Reducing Black Carbon Emissions from Residential Heating in the Arctic

EU-funded Action on Black Carbon in the Arctic – Technical Report 4

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Introduction

There is a general consensus that reducing black carbon emissions in the Arctic countries is an important step towards climate change mitigation. For policy makers there is an abundance of information on the negative effects of black carbon, best available techniques (BATs) and practices (BAPs) aimed at reducing pollution from the burning of wood, coal and other types of biomass. This document aims to give a summary of the relevant information and to serve as a guide to technologies and emission reduction measures that can be promoted to reduce black carbon emissions from residential heating in the Arctic.

WHAT IS BLACK CARBON?

Black carbon and co-emitted pollutants make up the smoke that comes from the burning of wood and other biomass, especially under conditions of poor or incomplete combustion. These co-pollutants are typically (but not limited to) carbon monoxide, organic carbon (OC) and volatile organic compounds (VOC), as well as greenhouse gases such as carbon dioxide (CO_2) and methane. Black carbon, methane and tropospheric ozone are considered short-lived climate forcers (SLCFs), meaning gases and particles that have a lifetime ranging from a few days to ten years (Norwegian Environment Agency 2019).

Black carbon consists of very small dark particles, categorized by air pollution experts as 'PM1.0', meaning Particulate Matter under 1.0 microns in diameter, which is about 1% of the diameter of a human strand of hair. Air quality laws regulate larger particles (PM2.5 and PM10), but neither PM1.0 nor black carbon. For stoves, it is important to remember that while black carbon is included under the broad definition of PM2.5, measures that reduce PM2.5 do not always reduce black carbon to the same extent; so black carbon should be measured and perhaps in future, regulated separately.

Black carbon only exists in the atmosphere for a few days to about three weeks after its release. During this time, the black carbon absorbs sunlight and heats its surroundings, contributing to global warming. This phenomenon, the albedo effect, is even stronger when the particles land on ice or snow, where their impact persists far longer.

To complicate matters, some of the emissions released along with black carbon are reflective and can have a cooling effect, and the composition of all these pollutants vary with the fuel burned and the combustion process. The net effect varies, but has been found to have a warming effect for the domestic sector in Arctic countries (Sand, 2016).

Even though combustion is never fully complete (and remember, it is incomplete combustion that gives rise to black carbon and its co-pollutants), it can become near complete, reducing black carbon and other emissions. Measures to improve combustion range from lighting the fire differently, to replacing old stoves with low emission stoves.

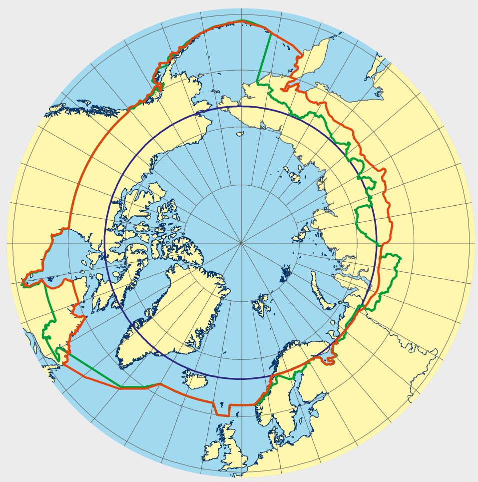


Figure 1: The Arctic. Picture taken from King (2016).

THE ALBEDO EFFECT AND THE ARCTIC[1]

Albedo is the amount of light that can be reflected by a surface without being absorbed. Light surfaces such as ice and snow have high albedo and are good at reflecting sunlight without absorbing it. Dark surfaces, such as the

1 There is not one single definition of the Arctic (Figure 1). The members of the Arctic Council are Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States.

ocean or bare rock, have low albedo, and absorb most of the solar radiation that hits it. This contributes to global warming.

Black carbon that falls on the ice and snow in the Arctic decreases the ability of the originally white surface to reflect solar radiation. This extra absorbed solar radiation heats, and eventually melts, the snow. What replaces the ice and snow is dark ocean water or land, bare ground with low albedo, further decreasing earth's ability to reflect sunlight, increasing temperatures, and further melting snow and ice. In other words, black carbon on ice and snow is an accelerator of global warming. An AMAP (2008) report presents an estimate of the effect black carbon emitted in the Arctic, and elsewhere, has on temperatures (this estimate is presented in Figure 3 on page 7). For a more thorough description of the albedo effect in the Arctic and other forcing mechanisms present in the Arctic, see the introduction of 'The Impact of Black Carbon on Arctic Climate' (AMAP 2011).

