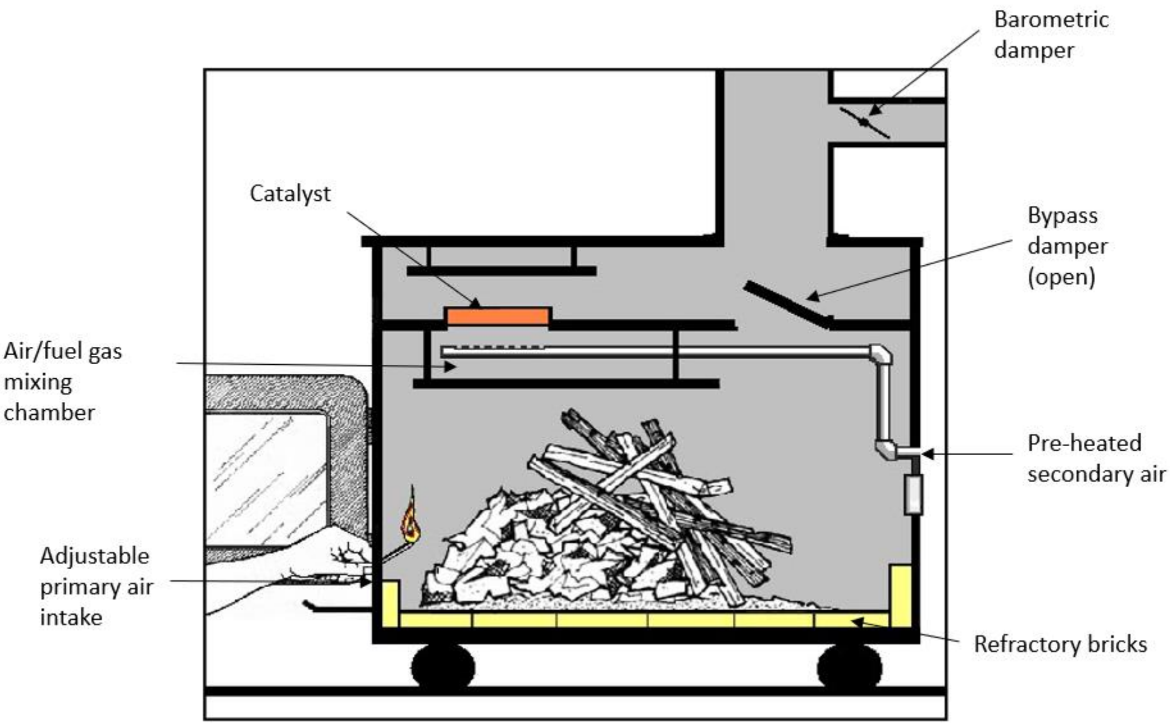

Figure 28: Ceramic catalytic wood combustion with bypass (Firecat, 2019)

The upper temperature limit of the catalyst is determined by the structural and chemical limit for the carrier material (if present), the washcoat (carrier of the active material and used to spread the material over a large surface) and active material, and the production process. The choice of catalyst will therefore determine the operating temperature. This upper limit is often above 500°C and will not be an issue with standard combustion installations. The high activation temperatures limit the applicability to flue gases that reach the *light-off* temperature just above the combustion chamber (Mack R. , et al., 2017)

<u>Location and installation:</u>
The aim is to ensure rapid heating and to remain above the activation temperature but at the same time not to exceed the maximum temperature (>500°C). In addition, the catalyst must remain easily accessible for the user for removal, cleaning, and replacement. If possible, the location should be chosen so that most of the heat released by the catalyst can still be maximally utilized and does not dissipate in the flue gas pipe. (White Beam, 2015)

Ceramic catalyst: A limitation of the ceramic catalyst is the reduction in natural airflow and a high pressure drop (see environmental benefit and cross media effects). This can be remedied by increasing the cross-section of the flue gas pipe to reduce the pressure drop, while maintaining the removal efficiency. If the flow resistance still appears to be too high and the appliance has insufficient natural draught, the installation of a flue gas fan (see paragraph 4.5.6) can offer a solution. (Mack R. , et al., 2017).

Metal catalyst: A metal catalyst causes less pressure drop due to its construction, and this has also been confirmed by various pressure drop measurements (Supplier information catalyst, 2019).

Maintenance:
The maintenance and cleaning of the chimney can be more difficult than with standard combustion appliances because the catalyst has to be removed during cleaning and in some cases, e.g. ceramic catalysts, they are fragile. (Pacific Energy, 2016) The catalyst itself is removed manually by the user and cleaned with water or dusted off. VITO surveyed five catalyst users which revealed that manual cleaning often takes place at fixed times, ranging from 1x/day to 1x/week during the heating seasons. Unfortunately the catalyst does not have a sensor to warn the user that the unit needs to be cleaned. The correct operation of the catalyst thus depends entirely on the common sense (and goodwill) of the user.

Life span:

Ceramic catalysts are subject to damage caused by physical contact, thermal shocks and blockages caused by an incorrectly adjusted bypass or moist wood. The catalyst honeycomb gradually breaks down and needs to be replaced over time.

Metal catalysts are slightly more robust because they are made entirely of metal and the precious metal is applied by means of electroplating. This makes them more resistant to rapid temperature changes and aggressive substances, and are less vulnerable during cleaning.

Globally speaking, the life span of a catalyst under normal use conditions is estimated to be 5 to 10 years.
Under poor conditions, such as when burning moist or low quality wood (such as resinous coniferous wood) and without adequate maintenance, the pores of the catalyst will clog, and the unit may lose its function after just a few years or even months. Extra attention must therefore be paid to burning the right fuel and to regular maintenance.

In Flanders, about one hundred combustion appliances with integrated catalyst are in circulation according to the catalyst supplier.

Preconditions for applicability:

Preconditions at which a catalyst is applicable, include :

- Temperature peaks of at least 300°C
- Optimal operating temperature of > 350°C
- Maximum temperature of 700°C
- Provide sufficient combustion air: negative pressure (draught) of the chimney must be at least 15 Pa (see also paragraphs 4.1.8, 4.1.9 and 4.1.10 about optimising the air supply)
- Catalyst must remain accessible for operation and maintenance
- Use of suitable (and sufficient) dry wood (see also paragraphs 4.6.1 and 4.6.3 about following heating tips and manufacturer's instructions)
- Combustion chambers must be closed (no open fireplaces)

→ **Environmental benefit**

The integration of catalysts in domestic wood-burning appliances can be an efficient secondary measure to reduce emissions from wood burning and remedy potential odour nuisance. The highest emission reduction is usually achieved for carbon monoxide. The reduction of hydrocarbons and unburnt organic particles is also possible. Finally, the catalyst also works as a sort of filter, retaining some of the fine particles (fly ash). The catalyst will work best at a nominal combustion regime.

- Ceramic catalysts:

For the Woodstoves2020 research project, which is aimed at developing innovative measures and technologies to further reduce wood combustion emissions, three ceramic catalysts (EnviCat 2520, and two custom-made units) were integrated at different locations in a stove and evaluated. This showed that catalysts fitted to the outlet of the combustion chamber reduced emissions on average 70% of CO, and 32% of *Organic Gaseous Carbon* (OGC)[5]. However, the emission reduction efficiency dropped as the test period (100 hours) progressed, to 70% of the initial removal efficiencies. Moreover, cleaning the catalyst did not have a positive effect on this efficiency drop. This is because the catalyst is deactivated by aerosol deposits (condensation), mainly K_2SO_4 and KCl, which partially blocked the active centres of the catalysts. Manual cleaning did not offer a solution and in this case the catalyst had to be replaced. (Mack R. , et al., 2017)

- Metal catalysts:

The following emission reductions were achieved with metal catalysts in various tests:
- 66% reduction of particulate matter emission (PM2.5) (DBFZ (2018); lab conditions; initial concentration 101 mg/m³).
- 75% reduction of PAHs: (source (Supplier information catalyst, 2019) (feedback document, maximum values obtained in different lab tests; initial concentration 2,538 µg/g)
- 66% reduction of CO: From "test results of SP Technical Research Institute of Sweden (November 2016)". The test was carried out with approx. 1.4 litres of Pd-catalyst which blocked the flue gas pipe completely (all smoke through the catalyst). The duration of the test included 4 combustion cycles (approx. 5 hours). Average inlet CO concentration to the catalyst 3500 ppm.
- 10%-50% reduction in hydrocarbons: The reduction of hydrocarbons was about 10% in a test comprising 4 combustion cycles (test results of *SP Technical Research Institute of Sweden* (November 2016), and 50% according to a short duration test by the DBFZ. (DBFZ, 2018).

To better understand the actual efficiency of a catalyst, the average removal efficiency must be calculated for the entire duration of the combustion process and over longer periods (preferably during a full heating season). The average removal efficiency of the emissions will be lower than the reported figures under laboratory conditions because the pollution is strongest at the start and at the end of combustion cycle and the catalyst does not function below the activation temperature. Figures of average removal efficiencies across one or more combustion cycles are only known for the removal of CO (66%) and hydrocarbons (10%). High concentrations of CO and methane cause a so-called "blocking" of hydrocarbons. High concentrations of contaminants in wood smoke require more catalyst volume resulting in a higher pressure loss which has to be compensated by a higher chimney or forced negative pressure with a flue gas fan. This is why a catalyst, regardless of the type,

[5] The initial concentrations linked to these removal efficiencies are unknown. The type of wood used included beech or birch, without bark, with a triangular shape. We refer to section 4.1 of the final Woodstoves2020 report for the other test conditions.

is more effective for PAHs if the stove has low emissions across the entire spectrum. Long-term reductions during a full heating season are not yet available.

In addition, the user is also an important factor in maintaining the removal efficiency and proper operation of the appliance. Unlike electrostatic precipitators, the user is not warned when the catalyst is dirty or clogged and is no longer working properly. The user will also have to clean the catalyst manually and at regular intervals, and this will not be done automatically. User behaviour therefore plays a crucial role in the efficiency of this measure.

Cross media effects:

Combustion: The catalyst may increase the flow resistance with as result insufficient airflow (high pressure drops and draught problems in the chimney), leading to poor combustion with higher emissions. Insufficient draught in the chimney increases the risk of potentially dangerous flue gases flowing back into the room. (Mack R. , et al., 2017) The installation of a flue gas fan (see paragraph 4.5.6) can solve this problem. A survey of five users regarding their experience with a metal catalyst asked about possible nuisances related to the use of the catalyst. This revealed that draught problems caused by the metal catalyst hardly occur when the unit is properly maintained and cleaned.

Use of materials: The catalyst is made from precious metals so the use and processing of precious metals such as Platinum (Pt), Rhodium (Rh), and Palladium (Pd) increases.

Waste (water) production:
During cleaning of the catalyst, the residues must be handled with care and prevented from eventually ending up in the air. The catalyst is cleaned with water under a tap and this produces waste water. The residual product generally consists of small amounts of solid particles, including:
- mineral components of the wood such as Calcium oxide
- foreign components attached to the wood such as sand and earth
- salts such as sulphates, chloride, carbonates, (hydr)oxides, nitrates, and ionic compounds;
- metallic oxide and aluminium oxide

Formation of dangerous substances:
There are indications that the use of a catalyst may under certain conditions increase the concentrations of chlorophenol and dioxins*(Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans* - PCDD/F). A study in Finland (Kaivosoja, et al., 2012) indicates increases of a factor of 4.3 and 8.7 for chlorophenol and dioxins respectively when using a catalyst with Platinum (Pt) and Palladium (Pd). The authors mention that the probable reason for this is the catalytic effect of Pt and Pd on the formation of these dangerous substances. This test was carried out on a poorly functioning sauna heater; it is therefore unclear whether the formation of dangerous substances is a risk with properly functioning combustion appliances.

→ **Financial aspects**

The additional cost for a stove with integrated metal catalyst is around 500 euros (price of stove without catalyst is 3,270 euros, with catalyst 3,770 euros incl. VAT (Supplier information catalyst, 2019) integrated in Altech stove).

The additional cost for a stove with integrated ceramic catalyst is around 300 euros. (Bullerjan, 2019)

4.2.2. ELECTROSTATIC PRECIPITATOR

→ **Description**

For the general operating principle of an electrostatic precipitator (ESP) we refer to paragraph 4.4.1. Although ESPs are mainly used as retrofit measure in existing appliances, in certain cases ESPs are also integrated in new combustion appliances, and in particular in pellet boilers. Figure 29 shows the operation of an integrated ESP in a pellet boiler:

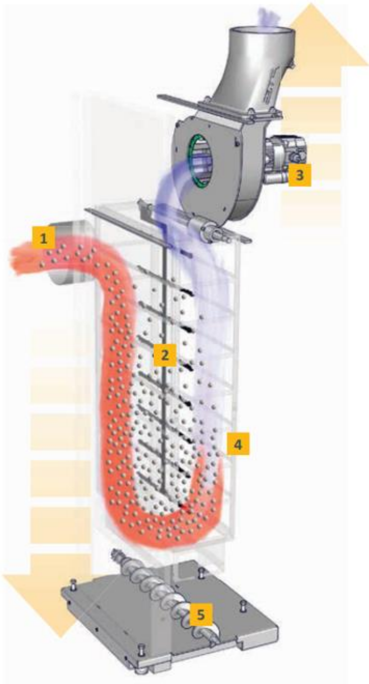

Figure 29: Operating principle of an integrated ESP in a pellet boiler (ETA Heiztechnik GmbH, 2019)

1) Flue gas inlet: The boiler flue gases are sucked in due to the negative pressure in the particle separator.
2) Electrode: The electrode charges the dust particles electrostatically.
3) Air intake fan: the intake fan on the boiler is attached to the separator. The entire boiler system operates with a single fan in negative pressure.
4) Cleaning drum: the electrostatically charged dust particles sink onto the walls of the separator and are transported downwards in a controlled manner
5) Axle screw: Separation of the separated dust and fly ash in an ash pan where it is compressed.

Cleaning is fully automatic in the case of integrated ESPs in new appliances. This is done by means of an ash removal system in which the entire boiler (the combustion chamber, the heat exchanger and the particle separator) are cleaned fully automatically with a single drive unit. (ETA Heiztechnik GmbH, 2019)

→ **Applicability**

For general restrictions on applicability we refer to paragraph 4.4.1.
Integrated ESPs are mainly used in pellet boilers. Models currently on the market include the PelletsCompact ETA PC (ETA Heiztechnik GmbH, 2019) and Fröling biomass boilers (Fröling, 2019). No applications were found for other types of appliances.

→ **Environmental benefit**

For the general description of the environmental benefit and cross-media aspects we refer to paragraph 4.4.1.

The distributor of integrated ESPs in pellet boilers expects an 85% reduction in fine particles over a long service life (Elmar Deutsch (ETA), personal communication, 2019). ETA HACK (without ESP) and ETA eHACK (with ESP) are included in the list of solid fuel appliances (see also paragraph 2.3.2). The difference between the fine particles emission of a pellet boiler without ESP and the same pellet boiler with ESP varies between 0 and 30%[6].

Specific figures on energy consumption were not found. These are expected to be similar to the figures for the ESP installed as retrofit (see paragraph 4.4.1).

→ **Financial aspects**

The investment cost of a boiler with integrated ESP is about 13,000 euros for a 20 kW model and 30,000 euros for a 130 kW ETA model. The price is about 2,000 euros cheaper for the same appliance without integrated ESP. (Gebäude- & Umwelttechnik24, 2019).

The operating costs are similar to an ESP installed as retrofit (see paragraph 4.4.1), but there is no cost for the manual cleaning of the unit. Flue gas fans can be controlled by means of a temperature probe or in function of the process.

4.3. EXISTING APPLIANCES – PRIMARY MEASURES

Because of technical limitations, most of the primary measures cannot simply be applied as a retrofit measure in existing appliances that don't have the measure yet. Furthermore, certain measures are only useful in the right configuration. For example, external air supply is only useful for airtight appliances and secondary air supply requires a second combustion zone or combustion chamber, etc.
The techniques for which a retrofit is possible:
- Heat recovery from flue gases (with a focus on (retaining) sufficient draught in the chimney)
- Heat storage (e.g. extra mass or boiler)
- Forced draught for sufficient air supply

For these techniques the same conditions apply as with new appliances.

[6] These emission results were obtained under test conditions and at nominal load, and from the list of solid fuel appliances (https://www.health.belgium.be/nl/e-services/lijst-van-verwarmingstoestellen)

4.4. EXISTING APPLIANCES – SECONDARY MEASURES

4.4.1. CATALYST

→ Description

The catalyst can be installed as retrofit in an existing appliance in the stove pipe. We refer to paragraph 4.2.1 for the general operation of a catalyst.
In Flanders, the ABCAT (After Burning CATalyst) exists on the market and can be installed as retrofit in the flue gas outlet of an existing stove.

