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UNECE Information Service

Palais des Nations
CH-1211 Geneva 10
Switzerland

Telephone: +41 (0) 22 917 12 34
E-mail: unece_info@un.org
Website: www.unece.org

For more information, consult the Convention's website:
www.unece.org/env/lrtap/welcome.html

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I. Introduction

1. The Executive Body at its thirty-seventh session (Geneva, 11–14 December 2017) adopted the 2018–2019 workplan for the implementation of the Convention (ECE/EB.AIR/140/Add.1), which included item 2.3.8, assigning to the Task Force on Techno-economic Issues the task of developing a code of good practice for solid-fuel burning and small combustion installations. This item was included in line with the respective recommendation of the ad hoc policy review group of experts (policy review group) (ECE/EB.AIR/WG.5/2017/3 and Corr.1, para. 25 (b)) on the 2016 scientific assessment of the Convention.[1]

2. The initial document was developed by experts of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development and the environmental authorities of the Italian regions of Lombardy, Friuli-Venezia-Giulia and Veneto and further elaborated and finalized by the technical secretariat of the Task Force on Techno-economic Issues,[2] in cooperation with an expert from Belgium and with a contribution from other members of the Task Force led by France and Italy.

3. At its thirty-ninth session (Geneva, 9–13 December 2019), the Executive Body adopted the code of good practice for wood-burning and small combustion installations contained in document ECE/EB.AIR/2019/5 by decision 2019/3 (ECE/EB.AIR/144/Add.1).

II.
Subject matter and scope

4. Item 2.3.8 of the 2018–2019 workplan, on the development of a code of good practice for solid-fuel burning and small combustion installations based on best available techniques, was included in line with the respective recommendation of the policy review group. The policy review group provided a rationale for such a recommendation to the Working Group on Strategies and Review at its fifty-fifth session (Geneva, 31 May–2 June 2017) (see informal document No. 6).

5. In line with the task included in workplan item 2.3.8 and the rationale presented by the policy review group, the present document covers the following deliverables:

   a) Good practices for domestic wood heating installations;

   b) Best available techniques for domestic wood heating installations.

6. The current document focuses on wood biomass only. It provides an overview of guidance documents, codes of good practice and communication materials with respect to domestic wood heating in several countries of the United Nations Economic Commission for Europe (ECE) region. In the future, depending on the information made available on solid fuels other than wood biomass, the present code of good practice could be further expanded, or a new separate code could be developed on domestic coal burning.

7. The present code of good practice can be applied to small wood fuel combustion installations for residential sector indoor heating with a rated thermal input of less than 100 kW. More specifically, the present document focuses on domestic wood local space heaters (fireplaces and stoves) and domestic wood boilers, in accordance with the above-mentioned rationale.

8. Domestic wood heating is a major source of emissions of particulate matter, including black carbon (BC), and organic pollutants, such as dioxins/furans, polycyclic aromatic hydrocarbons (PAHs) and benzo[a]pyrene (B(a)P), in the ECE region, resulting in poor local air quality conditions and significant negative effects on human health. The present document responds to the need to inform the general public of:

   a) Available best practices for domestic wood heating in order to minimize emissions and increase efficiency, reducing expenditure due to decreased storage needs and the use of wood, while reducing the negative impact on the environment and human health;

   b) The best heating devices currently available on the market;

   c) The proper origin and characteristics of wood biomass and the need to burn dry, clean wood and thus to avoid use of composite, treated and/or contaminated wood.

9. In particular, old models of stoves and fireplaces are inefficient and can release high levels of emissions. Nevertheless, incorrect use of new, high performance domestic heating devices with low emissions and high efficiency with non-optimal combustion can still cause high levels of emissions and reduce energy efficiency. Besides the type of combustion device, the crucial factors for minimizing real-life emissions are the proper sizing, installation and use of the device, including optimal combustion operation, proper start-up, no smouldering, maintenance and use of dry and clean firewood.

10. The present document makes available information to all Parties in the ECE region, with special considerations with respect to countries in Eastern Europe, the Caucasus and Central Asia added in section V below. The document is addressed in particular to national and local authorities and policymakers in general, serving as a background reference document for the development of awareness-raising materials (leaflets and guidance) for end-users at the regional, national and local levels.

III.
Definitions

A. Domestic heating installations

11. In the present document, domestic heating installations are defined as wood-burning devices for local spaces, or central indoor heating with a rated thermal input of less than 100 kW. This includes domestic fireplaces, stoves and boilers, manually or (semi-)automatically stoked, with or without heat storage capacity, with or without a connection to a central heating system, and using wood products of different types, shapes and sizes.

B. Wood

12. The present code of good practice focuses on wood biomass. To mark the distinction between wood and non-wood biomass, the following definitions apply:

    a) "Biomass" means the biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste, sometimes in the form of pellets;

    b) "Wood biomass" means 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 (compressed) sawdust;

    c) "Non-wood biomass" means biomass other than wood biomass, including straw, miscanthus, reeds, kernels, grains, olive stones, olive cakes and nut shells.

C. Efficiency of the heating system

13. The ratio between the heat provided by the heating system and the energy content of the fuel is defined as the thermal efficiency of the heating system.

14. Greater efficiency is one means to decrease emissions. However, as higher efficiency is achieved, emissions may not necessarily decrease at the same pace – particularly regarding black carbon emissions – given that some high-efficiency units depend on lower temperatures for less fuel use, but with less complete combustion.

IV. Domestic wood heating

A. Overview of existing guidance documents, codes of good practice and "burn wise" educational materials in several countries

15. The summary below provides an overview of existing guidance documents, codes of good practice and other materials existing within the ECE region, applied by the European Union and some other Parties to the Convention and designed to reduce emissions from residential wood combustion.

16. A recent report provided by the International Institute for Applied Systems Analysis – which hosts the Centre for Integrated Assessment Modelling under the Convention – on measures to address air pollution from small combustion sources,[3] also contains relevant information on actions implemented and good practice examples to reduce air pollution from domestic solid fuel burning in the European Union, including: awareness-raising and information campaigns; emission standards; replacement programmes; financial incentives; bans and restrictions; and improved maintenance.

17. The following list is non-exhaustive. Additional information can be found on the Task Force on Techno-economic Issues Clearing House of Control Technology website[4].

Austria

18. An article has been prepared on proper heating in small-scale combustion facilities by the Federal Ministry for Sustainability and Tourism.[5] Additional articles on heating in small-scale combustion facilities with low air emissions[6] have been published by other institutions and regional authorities.