HEALTH EFFECTS

Most agree that emissions of particulate matter, including black carbon, have negative health impacts but exactly how bad is harder to say. An indication of the order of magnitude is provided by a study on health impacts associated to pollution in China, covering all provinces and a 27-year time period. It was estimated that 850,000 people died in China in 2017 as a result of $PM_{2.5}$ pollution[2&3]. It is further estimated that 270 000 of these deaths are owing to pollution from solid fuels used in households[4].

A different way to look at health effects is to estimate the socioeconomic cost of health impacts, in monetary terms. This is a method that is often used by economists, and it can be useful in giving a common metric to effects spanning across different domains, such as biodiversity and health. Vista Analyse (2019) has written a report on measures to reduce emissions from the burning of wood, and in this report, they estimated the socioeconomic cost to health (in monetary terms) of burning wood. The highest health cost that they estimated for Norway was 2.5 EUR/kwh (when using wood as a fuel) which is considerable when considering that the cost of electricity assumed in this report is 0.1 EUR/kwh[5].

THE SUSTAINABILITY OF WOOD AS A FUEL

Wood is considered a sustainable fuel only when sourced from good forestry practices. The most agreed upon and widely used definition of sustainable wood management comes from the so-called Helsinki Resolution (1993):

"The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems".

What this means in practical terms may be hard to assess. What may be worth noting is that whether wood for fuel is considered a sustainable source will depend on the forestry practices of the wood in question.

The CO_2 emissions that arise from the burning of biomass are not accounted for in emission inventories, which means these emissions are not reported to the UNFCCC. This is because this CO_2 is considered a part of the natural carbon cycle.

SOURCES OF BLACK CARBON IN THE WORLD

Biomass burning accounts for approximately 50 per cent of BC emissions from anthropogenic sources (AMAP 2015). Figure 2 below shows the main categories of activities giving rise to BC emissions (only including BC emissions from energy related sources).

In Europe and North America, it is typically residential heating using biomass as a source of energy, such as stoves and fireplaces, that gives rise to household emissions of black carbon. In developing countries, household emissions typically arise from cookstoves using solid biofuel or coal (Finnish Meteorological Institute et al. 2013).

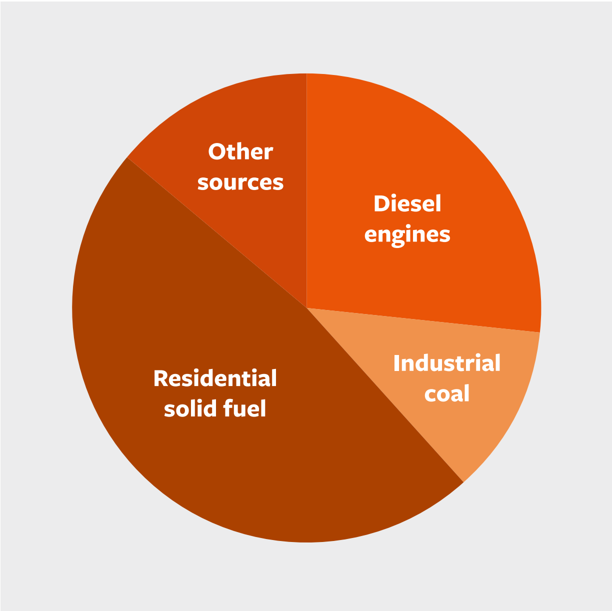


Figure 2: Sources of energy related emissions of black carbon by activity. Grand total is 4,600 Gg/year. Source: Bond et. al (2013)[6].

2 Black carbon is one component of $PM_{2,5}$.

3 The BC/$PM_{2,5}$ ratio varies and depends on a number of factors. In the European Environment Agency's database of emission factors (2019) BC as a share of $PM_{2,5}$ varies from 7 to 55%.

4 This figure does likely include the burning of coal.

5 As the total cost of health impacts is a function of the number of people exposed to local pollution, this cost is expected to be lower in less dense areas (and possibly higher in denser areas).