→ Applicability

For the general applicability, we refer to paragraph 4.2.1.
The applicability of a catalyst in the stove pipe has some additional limitations:

- The activation temperature is not reached so quickly when compared to the installation in the combustion chamber: required temperature peaks of at least 300°C. It is therefore recommended to install the catalyst as close as possible after the combustion chamber, where the flue gases have not excessively cooled down.
- A catalyst is best used after applying the primary measures to achieve optimal combustion. The life span of the catalyst may be shorter in old appliances due to damage caused by an excessive concentration of contaminants. (Mack R. , et al., 2017)

The retrofit ABCAT, shown in Figure 30, has been on the market for several years and several hundred of these are already in use in domestic combustion installations. Different catalyst diameters and lengths are available to suit the capacity of the stove (5 kW to 15 kW). When the stove is lit, the catalyst is in bypass mode and therefore not active. Immediately after lighting and closing the stove door, the catalyst is switched to operating mode. During this start-up phase, when the catalyst is in active mode but not yet sufficiently warmed up, it only filters without the catalytic action.

Figure 30: ABCAT catalytic converter built in as retrofit (Supplier information catalyst, 2019)

→ Environmental benefit

We refer to paragraph 4.2.1 for the general environmental benefits and cross media effects of a catalyst. According to the large-scale Woodstoves2020 study, the installation of a retrofit ceramic catalyst at the outlet of the post-combustion chamber gave unstable reductions, with a sharp drop in removal efficiency over time. The decreasing reduction efficiency is most likely caused by the deactivation of the catalyst. (Mack R. , et al., 2017).
A survey involving five users of metal catalysts asked why they had a catalyst fitted in their stove and indicated it was mainly after complaints from local residents about the odour nuisance. The complaints then stopped after the catalyst was installed.
According to a test by the distributor of metal retrofit catalysts, the following results can be obtained with the ABCAT catalyst as retrofit[7]:

Table 24: results of catalyst as retrofit (Supplier information catalyst, 2019)

Emission parameter concentration	Without ABCAT catalyst	With ABCAT catalyst	Difference
CO (mg/m³)	875	375	-57%
Fine particles (mg/m³)	39	14	-64%
NOx (mg/m³)	123	142	+14%
OGC (mg/m³)	104	51	-51%
PAHs (ug/g)	2,538	624.7	-75%

Long-term measurements as well as measurements of the complete combustion cycle may provide a better insight into the effective efficiency of these measures, but they are at the moment not (yet) available.

For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of a catalyst.

→ Financial aspects

Metal catalysts are available starting at €370, excluding installation. The installation involves replacing the first segment of the stove pipe behind the stove (Supplier information catalyst, 2019) Ceramic catalysts are available starting at €700 excluding installation (Chimcat, 2019).

At very high temperatures, non-precious metals (such as Ni, Cu, and Mg) are also suitable as catalyst. Due to the lower temperature in the case of a chimney construction, only precious metals (Pt, Rh, and/or Pd) can be used (lower activation temperature), and this may result in higher costs compared to integrated catalysts. (Mack R. , et al., 2017)

[7] These tests were carried out under laboratory conditions on a wood stove. The duration of this test is unknown.

4.4.2. ELECTROSTATIC PRECIPITATOR

→ Description

An electrostatic precipitator (abbreviated ESP) can be used as a secondary end-of-pipe measure to reduce emissions from wood combustion. Solid particles, i.e. soot and organic and mineral fine particles (including (primary) organic aerosols), can be separated from flue gases with an ESP by charging them electrostatically before the smoke leaves the flue gas pipe.

An electrode is placed in the flue gas pipe in the form of a metal wire or a small ball. A DC voltage of several tens of kilovolts is applied on it by means of a high voltage generator. A strong electrically charged field (corona) is created around the electrode. The fine particles which are generated during combustion and end up in this field are negatively charged and move towards the positively charged metal stove pipe or wall of the flue gas pipe which acts as a second electrode. The operating principle is shown schematically below in Figure 31:

a) Fine dust particles flow along with the hot flue gas
b) A high voltage electrode releases electrons
c) The electrons are drawn to the walls of the flue gas pipe. Fine dust particles are electrically charged and are also attracted by the walls of the flue gas pipe or chimney
d) The fine dust particles are collected on the inner walls and form larger flakes. These deposits are then removed (this can be done manually or automatically)

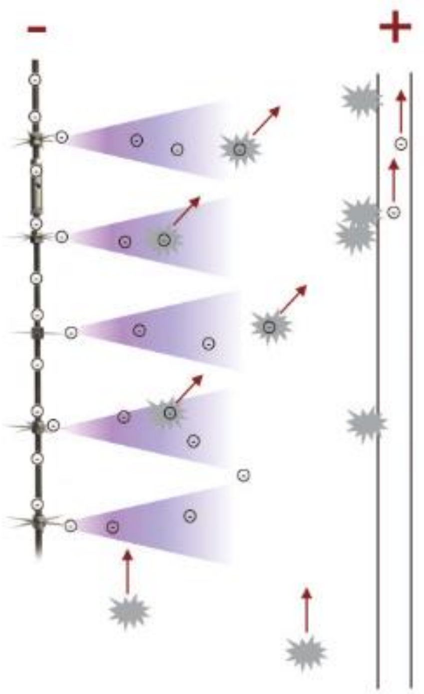

Figure 31: Operating principle of an ESP (Supplier information electrofilter, 2019)

The ESP will only work correctly if the electrode remains free of dust; there are two reasons for this. Firstly, to prevent that the strength of the electric field decreases (the more dust on the electrode, the weaker the electric field and therefore the lower the removal efficiency). Secondly, dust on the electrode can create a voltage bridge resulting in spark discharge (see also the paragraph on environmental benefit).

The migration speeds of particles in the ESP increase as the voltage of the electrode increases. In practice, the field strength is limited by sparks. At high field strengths, an ionised path (electric arc) can form between the electrode and the stove pipe or wall of the flue gas pipe. To prevent overloading of the transformer and to restore the electrical potential, such electric arcs must be extinguished. This is detected by the ESP control system which reduces the voltage by briefly switching off the current. After the electric arc is extinguished, the voltage between the electrodes is restored. The frequency of spark discharge increases with the electric field strength. During spark discharge, the field strength is temporarily lost and sparks can detach the dust from the collection surfaces, reducing collection efficiency. This means that the removal efficiency of an ESP increases with higher voltage between electrodes until the frequency of sparks becomes too high. The ESP control system can use a pre-set value of the desired sparks per minute when controlling the voltage.

An ESP applied as a retrofit measure has two variants: at the mouth of the chimney (Figure 32) or directly in the flue gas pipe immediately after the appliance (Figure 33). Mounting in the flue gas pipe can be done in two ways: by making a hole in the pipe in which the ESP is then placed and fastened with a sealing ring and tension strap, or with a T-piece in which the ESP is integrated. In Flanders the ESP is available from Polvo (Oekotube model) and Dutry (Kutzner + Weber, Airjekt model).

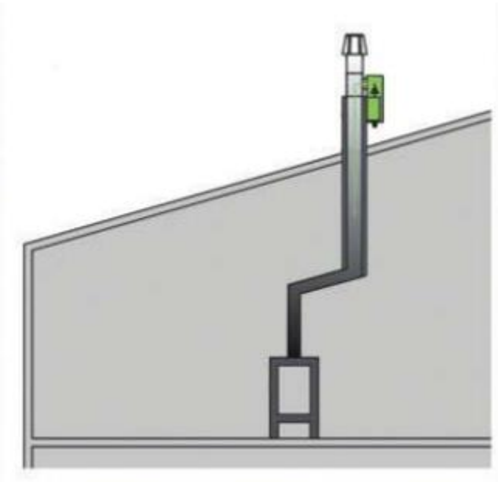

Figure 32: ESP fitted at the mouth of the chimney (Supplier information electrofilter, 2019)

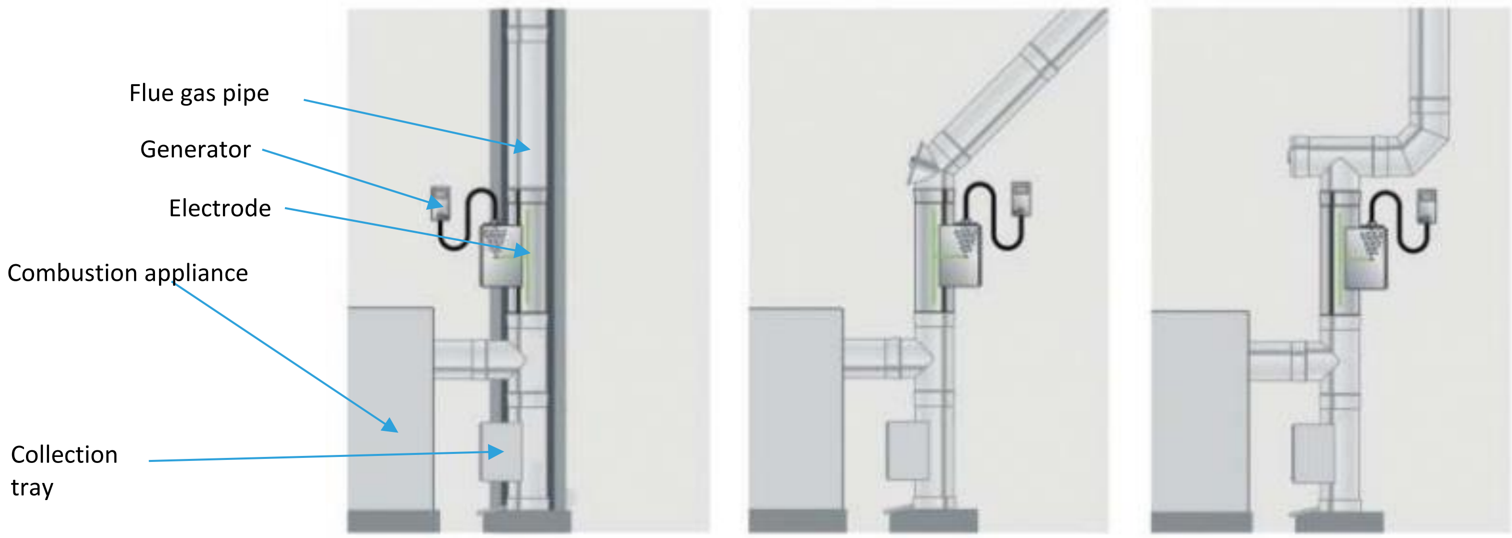

Figure 33: ESP fitted in the flue gas pipe (3 variants) (Supplier information electrofilter, 2019)

Maintenance of ESP systems can be via automatic cleaning and manual cleaning.

Automatic cleaning occurs in two steps: first, the accumulated fine particles on the walls of the flue gas pipe or chimney must be loosened, then the loosened fine particles must be removed from the appliance. There are three ways of loosening the fine particles:

- a built-in brush
- a magnetic vibrator coupled to springs on the inner wall
- water injection into the flue gas pipe (after measuring a certain pressure drop)

The fine particles (or slurry in the case of water injection) then falls into a pan which the user has to empty manually. The residues must be disposed of as waste. In some cases the automatic cleaning has to be initiated manually. (Obernberg & Mandl, 2011)

In the case of **manually cleaned** ESP systems, the fine dust held against the inner wall of the chimney or flue gas pipe must be removed regularly by chimney sweeps. Modern ESP devices continuously measure the distance between the electrode and chimney wall and indicate by means of signals when maintenance is required. The cleaning frequency and maintenance are strongly dependent on the type of stove, the ash residue of the fuel, the firing behaviour and the firing frequency. In general, this is estimated to be necessary once or twice a year. (Obernberg & Mandl, 2011), (Supplier information electrofilter, 2019)

→ **Applicability**

<u>General restrictions:</u>

An ESP is technically applicable on all types of domestic wood appliances: fireplaces, stoves, and boilers. However, it is not recommended to install an ESP in the case of flue gases that contain a lot of lipids (due to the increased risk of a chimney fire), such as flue gases from ovens used in restaurants. These appliances are, however, outside the scope of this BAT study.

When the ESP is installed, the transformer is adjusted according to the characteristics of the appliance and the chimney. If the appliance is replaced later (e.g. by a newer appliance with generally lower power), the transformer is modified and the ESP does not need to be replaced.

Restrictions for ESPs fitted at the mouth of the chimney:

The chimney diameter must have certain dimensions and depends on the manufacturer and the desired model. If the diameter is too wide, the removal efficiency will be too low. The top of the chimney can be made smaller/narrower if necessary.
In addition, there are some technical constraints to ensure the proper functioning of the ESP:

- To avoid damage to the ESP, the flue gas temperature may not exceed 250°C-400°C at the end of the chimney, depending on the type of ESP.
- The flue gas pipe must have a straight vertical duct of at least 38-160 cm, depending on the type of ESP. This is the length of the ribbon that acts as an electrode and the surface needed to charge all types of fine particles. The longer the remaining flue gas pipe after the ESP, the more fine particles are deposited on the walls of the pipe. In addition, fine particles must be able to collect at the bottom of the flue gas pipe.
- For pellet stoves and pellet boilers, a straight vertical piece of 50 cm is sufficient because the wood input is controlled and the surface needed to electrostatically charge the particles is smaller.
- Chimneys that protrude more than 1.5 m above the flat roof as well as sloping roofs complicate the installation and maintenance of the system due to the poor accessibility for the installer and the chimney sweep. This concerns most chimneys and in these cases the installation will require the use of an aerial work platform. Chimney cleaning can also be done from below.

Restrictions for ESPs in the flue gas pipe shortly after the appliance:

- The pipe must be made of a positively charged material in order to attract the negatively charged particles. Metal pipes are suitable for this, but also ceramic flue gas channels and masonry chimneys, provided they are earthed.
- It must be possible to install the ESP in an easily accessible and visible part of the flue gas pipe. This version can therefore only be used for boilers and stoves where the flue gas pipe is accessible, or for flue gas ducts that are difficult to reach, such as for built-in stoves, using an inspection hatch. In addition, there must be a straight vertical duct of at least 50 cm for pellet stoves and pellet boilers.
- The ESP in the flue gas pipe is suitable to a limited extent for all old boilers and stoves due to the possible condensation of tar on the electrode. (Obernberg & Mandl, 2011)
- The study by TU Graz (Obernberg & Mandl, 2011) estimated that about 1900 ESP appliances were in use (1200 Zumikon + 700 OekoTubes) in 2011. According to Polvo, approximately 140 OekoTube devices were installed in Belgium in 2019.

→ **Environmental benefit**

The environmental benefit of an ESP is the removal of particles that can be electrically charged, such as soot and organic and mineral fine particles, but has no effect on odour particles. The removal efficiencies reported in the literature vary widely, ranging from 11% to > 90%. This wide range is partly due to the fact that dust can agglomerate on the walls and later be released again, and partly to the fact that combustion conditions, appliance brands, and duration of the tests often differ.

In order to get a better insight of the removal efficiencies of ESP devices, several sources were screened (e.g. (Obernberg & Mandl, 2011), (Hartmann, Turowski, & Kiener, 2010), (Van Poppel, Baeyens, Aerts, & Divi-Divi), 2018)). The TU Graz Survey on the present state of particle precipitation devices for residential biomass combustion with a nominal capacity up to 50 kW in IEA Bioenergy Task32 member countries, contains useful independent information on the state of the art of ESP devices. Table 25 gives an overview of the removal efficiencies of different ESP devices according to the different sources:

Table 25: Overview of fine particle removal efficiencies of an ESP

Name of ESP	Installation	Combustion appliance	Average removal efficiency for fine particles	Type and duration of test	Cleaning method	Source information
ResidentialESP	Chimney	Old wood stove Old wood stove Multi stoker boiler Modern stove Old stove	54% - 61% 85% - 99% 80% 69% 55%	Field, 61 days Lab, 250 min Lab, duration unknown Field, 4,300 hours Field, 4,300 hours	Manual	TU Graz
Carola-KIT	Flue gas pipe	Modern stove Wood pellet boiler	87% 82%	Lab, duration unknown	Automatic	TU Graz
Zumikron	Flue gas pipe	Wood boiler Modern stove Old stove	41% 17% 11%	Field, 545 hours	Manual	TU Graz
OekoTube	Chimney	Modern pellet boiler	97%	Lab, 5 hours	Manual	TU Graz
Bosch	Flue gas pipe	Modern pellet boiler	70%	Lab, 860 hours	Automatic	TU Graz
RuFF-Kat	Chimney	Modern wood boiler	> 70%	Lab, duration unknown	Automatic	TU Graz
AL-Top – Schräder	Flue gas pipe	Modern wood boiler	48% - 82%	Lab, duration unknown	Automatic	TU Graz
SF20 – Spanner	Flue gas pipe	Modern boiler Old wood boiler	60% 25% and 80%[8]	Field, 410 hours Field, 2,900 hours	Automatic	TU Graz
Airbox	Above combustion chamber	Wood stove	60% - 80%	Lab, duration unknown	Manual	TU Graz
Kamin-Feinstaubkiller	Chimney	Old wood boiler	64%	Lab, 30 hours	Automatic	TU Graz

[8] 25% without bypass during the start-up phase, 80% with bypass during the start-up phase. Boilers with poor combustion require a bypass for the start-up phase. If there is no bypass, excessive soot is collected on the electrodes and this can cause short circuits.