Belgium

19. Information materials have been developed in Belgium to raise awareness of solid fuel and to strengthen end-users' capacity to burn it in the correct way in space heating installations.[7]

Denmark

20. Information material and publications have been prepared on the impacts of wood burning, proper use of wood-burning devices and other solutions.[8]

France

21. The French Environment and Energy Management Agency has published a user guide for wood-burning devices and a household guide on choosing equipment.[9]

Germany

22. Germany has prepared useful information designed to improve the practices of operators burning wood,[10] a film on burning wood the right way (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)[11] and a guide to clean and proper heating (German Environment Agency).[12]

Italy

23. In Italy, a number of regional authorities, especially in the northern part of the country, where the use of space heating wood-burning installations is quite widespread, have developed awareness-raising materials for end-users.[13]

Spain

24. In Spain, a regional authority has published awareness-raising materials for end-users.[14]

Switzerland

25. "Fairfeuern"[15] (fair heating) is an information platform of Swiss environmental departments that provides information, advice and tips on correct planning and use of wood heating installations. The association "Holzenergie Schweiz" provides flyers and publications in French, German and Italian on what fuels to use and how to start a fire.[16]

The United States of America

26. "Burn Wise" is a voluntary partnership programme bringing together the United States Environmental Protection Agency, other State agencies, manufacturers and consumers that emphasizes the importance of burning the right wood, the right way and in the right appliance.[17]

Canada

27. The Canadian Council of Ministers for the Environment approved the Code of Practice for Residential Wood Burning Appliances in 2012.[18] The Code was developed to address air pollution caused by residential wood burning. It provides guidance to support federal, provincial, territorial and municipal authorities. Canada has also developed a guide to residential wood heating[19] that provides information on how to heat safely with wood, dealing with installation, maintenance, safety, how to purchase and prepare wood for burning and how to burn it efficiently.

Belarus

28. An informative brochure developed for the Tyrol Region of Austria[20] has been translated into Russian by a non-profit association for users in Belarus.

B. Key information and considerations

1. Impact of wood combustion on emissions, air quality, health effects

29. Domestic wood combustion leads to the emission of a complex mixture of air pollutants. It is driven by a series of chemical reactions basically oxidizing the carbon and hydrogen present in the firewood to carbon dioxide (CO_2) and water. Incomplete combustion – mainly due to insufficient mixing of combustion air and fuel in the combustion chamber, a lack of available oxygen, insufficiently high temperatures and short residence times – results in emissions of carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), including BC, unburned hydrocarbons (non-methane volatile organic compounds (NMVOCs)) and organic pollutants such as PAHs (including B(a)P), dioxins/furans (polychlorinated dibenzo-p-dioxins and dibenzofurans) and hexachlorobenzene (HCB)). Different types of wood are characterized by different pollutant emissions in terms of relative percentage. Potassium cation, Sulfate anion, ultrafine particles with equivalent aerodynamic diameter less than 0.1 µm, Zinc, Iron, aluminium, total carbon (TC, mainly BC), levoglucosan and PAHs are the main pollutants concerned. Their relative emissions may change significantly for the same type of wood (for example, beech), depending whether the wood is burned in the form of pellets or logwoods, especially for TC/BC and PAH emissions.

30. PAHs, in particular B(a)P, are recognized by the World Health Organization as being dangerous for human health. Volatile organic compounds (VOCs) are precursors of ground-level ozone, as are nitrogen oxides (NOx), which are also generated by biomass combustion, mainly due to the nitrogen (N) content of the fuel. Both VOCs and NOx are pollutants covered by the Gothenburg Protocol. $PM_{2.5}$ resulting from combustion also affects human health, decreasing life expectancy.

31. It should also be noted that many of the NMVOCs emitted from stoves may condensate to solid/liquid particulates in, or at a short distance from, the chimney concerned.

2. Link with climate change and renewable energy objectives

32. Wood burning produces CO_2, but, in the frame of the United Nations Framework Convention on Climate Change, it is considered as CO_2-neutral in the global balance (emission/absorption) because the amount of CO_2 produced when wood is burned is assumed to be equal to that fixed by the trees and plants concerned during their lifetime.

33. BC resulting from wood combustion is known as a short-lived climate pollutant. Although BC has a short atmospheric lifetime of only a few days or weeks, its contribution to current global warming is not insignificant. BC causes a direct warming effect by its absorption of incoming sunlight and an indirect warming effect by its deposition on snow and ice, reducing the reflectivity (albedo) of snow and ice, hence leading to accelerated melting. BC deposition is especially relevant in the Arctic and mountainous regions, as well as throughout the northern part of the ECE region during the cold months of snow and ice when heating with wood is intensified. As BC has a very short residence time in the atmosphere, its reduction can have a noticeable positive impact on

global warming in the very near term. Reduction of BC provides synergy aspects with climate change policies.

3. Emission and energy performance of different types of domestic wood heating installations

34. There are several types of domestic wood heating installations used to provide heat in homes; within each broad type, there are many variations. An overview of the most common wood heating devices used for domestic heating purposes is provided below.

35. Small heating devices burning wood are usually classified based on their construction properties (factory- or site-built), the combustion technology used, the shape of the firewood applied (logs, pellets), combustive air draught (up-draught, down-draught) and the heat distribution system (local, central).

36. Older, single domestic heating devices are of a very simple design, while modern, more advanced devices are improved versions of the old conventional ones. Small domestic wood heating devices can be classified as follows:

   a) Open fireplaces;

   b) Partly closed fireplaces;

   c) Closed fireplaces;

   d) Wood stoves;

   e) Pellet stoves;

   f) Mass stoves;

   g) Boilers.

37. Data on technology-specific emission factors for different domestic wood burning technologies can be found in the *EMEP/EEA air pollutant emission inventory guidebook*.[21] Alternatively, Parties can use national emission factors or national methodologies to estimate emissions for reporting purposes if they are able to produce more accurate estimates.

38. Open fireplaces are the simplest combustion devices and are mainly used for occasional supplementary heating in residential dwellings and are primarily retained for aesthetic reasons and recreational use rather than space heating. In areas of energy or fuel poverty, open fireplaces are sometimes used as the primary heating source to reduce the energy bill. The open fireplace consists of a combustion chamber, which is directly connected to a chimney and has a large opening to a firebed. The heat generated by the open fire is transferred directly into the room in which the fireplace is located (by radiation and convection), without the use of water- or air-distribution pipes. Open fireplaces are typically an integral part of the structure of the property.