6 The figure is an adaptation of table 8 in Bond et. al (2013). For the purpose of this figure, an average of the SPEW and GAINS results in the table of the original source has been used

A NOTE ON COAL AND PEAT STOVES

This document primarily addresses black carbon emissions from wood stoves and boilers. Coal stoves however remain in wide use for heating in some Arctic, EU/EEA and UN ECE nations, especially in coal-rich countries such as Poland, the Czech Republic, Ukraine and in Central Asia; and both coal and peat stoves remain surprisingly common as well in the UK and Ireland. These stoves have use patterns that differ from wood stoves in many respects, especially in often being the sole source of household heat, as well as being used for cooking. However, many of the BATs and BAPs outlined here are equally applicable to coal and peat stoves, or applicable with some modification. It is worthy to note that household coal stoves per-unit emit more black carbon than wood stoves, and depending on the quality of the coal, also tend to emit far more harmful pollutants in terms of health impacts. Because of this, and also due to its high CO_2 emissions, most policy efforts on coal and peat stoves focus on replacement with other fuels or forms of energy to meet the same household purposes.

WHO IS THE TARGET AUDIENCE FOR THIS REPORT?

This report is written for anyone who can impact residential heating practices. While this can be government officials at a national level, it can just as often be officials or politicians at a local level, since much of the regulatory and political work aiming at reducing local air pollution takes place at a local government level.

The report is a basic and up-to-date guide to good residential heating practices that can reduce emissions of BC and its co-pollutants. In summary, this can have the following benefits:

- Cost reduction due to lower fuel use
- Health benefits due to lower levels of local pollution
- Climate change mitigation, especially in the Arctic as well as mountain regions with ice and snow and due to reduced methane emissions from wood burning[7].

These benefits can occur anywhere in the world but for reasons described above, the impact on climate change is particularly significant in Arctic countries where BC particles may land on snow and ice.

HOW TO READ THE DOCUMENT

The document is structured in the following sections:

- Best practices for keeping one's home warm. *This chapter describes measures that can be taken with little or no cost.*
- Heating systems. *This chapter is aimed at helping policy makers to assess under what conditions certain heating systems should be incentivized. Under what conditions are different heating systems (such as central heating) suitable, and how to choose technology solutions (e.g. a pellet boiler)? There are cost indications and a checklist for what should be considered when deciding on a given type of technology.*
- Policy instruments. *This chapter gives some examples of policy measures that exist to incentivize good heating practices, and experiences from using these policy practices.*

The objective of this report is to give a general understanding of how black carbon emissions can be reduced in the domestic heating domain. It also gives a general introduction to the different heating systems so that no, or little, previous knowledge is needed to make use of this report.

7 As mentioned previously, the CO_2 emissions from the burning of biofuels are not included in the emission inventory of countries, but methane emissions from woodburning are.

What do we know about the overall climate impact of BC?

In order to get an understanding of the impact of black carbon (BC) and the importance of black carbon mitigation compared to other greenhouse gases or short-lived climate forcers (SLCFs), it would be useful to apply the widely known metric *global warming potential* (GWP) to black carbon. Does a consensus-based value for GWP of BC exist? The answer is no: The 100-year global warming potential (GWP) of black carbon alone has been estimated at 900 by Bond et. al (2013). The same study suggests, however, that the forcing from some black carbon-rich activities, such as residential heating, co-emit particles that counteract the warming, under some conditions leading to a near-zero climate impact. Researchers debate whether a metric such as GWP is appropriate for black carbon, or if it is simply too ill-suited. A summary of the most important sources of the uncertainty and complexity associated to black carbon's contribution to global warming:

- Black carbon is co-emitted with other lighter-colored particles, some of which have a cooling effect. Whether the net effect is cooling or warming depends on geography and the mix of particles. Over ice and snow, the net effect is always warming.
- As described above, black carbon has a greater warming potential if landing on light surfaces such as snow and ice. This geographical dimension makes it difficult to generalize the global warming impact of BC.
- There are indirect effects following emissions of BC that counteract its immediate warming effect; one example is the way in which black carbon impacts cloud formation. Some of the indirect effects could have a cooling effect (Takemura and Suzuki 2019).

Figure 3 shows the impact of both short-lived climate forcers (including black carbon), compared to CO_2 on temperature increases, using the measure global temperature change potential (GTP) metric. As can be seen, black carbon has a significant impact on global warming, and the regional effect in the Arctic of black carbon is greater than on a general global level. GTP is used more widely to show the climate effect of black carbon emissions, such as in AMAP (2008).