OekoTube	Flue gas pipe	Modern stove	34% - 55%	Lab, duration unknown	Manual	Divi-Divi-VITO
Residential	Chimney	Old stove Modern stove	55% 69%	Field, duration unknown	Manual	Hartmann (2010)
SF20 Spanner	Flue gas pipe	Pellet boiler	80%	Field, duration unknown	Automatic	Hartmann (2010)

Overall, we can state that a lower removal efficiency is achieved on old combustion appliances and with practical (field) testing over a long period in comparison with short-term laboratory set-ups. The reasons for this may be that malfunctions are less quickly remedied, and the start-up phase always results in increased emissions. During laboratory testing, emissions of the combustion appliance are usually only measured when the combustion is at maximum and the ESP is fully functional. It is difficult to draw clear conclusions from these results, especially as combustion conditions, appliance brands and the duration of the tests often vary. Also the method for measuring fine particles may differ per test. The actual removal efficiencies in people's homes over a full season is likely to be comparable to the results of the field tests. We asked five independent ESP users to share their experience[9]. This showed that the colour of the smoke became visibly lighter after installing the ESP, indicating a visibly reduced emission of soot.

For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of an ESP.

Cross media effects:

Malfunctions:
The reviewed literature (see Table 25) revealed that laboratory tests often achieved a higher removal efficiency than field tests because, in practice, ESP malfunctions often occur that cannot be resolved quickly, consequently reducing the average efficiency. The malfunctions reported (Hartmann, Turowski, & Kiener, 2010) include:

- Loss of the airflow around the electrode
- Fuse tripping due to malfunctions and short circuits (especially when the dirt load is significant and sticks to the electrodes)
- Electrode breakage: this is often caused by improper cleaning of the electrode (e.g. when scratches are made when cleaning with a steel brush)
- Voltage loss at the electrodes
- Chimney draught problems (point of attention in problem situations where there is already a problem with the chimney draught)
- Infiltration of rainwater

In old domestic combustion appliances with a high initial concentration of fine dust in the flue gases, a considerable amount of dirt is collected on the electrodes and the insulation (see also Figure 34 below). This can lead to malfunctions and short circuits if the electrode is not cleaned in time. Some ESPs installed in old boilers with poor combustion therefore require a bypass in the combustion start-up phase to avoid soot deposits that may cause short circuits (Obernberg & Mandl, 2011)

[9] The ages of the appliances ranged from 5 years old for an insert cassette to 20 years old for a stove.

Figure 34: Zumikon ESP electrode clamp, disassembled for cleaning after use (Hartmann, Turowski, & Kiener, 2010)

According to the manufacturer, many of these malfunctions can be avoided by a correct installation and periodic maintenance of the ESP. The survey of a number of independent ESP users in Flanders[10] did not reveal any spark discharges or malfunctions that could reduce removal efficiency during the first year after installation. Experience with use of more than one year are unknown.

Electricity consumption:
The power of an ESP is between 10W and 100W, and depends on the capacity of the burner, the chimney diameter, and firing behaviour of the user. To obtain an estimate of the annual consumption, we take two types of users as an example: on the one hand the "heaters used to enjoy the decorative function of the flame or auxiliary heaters ('decorative' heaters)" and on the other hand the "main heaters".

The so called 'decorative' or auxiliary stoves or fireplaces are lit to create a pleasant atmosphere. We assume a use of the appliance of 10 hours per week for 4 months (18 weeks). The total consumption for 180 hours/year at 10-100 W corresponds to a range of 1.8-18 kWh/year.

The 'main heaters' use the boiler, stove or fireplace as their sole or main source of heating; we assume: 4 hours x 5 days a week + 2 x 12 hours in the weekend = 44 hours/week, 5 months (22 weeks). This corresponds to a total use of 968 hours/year at 10-100 Wh and an electricity consumption of about 9.6 to 96 kWh/year depending on the capacity of the ESP.

Noise:
Soot and ash deposition on a high-voltage electrode may cause spark discharge, which can lead to noise pollution. According to the study by TU Graz and Hartmann, complaints of noise pollution were received during all field tests, on the one hand from the users themselves due to the built-in fan, and on the other hand from neighbours due to the spark discharge). According to manufacturers, spark discharge can be avoided by a correct installation and adequate maintenance. As part of this BAT study, VITO surveyed the experience of five independent ESP users and they did not report any cases

[10] The users all had an ESP of the brand Oekotube. The combustion appliances ranged from 5 years old for an insert cassette to 20 years old for a stove.

of noise pollution during the first year after installation. Experience with use of more than one year is not available.

Safety:
There are no indications that an ESP increases the risk of a chimney fire when used for domestic wood heating applications. However, it is different in case of flue gases containing a lot of lipids (e.g. restaurants) or having very high temperatures (e.g. pizza ovens), but this falls outside the scope of this study.

Waste materials:
The dust that is separated by the ESP is waste. The quantity and composition of the dust depends on the quantity and quality of the dust that is released during combustion, and is therefore also linked to the type of appliance used and the combustion conditions. Contamination present in the flue gases (e.g. PAHs) will also be found in the separated dust particles.

→ **Financial aspects**

Investment cost:
The purchase price for an electrostatic precipitator is approximately 1,500 - 2,200 euros including mounting and installation (Obernberg & Mandl, 2011). It is advised to have the installation carried out by a professional installer and not as a do-it-yourself job. For poorly walkable roofs or chimneys that protrude more than 1.50 m, an aerial work platform will have to be used for the installation, at an additional cost of approx. 150 euros. (Supplier information electrofilter, 2019)

Operating cost:
The operating cost of an ESP mainly comprises the electricity consumption of the electrodes and the fan. With a power of 10W-100W, the cost is 0.39 - 3.9 euro cents per hour (with a cost of € 0.39/kWh (VREG, 2019)) that the unit is switched on. For the 'decorative heaters' this amounts to a cost of € 0.70 - 7.0/year. For the 'main heaters' this amounts to a cost of € 4 - 40/year.

Maintenance costs:
According to the distributors, a manual electrostatic precipitator should be cleaned once or twice a year, depending on the type of appliance and its use. The cost of a service visit is around 100-150 euros, depending on the number of flue gas pipes that need to be cleaned. The maintenance of the electrode is usually done together with the annual (in some cases mandatory, see also Chapter 2) chimney cleaning, and does not result in a significant additional cost. It is important not to use a steel brush as it may damage the electrode.

4.5. INSTALLATION OF APPLIANCES

4.5.1. CHOOSING AN APPLIANCE FOR A PARTICULAR USE

→ **Description**

Stoves with a capacity that is too low will not be able to heat the space in question sufficiently and will often become overheated, which can lead to damage to the stove housing. On the other hand, stoves with a capacity that is too high produce more heat than necessary. Consequently, the combustion process in these stoves will be reduced by reducing the air supply and by operating the

stoves at partial load with the risk of long-term smothering. Emission measurements (see paragraph 3.4.3) show that emissions at partial load are significantly higher than at nominal load of the appliance. It is therefore important that users choose an appliance with a capacity that is adapted to the heat demand in order to avoid using appliances at a partial load that is too low. This is all the more true for manually controlled appliances as these appliances perform best at rated capacity.
It is also recommended for boilers to fire them at nominal load as much as possible. In case of a boiler, the varying heat demand can be met by placing a heat buffer between the combustion installation and the release circuit in order to optimise the continuity of the combustion process and the operation at nominal load.
Pellet appliances have in addition the option to regulate the capacity, automatically or manually, within a predetermined capacity range.

→ Applicability

No technical restrictions are known.

→ Environmental benefit

Choosing the right appliance means that it can be fired more at nominal load, resulting in better combustion and consequently lower emissions.

→ Financial aspects

Choosing an appliance with the correct capacity has no relevant impact on the purchase price. However, the purchase of an extra buffer tank for boilers does imply an extra cost.

4.5.2. CORRECT INSTALLATION OF THE APPLIANCE

→ Description

The location of the appliance in the room is also essential for optimal heat distribution. Preferably, the appliance should be placed according to the following conditions:

- On an inside wall so that a minimum of heat is lost to the outside
- Near the stairs if it is recommended that the upper floor is also heated
- Slow heat release stoves should be placed centrally in the space to be heated
- At a location where there are good possibilities for the supply of external air and the removal of flue gases (see paragraph 4.1)

→ Applicability

The available space will help determine which type of appliance can be installed. With regard to the placement of the appliance there are requirements in terms of the distance to combustible materials, both for the side walls and the rear wall as well as for the floor. It is also important that in airtight houses the air supply is connected completely airtight in order to avoid negative pressure in the living space.

→ Environmental benefit

The placement itself has no direct impact on emissions, but there are factors that can increase efficiency, such as a suitable location with a minimum loss of heat.

→ Financial aspects

Placing the appliance in a good location does not cost extra. However, a correct placement may require the expertise of an installer, which may cost more.

4.5.3. External air supply

→ Description

Air can be supplied from the living area or via an external air inlet. In the case of external air supply, the air is extracted from outdoors by means of an air supply duct. This allows a controlled air supply, which benefits combustion and prevents flue gases from entering the living space due to negative pressure in the living space. In airtight houses with ventilation systems, external air supply is an absolute requirement as there is no natural supply of ambient air.

It is best to preheat the supplied secondary air in order to minimise heat loss in the combustion chamber (see paragraph 4.1.12). It is best not to preheat primary air in order to avoid accelerated combustion.

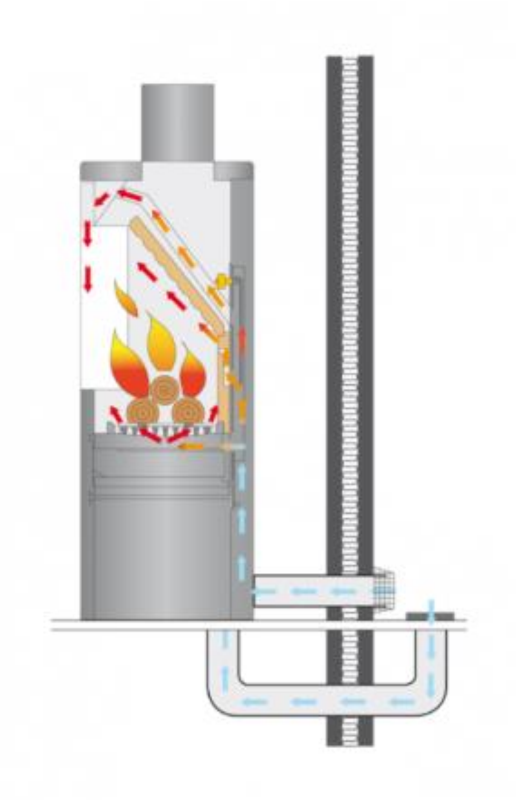

Figure 35: Illustration of an external air supply (blue arrows) for a wood stove (123-Kaminofen, 2019)

→ Applicability

This technique is generally always applicable. However, in existing situations it may not be obvious or even impossible to have access to external air supply.
In the case of appliances fired with pieces of wood, the supply of external air is almost always via natural draught; in the case of pellet appliances and wood-fired boilers, forced air supply with a flue gas fan is usually used (see paragraph 4.5.6).

→ Environmental benefit

The use of an external air supply increases energy efficiency as no warm air is extracted from the surrounding space for the combustion process. When external air is supplied, the supply of air is always sufficient and this benefits the combustion process when compared to a situation in which negative pressure can occur in the room in question with the risk of odour nuisance and flue gases entering the living space. Moreover, outside air also contains more oxygen than indoor air.

→ Financial aspects

The additional cost for external air supply depends on the location of the unit.

4.5.4. CORRECT INSTALLATION OF THE FLUE GAS PIPE

→ Description

Traditional chimneys (terracotta, brick, concrete) are often not adapted to modern appliances. Currently, stainless steel flue gas pipes are preferred.

A good placement of the chimney or flue gas flue pipe is key for the proper functioning of an appliance. A correct draught in the flue gas pipe ensures a good combustion process in the appliance. For the applicable standards, please refer to paragraph 2.3.5.
The flue gas pipe is preferably placed as vertically as possible and with a minimum of bends starting from the exit of the appliance. Horizontal pieces are best avoided or kept to a minimum. This is because the presence of horizontal pieces increases turbulence of the flue gases and this reduces the draught and because horizontal pieces do not contribute to the thermal draught despite increasing pressure losses.
Furthermore, the inside of a flue gas pipe should preferably be smooth and the pipe must be sufficiently high and have a constant diameter (also no constriction at the chimney mouth). Sufficiently high is described in the code of good practice, 'Prevention and control of environmental nuisance from small-scale air and vapour extraction systems', as follows (Departement Omgeving, 2017):
'A good execution puts the chimney mouth in the case of a pointed roof (equal to or more than 23° roof pitch) close to the ridge and at least 1 m above it. For roofs with a smaller pitch, the chimney should be 2.5 m higher than the roof edge. In the presence of neighbouring obstacles it may be necessary to raise the chimney to approx. 1 m above the ridge of the neighbouring obstacles.'
The diameter is subject to the desired flue gas velocity and the amount of flue gas that needs to be discharged. If the diameter of the flue gas pipe is too narrow, the flue gases are insufficiently discharged; if the diameter of the flue gas pipe is too wide, there is a greater risk of the flue gases cooling down, possibly resulting in condensation which in turn may disturb the draught. A round flue

gas pipe is preferable to a rectangular or square flue. Non-insulated flue gas pipes should not be located outside the house or as limited as possible as the flue gases cool down too much at a cold outside temperature and this results in insufficient draught.
The mouth of the flue gas pipe is best fitted with a good chimney cap, which the code of good practice, 'Prevention and control of environmental nuisance from small-scale air and vapour extraction systems', describes as follows : *A correctly designed chimney cap has a stabilising effect on the draught and prevents rain ingress*. (Departement Omgeving, 2017). Finally, the flue gas pipe mouth must be located in an undisturbed zone. This is a zone in which the discharge of flue gases into the atmosphere is not hindered by wind or other surrounding obstacles such as trees, roofs or other buildings. In addition, the mouth is best at a safe distance from windows and inlets to avoid nuisance indoors.

→ Applicability

When connecting the flue gas pipe, it is important to ensure that all connections are airtight.
In existing buildings, the existing situation must be taken into account before installing the chimney. This means that it is not always possible to meet the optimal conditions for the installation of a chimney. When installing a new stove it may be necessary to replace the entire flue gas pipe as well.

→ Environmental benefit

A well installed flue gas pipe contributes to an effective draught in the chimney which in turn contributes to good combustion with higher efficiency and lower emissions.
Installing a flue gas pipe in the living area may result in an additional increase in efficiency. A flue gas pipe in the house results in a higher start-up efficiency because the pipe is already warm and therefore has a better draught.

→ Financial aspects

The price for installing a flue gas pipe and chimney depends on several factors, including the length and diameter of the pipes and the type of appliance to which must be connected. In existing situations, the installation may involve additional costs to adapt to the existing situation or it may be necessary to completely renew the flue gas pipe. This has a significant impact on the price.

4.5.5. INSULATION OF THE FLUE GAS PIPE

→ Description

Insulation of the chimney reduces cooling of the flue gas. This is necessary in order to have sufficient draught in the chimney and thus maintain the negative pressure at the mouth of the chimney. This also prevents possible condensation of the flue gases in the chimney.
In the case of an uninsulated chimney, it is better that the chimney does not go directly outside, but first goes through the house and then out through the roof so that the lower zone in the chimney benefits from the indoor temperature, preventing the chimney from being too cold and thus resulting in insufficient draught.

→ **Applicability**

No technical restrictions are known. When using a double-walled flue gas pipe (see paragraph 4.1.12), the air in the outer duct forms an insulation layer for the inner duct.

→ **Environmental benefit**

Insulating the chimney contributes to an effective draught in the chimney which in turn contributes to good combustion with higher efficiency and lower emissions.

→ **Financial aspects**

No financial data about this is available, but the additional cost of insulation is usually rather limited.

4.5.6. FORCED DRAUGHT FOR SUFFICIENT AIR SUPPLY IN THE COMBUSTION CHAMBER

→ **Description**

Forced draught for sufficient air supply for combustion usually consists of a flue gas fan in the flue gas pipe or a rotating hood cap on the chimney mouth. It is used to optimise the air supply if natural draught is insufficient. Flue gas fans can be controlled by means of a temperature probe or in function of the process. A rotating cap uses the force of the wind and the rising, warm flue gases. The hood cannot be controlled and is generally less efficient and not as reliable as a flue gas fan. However, a rotating cap does prevent the flue gases from flowing back down the chimney.

In addition to forced air supply for combustion, forced air supply for convection is also possible, which contributes to the transfer of to the environment. This fan can be controlled manually (user decides when to the fan is in operation or not) or thermodynamically (based on a temperature measurement, the fan is switched on/off, optionally combined with speed control (e.g. for pellet stoves),). With the latter, the temperature measurement is determined per appliance depending on the construction of the appliance and the type of temperature measurement, typically under the fire plate or on the rear wall.
This air supply for convection has no influence on the combustion process and/or the corresponding emissions.

→ **Applicability**

No technical restrictions are known. There is normally sufficient natural draught with a well-designed flue gas pipe, and this measure should not be applied as standard.
Pellet-fired stoves, built-in stoves and inset stoves sometimes use forced draught, while other wood-fired stoves seldom or never use forced draught.

→ **Environmental benefit**

Where insufficient natural draught is present, a forced draught for air supply contributes to a more optimal combustion which increases efficiency and reduces emissions. In addition, soot deposits and

condensation in the flue gas pipe are also reduced. Flue gas fans, like all fans, require some energy consumption and also produce some noise.
In this respect it is important that the flow rate of the air supply is adjusted correctly. If the air supply is too high, combustion may be incomplete, causing the emissions to increase.