39. Open fireplaces are characterized by high excess of combustion air and incomplete combustion of firewood, typically resulting in low energy efficiencies (around 10 to 15 per cent) and significant emissions of $PM_{2.5}$ and associated pollutants that are higher than with other installations. Open fireplaces are definitely not state-of-the-art devices and generally use the least efficient and least clean wood-burning technology.

40. Unlike the above-mentioned open fireplaces, which are usually site-built, closed or partly closed fireplaces are defined, pre-fabricated devices, which can be free-standing (installed as stand-alone units) or inserted in a recess (built in a pre-existing open fireplace).

41. Partly closed fireplaces are equipped with louvers and glass doors to reduce the intake of combustion air, but the distribution of combustion air is not specifically controlled. Combustion conditions compared with open fireplaces are, therefore, only slightly improved. Closed fireplaces are equipped with front doors, fully closing the opening towards the area being heated, and have air flow control systems. In closed fireplaces, the temperature in the combustion chamber can reach up to 400° C or more and the retention time of the combustion gases in the combustion zone is longer compared with open fireplaces. All closed fireplaces have intakes for incoming air; modern units may also be equipped with automatic control valves, catalytic converters and fans directing additional heat into the living area.

42. Thanks to their combustion mechanics, closed fireplaces are characterized by higher energy efficiencies (often close to 55 per cent) and lower emissions than open fireplaces. Recent technological developments have improved the performance of

closed fireplaces, making them a more efficient and cleaner wood-burning option, with efficiencies of up to 80 per cent or more and with emission profiles similar to those of modern stoves.

43. Wood stoves come in many shapes, types and sizes. They can be divided into conventional radiating stoves, advanced or modern stoves (catalytic, non-catalytic, hybrid), smart stoves (semi-automated), mass stoves (heat-accumulating stoves) and stoves installed as inset or freestanding. Wood stoves are mainly produced in steel or cast iron, except for mass stoves, which are usually built on site with bricks, stone or ceramic materials. Different kinds of firewood can be used, such as wood logs and wood pellets. Mass stoves and pellet stoves are discussed separately in subsections below.

44. Wood stoves can be installed as a free-standing unit or fitted within the firebox of masonry fireplaces. An insert can convert a conventional fireplace into a more effective heating system. Wood stoves are devices in which firewood is combusted to provide useful heat that is transmitted to its immediate surroundings (room heating) by radiation and/or convection. In some parts of the ECE region, as a result of energy poverty, free-standing wood stoves may also be used for cooking and heating water for bathing and cleaning.

45. Various combustion principles (such as down-burning, up-burning, combinations) are used with regard to conventional radiating wood-fired stoves. All these old-style devices typically have a low efficiency in the range of 40 to 50 per cent and high emissions of pollutants, mainly originating from incomplete combustion (PM, CO, NMVOCs and PAHs). Down-burning stoves (the majority of older stoves) have higher emissions compared to up-burning stoves, due to more incomplete combustion. The autonomy of conventional stoves (the ability to operate without user intervention) is low.

46. Modern wood stoves using more advanced technologies are characterized by better efficiencies, lower emissions and less wood use compared to traditional stoves. Stoves with advanced combustion technologies – characterized by improved air control, improved utilization of secondary air in the combustion chamber, multiple air inlets and preheating of secondary air – have efficiencies ranging from 55 to 75 per cent. Stoves equipped with a catalytic converter reducing PM emissions caused by incomplete combustion are more expensive than non-catalytic stoves, but can hold a fire longer, tend to be more efficient (up to 75 to 80 per cent or more) and are cleaner. Hybrid stoves, using both non-catalytic and catalytic technology, achieve efficiencies of 80 per cent or more.

47. The newest generation of wood stoves is more and more aiming at automation, using sensors and computer chips to adjust air flow electronically, thus diminishing the influence of the operator and wind speed. These (semi-) automated stoves, so-called smart stoves, can be equipped with other functions or features, such as the possibility to be used as thermostatic stoves, where the user sets the desired temperature and overheating of the room is avoided, or the possibility to alert the user when refilling of firewood is optimal. There are smart stoves that can be connected to Wi-Fi, allowing the transmission of combustion data to the producer for checking and adjustment. Smart stoves are an emerging class of stove that is gaining popularity.

48. Pellet stoves are fuelled using wood pellets instead of wood logs. Pellets are mainly made of dried sawdust, compressed into small cylinders. Pellets are more homogeneous and have lower moisture content than wood logs, and therefore result in better combustion quality. Moreover, pellets are automatically fed into the combustion chamber by means of a loading device, adjusting the load according to heat demand. Modern pellet stoves are also often equipped with an active control system for supply of combustion air and thermostats to maintain a constant temperature in the room. Pellet stoves are installations with a higher performance compared to traditional stoves. The best performing pellet stoves can reach efficiencies of 70 to 90 per cent or more. Emissions from pellet stoves are considerably lower compared to traditional wood stoves.

49. Mass stoves, or masonry stoves, are large heaters built with masonry, ceramic, bricks, tiles or soap

stone. The basic principal of masonry stoves is that they store the generated heat from the fire into the masonry thermal mass and then slowly release it by radiation into the building's living space over a longer period of time. The flue is ducted in such a way that it travels a long distance through this mass. Because of the large thermal capacity of masonry materials, such stoves keep a room warm for many hours (8–12) or days (1–2) after the fire has burned out; that is why they are called heat-accumulating, or heat-storing, stoves. Their combustion chambers can be equipped with horizontal strips or inclined, perpendicular baffles made of steel or fireproof material, which improve combustion quality and efficiency. Owing to increased residence time of fuels in the combustion zone, there is a decrease in pollutant emissions compared to conventional radiating stoves. Masonry stoves' combustion efficiency ranges from 60 to 80 per cent and their autonomy from 8 to 12 hours. Masonry stoves are large and expensive installations. Site-built masonry heaters tend to be even more expensive than factory-built masonry heaters, as skilled masons need to be on site for several days for the purposes of their construction.

50. Wood-fired boilers are installations that typically have greater capacities than wood stoves and fireplaces. They are equipped with one or more heat generators and provide heat to a water-based central heating system in order to increase to, and subsequently maintain at, the desired level the indoor temperature of one or more enclosed spaces. They are used for indirect heating of one or more rooms. With wood-fired boilers, wood logs, pellets or chips can be used as fuel. Automated log-fired boilers are available, but most automated wood-fired boilers use pellets or chips. Along with automated fuel-loading, modern automated pellet- or chip-fired boilers also have automated sensors to control combustion (supply of combustion air). The burners can have different designs, such as underfeed burners, horizontally fed burners and overfired burners. These automated boilers can achieve high efficiencies of 80 per cent or more, with emission levels that are much lower than those of traditional stoves.