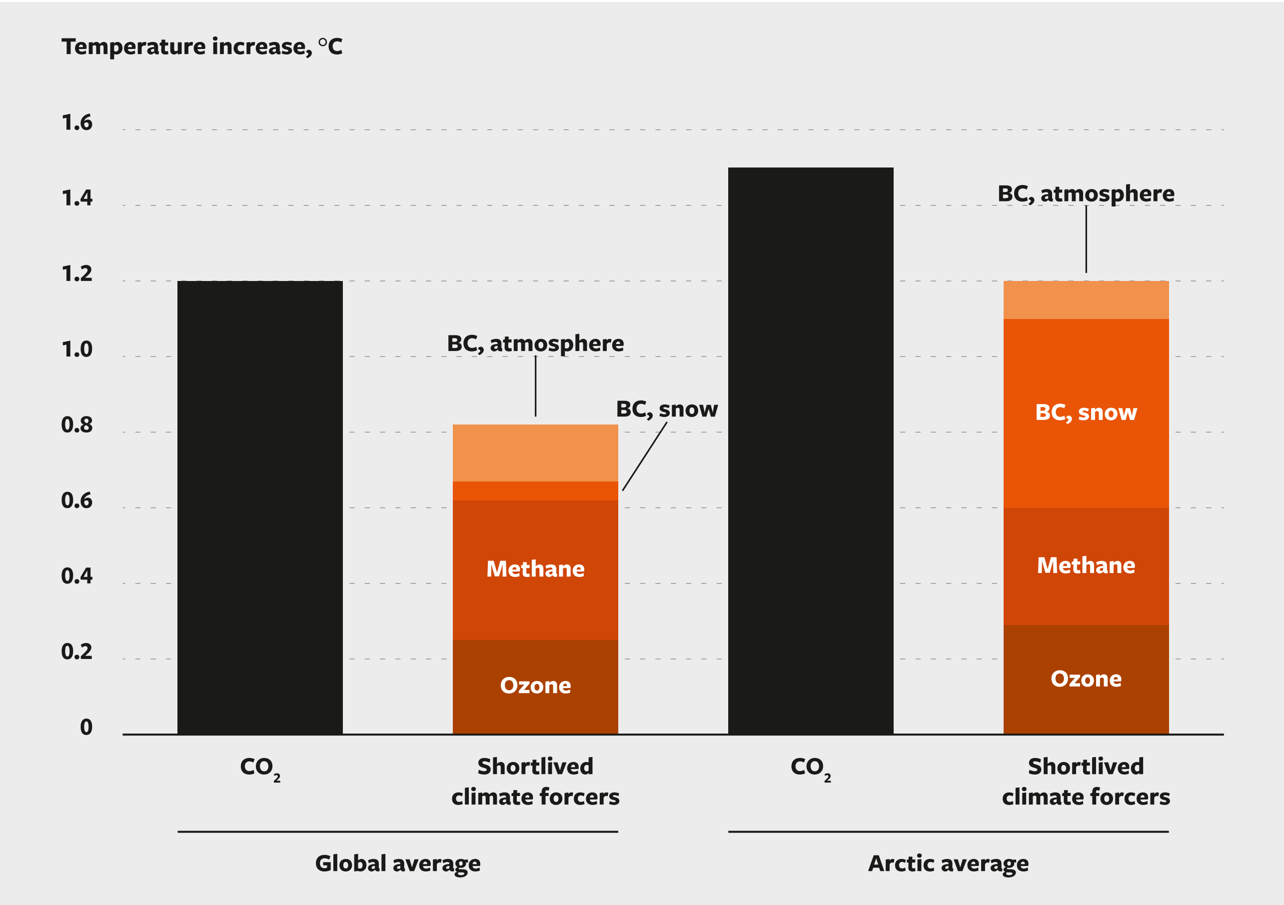


Figure 3: Temperature increase of black carbon and other short-lived climate forcers. Source: AMAP (2008).

Best practices for keeping one's home warm efficiently

In the following, measures that can be taken in addition to choosing appropriate heating devices (boilers, panel heaters, etc.) are described. These measures have in common that they reduce the negative impacts associated with generating heat – either directly by reducing emissions of black carbon or other pollutants – or indirectly by reducing the required fuel needed for a given amount of heat produced. They therefore may also be cost-saving measures.