If construction is good and sufficient natural convection is available, there will be no measurable influence on combustion and the measure will therefore have no added value.

→ **Financial aspects**

The additional cost of this investment concerns the installation of a flue gas fan in the flue gas pipe or a rotating cap on the chimney mouth, including the necessary electrical equipment and integration of the controls.

4.5.7. Installation by a specialist installer

→ **Description**

The primary and secondary measures described in paragraphs 4.1, 4.2, 4.3 and 4.4, as well as the proper installation of a flue gas pipe and chimney, contribute to achieving optimal combustion and a reduction of emissions. For the correct operation of the appliance on the one hand and the flue gas pipe on the other hand, it is very important that everything is installed and connected correctly.

→ **Applicability**

No technical restrictions are known.

→ **Environmental benefit**

For most of the measures described in chapter 4, it is essential that they are installed correctly. A faulty installation may increase the risk of emissions instead of reducing it. Installation by a competent installer reduces the risk of installation errors.

→ **Financial aspects**

Installation by a specialist installer results in an additional cost. For inset appliances, freestanding stoves and non-automated boilers, the installation cost is 250 to 1500 euros. For automated boilers, this amounts to between 2000 and 3000 euros (Ademe, 2018).

4.5.8 Provide dry and ventilated storage space for wood (indoors or outdoors)

→ **Description**

For wood-based systems, it is essential to use dry wood to limit emissions. The wood must therefore be sufficiently dry before it is used as firewood. For this purpose it is best to stack the wood in such

a way that there is sufficient ventilation to allow the wood to dry in a location protected from the rain. A suitable storage place and method can significantly reduce the drying time of wood. The humidity of the wood can easily be measured with a wood moisture meter. The optimal moisture content for pieces of wood is between 10% and 20%. According to the website https://www.ecopedia.be/pagina/wanneer-mijn-hout-droog-genoeg-om-te-stoken, the humidity of the wood is preferably lower than 15%.
In the case of pellets, a distinction is made between systems that are manually refilled per bag and systems with automatic feed from a silo. Both systems require sufficient space for dry storage of the bags of pellets on the one hand and for the installation of a storage silo on the other hand.

→ Applicability

There are no technical restrictions known besides the presence of sufficient space.

→ Environmental benefit

Burning dry wood contributes to achieving optimal combustion which increases efficiency and reduces emissions.

→ Financial aspects

The cost of dry wood storage varies greatly depending on the chosen application and the space already available. A wood moisture meter can be purchased from 10 euros.

4.6. USE OF APPLIANCES

4.6.1. FOLLOW WOOD BURNING TIPS

→ Description

For wood stoves and fireplaces it is best to take the following tips into account.
The start-up phase is best as short as possible as in this phase the appliance is not yet up to temperature and the combustion gases are therefore not at a high temperature for enough time to burn completely. As a result, high emissions can initially be observed. The quicker the fire starts, the quicker the appliance is at temperature. The following measures should therefore be taken into account for the start-up phase:

- Fully opening the air supply;
- Stacking wood with the most flammable material at the top and lighting the wood pile from above.
- Good stacking of the logs with enough space in between for good air circulation

Once the fire burns well, the primary air supply may be closed or reduced, but the secondary air supply must remain at a sufficient level to maintain optimal combustion and avoid smothering. Next, it is best to add small amounts of wood regularly instead of a lot of wood every now and then. On the other hand, it must be avoided that the door is opened too often as this causes the temperature in the combustion chamber to drop each time.

Always burn clean and dry pieces of wood. Composite wood contains glues and other plastics that produce a lot of air pollution and soot when burned. Resinous coniferous wood and wood with bark or branches is also not suitable as firewood.

Sufficient air supply is always required during the combustion process. If the air supply is too low, the fire receives too little oxygen and combustion will be incomplete.

When the fire has gone out and only ashes remain, the air supply can be closed to avoid heat loss through the flue gas pipe.

Pellet stoves and boilers are usually sufficiently automated so that the most optimal combustion is automatically pursued.

→ **Applicability**

No technical restrictions are known.

→ **Environmental benefit**

Following wood burning stove tips contributes to optimal combustion.

→ **Financial aspects**

No data on the financial impact are known.

4.6.2. LIMIT WOOD BURNING IN THE EVENT OF HIGH FINE DUST CONCENTRATIONS AND UNFAVOURABLE WEATHER CONDITIONS

→ **Description**

Wood burning produces emissions of fine particles among other things. At times when there are high concentrations of fine particles in the ambient air or with adverse weather conditions when the dispersion of dust emissions is hindered (e.g. wind-still weather, temperature inversion), it is advisable to use your fire as little as possible in order to limit additional emissions of fine particles. Because users of wood-burning stoves cannot be expected to decide for themselves when circumstances are unfavourable, the Flanders Environment Agency VMM gives heating advice. If the average measured fine dust concentration in Flanders during the last 24 hours is higher than 50 µg/m³ and no improvement is predicted, VMM advises not to burn any or as little wood as possible (see https://www.vmm.be/lucht/luchtkwaliteit/stookadvies). If the forecasts subsequently indicate that there is little chance that concentrations will remain above the limit of 50 µg/m³ for the next 24 hours, the advice will be withdrawn.

→ Applicability

In principle, the measure applies well to appliances that are used as 'decorative' heaters or for supplementary heating. For appliances that are used as the sole or main source of heating, it is less obvious to stop burning wood altogether.

→ Environmental benefit

By limiting wood burning, the emissions from wood burning are reduced.

→ Financial aspects

There are no direct costs associated with this measure.

4.6.3. FOLLOW THE MANUFACTURER'S INSTRUCTIONS

→ Description

Many different appliances are available on the market. Due to the rapid evolution in development and performance, the optimal burning process is not necessarily the same for all appliances. For example, there can be differences in terms of air supply control, maintenance, etc. Moreover, it is also important to only use the fuel(s) recommended by the manufacturer. It is therefore recommended, if available, to follow the manufacturer's instructions for each appliance, which may include a manual and/or training.

→ Applicability

This measure applies to any appliance that has the necessary instructions.

→ Environmental benefit

The correct use of an appliance contributes to optimal combustion and this benefits efficiency and emissions.

→ Financial aspects

Following the manufacturer's instructions costs nothing.

4.7. MAINTENANCE OF APPLIANCES AND FLUE GAS PIPES

4.7.1. REGULAR MAINTENANCE OF APPLIANCE + FLUE GAS PIPE

→ Description

Regular maintenance of the appliance and the flue gas pipe contributes to continuous good operation.
The maintenance of a wood stove consists of regularly cleaning the glass window and regularly removing the ashes. The soot deposited on the glass window is limited if combustion is good, so this is in fact a visual verification of a good combustion. It is also necessary to inspect the flints in the combustion chamber, check that the door closes properly and clean the catalyst, if present. For all systems it is recommended to have an annual inspection and maintenance carried out by a professional. The annual inspection and maintenance can be carried out by the supplier/installer or a specialised company. In the case of a wood stove, this can also be done by the user himself. The annual maintenance includes cleaning behind the insulation, cleaning the air inlets, checking and, if necessary, replacing all the seals and insulation material and cleaning the flue gas pipe (because of the risk of chimney fire).
Mass stoves have many channels through which the flue gas passes before it enters the chimney. These include many horizontal channels which require extra servicing attention because of soot deposits in these channels and the resulting reduction in operation and efficiency.
The flue gas channel can also be cleaned by a chimney sweep, but the latter is generally not able to carry out the maintenance of the appliance itself.

Pellet appliances often display a message on the appliance itself indicating that maintenance is required. In some cases, the appliance stops working if it is not serviced.
For boilers, there is a legal maintenance obligation (see paragraph 2.3.1).

→ Applicability

No limitations are known.

→ Environmental benefit

The presence of dirt, ashes, etc. in the combustion chamber hinders the efficient combustion of the fuel.

→ Financial aspects

Maintenance by a skilled professional entails an additional cost.

4.8. SURVEY RESULTS

As part of the BAT study, a survey of manufacturers and importers was organised in order to obtain a better picture of the technologies used with regard to better combustion and the reduction of emissions and the environmental performance of these techniques. This survey was sent out to the

CIV members of CIV (sector federation of manufacturers and importers of stoves and fireplaces) of Agoria and the members of the ODE bio-energy platform. It should be noted that this survey was mainly aimed at the 'better' brands and is not representative of all the appliances on the market. The relatively simple models that, for example, are offered in DIY stores are not included in this survey. However, it was asked to fill in the questionnaire for both the most expensive and the cheapest models as well as the best performing and the least performing appliances. Note that it concerns the theoretical performance in lab conditions and that in practice this can deviate significantly (see paragraph 3.4.3).

When discussing the results, a distinction is made between wood-fired appliances and pellet-fired appliances. A summary of the results can be found in appendix 5.

4.8.1. Wood-fired appliances

The wood-fired appliances (41) are all stoves. No information is given about wood-fired boilers. However, three appliances (2 freestanding stoves and 1 built-in appliance) do have a central heating connection.
The distribution by appliance type is as follows for the 41 appliances (all are with local heat output and closed combustion chamber):

- inset stove/cassette: 4
- built-in stove: 18
- freestanding stove - not slow release 13
- mass stove: 6

→ Applied techniques

The survey shows that the following technologies are already being used frequently:

- flame baffle plate is applied as standard
- insulation of the combustion chamber: mainly refractory plates and refractory bricks are used. Some models have a combustion chamber which is doubled with cast iron plates as a form of insulation.
- Glass window: except for one model (freestanding stove), they all have a glass window, of which 11 with double glazing and 1 with coated glass. 6 appliances (5 built-in stoves and 1 freestanding stove) have a glass window on more than 1 side, always single glazing. 5 of the 6 mass stove models have double glazing; inset stoves always have single glazing. The coated glass was used on a freestanding stove with central heating connection.
- Post-combustion: most of the appliances have post-combustion, 1 inset stove (cheapest model) has no post-combustion. 30 of the 46 appliances have a post-combustion zone, 10 have a separate combustion chamber.
- Staged air supply: most of the appliances with secondary combustion have primary, secondary and glass cleaning air. Only 4 appliances do not have glass cleaning air of which 3 are built-in stoves with a glass window on more than one side and 1 is a freestanding stove without glass.
- The air supply is mainly controlled manually by means of a mono-control.
- The air supply on most appliances is external by means of natural draught. 34 appliances were specified as being airtight and 32 have secondary air pre-heating.

The following techniques are used regularly in the various types of appliances:

- A grate in the combustion chamber is found on 18 appliances with a slightly higher frequency in freestanding stoves and mass stoves.
- Heat-reflective material occurs in all types of appliances but is not used as standard.
- More than half of the mass stoves and freestanding stoves have a vertical combustion chamber; this is not so much the case for built-in stoves (5 out of 18).
- Approximately half of the appliances have a heat recovery system for flue gases; this is true for 5 of the 6 mass stoves.
- Slightly more than half of the appliances have been tested for operation at partial load, and this mainly for freestanding stoves.

Techniques only used sporadically or which are specific to a particular type of appliance:
- Convection fans are only available with inset stoves (always, 4 appliances) and built-in stoves (7 of 18 appliances). The control system is usually based on a temperature sensor.
- Automatic operation is used to a limited extent and, if applied, a measurement of the temperature in the flue gas is the most common control (full automatic control: 8 of the 41 appliances).
- Heat storage in mass is specific to mass stoves (6 appliances), heat storage in water is applied in appliances with a central heating connection (3 appliances).
- Catalysts or electrostatic precipitators are not used as standard.

→ **Performance**

The performances relate to those in lab conditions, but there is still considerable uncertainty about environmental performance in real-life conditions (see paragraph 3.4.3).

In terms of efficiency, it is clear that on average, mass stoves achieve the highest efficiency. However, freestanding stoves and built-in stoves may also achieve efficiencies comparable to the best-performing mass stoves, i.e. 90%.
The differences are more pronounced in terms of emissions, both between the different brands and between the different types and/or techniques used.
- The CO emissions vary from 317 to 1,250 mg/Nm³ with the exception of 1 appliance with an emission of 1,950 mg/Nm³. The appliance in question is an inset stove without secondary combustion. In addition, higher emission values for particulate matter and HC are also determined for this appliance. No distinction can be made on the basis of capacity, price or efficiency with regard to CO emissions. In terms of appliance type, inset stoves generally have higher CO emissions than the other types. The lowest emissions are achieved with freestanding stoves and mass stoves. Certain brands have significantly lower emissions.
- As far as particulate matter is concerned, no appliance type or brand has significantly lower emissions than others. The variation between the different appliance types is similar.
- A similar variation between the different appliance types can also be seen for NOx emissions, only for mass stoves NOx emissions are always relatively higher.
- No distinction can be made on the basis of capacity, price or efficiency with regard to HC either. However, these emissions are significantly lower for all mass stoves, although for inset stoves, built-in stoves and freestanding stoves, appliances with low HC emissions are also available. All manufacturers have models with low emissions but strong variations exist between the different types of appliances.

Compared to the Ecodesign Regulation, we can conclude that with the exception of one appliance, all appliances comply with the requirements of the Ecodesign Regulation. The appliance that does not comply has no post-combustion and shows higher emissions of CO, PM and HC.

Table 26 gives an overview of the best values reported for the appliances in the survey. The appliance that does not comply with the requirements of the Ecodesign Regulation was not taken into account. The table first shows the values based on the Ecodesign Regulation, both the requirements and the indicative benchmark for best performing appliance as an example of a good combination. Next, the table consists of three parts, first taking into account all the appliances in the survey, and then broken down by capacity, i.e. lower or higher than 10 kW power. For each of these, the following performances were then added:

- best reported performance per parameter
- performances of the appliances, with for one or more parameters, respectively the highest and lowest score of all appliances included in the survey.

From this we can further conclude that the survey already includes appliances that score better per parameter than those included as an indicative benchmark for best performing appliance in the Ecodesign Regulation. For wood stoves we see the following figures as a minimum:

- CO: 317 mg/m³
- PM: 6 mg/m³
- NOx: 44 mg/m³
- HC: 20 mg/m³
- Efficiency 90.2%

In addition, these appliances score significantly better than the Ecodesign requirements across the board.

On the other hand, the models that score least well are often only slightly better than the Ecodesign requirements in terms of emissions.

Overall, the number of appliances based on the survey (40 appliances) that outperformed the benchmark ‘best performing’ for one or more parameters:

- CO: 2 appliances better
- PM: 10 appliances better
- Efficiency: 5 appliances better
- NOx: 2 appliances better
- HC: 8 appliances better

Compared to the Ecodesign example of a good combination, 3 appliances in the survey score better for each of the parameters (see Table 27). All appliances are freestanding appliances; the first two with a central heating connection. All appliances have a flame baffle plate, insulation, post-combustion zone, airtight design, external air supply, pre-heating of the secondary combustion air and heat recovery. Appliance 1 and Appliance 2 also have a grate, and coated and double glazing respectively with a glass window the size of the combustion chamber. The air supply is partly controlled manually (primary air supply) and partly based on the central heating coupling (secondary and glass cleaning air). Appliance 3 has heat reflective material and single glazing with glass on more than one side. The air supply for this appliance is on the basis of mono-control. With regard to the shape of the combustion chamber, appliance 2 and appliance 3 have a vertical combustion chamber.

Table 26: Emission figures based on the survey for appliances fired with pieces of wood

Appliances with closed front – solid fuel other than wood pellets (EU) 2015/1185	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC (OGC) mg/m³
Ecodesign requirements	65 %	40	1500	200	120
Ecodesign - indicative benchmark for best-performing appliance	86 %	20	500	50	30
Ecodesign - example of good combination	83%	33	1125	115	69
Survey Best reported performance per parameter	90.2%	6	317	47	20
Appliance survey Lowest CO Lowest HC	81%	26	317	86	20
Appliance survey Lowest PM appliance 1	80%	6	625	127	48
Appliance survey Lowest PM appliance 2	83%	6	835	99	77
Appliance survey Highest efficiency	90.2%	18	435	121	25
Appliance survey Highest NOx	83.5%	32	625	147	34
Appliance survey Highest CO appliance 1	84%	27.1	1250	112	96
Appliance survey Highest CO appliance 2	75%	14	1250	120	83
Appliance survey Highest PM	80.6%	40	1000	88	35
Appliance survey Lowest NOx Highest HC	80%	30	1140	47	110
Appliance survey Lowest efficiency for appliance 1	75%	14	1250	120	83
Appliance survey Lowest efficiency for appliance 2	75%	15	775	58	23
Survey Best reported performance per parameter Capacity < 10 kW	90.2%	6	317	70	20
Appliance survey Lowest CO Lowest HC	81%	26	317	86	20
Appliance survey Lowest PM appliance 1	80%	6	625	127	48
Appliance survey Lowest PM appliance 2	83%	6	835	99	77
Appliance survey Highest efficiency	90.2%	18	435	121	25
Appliance survey	84%	15	875	70	28

Lowest NOx					
Appliance survey Highest CO Highest HC	84%	27.1	1250	112	96
Appliance survey Highest PM	84%	35	1021	139	53
Appliance survey Highest NOx	80.92%	26	898	146	87
Appliance survey Lowest efficiency	75.3%	29	880	105	23
Survey Best reported performance per parameter Capacity >= 10 kW	86.7	10	575	47	23
Appliance survey Lowest CO	76%	31	575	105	26
Appliance survey Lowest PM	82%	10	1087.5	99	88.7
Appliance survey Highest efficiency	86.7%	24	750	91	47
Appliance survey Lowest NOx Highest HC	80%	30	1140	47	110
Appliance survey Lowest HC	75%	15	775	58	23
Appliance survey Highest CO	75%	14	1250	120	83
Appliance survey Highest PM	80.6%	40	1000	88	35
Appliance survey Highest NOx	83.5%	32	625	147	34
Appliance survey Lowest efficiency for appliance 1	75%	14	1250	120	83
Appliance survey Lowest efficiency for appliance 2	75%	15	775	58	23

Table 27: Emission figures of appliances fired with pieces of wood from the survey with performance better than the example of a good combination in the Ecodesign Regulation

	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC (OGC) mg/m³
Appliance 1	86.7%	24	750	91	47
Appliance 2	90.1%	22	500	90	22
Appliance 3	84%	15	875	70	28

4.8.2. PELLET-FIRED APPLIANCES

The 14 pellet-fired appliances are of the following types:

- 5 boilers
- 6 freestanding stoves without slow heat release
- 3 mass stoves

All the appliances that only work with pellets have an automatic fuel supply. 2 of the appliances can burn both pellets and wood.