4. Impact of sizing, placement, commissioning, use, maintenance and control of domestic wood-heating devices on emissions and efficiency

51. Besides the type of the heating device, its proper sizing and installation adjusted to the heat demand, as well as good use and maintenance of the heating device, with sufficient attention to inspection and enforcement, are of great importance in keeping emissions low and efficiencies high in real life operations. Particularly for manually stoked devices, the user plays an important role regarding the level of emissions and efficiency through the considerable influence of use and maintenance of the heating device.

52. It is important that any heating device purchased should be not only energy-efficient and environmentally friendly, but also adjusted to the heating and energy demands of the place of residence in question. It is also important that due attention be paid to the correct placement of the device and the chimney, taking into account the immediate environment of the chimney, and that the device be properly adjusted and maintained and used correctly (for example, fired with the correct air supply, correctly lit and at favourable atmospheric conditions).

53. The ignition phase is one of the most critical phases given that combustion temperature in this start-up phase is still low. The commonly used "bottom-fire" ignition method, by which the fire is lit at the bottom, produces about 75 per cent more emissions of fine PM than the modern "top-fire" ignition method. Furthermore, the correct regulation of air supply by the user is critical in guaranteeing the sufficient quality of the combustion process (and, as such, keeping emissions low). Smouldering the heating device, for instance, by minimizing air supply, produces 10 times more emissions of $PM_{2.5}$ than when operated at normal conditions. Unfortunately, this technique is still applied by a considerable share of users.

54. Poor maintenance of the heating device, the air supply or the flue gas channel in general leads to an insufficiently high air supply, with a negative impact on the quality of the combustion process.

55. It should be noted that the latest generation of wood stoves and boilers are increasingly focusing on automation, with automatic control of, among other things, air supply, fire wood supply and ignition. As a result, the influence of the user and wind speed, which has an effect on chimney draught, decreases strongly and emissions are reduced.

5. Impact of quality of domestic firewood on emissions and efficiency

56. An efficient and low-emitting fire also requires good firewood of the right shape and in the right amount. Firewood for domestic heating exists in different shapes and forms (wood logs, wood pellets, wood chips, wood briquettes), each with its own characteristics, emission profiles (PM, PAH, BC), advantages and disadvantages. Wood logs are cheaper than pellets and briquettes. Often, non-commercial (not purchased) firewood is used.

57. The type of firewood – classified as soft or hard wood, depending on its weight, shape, size, density, thickness, caloric value, bark share and moisture content – has an impact on the burning temperature, operation, efficiency and level of emissions of the heating device. For combustion purposes, oak, ash, beech, maple and fruit trees (except the cherry tree) are all considered as high-quality firewood. The wood of chestnut, birch and alder trees is of decent quality, and that of linden, poplar and willow trees is of acceptable quality.

58. The moisture content of wood has, in particular, a significant impact on emissions and efficiency of combustion. Wood must be sufficiently dried before use, preferably with wood logs preferably having a moisture content of 10 to 20 per cent. The use of wood with a moisture content of 20 per cent can reduce emissions of $PM_{2.5}$ by 75 per cent compared to the use of wood with a moisture content of 30 per cent. The consistent use of dry and good quality wood contributes to the further reduction of domestic wood-heating emissions. Wood pellets can be characterized as a stable and standardized fuel with a low moisture content of around 10 per cent. Wood logs are less homogenous in size, moisture content and bark share than wood pellets and require more attention in their use as firewood. The use of composite and treated wood must be avoided at all times.

59. Combustion of soft wood normally results in higher emissions than combustion of hard wood. Soft wood lights up easily, which is helpful in starting a fire, burns faster and develops a long flame. It is used in heating devices where a long, round flame is required. Poplar, alder, chestnut and willow are examples of soft wood. Smaller wood logs also tend to burn faster, possibly resulting in higher emissions. The optimal size of wood logs should be indicated in the heating device manual.

60. Hard wood is more compact and is characterized by slower combustion and short flames. Hard wood burns more slowly and more uniformly, generating less emissions of pollutants. It needs more combustion air than soft wood. Consequently, it is more suitable for domestic heating. Elm, oak, holly, beech, ash and locust are examples of hard wood. Other elements to consider when choosing the right firewood adjusted to the wood-heating system are its origin, sustainable character and storage needs (greater for wood logs than for wood briquettes and pellets) and the existence of a certification system.

C. Good practices for domestic wood heating

61. The present section provides recommendations and good practices to support end-users in their choice of a heating device and to encourage its correct use. Good practices can be centred around four key pillars: burn the right wood, the right way, in the right heating device and maintain and clean the heating device or chimney on a regular basis.

62. Awareness-raising campaigns to promote the use of safer, more energy-efficient and less polluting heating devices and the application of best burning techniques can, in general, be a good tool for reducing emissions and negative impacts from domestic wood heating. The subsections below provide information on good practices that could be recommended within such communication campaigns. However, not all the recommendations listed can be applied to all types of heating installations (fireplaces, stoves, boilers). Some further differentiation is still required.

1. Selection of heating installation

63. In order to reduce environmental impact and to improve energy efficiency, careful consideration should be given to the type, size and installation requirements of the heating device. When choosing a new heating system for a house, alternative heating systems other than wood boilers and stoves and with less emissions and higher efficiencies should be considered; this includes heat pumps, photovoltaics, solar boilers and connection to a local heating network. If a wood-heating installation is chosen, the following practices are recommended:

a) Choose a heating installation that uses best available techniques to reduce emissions and increase efficiency. Emissions from automated heating installations, with automatic control of air supply, feed and ignition, and, consequently, decreased influence of user and wind speed, are considerably lower than those from manually operated heating devices;

b) Choose a heating installation that matches the size of the space to be heated and that is adjusted to its function (primary or additional heating source). The heat demand should be calculated based on the volume of the room(s) to be heated, with due consideration of heat dispersion, degree of insulation of the building and outdoor temperature. A heating installation that is too large for the room will overheat the space quickly and will have to be operated with slow, smouldering fires much of the time to avoid overheating the room, resulting in high emissions and low efficiency. An undersized heating installation can be damaged by frequent over-firing to keep up with heat demand. Heating installations of the correct size will use less firewood;