Optimizing the distribution of heat

Heat systems can be controlled to optimize distribution across time in various ways. Some examples below:

- Most pellet stoves can be controlled by a thermostat, which means that one can pre-set the room temperature and the pellet stove will adjust itself when the temperature exceeds or goes below the 'target' temperature. Some pellet stoves also give the opportunity to pre-select a day- and time-specific program, such that the temperature may be lower at night.
- A pellet boiler has some of the same properties as a pellet stove in the sense that it ignites when there is a need for more heat.
- A wood boiler can be combined with an accumulator tank storing warm water. This means that combustion of wood does not have to take place every time there is a need for additional heat.
- Modern panel heaters can be both timed and/or remote-controlled by one's phone. This means that the house can be warm by the time somebody gets home without having been heated all day. Most panel heaters sold today will support such a system.

Not all heat devices support such heat distribution mechanisms, but it is worth checking if the heat system in one's house does, and if this opportunity has not been fully taken advantage of.

Burn right and loading properly

Burning in the right way can reduce emissions up to 80% (Pearson et al, 2018). Governments have aimed for some time at reducing emissions by distributing information on how to light and burn stoves and boilers more efficiently.

Burning right is a science. There exists a significant amount of research dedicated to this field. Some of the advice runs counter to what was considered good practice in the past, as knowledge on how to burn right has evolved quite a bit in the past decade. A summary of the most common advice is:

- Use dry wood. Never burn processed wood or trash.
- Make sure there is enough air in the firebox to allow good oxygen supply to the fire.
- Light the fire from the top. Larger and heavier logs should be at the bottom, the smaller logs in the middle and some firelighters/small pieces of wood on the top. While this may be counter-intuitive, the fire will in fact spread downwards while at the same time warming both the combustion chamber and chimney. If the chimney heats first, combustion also continues as the smoke travels through the chimney, and there will be less soot and fewer BC emissions.
- Use the right amount of wood: this can vary across stoves/fireplaces but as a rule of thumb about 25 per cent of the volume should be filled with wood (Sintef 2016). Many consumers overload their fireboxes, assuming the more fuel the warmer the fire; but the opposite actually is true.
- Read and keep the instructions on the wood stove or boiler. All stoves are different.
- Do not burn waste: a stove is not built with the same properties as a waste incinerator. Waste incinerators have much higher combustion temperatures and have filter systems. One of the reasons for not burning

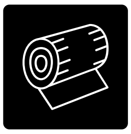
waste in your stove is that when waste such as plastics are burned at non-optimal temperatures, it produces pollutants that have negative impacts on human health, such as dioxins. Burning cardboard and paper in your stove can lead to large amounts of particulates and will increase the risk of chimney fires. Other organic waste can have a high water content and reduce the combustion temperature and efficiency of the fire.
- Maintenance of the stove at regular intervals, in accordance with manufacturer instructions as this also decreases emissions (2015).

It is easier to understand how to light the fire properly when watching videos on how this should be done. Note that some older videos found online will show that the fire should be lit from below, as it is a more recent development that the fire should be lit from the top. The following video will give a good introduction (the video is in Norwegian but the visuals give sufficient information):
https://www.youtube.com/watch?v=0K3pxyZk5mM.

Note that some technology providers post videos on their websites on how each specific stove or fireplace should be lit.

For a more detailed description on the choice of biomass, fuel loading and lighting, please refer to 'Code of good practice for wood-burning and small combustion installations' (UN Economic and Social Council 2019), p. 13 onwards.

Increased insulation

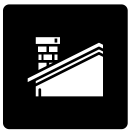


Post-insulation measures are something to consider for buildings built in the 1970s or earlier to increase energy efficiency and thus, decrease emissions from woodburning. Insulation reduces the heat loss from a building, and this effect increases with cold weather. Increased insulation will therefore reduce the heating needs on the days where it is most needed.

The best time to do so is along with a renovation of the building that includes the façade. Post-insulation is of course a trade-off between a high energy bill and the one-time cost of the insulation. For relatively energy-efficient buildings, added insulation may not be the best or most cost-effective option.

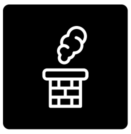
Energy-related building regulations and practices vary between countries, and policies for increased insulation must be adapted to the specific local building stock and climate.

Clean the chimney



Clean the chimney regularly. In Norway, chimneys are checked every four years, and this is the responsibility of local governments; in Sweden, it is required annually (or every third year for vacation homes). A chimney that has not been swept in a long time will have a lot of soot, which can lead to a high risk of chimney fires.