→ **Applied techniques**

- The survey clearly shows that most of the technologies are frequently used:
- A flame baffle plate is present in all appliances
- Grate in the combustion chamber is present for all appliances
- All appliances are airtight.
- With respect to the combustion chamber insulation, there are two appliances for which it is indicated that the insulation consists of cast iron for insulation, all the other appliances have insulation of refractory bricks or plates.
- The automatic control of the air supply is based on a pressure measurement for most appliances, especially for the boilers. For the stoves, the control is additionally based on the flame temperature or the temperature of the flue gas. 2 mass stoves do not have an automatic control, but a manual control by means of a mono-control.
- The air supply is always external, partly by natural draught and partly by forced air supply.
- The fuel supply in the case of pellets is always automatic; for combined appliances the supply of wood is manual.
- With regard to post-combustion, a post-combustion zone is also mainly used for pellet appliances. All pellet boilers have this post-combustion zone. The mass stoves have a post-combustion zone or a separate combustion chamber. For 5 of the 6 freestanding stoves without slow heat release it is indicated that they do not have post-combustion, but 3 of them do have primary, secondary and glass cleaning air. Two systems have, according to the manufacturer, no post-combustion and only primary air supply, but in terms of emissions they achieve similar results as the other systems. For 1 appliance it is indicated that it does not have heat recovery of the flue gases.
- Some technologies are always used in pellet stoves but less so in pellet boilers. All stoves have heat reflective material, with the boilers it is 2 of the 5 systems.
- All 9 pellet stoves from the survey have a glass window of the same size or smaller than the combustion chamber, 4 of them are double-glazed. Boilers do not have a glass window. Most stoves (8 out of 9) also have a vertical combustion chamber, with the boilers this is only 2 out of 5.

Techniques that are only sporadic:

- 3 models of the pellet stoves have an integrated flue gas fan.
- Convection fans are rare and only present in two freestanding stoves without slow heat release.
- Catalysts or electrostatic precipitators are not used in the appliances from the survey.

→ **Performance**

Performance relates to the performance in lab conditions, but there is still considerable uncertainty about environmental performance in real-life conditions.

As far as emissions are concerned, it is clear that they are usually much lower for CO, PM and HC than for wood-fired appliances. For 2 mass stoves that can burn both pellets and wood, the emissions are comparable to those of the wood-fired appliances. The efficiency of the boilers is also clearly higher than that of the stoves.

In accordance with the comparison done between the appliances fired with pieces of wood in the survey and the Ecodesign requirements, such comparison was also done for pellet stoves (see Table 28) and pellet boilers (see Table 29). Note that the Ecodesign Regulation does not specify the type of appliance in the 'example of good combination' and that emission figures for the example of good combination are higher for some parameters than the emission requirements for pellet stoves.

From the analysis we can conclude that all pellet appliances in the survey meet the Ecodesign requirements. Compared to the indicative benchmark 'best performing appliance', there are parameters for which appliances score better, but there are also parameters for which there are no appliances from the survey that score better than the indicative benchmark. For the pellet stoves, there are no appliances that score better for NO_X and efficiency. For the pellet boilers, there are no appliances that score better for CO, PM and HC. For the parameters with a better score we mention the following numbers based on the survey:
Pellet stove: (7 out of the 9 appliances considered which are only pellets, the combi appliances with wood are excluded)

- CO: 6 appliances better
- PM: 3 appliances better
- HC: all 6 appliances better

Pellet boiler:

- Efficiency: all 5 appliances better
- NOx: 2 appliances better

Table 28: Emission figures based on the survey for pellet stoves

Appliances with closed front – wood pellets as fuel (EU) 2015/1185	Seasonal energy efficiency	Dust/PM mg/m³	CO mg/m³	NOx mg/m³	HC mg/m³
Ecodesign requirements	79%	20	300	200	20
Ecodesign - indicative benchmark for best performing appliance	94%	10	250	50	10
Ecodesign - example of good combination	91%	22	312	121	22
Survey Best reported performance per parameter	93.6 %	5	14	109	1
Appliance survey Lowest CO Lowest PM Highest HC	90.5%	5	14	112	6
Appliance survey Lowest NOx Highest efficiency	93.6	16	37	109	4
Appliance survey Lowest HC	90.9%	17	27	142	1
Appliance survey Lowest efficiency	90.3	16	43	123.5	<3
Appliance survey	93.2%	8	84	146	<3

Highest CO **Highest NOx**					
Appliance survey **Highest PM**	92.7%	18	46	114.5	<3

Table 29: Emission figures based on the survey for pellet boilers

Solid fuel boiler – automatically stoked (EU) 2015/1189	**Seasonal energy efficiency**	**Dust/PM mg/m³**	**CO mg/m³**	**NOx mg/m³**	**HC mg/m³**
Ecodesign requirements	75% (>20 kW) 77% (>20 kW)	40	500	200	20
Ecodesign - indicative benchmark for best performing appliance	96% for cogeneration connection 90% with flue gas condenser 84% other boilers	2	6	97	1
Ecodesign - example of good combination	81%	7	6	120	2
Survey **Best reported performance per parameter**	107.3	9	9	92	1
Appliance survey **Lowest CO** **Highest NOx** **Lowest HC** **Highest efficiency**	107.3%	13	9	123	<1
Appliance survey **Lowest PM** **Lowest NOx** **Lowest efficiency**	93.4%	9	22	92	1
Appliance survey **Highest CO** **Highest PM** **Highest HC**	95.3%	19	45	106	1

Compared to the example of a good combination, there are 2 pellet stoves (see Table 30) that score better across the board but no boilers that score better. Both appliances are freestanding with a flame baffle plate, grate, insulation, heat reflective material, single glazed, vertical combustion chamber, airtight design, external air supply and heat recovery. The glass window of the first appliance is equal to the size of the combustion chamber; on the second appliance it is smaller. Appliance 1 only has a primary air supply which is controlled by means of a pressure measurement. Appliance 2 also has secondary and glass cleaning air which is controlled by measuring the flame temperature. Appliance 2 also has preheating of the secondary air and an integrated flue gas fan.

Table 30: Emission figures for pellet stoves from the survey with performance better than the example of a good combination in the Ecodesign Regulation

	Seasonal energy efficiency	**Dust/PM mg/m³**	**CO mg/m³**	**NOx mg/m³**	**HC (OGC) mg/m³**
Appliance 1	93.6	16	37	109	4
Appliance 2	92.7%	18	46	114.5	<3

CHAPTER 5. SELECTION OF THE BEST AVAILABLE TECHNIQUES

In this chapter we evaluate the environmentally-friendly techniques mentioned in chapter 4 in terms of their technical feasibility, environmental impact and economic feasibility, and we indicate whether or not the above-mentioned environmentally-friendly techniques can be regarded as BAT for domestic wood heating.

The BAT selection in this chapter should not be used as a stand-alone parameter but should be seen in the overall context of the study. This means that both the description of the environmentally-friendly techniques in chapter 4 and the translation of the BAT selection into recommendations in chapter 6 should be taken into account.

5.1. EVALUATION OF THE AVAILABLE ENVIRONMENTALLY-FRIENDLY TECHNIQUES

The available environmentally-friendly techniques in chapter 4 are tested against a number of criteria in Table 31. This multi-criteria analysis makes it possible to judge whether a technique can be considered Best Available Technique (BAT). The criteria cover not only the environmental aspects (air, odour, water, energy, waste, etc.) but also technical feasibility and economic aspects. This enables an integral assessment, in accordance with the definition of BAT (see Chapter 1).

Notes on the criteria in Table 31:

→ **Technical feasibility**

- proven: indicates whether the technique is actually applied:
  "-": not proven;
  "+": proven;
- general applicability: indicates whether the technique is generally applicable without technical limitations for every type of appliance and any user profile:
  "-": not generally applicable;
  "+": generally applicable;
- safety: indicates whether the technique, if correctly applied, increases the risks of fire, explosion and occupational accidents in general:
  "-": increases risk;
  "0": doesn't increase risk;
  "+": reduces risk;
- quality: indicates whether the technique affects the quality (e.g. reliable operation or the lifetime of the appliance)
  "-": lowers quality;
  "0": no effect on quality;
  "+": increases quality;
- overall: assess the overall technical feasibility of the technique:
  "+": if all above mentioned "+" or "0";
  "-/+" if all above mentioned "+" or "0" and applicability "-";

"-": if at least one of above mentioned (except applicability) "-".

→ **Environmental benefit**

- waste water: presence of pollutants in water as a result of domestic wood heating;
- air (VOC+PAH, dust, CO): presence of pollutants in the atmosphere as a result of domestic wood heating;
- odour: odour nuisance due to domestic wood heating;
- waste: the creation of waste streams as a result of domestic wood heating;
- energy: energy efficiency of domestic wood heating and use of electricity;
- overall: estimated impact on the environment as a whole.

A qualitative assessment is given for each of the above criteria for each technique:

- "-": negative effect;
- "0": no/negligible impact;
- "+": positive effect;
- "+/-": sometimes a positive effect, sometimes a negative effect.

→ **Economic feasibility**

- "+": the technique cuts costs;
- "0": the technique has a negligible impact on the costs;
- "-": the technique increases costs, the additional costs are deemed to be bearable for the user and are in reasonable proportion to the environmental benefit achieved;
- "-": the technique increases costs, the additional costs are not deemed to be bearable for the user or are not in reasonable proportion to the environmental benefit achieved.

In the last column an assessment is made as to whether the considered technique can be selected as best available technique (BAT: yes or BAT: no). Where this is highly dependent on specific circumstances, BAT: cbc (on a case-by-case basis) is given as the assessment.

The process followed in the BAT selection is shown schematically in the figure below:

- First, the technical feasibility of the technique (the so-called "candidate BAT") is assessed, taking into account product quality and safety (step 1).
- If the technique is technically feasible, the impact on the different environmental compartments is assessed (step 2). An overall environmental assessment can be made by evaluating the effects on the different environmental compartments . The following elements are taken into account for this:
  If one or more environmental scores are positive and not negative, the overall effect is always positive;
  If there are both positive and negative scores, the overall environmental impact depends on the following elements:
    - the shift from a less controllable to a more controllable compartment (e.g. from air to waste);
    - relatively greater reduction in one compartment compared to an increase in another;

    - the desirability of reduction based on policy; derived, among other things, from the environmental quality objectives for water, air, etc. (e.g. "distance-to-target" approach).
- If the overall environmental impact is positive, an assessment is made as to whether the technique involves additional costs, or whether these costs are in reasonable proportion to the environmental benefit achieved (step 3).
- Candidate BAT that cannot be combined (because a combination is not possible or meaningful) are compared with each other, and only the best is retained as a BAT candidate (step 4).
- In the end an assessment is made as to whether the considered technique can be selected as Best Available Technique (BAT) (step 5). A technique is BAT if it is technically feasible, improves the environment (overall), is economically viable (assessment "-" or better) and if there is no "better" candidate BAT. Where this is highly dependent on the situation under consideration, preconditions can be linked to the BAT selection.

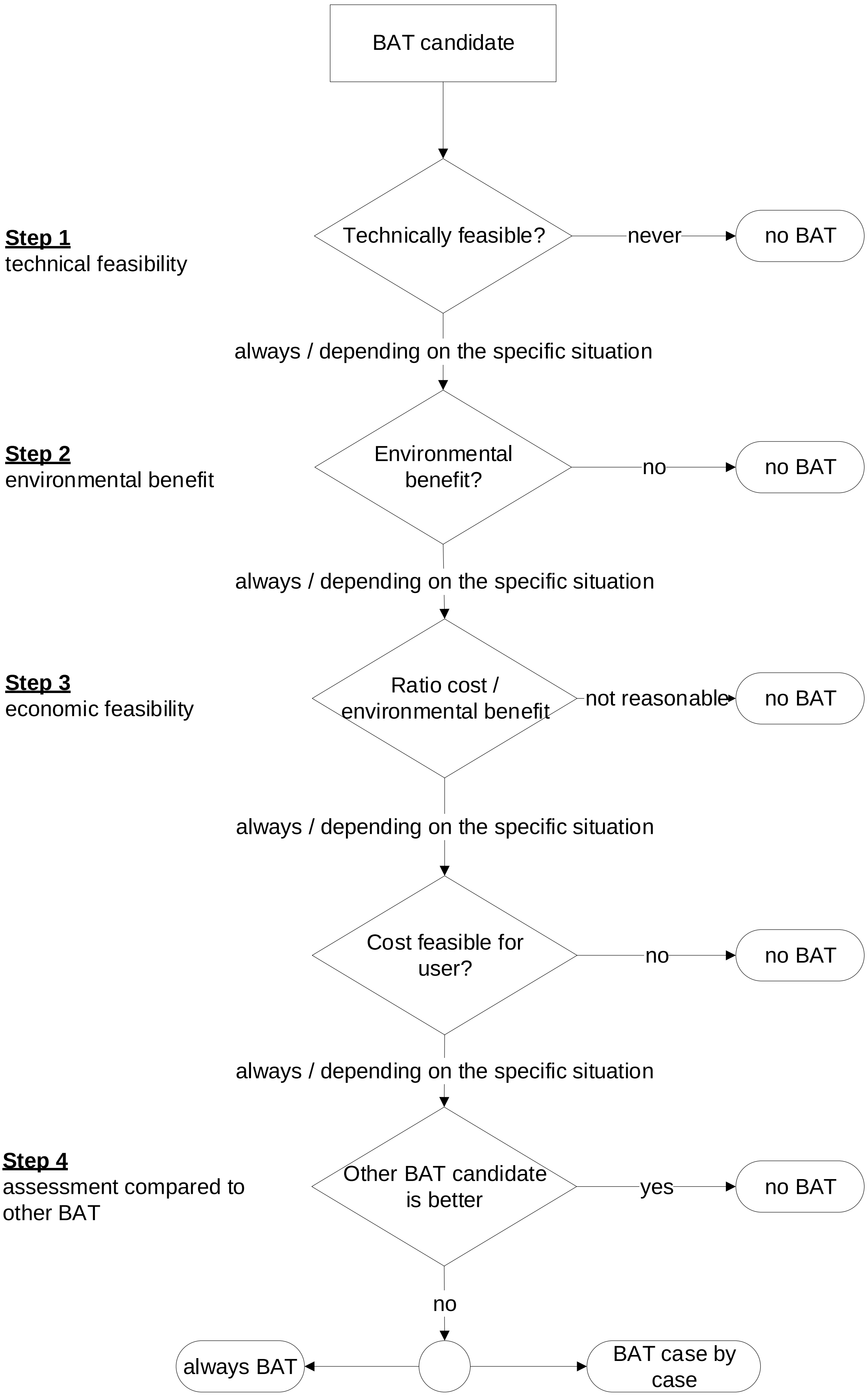

Figure 36: Selection of BAT based on scores for different criteria

→ **Important notes regarding the interpretation of Table 31**

When interpreting the table below, the following points should be kept in mind:

- The assessment of the various criteria is based, among other things, on:
  - operators' experience with this technique;
  - BAT selections carried out in other (foreign) comparable studies;
  - advice given by the steering committee.
  - assessments by the authors
  - Where necessary, additional explanations are provided in a footnote.
- The assessment of the criteria is to be regarded as indicative and does not necessarily apply in each individual case. The assessment therefore in no way releases an appliance manufacturer, installer or user from the responsibility to examine, for example, whether the technique is technically feasible in his/her specific situation, or whether it compromises safety, does not cause unacceptable environmental nuisance or is excessively expensive. When assessing a technique, it is also assumed that the appropriate safety/environmental protection measures are always taken.
- The table should not be used as a stand-alone parameter but should be seen in the overall context of the study. This means that the description of the environmentally-friendly techniques in chapter 4 as well as the textual summary of the conclusions regarding the BAT selection in paragraph 5.2 and the translation of the table into recommendations in chapter 6 should be taken into account.