c) Choose a certified heating installation or one bearing a high energy efficiency label or eco-label, if possible. Certification or labelling guarantees the appropriate quality of the heating installation and compliance with safety regulations and/or minimum efficiency and emission requirements;

d) Choose a heating installation according to available indoor or outdoor firewood (logs, pellets, chips) storage capacity;

e) Avoid installing an open fireplace. Heating with an open fireplace is inefficient and results in significant emissions; poor indoor air quality can cause a fire if burning material leaps out;

f) Ask for a user manual when purchasing a heating installation. The user manual should be easy to read and to use and should contain all necessary information specific to the heating installation, especially regarding its proper use;

g) Foresee that the combustion air for the heating installation is extracted from outside the house, through proper piping. This ensures safer operation and reduces heat loss. Requirements concerning insulation, airtightness and ventilation of energy-efficient buildings should be taken into account for the management of air intake for the heating installation;

h) Use licensed/qualified technicians for the installation of the heating device;

i) Ensure that the flue gas channels and chimney are well placed. The chimney must extend above the ridge of the roof and adjoining buildings. The diameter of the flue gas channels must be adjusted to the heating installation in order to avoid a bad chimney draft and the risk of a chimney fire. Have the flue gas channels and the chimney installed by a specialized technician. Corners in the flue gas channel and horizontal lines should be avoided;

j) Use state-of-the-art technologies to ensure good discharge conditions for exhaust gases.

2. Selection of firewood

64. The choice of firewood to be used as fuel is essential for the proper operation of the heating installation and for reducing the impact on air quality and the environment. Recommended good practices are provided below.

For the use of traditional wood logs

65. Burn dry, seasoned wood. Wood burns best with a moisture content of 15 to 20 per cent. Dry wood lights up and burns easily, resulting in lower emissions than when wet wood is burned. With increasing moisture content of the wood, ignition becomes more difficult, combustion temperature and energy efficiency decrease and emissions increase due to more incomplete combustion. Wood that is too dry may also increase emissions of soot particles. A cheap and easy way to check the moisture content of wood and to make sure it is ready to burn is to make use of a wood moisture meter. Measure the moisture content inside the wood log after the wood log has been split, testing the newly split side. Dry hardwoods have the best combustion efficiency and produce less smoke and emissions.

66. Do not burn wet or green unseasoned wood, as it generates more smoke than dry wood. Properly seasoned wood is generally darker, shows some slits in the logs, feels lighter than wet wood and generates an empty sound when struck against other logs.

67. Purchase seasoned wood in summer (June and July) and leave it to continue to dry under the sun, sheltered from the rain. Non-commercial wood, collected by end-users, should be split into logs, stacked and covered and left to dry for at least one or two years or drying seasons before being used, depending on the type of wood and ventilation of the woodpile. Hard woods require more time for sufficient drying than soft woods.

68. Stack the split wood outside the house, in a sheltered place off the ground and in an orderly way, with good air flow beneath and between the logs. The upper part of the stack should be covered to protect the wood from rain and snow and to allow the seasoning process to continue. The sides of the stack should not be covered, since that would hinder air flow.

69. To the extent possible, keep the wood ready for daily use in a warm place. Wood burns better when not cold.

70. Use only clean and untreated wood, with a minimum share of bark and leaves. Sand and/or mud on the wood make it less efficient for combustion. Avoid, discourage or forbid the use of composite and treated wood (painted, coated, processed with wood protection products, plywood), synthetic materials (plastic-coated paper, plastic packaging materials) and all forms of waste (from building demolition or renovation, from packaging, from furniture, household trash), including for lighting the fire. The combustion of such materials causes increased emissions of harmful and toxic substances like heavy metals, VOCs and persistent organic pollutants and may also damage the heating installation and chimney. It should be highlighted that, as a general rule, wastes and waste wood should never be burned in a domestic heating installation.

71. Place the right amount of wood in the heating installation and use the right quality and size of wood, as indicated in the manufacturer's instructions. In order to avoid damaging the internal coating materials of the installation because of overly high temperatures, do not overload the heating installation. The optimal size of the wood should be indicated in the user manual.

72. Use logs of a similar size, preferably split rather than round logs. Split wood seasons faster than whole wood.

73. Use split wood logs of proper size that fit in the heating installation's firebox. Follow the manufacturer's instructions. In general, avoid using logs longer than 40 cm and wider than 15 cm. Smaller logs allow for better storage and drying before use and better combustion. Open space between the combustion chamber wall and the wood logs will help improve combustion.

74. Use locally cut firewood to minimize fuel consumption for transport and to reduce the risk of introducing potentially harmful insects into new areas. Preferably purchase wood with a certification/label, if available. This will minimize potential negative impacts on the environment, climate and biodiversity.

For use of wood pellets

75. For pellet stoves and boilers, choose pellets of high and stable quality (no impurities, no bark, low ash content, high caloric value, moisture content around 10 per cent) that meet the manufacturer's recommendations. This will reduce emissions during

combustion. Preferably buy pellets that are certified (for example, DINplus, ENplus) and/or labelled (for instance, Programme for the Endorsement of Forest Certification (PEFC) or Forest Stewardship Council (FSC)). Certified wood pellets must comply with strict technical standards. Labels like PEFC and FSC guarantee that the wood used to produce the pellets comes from sustainably managed forests. Check that not too much wood dust is present in the pellet bags. High quality pellets are well pressed and not shredded. Pellets are dense, have fewer storage needs and are most suitable for use in automated heating installations.

For use of artificial wood logs (sawdust logs), wood briquettes, wood chips

76. Consult the manufacturer's manual before using sawdust logs, wood briquettes or forms of firewood other than traditional wood logs or pellets. Use only the fuel recommended by the manufacturer. Do not use artificial logs or briquettes in a heating installation designed for the use of traditional logs. The higher energy content of sawdust logs or wood briquettes may overheat heating installations designed for traditional logs. Store sawdust logs, briquettes and wood chips indoors.