Air-cleaning technology (electrostatic precipitators)



Electrostatic precipitators filter and reduce a large share of particulate matter emissions (including black carbon) that arise from the burning of biomass. They can be installed in the chimney or within the combustion unit itself. As particulate matter emissions have a local effect, in addition to the (global) climate effect, electrostatic precipitators can be installed/incentivized in areas with particularly high levels of particulate matter pollution.

This technology is not widespread in the residential sector. This is likely due to its relatively high investment cost (about 2,000 EUR)[8]. A few years ago, a campaign took place in the Swiss mountain village of Saas-Fe in which the installation of electrostatic precipitators was subsidized. In a study carried out on behalf of the Swiss Federal Office for the Environment, the effect of a large number of these electrostatic precipitators was measured. This study (Fachhochschule Nordwestschweiz FHNW 2020) found that they do have an effect of decreasing pollution, but only if they are regularly maintained. The study is only available in German but the Swiss Federal Office for the Environment (FOEN, or in German: BAFU) can be a source of information for lessons learned from the subsidy of electrostatic precipitators.

8 Estimate from email correspondence with Beat Mueller, BAFU (the Swiss Environmental Agency)

Other fuel options – some examples

District heating

A city planner may consider creating a network of district heating. District heating has multiple advantages, such as enabling heat recovery from waste incineration, including waste from the forest industry which might otherwise be burned in the open. To create a district heating network is a decision that depends on a number of factors and tends to be applicable only in large urban areas, although some smaller villages and islands have piloted district heating methods on a smaller scale.

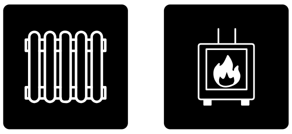
However, some municipalities such as Copenhagen have seen a tendency by some consumers to actively terminate their connections to existing district heating systems when purchasing wood stoves, in order to save costs for heating the household. Preservation of existing district heating systems, given their low emissions compared to heating with biomass, should be prioritized by municipal officials.

Solar and wind

One way to reduce dependence on both fossil fuels and biomass (both giving rise to global warming, the latter giving rise to BC emissions), is by producing one's own electricity from renewable sources. It has become more widespread in recent years for stand-alone houses to have solar panels installed, or for energy companies to offer buy-back programs that result in consumer savings. Yet, technical expertise to install and maintain solar panels is not available everywhere, which may limit this option in some areas. Installation costs also may present a barrier to some consumers, although falling prices and subsidies may address this. During the 2020 Covid-19 crisis, the IEA stated that these sources proved more resilient compared to fossil fuels, which may help speed their adoption, as stated by Climate Home News (2020).

Heating systems – central or space heating

In the following, different heating systems are presented. Two main categories of heating systems are considered: central heating and space heating. Central heating entails generating heat in (typically) one place in the building, or even more centrally (if a district heating network is in place and connected to the building), and transporting this heat as either hot air or as hot water to, for example, radiators or through pipes in the floor (floor heating). The source of heat in a central heating system can be either a heat pump or a boiler running on fossil fuels, biofuels, or electricity. Space heating, on the other hand, is anything from fireplaces to panel heaters warming the air around it.



Central heating, Space heat

The following describes which heating technologies are better suited under different circumstances.

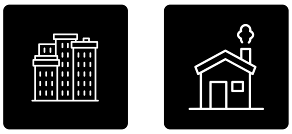
BEST AVAILABLE TECHNOLOGIES (BATS)

In the next sections we will introduce central heating and space heating systems and existing BATs applicable to these two systems. These heating systems range from heat pumps to fireplaces.

APPLICABILITY

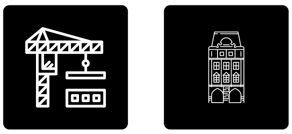
Different heating systems and associated technologies have different comparative advantages depending on circumstances.

A distinction is made between:



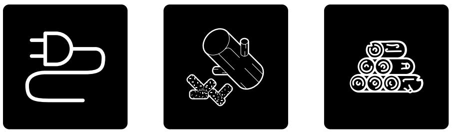
Apartment buildings, Stand-alone houses

And further between



Buildings under construction, Existing buildings (retrofit)

We will also show which sources of energy fuel these technologies.