Specifically for this study, the assessments of BAT and BAT cbc (case-by-case) should be understood as follows:

- BAT: the technique is considered necessary to achieve the BAT associated performance levels for the type of appliance concerned (see paragraph 5.2) and should therefore be used as a standard.
- BAT cbc: the technique may contribute to achieving the BAT associated performance levels but is not necessarily present in every appliance. The reasons why techniques are assessed as BAT cbc vary. More information can be found in the footnotes to Table 31 and in the textual summary of the BAT assessment in paragraph 5.2.

Table 31: Evaluation of available environmentally-friendly techniques and selection of BAT[11]

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.1 Design of new appliances – Primary measures																
4.1.1 Flame baffle plate	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.1. 2 Grate in the combustion chamber – pieces of wood	+	0	-	0	**+/-**[12]	0	+/-	+/-	+/-	+/-	0	+/-	0	**+/-**	**0**	**Cbc**
4.1. 2 Grate in the combustion chamber – pellets	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.1. 3 Insulation of the combustion chamber(s)	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.1. 4 Use of heat-reflective material in the combustion chamber	+	0	-	0	**+/-**[13]	0	+	+	+	+	0	+	0	**+**	**0/-**	**Cbc**

[11] See VMM comments on the BAT assessment in Appendix 2

[12] Depending on the strategy chosen by the appliance manufacturer (how techniques are precisely implemented and combined with each other), a grate may or may not be appropriate for appliances fired with pieces of wood.

[13] Depending on the strategy chosen by the appliance manufacturer (how techniques are precisely implemented and combined with each other), heat-reflective material may or may not be appropriate.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.1.5 If a glass window is present, glass window with small surface area.	+	0	-	0	**+/-**[14]	0	+	+	+	+	0	+	0	**+**	**0**	**Cbc**
4.1.5 If a glass window is present, double-glazing, triple-glazing or coated glass.	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**-/--**[15]	**Cbc**
4.1.6 Vertical combustion chamber	+	0	-	0	**+/-**[16]	0	+	+	+	+	0	+	0	**+**	**0**	**Cbc**
4.1.7 Presence of a second combustion chamber or combustion zone/duct for post-combustion	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.1.8 Staged air supply	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.1.9 Air supply control – mono control of air supply - pieces of wood	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**[17]

[14] From a technical point of view, a glass window with a small surface area is recommended, but for devices used to enjoy the decorative function of the flame ('decorative' heaters), a large/larger glass window is desirable for the fire view.

[15] From a technical point of view, the use of double glazing, triple glazing or coated glass is recommended, especially for large glass windows. However, this means an additional cost for the device, which, depending on the user's profile may or may not be in reasonable proportion to the improved environmental performance.

[16] A vertical combustion chamber cannot be used in every appliance; for example, an inset stove or cassette does not have sufficient space for a vertical combustion chamber. A horizontal combustion chamber may be desirable for 'decorative' stoves where the visual aspect is important. A vertical combustion chamber is BAT for pellet-fired, freestanding appliances.

[17] Controlling the air supply with a mono control is BAT for appliances fired with pieces of wood, unless an automatic air supply control is used.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.1.10 Air supply control – Automatic control of air supply and air circulation - pieces of wood	+	0	+	0	**+**	0	+	+	+	+	0	+	-	**+**	**-/--[18]**	**Cbc**
4.1.10 Air supply control – Automatic control of air supply and air circulation - pellets	+	0	+	0	**+**	0	+	+	+	+	0	+	-	**+**	**-**	**Yes**
4.1.11 Airtight design of the appliance	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.1.12 Preheating air supply for combustion	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.1.13 Flue gas heat recovery system	+	0	-	0	**+/-[19]**	0	+	+	+	+	0	+	0	**+**	**-/--[20]**	**Cbc**

[18] Automating the air supply for appliances fired with pieces of wood has an additional cost which, depending on the profile of the user (e.g. number of hours one intends to use the appliance, time/effort one is willing to invest in correct firing behaviour, maintenance, etc.) and on the type of appliance (boiler, fireplace or stove), may or may not be in reasonable proportion to the improved environmental performance and ease of use. An automatic control is always BAT for boilers and stoves/fires that use pieces of wood and run for many hours throughout the year.

[19] Depending on the strategy chosen by the appliance manufacturer (how techniques are precisely implemented and combined with each other) and the necessary space for a heat recovery system, such a system may or may not be appropriate.

[20] The economic feasibility (payback period) depends on the specific situation.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.1.14 Stimulate stoking at nominal load as much as possible by offering appliances in different capacity classes and with an appropriate capacity range	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes[21]**
4.1.15 Automatic fuel supply - appliances fired with pieces of wood	+	0	-	0	**+/-[22]**	0	+	+	+	+	0	+	0	**+**	**0/--[23]**	**Cbc**
4.1.15 Automatic fuel supply - pellet appliances	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0[24]**	**Yes**
4.1.16 Advanced combustion process control based on room temperature and weather conditions	+	0	-	0	**+/-[25]**	0	+	+	+	+	0	+	0	**+**	**-/--**	**Cbc**
4.2 Design of new appliances – Secondary measures																

[21] Appliances that are used for ‘decorative’ heating usually have a larger combustion chamber and more capacity than necessary because of the desired fire view.
[22] Automatic fuel supply is not applied as standard and imposes requirements in terms of the shape and size of the firewood.
[23] Appliances fired with pieces of wood with automatic fuel supply come with a significant additional cost. Depending on the application and user's profile, the additional cost may or may not be in reasonable proportion to the improved environmental performance.
[24] Pellet appliances always have an automatic fuel supply, so there is no additional cost.
[25] Advanced combustion process control is only applied sporadically. The combustion process can probably be optimised even further and emissions also.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.2.1 Catalyst	+	0	-	0	**+/-**[26]	-	+	+	+	+	-	0	0	**+**[27]	**-/--**[28]	**Cbc**
4.2.2 Electrostatic precipitator	+	0	-	0	**+/-**[29]	0	0	0	+	0	-	0	-	**+**	**-/--**[30]	**Cbc**
4.3 Existing appliances – Primary measures																

[26]Depending on the strategy chosen by the appliance manufacturer (how techniques are precisely implemented and combined with each other) integrating a catalyst in a new appliance is BAT. The proper functioning of the technique is highly dependent on user behaviour (e.g. regular maintenance) and therefore only suitable for users who are willing to make the necessary efforts.

[27] The use of a catalyst may increase emissions of harmful substances (chlorophenol and dioxins). A study in Finland (Kaivosoja, et al., 2012) indicates increases of a factor of 4.3 and 8.7 for chlorophenol and dioxins respectively. The reason for this is the catalytic effect of Pt and Pd on the formation of these dangerous substances. This test was carried out on a poorly functioning sauna heater; it is therefore not yet clear whether the formation of dangerous substances is a risk with properly functioning combustion appliances.

[28] The technique has an additional significant cost which, depending on the profile of the user (e.g. number of hours one intends to use the appliance, time/effort one is willing to invest in correct firing behaviour, maintenance, etc.) and on the type of appliance (boiler, fireplace or stove),) may or may not be in reasonable proportion to the improved environmental performance.

[29]Depending on the strategy chosen by the appliance manufacturer (how techniques are precisely implemented and combined with each other) integrating an electrostatic precipitator in a new appliance is BAT. The proper functioning of the technique is highly dependent on user behaviour (regular maintenance and correct stoking) and therefore only suitable for users who are willing to make the necessary efforts.

[30] The technique has an additional significant cost which, depending on the profile of the user (e.g. number of hours one intends to use the appliance, time/effort one is willing to invest in correct firing behaviour, maintenance, etc.) and on the type of appliance (boiler, fireplace or stove),) may or may not be in reasonable proportion to the improved environmental performance.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
Flue gas heat recovery system	+	0	-	0	**+/-[31]**	0	+	+	+	+	0	+	0	**+**	**-/--[32]**	**Cbc**
Heat storage	+	0	-	0	**+/-[33]**	0	+	+	+	+	0	+	0	**+**	**-/--[34]**	**Cbc**
Forced draught	+	0	-	0	**+/-[35]**	0	+	+	+	+	0	0	-	**+**	**-[36]**	**Cbc**
4.4 Existing appliances – Secondary measures																

[31] A heat recovery of the flue gases may or may not be possible depending on the existing situation and the necessary space for a heat recovery system.

[32] For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of a heat recovery system for flue gases on an old appliance.

[33] heat storage may be possible depending on the existing situation.

[34] For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of heat storage on an old appliance.

[35] Only applicable if there is insufficient draught in the flue gas pipe.

[36] For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of forced draught on an old appliance.

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.4.1 Catalyst	+	0	-	0	**+/-**[37]	-	+	+	+	+	-	0	0	**+**[38]	**-/--**[39]	**Cbc**
4.4.2 Electrostatic precipitator	+	0	-	0	**+/-**[40]	0	0	0	+	0	-	0	-	**+**	**-/--**[41]	**Cbc**

[37] The installation of a catalyst is technically feasible if there is a closed and easily accessible flue gas pipe near the combustion chamber, and if the combustion appliance is operating correctly (without defects). The proper functioning of the technique is highly dependent on user behaviour (e.g. regular maintenance, correct stoking) and therefore only suitable for users who are willing to make the necessary efforts.

[38] The use of a catalyst may increase emissions of harmful substances (chlorophenol and dioxins). A study in Finland (Kaivosoja, et al., 2012) indicates increases of a factor of 4.3 and 8.7 for chlorophenol and dioxins respectively. The reason for this is the catalytic effect of Pt and Pd on the formation of these dangerous substances. This test was carried out on a poorly functioning sauna heater; it is therefore unclear whether the formation of dangerous substances is a risk with properly functioning combustion appliances.

[39] The technique has a significant additional cost (from €370, excluding the installation) which, depending on the profile of the user (e.g. number of hours one intends to us the appliance, time/effort one is willing to invest in correct firing behaviour, maintenance, etc.) and on the type of appliance (boiler, fireplace or stove), and the age/environmental performance of the appliance, may or may not be in reasonable proportion to the improved environmental performance. For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of a catalyst (see discussion in paragraph 5.2.5).

[40] The installation of an electrostatic precipitator is technically applicable under certain conditions (e.g. diameter of the flue gas pipe). The proper functioning of the technique is highly dependent on user behaviour (e.g. regular maintenance and also correct stoking) and therefore only suitable for users who are willing to make the necessary efforts.

[41] The technique has a significant additional cost (€1,500 - €2,200 including installation), which, depending on the profile of the user (e.g. number of hours one intends to use the appliance, time/effort one is willing to invest in correct firing behaviour, maintenance, etc.) and on the type of appliance (boiler, fireplace or stove), and the age/environmental performance of the appliance, may or may not be in reasonable proportion to the improved environmental performance. For old, polluting appliances, it is in any case necessary to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of an ESP (see discussion in paragraph 5.2.5).

Technique	Technical feasibility					Environmental benefit									Economic feasibility	BAT wood
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**		
4.5 Installation of appliances																
4.5.1 Choosing an appliance according to need	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.5. 2 Correct installation of the appliance	+	+	+	+	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.5.3 External air supply	+	+	-	0	**+/-**[42]	0	+	+	+	+	0	+	0	**+**	**-**	**Cbc**
4.5.4 Correct installation of the flue gas pipe	+	+	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.5.5 Insulation of the flue gas pipe	+	+	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.5.6 Forced draught for sufficient air supply in the combustion chamber	+	0	+	0	**+**[43]	0	+	+	+	+	0	0	-	**+**	**-**	**Cbc**
4.5.7 Installation by a specialist installer	+	+	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**-**	**Yes**
4.5.8 Provide a dry and ventilated storage space for wood (indoors or outdoors)	+	0	+	0	**+**	0	+	+	+	+	0	+	0	**+**	**0/-**	**Yes**
4.6 Use of appliances																

[42] Airtight living spaces require an external air supply. External air supply is not possible in all situations and depends on the location of the appliance and the existing home.
[43] Only applicable if there is insufficient draught in the flue gas pipe.

Technique	**Technical feasibility**					**Environmental benefit**										
	Proven	Safety	Generally applicable	Quality	**Global**	Waste water	Smell	VOC+PAH	Dust	CO	Waste	Energy efficiency	Energy - electricity consumption	**Global**	**Economic feasibility**	**BAT wood**
4.6.1 Follow wood burning tips	+	0	+	+	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.6.2 Limit wood burning in the event of high fine dust concentrations and unfavourable weather conditions	+	0	+	0	**+**	0	+	+	+	+	0	0	0	**+**	**0**	**Yes**
4.6.3 Follow the manufacturer's instructions	+	0	+	+	**+**	0	+	+	+	+	0	+	0	**+**	**0**	**Yes**
4.7 Maintenance of appliances and flue gas pipes																
4.7.1 Regular maintenance of appliance + flue gas pipe	+	+	+	+	**+**	0	+	+	+	+	0	+	0	**+**	**-**	**Yes**

5.2. CONCLUSIONS

The conclusions of the BAT assessment for domestic wood heating in Table 31 can be summarised as follows.

5.2.1. BAT FOR THE DESIGN OF NEW APPLIANCES

In order to optimise combustion conditions, reduce emissions and optimise energy efficiency, BAT requires that a combination of techniques (measures) are applied when designing new appliances. How the measures are implemented in practice and combined with each other is part of the technical know-how of the various stove manufacturers. The various stove manufacturers make different choices that may result in equivalent environmental performance. It is not the intention of the BAT study to be restrictive in this respect.

Appliances are designed to comply with the applicable emission and energy efficiency requirements under standardised test conditions. Environmental performance in real-life conditions of use (varying combustion conditions which are not always ideal) will be lower than the performance measured in labs under standardised test conditions. The items for which the test procedures deviate from the real-life conditions include:

- Starting (and extinction) of the fire generally not included
- Burning at partial load usually not included
- The condensable fraction of dust is generally not measured
- Ideal negative pressure
- Ideal fuel quality (moisture content, no bark, etc.)
- Ideal wood species (e.g. no resinous coniferous logs)
- Ideal fuel dimensions
- Ideal fuel quantity
- Ideal installation
- Ideal set up and use (e.g. control of air supply)
- Pre-heated appliance

The installer and the user may inadvertently reduce the environmental performance in real-life conditions significantly (see further - BAT for installation, use and maintenance of appliances). The manufacturer can remedy this by designing appliances in such a way to eliminate the influence of (incorrect) user behaviour as much as possible so that the performance in actual conditions deviates less from the standardised test conditions.

TableTable 32 summarises BAT for the design of the different types of appliances. Techniques specifically aimed at eliminating (incorrect) user behaviour as much as possible and thus at reducing emissions during use are marked with an asterisk (*) in the left column. The assessments of BAT and BAT cbc (case-by-case) should be understood as follows:

- BAT: the technique is considered necessary to achieve the BAT associated performance levels for the type of appliance concerned and should therefore be fitted as standard in every new appliance of this type, regardless of the user's profile.
- BAT cbc: the technique may contribute to achieving the BAT associated performance levels but is not necessarily present in every appliance. More information about the cbc assessment can be found for each appliance type below the table.

The cbc assessments depend on the one hand on the strategy chosen by the equipment manufacturer (how techniques are implemented and combined with each other), whereby the absence of a particular technique can be compensated by other techniques and how they are implemented.
On the other hand, the cbc assessment also depends on the intended application and the profile of the user. For example, users have different requirements (e.g. a large fire view) for appliances used primarily for 'decorative' or auxiliary heating than for appliances used as a single or main source of heating. This has consequences for the technical applicability of some techniques. Moreover, an appliance that is daily long term in use during the winter has a greater environmental impact over the year compared to the same appliance that is used only occasionally for 'decorative' or auxiliary heating. Techniques to reduce emissions or increase energy efficiency can therefore be economically justified (cost-efficient) more easily for a certain type of appliance as the number of operating hours increases.

Table 32: Overview of BAT and BAT cbc (case-by-case) per type of appliance[44]

	Technique ***Techniques specifically aimed at eliminating (incorrect) user behaviour as much as possible and thus at reducing emissions during use are marked with an asterisk (*) in the left column.***	**See paragraph**	**Open fireplace**	**Wood stove**	**Pellet stove**	**Mass stove**	**Wood-burning boiler**	**Pellet boiler**
	Flame baffle plate	4.1.1	/	BAT	BAT	BAT	BAT	BAT
	Grate in the combustion chamber	4.1.2	/	cbc	BAT	cbc	cbc	BAT
	Insulation of the combustion chamber	4.1.3	/	BAT	BAT	BAT	BAT	BAT
	Use of heat-reflective material in the combustion chamber	4.1.4	/	cbc	cbc	cbc	cbc	cbc
	Keep the surface area of the glass window as small as possible	4.1.5	/	cbc	cbc	cbc	n/a[45]	n/a[45]
	Use double-glazed, triple-glazed or coated glass for the glass window	4.1.5	/	cbc	cbc	cbc	n/a[45]	n/a[45]
	A vertical instead of horizontal combustion chamber	4.1.6	/	cbc	cbc	cbc	BAT	BAT
	Presence of a 2nd combustion chamber or combustion zone/duct for post-combustion	4.1.7	/	BAT	BAT	BAT	BAT	BAT
	Staged air supply	4.1.8	/	BAT	BAT	BAT	BAT	BAT
*	Air supply control – mono-control	4.1.9	/	BAT[46]	n/a[47]	BAT[46]	BAT[46]	n/a[47]
*	Air supply control – automatic control of air supply and air circulation	4.1.10	/	cbc	BAT	cbc	BAT	BAT
	Airtight design of the appliance	4.1.11	/	BAT	BAT	BAT	BAT	BAT

[44] See VMM comment on the BAT assessment in Appendix 2
[45] No glass window present
[46] If automatically controlled air supply is not BAT.
[47] Because automatically controlled air supply is BAT.