3. Fuel loading

77. Good burning requires correct loading of the combustion chamber. The following practices are recommended for manual loading with wood logs:

    a) Load the wood logs horizontally and long side perpendicular to the door of the combustion chamber when the combustion chamber is narrow;

    b) Load the wood logs horizontally and long side parallel to the door of the combustion chamber when the combustion chamber is wide, but shallow;

    c) Load the wood logs vertically when the combustion chamber is narrow, but high;

    d) In mass stoves (heat storage stoves), load the wood logs horizontally and "front head";

    e) In squared combustion chambers, load the wood logs in a crossed manner, with about 4–8 cm of free space between the logs, allowing for a good air flow;

    f) Consult the manufacturer's manual for any loading instructions specific to the heating installation;

    g) Keep the firing burning, especially when the heating installation (stove) serves as the primary or sole heating source. Add logs before the flames disappear. Most of emissions arise during the start-up phase and a hot stove burns more efficiently with lower emissions.

4. Lighting the fire

78. The ignition phase is a critical phase of the firing cycle for ensuring good combustion and efficiency of the heating installation and for keeping emissions low. The practices set out below for manual fire lighting for local space heaters such as stoves and fireplaces are recommended.

Before lighting the fire

79. Check air supply and flue gas channel. Make sure that sufficient air is fed into the house. If necessary, switch off the kitchen ventilation. Ideally, the heating installation should be connected to the external air supply. The larger the installation, the more combustion air is needed. Check whether there is sufficient upwards draft (air flow) in the flue gas channel, for example, by putting your hand in it and lighting a match or some paper, if physically possible.

Lighting the fire

80. Never fully fill the combustion chamber; when lighting the fire, fill half of the combustion chamber up to maximum.

81. Place the most flammable material at the top of carefully stacked pieces of dry wood and light the fire from above, at or just below the top. There are less emissions released during the ignition phase when this so-called top-down fire method (Swiss method) is used, as it reduces incomplete combustion. The thicker wood logs are placed at the bottom. For a few heating installations, the recommended practice for lighting the fire is the bottom-fire method, with the fire being lit from below. Check the manufacturer's manual for instructions.

82. Use dry kindling (dry sticks) or natural firelighters as flammable material to start the fire at the top. Avoid using newspaper to light the fire. Newspaper is printed and the ink burns with it. Do not use gasoline, kerosene or charcoal as fire starters.

83. Open the air supply of the heating installation completely when you light the fire. Reduce the air supply a little as soon as the fire burns well and a good hot fire has been established. Make sure that the flames do not get smaller. If the heating installation sucks in too much air (oxygen), the firewood burns too brightly and it will not have sufficient time to burn completely and the chimney will suck in sparks. If the air supply is too low, emissions of soot particles and other harmful substances, such as CO, will increase.

84. Put new wood on the fire in time, when the combustion temperature is still high and before the flames begin to disappear.

85. Add small quantities or pieces of wood regularly to avoid overloading and close the door as quickly as possible. This ensures optimal burning with less emissions of harmful substances.

86. Load larger pieces of split wood only after there is a vigorous fire or a suitable bed of embers has formed.

87. Control the amount of heat being released by controlling the loading of the firewood, rather than by trying to control the air supply.

88. When not loading, for safety reasons, keep the front door of the heating installation closed and locked, unless otherwise recommended by the manufacturer.

5. Combustion

89. Poor combustion results in reduced energy efficiency and higher emissions of air pollutants, especially of fine particulate matter, and creates creosote build-up on the interior surfaces of the chimney flue, reducing the chimney draft and creating a chimney fire hazard. There are three phases of wood combustion, mainly in reference to the temperature of the process: drying; pyrolysis; and gasification and combustion.

Drying

90. When wood is heated, water begins to evaporate from its surface. Evaporation typically starts below 100° C. Up to a temperature of 150–200° C wood loses the water it contains. As evaporation occurs, the temperature in the combustion chamber temporarily decreases, slowing the process of combustion and decreasing the thermal efficiency of the heating installation. This is the main reason for not using unseasoned wood. The wetter the wood, the more energy will be required to dry it and the lower the efficiency of wood combustion. High moisture content in wood leads to incomplete combustion, reduced thermal efficiency and increased emissions of air pollutants.

Pyrolysis

91. At a temperature of around 200° C, wood starts to break down into volatile substances and solid carbon. The volatile fraction of wood – more than 75 per cent of the whole mass of wood – evaporates. At around 400° C, most of the volatile components have evaporated.

Gasification and combustion

92. This phase, starting between 500° C and 600° C and continuing up to about 1,000° C, consists of complete oxidation of gases. Combustion is completed when all wood components have completed their chemical reaction with oxygen. However, 100 per cent complete combustion of wood is a purely theoretical concept due to limiting conditions, such as the right degree of mixture between air and fuel, which is quite difficult to achieve in a short time. When the conditions for complete combustion are not ideal, emissions of harmful substances increase.

93. In reality, during combustion, the three above-mentioned phases overlap in a complex way, rather than occurring at distinct moments in time.

94. The main reasons for incomplete combustion are:

a) Incorrect or poor mixing of the combustion air and combustible gases generated by firewood in the combustion chamber, caused, for example, by the design of the combustion chamber or improper loading of logs;

b) A lack of combustion air (oxygen) in the combustion chamber, caused, for example, by insufficient air supply;

c) The combustion temperature is too low, for example, due to the use of unseasoned firewood or excess air flow through the combustion chamber;

d) The residence time in the combustion chamber is too short;

e) Overloading of the combustion chamber with wood.

95. Incomplete combustion is shown by incomplete oxidation of gases and an increase in organic unburned fractions. Consequently, CO, PM and VOC emissions may increase.

96. In recent decades, technological innovation has gradually increased the efficiency of wood heating installations (stoves), with substantial reductions in CO and other harmful emissions. However, for wood, achievement of optimal burning conditions for complete combustion remains difficult, especially compared with natural gas combustion, for which a good mix of combustion air and fuel gas, and also turbulence, are considerably easier to achieve. This is the reason why CO and VOC emissions from wood combustion are significantly higher than those from natural gas combustion, even with the most efficient wood-heating installations. On the other hand, natural gas use in stoves produces greenhouse gases emissions from CO_2 and from fugitive methane emissions, which have impacts on climate and air quality through tropospheric ozone formation. All heating sources therefore bring trade-offs. Increased automation can significantly reduce emissions from wood combustion, including of black carbon, which is also a climate forcer.