Electricity, Wood chips/pellets, Wood logs

ENERGY NEEDS

An important consideration to take into account when deciding between these heating systems is the energy need of the building. Generally, it can be said that central heating systems have higher investment costs, especially for the heat distribution system. On the other hand, central heating systems allow for heating technologies which may have lower operational costs. When planning the construction of a new building, one has the choice between installing a central heating distribution system or relying on individual space heaters. Since installing a heat distribution system in an existing building is likely to be more complicated and costly than in a new building, we differentiate between the two.

In general, it can be said that central heating systems require a greater energy need to justify the investment costs. While it may be fairly straightforward to install a central heating system in a building under construction, the building may at the same time be constructed with a high energy efficiency rating and thus such low energy needs that it may not be worth it to invest in the central heating system. In such cases, BAT solutions for space heat (see sections on this below), may be the best option.

HEATING SOLUTIONS WE PRESENT

The aim of this guidance document is to present BATs that ensure a low level of black carbon emissions at the same time as being energy efficient and economically viable solutions for the end user.

SCOPE OF THE TECHNOLOGIES WE DISCUSS

We will in this document discuss heating options that may replace emission sources of black carbon. For example: heat pumps may replace other heat sources, a BAT wood log boiler may replace an old wood log boiler or a fossil-fuel boiler and so on. In heating there are multiple opportunities for efficiency gains and emission reductions through switching to new technologies or using the technologies optimally (when and where they have their comparative advantage). We will offer a simplified overview of what residential heating options exist. We will not discuss direct electric space heaters as we assume that where biomass heating solutions are the preferred option, it is because these options have a comparative advantage over electric panel heaters. This comparative advantage may have to do with relatively low-priced biomass being available. We will, in other words, focus on solutions that for the individual household, may economically compete with today's emission sources of black carbon in residential heating.

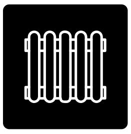
COMMON COMBINATIONS OF HEATING SYSTEMS

Central heating distribution solutions are generally dimensioned to cover the entire building's heating needs, i.e. without necessary supplementary space heating equipment. In certain cases, such as with central heating driven by a heat pump, it is necessary to have an additional heating system to assist the heat pump under very cold conditions, e.g. a panel stove. However, certain applications may be common independently of the main heating systems, such as electrically-heated floors in certain rooms (e.g. bathrooms). In addition, wood fireplaces or stoves may be installed for comfort or as a backup heating solution.

It is more common to have a broader set of heating equipment in buildings which rely on space heating systems. Panel stoves is here the most common heating equipment, as these can easily be distributed throughout a building. Air-to-air heat pumps provide heat at one source point and are often supplemented by panel stoves.

Wood stoves (and fireplaces) are generally not the sole heating solution installed in a building. With few exceptions, these stoves require frequent attention to maintain heating, and other heating sources such as electricity are required to maintain a constant acceptable temperature. In buildings without central heating systems, panel stoves are the most common combination with wood stoves.

Central heating – heat pump or boiler

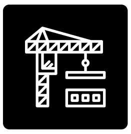


Only central heating using **water** as the medium of heat distribution (water-borne heat) is considered. This entails that there is typically one boiler or heat pump centrally located in the building that heats water. The hot water is distributed through pipes in the building to radiators or to provide floor heating.[9]

APPLICABLE FOR?

Central heating systems are suited to both apartment buildings and stand-alone houses. **Heat pumps** can be used to serve the energy needs of both smaller and larger buildings, both residential and commercial. Different types of heat pumps can be used, depending on energy needs and the available sources of energy (see the chapter on 'Choice of heat pump'). BATs for boilers is also be considered under the section 'Choice of boiler'. The choice of boiler depends largely on available fuels locally.

As mentioned in the previous section, installing a central heating distribution system is most economical for new buildings as these systems may be expensive to retrofit. However, if there is already a central heating system in place, changing the existing heat source, typically a boiler, to a new and more efficient technology heat source (such as a heat pump or a biofueled boiler) is fairly straightforward. *It may be obvious, but it is important to note that a heat pump or a BAT boiler can replace any boiler in an existing central heat system, as long as the energy requirement is met by the new solution.* Thus, implementing a BAT for central heating is well suited to buildings under construction



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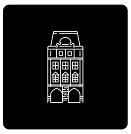
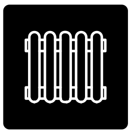




existing buildings with a central heating system in place.

If the energy need is sufficient, it could also be economically viable to install a central heating distribution system in an existing building or stand-alone house.