	Preheating air supply for combustion	4.1.12	/	BAT	BAT	BAT	BAT	BAT
	Flue gas heat recovery system	4.1.13	/	cbc	cbc	cbc	cbc	cbc
*	Stimulate stoking at nominal load as much as possible by offering applian-ces in different capacity classes and with a limited capacity range	4.1.14	/	BAT	BAT	BAT	BAT	BAT
*	Automatic fuel supply	4.1.15	/	cbc	BAT	cbc	cbc	BAT
*	Advanced combustion process control based on room temperature and weather conditions	4.1.16	/	cbc	cbc	cbc	cbc	cbc
	A catalyst integrated in the appliance	4.2.1	/	cbc	cbc	cbc	cbc	cbc
	An electrostatic precipitator integrated in the appliance	4.2.2	/	cbc	cbc	cbc	cbc	cbc

→ **Open fireplaces**

No techniques are available to reduce the emissions or to increase the energy efficiency of open fireplaces. The combustion process in an open fire is therefore uncontrolled. Due to the significant supply of air, heat loss in the combustion chamber is high and the released gases are emitted quickly. This prevents adequate mixing of these gases with the air in the combustion zone while the residence time is also quite short so that no or limited post-combustion takes place. Energy efficiency is very low and emissions are high. For these reasons, the use of open fireplaces for domestic wood heating/combustion is **not considered as BAT**. Existing open fireplaces should therefore be put out of use and potentially replaced with another heating appliance.

→ **Wood stoves**

Modern wood stoves are generally equipped with a number of measures (referred to in the table as BAT or BAT cbc) to improve their energy and environmental performance. As a result, they perform better than open fireplaces and better than older wood stoves that are not yet equipped with these measures. By applying these measures, wood stoves can meet the Ecodesign requirements that apply to them (= performance under standardised conditions, see Table 7).
The measures indicated as BAT for wood stoves in Table 31 are nearly all fitted as standard in new appliances. The measures indicated with cbc (case-by-case) are not all present as standard all the time, but many new wood stoves do have one or more of these measures. As mentioned earlier, this depends on the one hand on the strategy chosen by the stove manufacturer and on the other hand on the intended use of the appliance and the user's profile (e.g. number of hours that the appliance is intended to be used, time/effort the user is willing to invest in good heating practice, maintenance, etc.):

- Limiting the surface area of the glass window and a vertical instead of a horizontal combustion chamber are beneficial for the environmental and energy performance of the appliance, but this is not compatible with a large fire view and therefore not applicable if the user wishes a large fire view (in the case of ‘decorative’ heating).
- The use of double-glazed, triple-glazed or coated glass for the glass window can improve the performance of stoves with (large) glass windows, but this does come with a significant additional cost which may or may not be considered acceptable depending on the user's profile and the price range of the appliance.

- In the case of appliances with automatic control of air supply and air circulation, the user's influence (incorrect stoking practice) is limited (= limitation of emissions in real-life conditions). Such appliances fired with pieces of wood are already available on the market but still come at a significant additional cost. This has to be weighed against the environmental gains achieved and the greater ease of use. The additional cost will be more quickly justified (cost efficient) for users who use the appliance many hours throughout the year. For users who use their appliance less frequently and for shorter periods ('decorative' or auxiliary heating), the benefits are limited and the use of a mono control is also considered to be BAT.
- Appliances with advanced control of the combustion process are only available to a limited extent and the additional cost is still high. Further developments are expected in this area.
- Appliances with automatic fuel supply impose requirements in terms of shape and size of the firewood. They are only available to a limited extent and come at a significant additional cost.
- The proper functioning of an integrated catalyst or electrostatic precipitator is highly dependent on user behaviour (e.g. regular maintenance and also correct stoking practice) and therefore only suitable for users who are willing to make the necessary efforts. These measures also come at an additional cost that has to be weighed against the environmental gains. The additional cost will be more quickly justified (cost efficient) for users who use the appliance many hours throughout the year.

In the category of wood stoves, a distinction is made between **inset stoves, built-in stoves and freestanding stoves**. In general, the same techniques are BAT for these three types and the Ecodesign requirements do not distinguish between the three types. However, with inset stoves, the available space in which the appliance is to be placed must be taken into account, so a vertical combustion chamber is not an option. freestanding stoves have better heat transfer because they are freestanding, and this means they can achieve a high energy efficiency.

→ **Pellet stoves**

Pellets have a more constant quality compared to pieces of wood due to the production process on the one hand and the standards and quality labels that apply to them on the other hand. They can also be poured like a liquid. This is an advantage in terms of optimising the combustion process and automating the fuel supply. Modern pellet stoves are therefore equipped with automatic air supply control and with automatic fuel supply as standard. By applying these BAT, pellet stoves comply with the Ecodesign requirements for these appliances (= environmental performance under standardised test conditions, see Table 33), and the influence of the user (incorrect stoking practice) is limited (= limitation of emissions in real-life conditions). Modern pellet stoves consequently have a better energy and environmental performance than wood stoves.
Keeping the surface area of the glass window to a minimum, the use of double-glazed, triple-glazed or coated glass, and the advanced control of the combustion process and the integrated catalyst or electrostatic precipitator are assessed for pellet stoves as BAT cbc, with the same conditions of applicability as for wood stoves. A vertical arrangement of the combustion chamber is considered BAT for freestanding pellet stoves.

→ **Mass stoves**

The main difference between mass stoves and ordinary wood stoves is that mass stoves store heat in ceramic materials such as soapstone, tiles and/or clay and then gradually release the heat to the space in the form of radiant heat, which is experienced as very pleasant. The flue gases also travel a much longer distance than in ordinary wood stoves which means that the absorption of residual heat from the flue gases is much better. The BAT techniques for mass stoves are similar to those of stoves without slow heat release. The Ecodesign requirements also make no distinction between mass stoves and appliances without slow heat release.

→ Wood-burning boilers

In general, similar BATs apply to wood-burning boilers as for wood-burning stoves. Boilers are not located in the living area so there is no need for a fire view. A window is consequently not necessary (which is beneficial for the environmental and energy performance). Also, the combustion chamber can always be set up in vertical position. The additional cost of an automatic air supply control is relatively low when compared with wood stoves, and this additional cost is justified (cost efficient) for boilers because the appliance is always used for main heating. Consequently, a vertical combustion chamber and automatic air supply control are BAT for wood-burning boilers. Wood-burning boilers can be hand-fired and therefore have a lower environmental performance than pellet boilers, which are always fired automatically (see also Ecodesign requirements). Automatic fuel supply for wood-burning boilers comes at a significant additional cost.

→ Pellet boilers

In general, similar BATs apply to pellet boilers as for pellet stoves. Boilers are not located in the living area so there is no need for a fire view. A window is consequently not necessary (which is beneficial for the environmental and energy performance). Also, the combustion chamber can always be set up in vertical position. Pellet boilers are always fired automatically and partly because of this have a better environmental performance than hand-fired (pieces of wood) boilers (see also Ecodesign requirements).

→ Environmental performance levels associated with BAT

New appliances must meet at least the Ecodesign requirements under test conditions (from 1/1/20 for boilers and from 1/1/22 for stoves). In addition, the Ecodesign regulations also provide 'indicative benchmarks for best performing appliances' and 'examples of good combinations'. An important note regarding the indicative benchmarks is that when the regulations entered into force there was no appliance on the market that met all the requirements at the same time. There were several appliances on the market that met one or more of these requirements. The examples of 'good combinations' refer to existing appliances.

Table 33: Environmental performances according to Ecodesign regulations (emissions @13% O_2 for stoves and @10% O_2 for boilers)

	Seasonal energy efficiency (%)	Dust (mg/Nm³)	OGC (mg/Nm³)	CO (mg/Nm³)	NOx (mg/Nm³)
Requirements					
Wood stove	65	40	120	1500	200
Pellet stove	79	20	60	300	200

Manually fired boiler	75/77[48]	60	30	700	200
Automatically fired boiler	75/77[48]	40	20	500	200
Indicative benchmark for best performing appliances					
Wood stove	86	20	30	500	50
Pellet stove	94	10	10	250	50
Boilers	94/90/84 [49]	2	1	6	97
Good combination					
Wood stove	83	33	69	1125	115
Pellet stove	91	22	6	312	121
Boilers	81	7	2	6	120

The survey of stove manufacturers, which was organised as part of the BAT study, shows that there are several appliances on the market that exceed the Ecodesign requirements by applying BAT, and this is the case for all parameters simultaneously. This is an indication that these requirements may need to be updated. The survey also reported appliances that achieved the 'indicative benchmarks for best performing appliance' in the Ecodesign regulations for one or more parameters but not for all parameters simultaneously. This is an indication that these benchmarks can still be considered ambitious. There are appliances that exceed the 'example of good combination', namely for wood stoves. For more information about the performance levels reported in the survey, see paragraph 4.8.

The Ecodesign requirements relate to environmental performance measured in labs under standardised test conditions. As mentioned above, environmental performance in real-life conditions of use (varying combustion conditions which are not always ideal) will be lower than the performance measured in labs under standardised test conditions. The environmental performance in actual conditions is still subject to considerable uncertainty and no emission levels associated with BAT can be determined for this purpose. As a result, it is also uncertain whether appliances that perform best in lab conditions also perform best in real-life operating conditions. Techniques specifically aimed at eliminating (incorrect) user behaviour as much as possible (indicated with an asterisk (*) in tableTable 32) reduce the difference between emissions in real-life and laboratory conditions.

When purchasing a new appliance, a well-considered choice must be made between the various appliance types (e.g. a pellet appliance or a wood-burning appliance). Environmental and energy performance deserve due attention. For example, pellet appliances have a better environmental and energy performance than wood-burning appliances. However, other arguments also play a role when choosing an appliance (e.g. price of the appliance, profile of the user (e.g. number of hours the user wants to use the appliance, time/effort the user will invest in correct heating practice, maintenance, etc.), availability of own (cheap) wood, etc.).

5.2.2. BAT FOR INSTALLATION OF APPLIANCES

To ensure that the appliance can operate in optimal conditions and achieve its optimal environmental performance, the following measures are BAT:

- Choice of the appliance according to need (see paragraph 4.5.1)
- Correct installation of the appliance (see paragraph 4.5.2)

[48] For boilers max 20 kW / >20 kW

[49] For cogeneration boilers/with flue gas condenser/for other boilers

- Correct installation of the flue gas pipe (see paragraph 4.5.4)
- Insulation of the flue gas pipe (see paragraph 4.5.5)
- Installation by a specialist installer (see paragraph 4.5.7)
- Equipped with dry and ventilated storage space for wood (inside or outside) (see paragraph 4.5.8)

Providing an external air supply (see paragraph 4.5.3) offers safety benefits (CO poisoning) and is an absolute necessity (BAT) for appliances installed in modern, airtight homes. External air supply also offers advantages in older dwellings that are not airtight, but there may be technical limitations to installing such a system. For older, non-airtight houses, the technique is therefore assessed as BAT cbc (case-by-case).

Providing forced draught for sufficient air supply in the combustion chamber (see paragraph 4.5.6) only makes sense if there is insufficient natural draught in the flue gas pipe; this is therefore only BAT in these circumstances.

5.2.3. BAT FOR USE OF APPLIANCES

To avoid unnecessarily high emissions when using the appliance, it is BAT to use the appliance correctly. The following measures are considered to be BAT:

- Following stoking tips, including the use of suitable and sufficiently dry wood (see paragraph 4.6.1)
- Limit wood burning in the event of high concentrations of fine particles and unfavourable weather conditions (see paragraph 4.6.2)
- Follow the manufacturer's instructions (see paragraph 4.6.3)

5.2.4. BAT FOR MAINTENANCE OF APPLIANCES AND FLUE GAS PIPES

To prevent the environmental and energy performance of appliances deteriorating unnecessarily during their lifetime, the following measure is BAT:

- Regular maintenance of the appliance and the flue gas pipe (see paragraph 4.7.1)

5.2.5. BAT FOR EXISTING APPLIANCES (RETROFIT)

Most of the primary measures that are selected as BAT for new appliances cannot simply be applied as a retrofit measure in existing appliances not yet equipped with these measures, due to technical limitations. Moreover, certain measures are only useful in the correct configuration, and a full renewal of the installation must be weighed against the application of retrofit measures. The following measures can be applied as retrofits in certain situations and are assessed as BAT cbc (case-by-case) (see paragraph 4.3):

- Flue gas heat recovery
- Heat storage
- Forced draught

The following secondary measures can be implemented to reduce emissions from existing (old or new) appliances, provided a number of technical preconditions are met.

- Installation of a catalyst, especially in case of odour nuisance (see paragraph 4.4.1)
- Installation of an electrostatic precipitator (see paragraph 4.4.2)

The proper functioning of an integrated catalyst or electrostatic precipitator is highly dependent on user behaviour (e.g. regular maintenance and also correct stoking) and therefore only suitable for users who are willing to make the necessary efforts. There is still some uncertainty about the emission reductions achieved with these techniques, due in part to the lack of measurements in real-life conditions. These techniques come at an additional significant cost which, depending on the profile of the user (e.g. number of hours the appliance is to be used, time/effort the user is willing to invest in correct stoking practice, maintenance, etc.) may or may not be in reasonable proportion to the improved environmental performance. For old, polluting appliances, it is in any case necessary (if you want to continue using wood to heat) to compare the purchase price of a new, more efficient appliance (with not only lower emissions but also higher energy efficiency) with the installation of a catalyst or electrostatic precipitator. The advantages and disadvantages of replacing an old, polluting appliance with a new, more efficient one compared to the installation of a catalyst or ESP are summarised in Table 34.

Table 34: Advantages and disadvantages of appliance replacement, retrofit with catalyst and retrofit with electrostatic precipitator (ESP)

Aspect	Replacement with a new, more efficient appliance	Retrofit – catalyst	Retrofit – ESP
Cost	😐 Stove (pieces of wood, pellet) €1,000 - €7,500, depending on type of appliance excluding installation ☹ Boiler/mass stove (pieces of wood, pellets) €3,000 - €20,000, depending on appliance type excluding installation	☺ from €370 excluding installation	😐 €1,500 - €2,200 including installation
Electricity consumption	☺/😐 A limited consumption for appliances with fans, automatic control of air and/or fuel supply No additional consumption for other appliances	☺ No consumption	😐 Limited consumption (10 - 100W)
Wood consumption	☺ Lower consumption thanks to higher energy efficiency*	😐 No effect	😐 No effect
Dust emissions	☺ Reduction*	☺ Reduction**	☺ Reduction**

Emissions of VOC/PAH, CO and odour	☺ Reduction*	☺ Reduction**	☹ No effect
Maintenance	☺ Maintenance of the appliance and flue gas pipe	☹ Maintenance of the appliance and flue gas pipe + daily/weekly cleaning of catalyst	😐 Maintenance of the appliance and flue gas pipe + annual or half-yearly cleaning of ESP (possibly combined with cleaning of flue gas pipe)
Waste materials	☺ Lower, thanks to more limited ash formation	😐 Limited quantity	☹ Larger quantity
Remarks regarding applicability	In the case of replacement, the right choice can be made in terms of type and capacity of the appliance and for a correct installation. Depending on the situation, the installation of a new appliance may require demolition work indoors. Existing problems with insufficient draught in the chimney will not be solved by installing a new appliance and must therefore be remedied beforehand.	Temperature peaks of at least 300°C are required for proper operation of the catalyst. The catalyst should therefore be placed as close as possible to the combustion chamber, where the flue gases have not cooled down too much. When used in old, highly polluting appliances, the catalyst will lose its proper function due to an excessive concentration of pollutants.*** Existing problems with insufficient draught in the chimney can be exacerbated by installing a catalyst and must therefore be remedied beforehand.	The installation of an electrostatic precipitator is subject to technical preconditions (dimensions and accessibility of the flue gas pipe; for more info see paragraph 4.4.2). A considerable amount of dirt is collected on the electrode when used in old, highly polluting appliances. This can lead to malfunctions and short circuits if the electrode is not cleaned in time. To avoid these problems, a bypass is sometimes provided in the start-up phase of combustion when emissions are high.*** Existing problems with insufficient draught in the chimney can be exacerbated by the installation of an ESP and must therefore be remedied beforehand.

* The size of the effect depends on the difference in performance between the old and the new appliance, and on how the device is used and maintained.
** With correct user behaviour (e.g. regular maintenance). There are indications that a catalyst may increase emissions of harmful substances under certain conditions (see paragraph 4.1.2 for more information). This must be investigated further.
*** For highly polluting appliances, retrofit measures are less appropriate due to these restrictions, and replacement with a new, more efficient appliance is the preferred option.