97. In the light of the above-mentioned considerations, recommended good practices, in particular for manually operated heating installations such as stoves, are the following:

a) Ensure that a high temperature is achieved in the combustion chamber as soon as possible and that it is maintained. This allows for the optimal and efficient performance of the heating installation and will reduce emissions of harmful pollutants, production of ashes and creosote build-up in the chimney and increase efficiency. Optimal and efficient burning will result in lower fuel costs for the consumer;

b) Keep the flame vivid and "warm". Blue, yellow-red or light red flames indicate good combustion. Red or dark red flames are an indicator of poor combustion;

c) Do not keep the fire smouldering. Dirty glass doors or dirty smoke from the chimney are signs that the fire needs more air, the firebox temperature is not hot enough or the firewood is too wet;

d) Check the smoke leaving the chimney (visual control). With a good combustion, the smoke at the chimney exit should almost be transparent. If it is dense and coloured yellow or dark grey, combustion is not taking place correctly and adjustments are needed in the fuel and/or operation of the heating installation. In very cold conditions, harmless "white smoke" – consisting of water droplets – may be formed;

e) Make sure that the smoke from wood burning does not smell. A good combustion of the firewood in the heating installation should not generate smoke that smells. Smoke that smells points to a significant amount of harmful substances that are generated and emitted due to poor combustion;

f) If possible, measure the temperature in the chimney. The temperature of the flue gases in the chimney should be around 150° C - 200° C. If it is lower, there is a risk of condensation in the chimney;

g) Check the colour of the ashes. In good combustion conditions, ashes are grey or white. Poor combustion results in ashes that are dark and heavy or the head of the fireplace becoming black and dirty. Both of those phenomena are strong indicators of possible creosote build-up in the chimney, which greatly increases the chance of a chimney fire. Such fires, because they often burn for some time before being detected, frequently result in severe home damage and mortality;

h) Regularly remove ashes from the heating installation unit using a proper installation equipped with a cover and opening allowing proper air intake.

6. Extinguishing the fire

98. Recommended good practices, in particular for manually operated heating installations like stoves, are as follows:

   a) Collect the glowing biomass for better combustion;

   b) Wait until the ember is burned, before completely shutting off the air supply.

7. Maintenance and inspection

99. Like all technical installations, a wood-fired heating installation also requires regular maintenance and inspection. Proper maintenance and inspection will contribute to cleaner (less emissions of pollutants, less ashes), more efficient, more economical and safer burning.

100. Recommended good practices are as follows:

   a) Remove ashes on a regular basis, or as needed, every day, week or three weeks, depending on the performance of the combustion. Too much ash in the firebox can have a negative impact on the performance of the heating installation (for example, it can clog air intakes). Leaving some ash (2 cm) in the firebox will keep the embers hot and make it easier to restart the fire, with fewer emissions compared to a completely new ignition process;

   b) Clean the firebox and area around the firebox on a regular basis;

   c) Have a qualified technician inspect and maintain the heating installation and chimney on a regular basis, preferably, at least once a year, and more frequently when used as the primary heating source in a cold climate. Qualified technicians and/or chimney sweeps should regularly check the heating installation and chimney to detect possible damage or malfunctions. The chimney should be cleaned at least once a year to remove creosote deposits. The seals and possible contamination of the fresh air supply installation of the heating installation must also be checked. In some countries, local authorities are authorized to carry out visual inspections of wood-fired heating installations;

   d) Follow the instructions and advice on frequency of maintenance contained in the manufacturer's manual.

D. Best available techniques for domestic wood-heating installations

101. The following references contain useful information on best available techniques for domestic wood-heating installations:

   a) Guidance document on control techniques for emissions of sulphur, nitrogen oxides, volatile organic compounds, and particulate matter (including PM_{10}, $PM_{2.5}$ and black carbon) from stationary sources (ECE/EB.AIR/117), with information on domestic heating installations in section VII.A;

   b) International Institute for Applied Systems Analysis report on measures to address air pollution from small combustion sources;[22]

   c) EMEP/EEA air pollutant emission inventory guidebook;[23]

   d) Preparatory studies on solid fuel heating installations for the European Union Ecodesign Directive;[24]

Best available combustion technologies

102. The technology for domestic wood-heating installations has evolved significantly over the past decade in several parts of the ECE region. Examples of technological improvements are as follows:

   a) Higher air-tightness allowing for better air control. Robust and compact heating installations with high quality welding lines reducing the risk of incorrect/undesired incoming air and with a solid small chamber door with a reliable and improved locking mechanism;

   b) Improved air control; air control with the addition of primary air at the bottom, secondary air at the height of the flames and, sometimes, tertiary air within the top of the flames;

c) The use of heat-reflective materials in the combustion chamber, which increases the starting temperature. The use of refractory material, as coating in the combustion chamber, protects the materials and reduces heat loss;

d) A post-combustion chamber that ensures that flue gases burn longer and better. There are two combustion chambers: a main combustion chamber and a secondary post-combustion chamber, in particular for boilers;

e) Improved tuning of the air supply to the desired heating capacity;

f) Automation of air supply and combustion. Heating installations equipped with electronic or thermal/mechanical systems;

g) Option to equip local space heaters such as stoves with a heat recovery system to increase efficiency or to ensure connection to a heat storage system to improve heat distribution.

103. The following is a list of advanced and innovative technologies for domestic wood-heating installations:

a) New advanced stoves equipped with improved air control, reflective materials and two combustion chambers;

b) New smart stoves with automated control of air supply and combustion, thermostatic control, Wi-Fi-connected to collect and send combustion data to the manufacturer for better service;

c) New advanced masonry stoves, operating at high efficiencies and low emissions;

d) New advanced pellet boilers: fully automated boilers (electronic control of air supply, lambda sensors), condensing boilers, using standardized pellets;

e) Wood carburettor boilers using log wood or chip wood;

f) Heat accumulating equipment with heat accumulating reducing stop/start frequencies and operation at partial load, which generates higher emissions than operation at full load;

g) Other: flue gas recirculation, reverse combustion, gasifier.