For the three options, there is a relatively high degree of uncertainty about the amount of the environmental gain (% emission reduction) achieved under real-life conditions. However, the following can be concluded:

- The absolute environmental gain (in kg emission reduction/year) for each of the three options will be greater for an appliance that is daily long term in use during the winter period than for the same appliance that is only used occasionally for 'decorative' or auxiliary heating. As an appliance is used more frequently and for longer periods of time, it has higher emissions over the year (in kg/year). The same percentage reduction therefore results in a greater absolute reduction for a certain type of appliance as the number of operating hours increases.
- The same percentage reduction results in a greater absolute reduction for the most polluting appliances (with high emissions) than for relatively better performing appliances (with lower emissions). The absolute environmental gain (in kg emission reduction/year) will therefore be greater for each of the three options when applied to the most polluting appliances than when applied to relatively better performing appliances[50].

The largest potential environmental gains can therefore be realised with highly polluting appliances that are daily long term in use during the winter period; the lowest with relatively better performing appliances that are only used occasionally for 'decorative' or auxiliary heating.

Replacement with a new, more efficient appliance is usually the most expensive measure of the three options. On the other hand, this measure, with correct user behaviour, in principle has a beneficial effect on all environmental aspects (emissions of dust, VOC/PAH, CO and odour). Thanks to the higher energy efficiency of new appliances, savings can also be made on wood consumption. This is interesting both from a financial point of view (for users who do not have free/own wood) and from an environmental point of view (burning less wood = lower emissions). The relatively high cost of this measure is most justified (cost-efficient) for appliances where the greatest potential environmental gain can be realised: for highly polluting appliances (e.g. old wood stoves) that are daily long term in use during the winter period. Moreover, for highly polluting appliances, retrofit measures are less appropriate due to the restrictions mentioned in Table 34, and replacement with a new, more efficient appliance is therefore the preferred option. When appliances are less polluting and/or are used less frequently and for shorter periods of time ('decorative' or auxiliary heating), the potential environmental benefit of replacing them with a new, more efficient appliance decreases and this measure becomes less cost-efficient. The retrofit measures can then be an interesting alternative. These measures are relatively cheaper, and if used and maintained correctly, they still offer an additional environmental gain. The ESP focuses on limiting dust emissions, the catalyst also removes dust but is mainly used for odour problems.

[50] With the possible exception of retrofitting with a catalyst, considering it can lose its proper function in very poor combustion conditions = for the most polluting appliances.

CHAPTER 6. RECOMMENDATIONS BASED ON THE BEST AVAILABLE TECHNIQUES

Knowledge regarding BAT enables policy makers, manufacturers, installers, users and other stakeholders to take better substantiated measures to reduce the environmental impact of domestic wood heating. The information in this BAT study can provide inspiration for the development of various policy initiatives.

This could include awareness-raising actions (information campaigns), offering training (e.g. to users, installers), developing codes of good practice (e.g. for installation, maintenance, use), offering financial incentives (premiums), or drawing up regulations at the Flemish, Belgian and European levels. It is not within the scope of the BAT study to make concrete recommendations in this respect. It is clear, however, that in order to achieve an effective reduction in emissions, it is necessary to work on several tracks at the same time:

- improve the performance of appliances being introduced on the market
- replace old, polluting appliances with new ones (wood or non-wood), apply retrofit measures and/or impose restrictions on use
- proper installation of appliances
- correct use of appliances, including use of sufficient dry wood
- regular maintenance of appliances

BAT studies usually also make recommendations for the ecology premium. This is a financial compensation given to companies that will make ecology investments in the Flemish Region. As private individuals (households) are not eligible for the ecology premium, this is not relevant for domestic wood heating.

CHAPTER 7. EMERGING TECHNIQUES

This chapter discusses a number of emerging techniques that were identified during the preparation of the BAT study. Emerging techniques are new techniques for an activity which, if developed commercially, can provide either a higher overall level of environmental protection or at least the same level of environmental protection and greater cost savings than the best available techniques. These are techniques that are not yet applied on an industrial scale or that are still under development and may become BAT in the future. Techniques that address environmental problems that have only recently received attention are also discussed here. In addition, this chapter also provides recommendations for further research and technological development.
If this BAT study is reviewed in the future, it is recommended to investigate whether the emerging techniques have become BAT and whether further research has led to new insights.

7.1. EMERGING TECHNIQUES

No emerging techniques were identified when the study was prepared. This does not mean that there are no further technological developments for domestic wood heating. Several manufacturers and research institutes are investigating possibilities for technological improvements, e.g. in catalysts, heat accumulating materials, and other aspects. As a result, we expect that in the future new appliances will come onto the market with better performance than the current generation of appliances. The technological improvements mainly relate to the entire combustion concept and to the coordination and optimisation of techniques described in this BAT study, rather than to completely new 'emerging techniques'.

7.2. RECOMMENDATIONS FOR FURTHER RESEARCH AND TECHNOLOGICAL DEVELOPMENT

While preparing the BAT study we found in several areas that relatively little scientifically validated information exists to assess the real-life environmental impact of domestic wood heating and to assess the effectiveness of measures. This has created many uncertainties. Further research is recommended for the following aspects, among others:

- Measuring methods for dust, including the condensables fraction
- The emissions from appliances in real-life conditions and the influence of the various factors influencing them (type and age of appliance, types of wood used, stoking practice, presence of secondary measures such as an electrostatic precipitator or a catalyst)
- The improvement of emission factors used for drawing up emission inventories
- The performance of secondary measures (retrofit) in practice over the entire combustion cycle and lifetime
- The formation of secondary organic aerosols and their proportion of primary emissions.

In addition, it also remains important that manufacturers and research institutes carry out research into possibilities for technological improvements in new appliances (see also paragraph 7.1)

CHAPTER 8. BIBLIOGRAPHY

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APPENDIX 1: MEMBERS OF THE STEERING COMMITTEE WHO CONTRIBUTED TO THE BAT STUDY

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The above persons represented the companies on the steering committee for this study.

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- Jordy Vercauteren, VMM, Flanders Environment Agency

The above persons represented the administrations and government institutions on the steering committee for this study.

Appendix 2: Final comments

This report corresponds to what the BAT knowledge centre currently considers to be BAT and the associated designated recommendations. The conclusions of the BAT study are partly the result of consultation in the steering committee but do not bind the members of the steering committee.

This appendix sets out the comments or dissenting views expressed by members of the steering committee and the steering group on behalf of their organisation on the draft of the final report. According to the procedure followed within VITO's BAT Knowledge Centre for carrying out BAT studies, these comments or dissenting opinions are not included anymore in the text (unless they are minor text corrections) but are included in this appendix. In the relevant chapters reference is made to this appendix with footnotes.

Comment from VMM

VMM declares that it does 'not approve' this study: Although we consider it to be a very detailed, high-level study and we certainly agree with the majority of the findings, we do not agree with the granting of BAT and BAT cbc (case-by-case) for various techniques. In our opinion, the criteria for BAT are not high enough and more techniques should be labelled as BAT (as such). When we look at the most important category of wood stoves, we find that the techniques that are now classified as BAT are standard in most stoves sold today. We also feel that when assessing whether a technique is cost-efficient or not, too little account is taken of the latest figures on environmental damage costs (see Green Deal Action 2.2.4 Research into the environmental damage costs of different technologies for domestic heating https://omgeving.vlaanderen.be/sites/default/files/atoms/files/2019-Milieuschadekosten-woningverwarming.pdf). We therefore have the impression that cost efficiency is viewed from the point of view of the buyer or seller rather than from the full social cost over the entire lifetime of an appliance. In addition, we also believe that factors such as the necessity of 'decorative' heating, desired fire view, etc. should not play a role in the BAT assessment as they are not part of the BAT criteria: environmental benefits, technical feasibility and economic feasibility (see paragraph 1.1.2).

Response from VITO

Response regarding the assessment BAT cbc
As explained in paragraph 5.1, the assessments BAT and BAT cbc (case-by-case) should be understood in this BAT study as follows:

- BAT: the technique is considered necessary to achieve the BAT associated performance levels for the type of appliance concerned (see paragraph 5.2) and should therefore be standard in every appliance.
- BAT cbc: the technique may contribute to achieving the BAT associated performance levels but is not necessarily present in every appliance. The reasons why techniques are assessed as BAT cbc vary. More information can be found in the footnotes to Table 31 and in the textual summary of the BAT assessment in paragraph 5.2.

Achieving the environmental performance levels associated with BAT should be considered as the ultimate goal for new appliances. For this purpose, at least the techniques that have been assessed as 'BAT' will have to be present, but generally also one or more (usually not all) techniques that have been assessed as 'BAT cbc'.

Response regarding the assessment of the economic feasibility
The assessment of economic feasibility in a BAT study is based on 2 criteria, as explained in paragraph 5.1:

- Cost feasibility (the additional costs are considered to be bearable for the user), and
- Cost efficiency (the additional costs are in reasonable proportion to the environmental gain)

For a technique to be eligible as BAT, both criteria must be met. This study has therefore taken into account both the costs for the buyer/user and the social costs.

Reaction with regard to taking into account factors such as the desire for 'decorative' heating and fire view

It was decided for this BAT study to evaluate the different types of appliances/applications, including appliances used for 'decorative' heating, where the user wants a nice fire view. The reasoning behind this is that appliances intended for 'decorative' heating are currently offered on the (European) market, and will continue to be offered in the future (unless there is an explicit ban on this). Private individuals will continue to buy and use these appliances. In that respect, it seems better to direct these individuals towards the best 'decorative' stoves available on the market, rather than indicating that these types of appliances cannot be BAT. The latter would reduce support for this study as well as its possible further embedding or application in other policy instruments.

This approach is similar to that used in other BAT studies. For example, the BAT study on dry cleaning (2019) evaluates BAT for appliances using PER (perchloroethylene) and BAT for appliances using alternative solvents, as a complete phase-out of PER is not yet under consideration.

APPENDIX 3: EXCEL FILE 'CORRELATION TABLE'

Available via www.emis.vito.be/bbt

This appendix compares the classification of types of appliances used in the various regulations and eco-labelling systems and indicates which types correspond to each other in terms of content.

Appendix 4: Excel file 'Overview of standards'

Available via www.emis.vito.be/bbt

This appendix contains an overview of the requirements from the various regulations and eco-labelling systems for different types of appliances and different parameters, and lets you (via the 'Pivot table' tab) generate different tables so you can compare them in different ways.

Appendix 5: Survey results

APPLIANCES FOR PIECES OF WOOD					
	All	insert fireplace	Inset stove	Free-standing stove without slow heat release	Free-standing stove with slow heat release
General					
number	41	18	4	13	6
Appliance data					
rated capacity - minimum	2.00	8.00	4.90	4.00	2.00
rated capacity - maximum	26.00	26.00	11.00	14.50	4.80
rated capacity - average (kW)	10.40	15.46	8.55	7.09	3.60
average minimum capacity (kW)	5.45				
average maximum capacity (kW)	13.12				
price - minimum	680.00	2,140.50	1,920.00	680.00	3,381.00
price - maximum	11,139.70	7,325.00	2,870.00	5,223.00	11,139.70
price - average	4,068.66	4,106.98	2,426.75	2,738.02	7,931.40
Fuel					
Automatic fuel feeding	0				
Presence of techniques to optimise the combustion process					
flame baffle plate present	41	18	4	13	6
grate in the combustion chamber	18	5	2	7	4
Insulation of the combustion chamber					
refractory bricks (e.g. Chamotte)	18	7	1	4	6
refractory plates (e.g. Vermiculite)	21	11	2	8	0
refractory cloth	0	0	0	0	0
heat-reflective material in the combustion chamber	28	11	3	10	4
glass window					
front, smaller than combustion chamber size	9	4	0	1	4
front, same size as combustion chamber	25	9	4	10	2
glass window on more than 1 side	6	5	0	1	0
no glass window present	1	0	0	1	0
single-glazed	28	13	4	10	1
double-glazed	11	5	0	1	5
triple-glazed	0	0	0	0	0
coated glass	1	0	0	1	0
vertical combustion chamber	16	5	0	7	4
post-combustion					
separate post-combustion zone in combustion chamber	30	12	3	11	4

secondary combustion chamber	10	6	0	2	2
others	1	0	1	0	0
convection fans					
not present	30	11	0	13	6
yes, manual operation	3	2	1	0	0
yes, based on temperature sensor	8	5	3	0	0
others	0	0	0	0	0
staged air supply					
primary air supply	1	0	1	0	0
primary + secondary air supply	4	3	0	1	0
primary, secondary and glass cleaning air	28	9	2	11	6
primary, secondary and tertiary air supply	0	0	0	0	0
primary, secondary, tertiary and glass cleaning air	8	6	1	1	0
others	0	0	0	0	0
Air supply control					
manually, separately for each air supply	4	0	0	4	0
manually, with mono control	21	11	2	5	3
semi-automatic	6	3	1	2	0
automatic, flue gas temperature measurement	3	0	1	1	1
automatic, flame temperature measurement	2	0	0	0	2
automatic, pressure measurement	2	2	0	0	0
automatic, lambda sensor	1	0	0	1	0
others	0	0	0	0	0
External air supply					
not present	2.00	0.00	1.00	1.00	0.00
by means of natural draught	39.00	18.00	3.00	12.00	6.00
by means of forced air supply	0.00	0.00	0.00	0.00	0.00
Preheating of secondary combustion air	32.00	12.00	3.00	11.00	6.00
Flue gas heat recovery system	19.00	7.00	2.00	5.00	5.00
Is the appliance completely airtight?	34.00	15.00	3.00	10.00	6.00
Has the appliance been tested at partial load?	23.00	7.00	2.00	10.00	4.00
Heat storage					
not present	24.00	13.00	2.00	9.00	0.00
in mass	6.00	0.00	0.00	0.00	6.00
in liquid (boiler)	2.00	2.00	0.00	0.00	0.00
in PCM	0.00	0.00	0.00	0.00	0.00
others	4.00	1.00	0.00	3.00	0.00

PELLET APPLIANCES				
	All	freestanding stove without slow heat release	freestanding stove with slow heat release	boiler
General				
number	14	6	3	5
Appliance data				
rated capacity - minimum	2.00	2.50	2.00	16.00
rated capacity - maximum	32.00	16.10	5.00	32.00
rated capacity - average (kW)	10.80	6.70	3.00	20.40
average minimum capacity (kW)	4.95			
average maximum capacity (kW)	12.66			
price - minimum	2,370.00	2,370.00	3,975.21	5,899.00
price - maximum	10,862.00	5,298.00	9,595.04	10,862.00
price - average	6,241.63	4,322.50	7,404.96	7,846.60
Fuel				
automatic fuel feeding	12			
Presence of techniques to optimise the combustion process				
flame baffle plate present	13	6	3	4
grate in the combustion chamber	14	6	3	5
Insulation of the combustion chamber				
refractory bricks (e.g. Chamotte)	8	0	3	5
refractory plates (e.g. Vermiculite)	4	4	0	0
refractory cloth	0	0	0	0
Heat-reflective material in the combustion chamber	11	6	3	2
glass window				
front, smaller than combustion chamber size	6	3	3	0
front, same size as combustion chamber	3	3	0	0
glass window on more than 1 side	0	0	0	0
no glass window present	5	0	0	5
single-glazed	5	4	1	0
double-glazed	4	2	2	0
triple-glazed	0	0	0	0
coated glass	0	0	0	0
vertical combustion chamber	10	5	3	2
post-combustion				
separate post-combustion zone in combustion chamber	8	1	2	5
secondary combustion chamber	1	0	1	0
others	5	5	0	0
convection fans				
not present	12	4	3	5

yes, manual operation	0	0	0	0
yes, based on temperature sensor	2	2	0	0
others	0	0	0	0
staged air supply				
primary air supply	2	2	0	0
primary + secondary air supply	5	0	0	5
primary, secondary and glass cleaning air	7	4	3	0
primary, secondary and tertiary air supply	0	0	0	0
primary, secondary, tertiary and glass cleaning air	0	0	0	0
others	0	0	0	0
Air supply control				
manually, separately for each air supply	0	0	0	0
manually, with mono control	2	0	2	0
semi-automatic	0	0	0	0
automatic, flue gas temperature measurement	1	1	0	0
automatic, flame temperature measurement	4	3	1	0
automatic, pressure measurement	7	2	0	5
automatic, lambda sensor	0	0	0	0
others	0	0	0	0
External air supply				
not present	0.00	0.00	0.00	0.00
by means of natural draught	6.00	3.00	3.00	0.00
by means of forced air supply	8.00	3.00	0.00	5.00
Preheating of secondary combustion air	7.00	4.00	3.00	0.00
Flue gas heat recovery system	13.00	5.00	3.00	5.00
Is the appliance completely airtight?	14.00	6.00	3.00	5.00
Has the appliance been tested at partial load?	11.00	6.00	0.00	5.00
Heat storage				
not present	4.00	4.00	0.00	0.00
in mass	5.00	2.00	3.00	0.00
in liquid (boiler)	5.00	0.00	0.00	5.00
in PCM	0.00	0.00	0.00	0.00
others	0.00	0.00	0.00	0.00