V.
Situation in Eastern Europe, the Caucasus and Central Asia

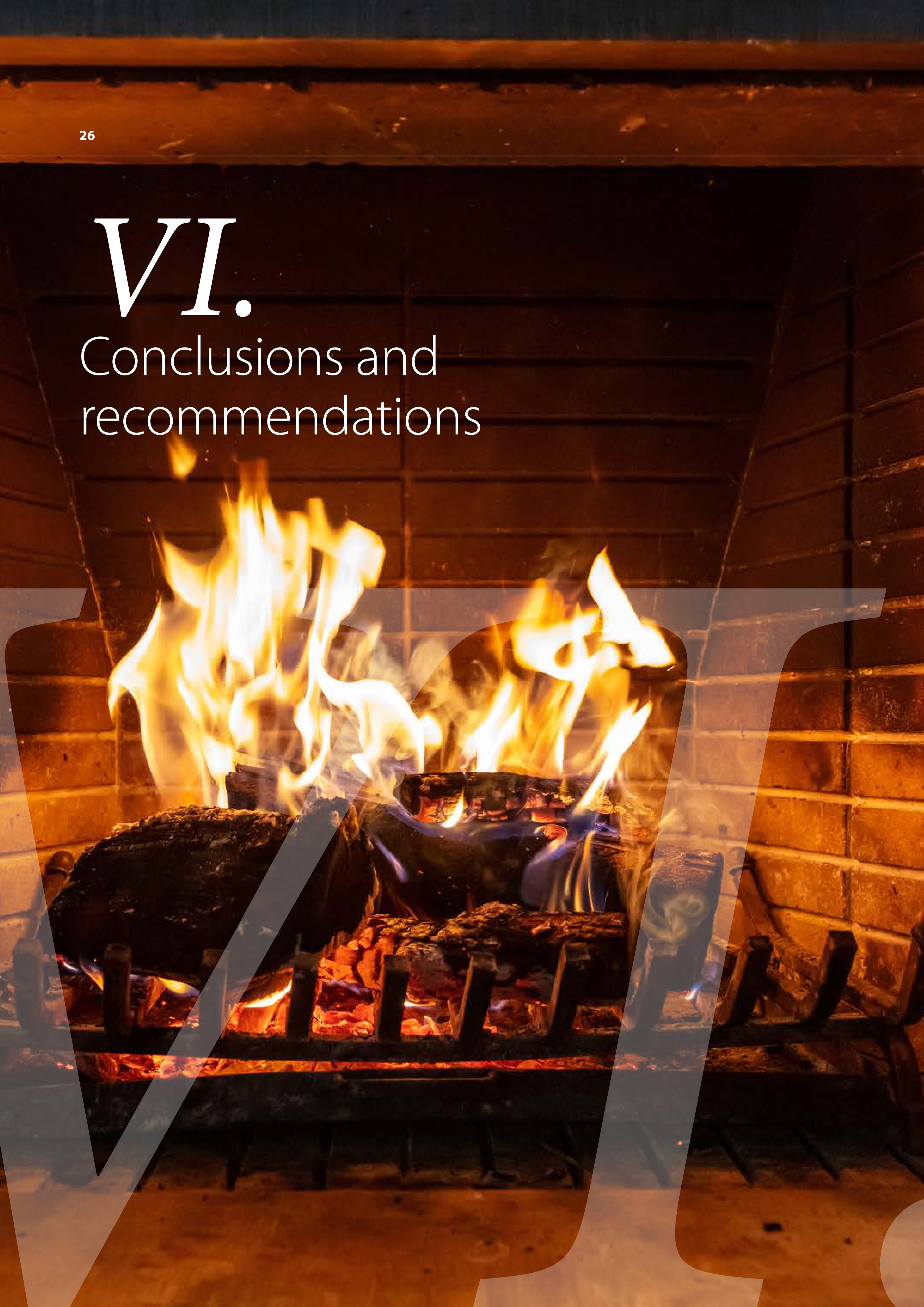
104. The fuel profile for the domestic heating and appliances sector varies significantly between countries and within the States of Eastern Europe, the Caucasus and Central Asia. For example, in the Russian Federation, populations in different regions use natural gas, heavy oil, hard coal, fire wood or even waste as fuel for heating and cooking. Moreover, small sources of emissions, such as private home heating systems, cooking stoves and other appliances that use coal, firewood or other fuels, have not been considered by national environmental regulatory frameworks in the region at large.

105. Starting some years ago, the issue of air pollution in cities and urban areas gained attention across countries, leading to a number of initiatives aimed at assessing key air pollution sources and finding possible ways to tackle emissions. More specifically, in the Russian Federation, several major industrialized cities conducted complex air pollution assessments in the period 2010–2018, addressing industrial, transport and domestic sources of air pollutants. Several studies clearly showed significant contributions of small domestic burning of fuels – primarily coal, firewood, and heavy oil – to air pollution. The pollutants generated by the combustion of the above-mentioned fuels have adverse effects on human health and the environment.

106. Small combustion devices used in the region are very different in design. In some cases, the devices are used not only for heating but also for cooking. Masonry stoves are commonplace in rural areas and small cities, although boilers have become more popular. Often, masonry stoves are fitted within fireplaces. Currently, there are no nationally adopted guidance documents, codes of good practice or educational campaigns in countries in Eastern Europe, the Caucasus and Central Asia.

107. Despite recent developments, there is still considerable room for improvement of understanding of the issue. Countries differ in their capacity to fully address and potentially regulate this sector. Awareness-raising and capacity-building aimed at this sector could be further considered.

VI.
Conclusions and recommendations



108. The present voluntary code of good practice provides a series of recommendations and practical advice, which, if adopted, and subsequently applied, could significantly reduce emissions from wood biomass burning for space heating and its adverse effects on human health and the environment. At the same time, the related emission reductions of BC would contribute to reduction of the impact on the climate. Moreover, the end-users would benefit from reduced expenses as a result of the increased efficiency of installations and the subsequently reduction in the amount of wood burned.

109. The Parties are invited to make use of this code of good practice as a background reference document for developing information materials in their respective national languages, with the aim of disseminating information to the wider end-user community.

110. In the future, subject to the availability of additional information on solid fuels other than wood biomass and on innovative wood-heating technologies and flue gas cleaning technologies, the present code of good practice could be further expanded.

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Code of good practice for wood-burning and small combustion installations

Domestic wood heating is a major source of emissions of particulate matter, including black carbon (BC), and organic pollutants, such as dioxins/furans, polycyclic aromatic hydrocarbons (PAHs) and benzo[a]pyrene (B(a)P), in the ECE region, resulting in poor local air quality conditions and significant negative effects on human health. The present document responds to the need to inform the general public of:

- Available best practices for domestic wood heating in order to minimize emissions and increase efficiency, reducing expenditure due to decreased storage needs and the use of wood, while reducing the negative impact on the environment and human health;
- The best heating devices currently available on the market;
- The proper origin and characteristics of wood biomass and the need to burn dry, clean wood and thus to avoid use of composite, treated and/or contaminated wood.

Information Service
United Nations Economic Commission for Europe

Palais des Nations
CH - 1211 Geneva 10, Switzerland
Telephone: +41(0)22 917 12 34
E-mail: unece_info@un.org
Website: http://www.unece.org

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