Note that in some places permissions by local authorities are needed when installing a central heating system. This is especially relevant for air-to-air-heat pumps as they will affect the façade (as one part of a heat pump is located on the exterior of the building).

9 There is also an option to use warm air for heat distribution

HEAT PUMP OR BOILER

As previously mentioned, a heat pump is often the preferred source of central heating if:

- It is possible to utilize ambient heat sources locally (from a nearby waterbody, from the ground or from the air) to meet the demands of the residential unit (the apartment building or the stand-alone house).
- You live in a building that is newer and/or has not been declared protected (when building a heat pump, part of the installation has to be on the façade of the building).
- A heat pump may be a source of noise depending on the model and where it is located in the building/house.
- Improperly installed heat pumps may be a source of hydrofluorocarbons (HFCs), a powerful and long-lived group of greenhouse gases. It is important to make sure the heat pump is a best available technology and installed by a professional.

As can be seen from the list above, heat pumps do require some conditions to be met. If these are not met, a wood-fired BAT boiler may be a better option. Boilers may be a good option if:

- A heat pump is not feasible/desirable.

Different types of boilers are discussed later in the report. Figure 4 shows an illustration of a central heating system with a boiler as the source of heat.

Figure 4: Water-borne heat in a residential building with a wood log/pellet boiler in the basement. Image credit: Enova.

Cost implications are considered under the section 'Choice of heat pump' and sections concerning different BATs for boilers.

Central heating – Choice of heat pump

In order to evaluate whether a heat pump is a good option, one must first assess which heat pumps are relevant for the specific residential unit. The main types of heat pumps in water-borne heat systems are: water-to-water (using the ambient energy in seawater, rivers or lakes); geothermal (using ambient energy in the ground); or air-to-water (using ambient energy from the outdoor air). The notation '(...) to water' implies that these heat pumps are part of a water-borne heat system.

The following considers the conditions under which each of these options are suitable. Note that the preferred heat pump option can be compared to the preferred boiler option (see the next section on boilers). All heat pumps discussed here run on electricity.

WATER-TO-WATER HEAT PUMPS

Seawater, lakes, or rivers can serve as significant sources of energy. Large residential complexes can be served by this source of energy. Water-to-water heat pumps may be a good fit for:

- Residential units with an energy need of about 30,000 kWh annually or above (Enova 2019e).
- The residential unit must have access to seawater, a lake or a river at a maximum of 100 meters distance from the residential unit (Norsk varmepumpeforening 2019)[10].

Note that a permission from authorities may be required to install a water-to-water heat pump.

GEOTHERMAL HEAT PUMPS

There are different types of geothermal heat pumps. They have in common that they use thermal energy from the sun stored below the ground (in the bedrock, a sub-surface swamp, in ground water or in the soil). Geothermal heat pumps may be suitable for:

- Residential units with an energy need of about 30,000 kWh annually or above (Enova 2019e).
- Residential units with a large (200–600 m^2) area at one's disposal surrounding the residential unit, or alternatively, access to ground water.

10 Rivers may be a challenging source of energy as the current of the river may give rise to wear and tear of the pumps that need to be installed in the water.

AIR-TO-WATER HEAT PUMPS

Air-to-water heat pumps utilize the ambient energy in the outdoor air to heat. Figure 5 shows an illustration of a central heating system with a heat pump as the source of heat. They function in temperatures down to -25 °C degrees (Nibe 2019). They may be suitable for:

- Residential units with an energy need of about 25,000 kwh annually or above (Enova 2019d).
- Residential units that may attach something to the façade of the building (permission may be needed for this).
- Residential units in areas that have relatively mild winters.

Figure 5: House with heat pump and water-borne heat distribution. Image credit: Enova.

ENERGY EFFICIENCY GAINS

Heat pumps typically run on electricity. They extract heat from low temperature sources (air, water, or ground water) and deliver heat to the heat distribution medium (typically water). To measure their efficiency, a value called the SCOP (Seasonal Coefficient of Performance) is used. If a heat pump gives 40,000 kwh for which it needs 10,000 kwh of electricity to produce, it has a SCOP of 4. Below we show SCOP values for the different types of heat pumps discussed above.

	Water/ geothermal	Air
SCOP[11]	**4.1**	**3.5**

ECONOMIC IMPACTS

Below is an example of economic impacts for a residential unit with heat related energy consumption of 15,000 kWh annually.

Table 1: Savings are relative to the energy requirement in the form of electricity in the absence of a heat pump. For assumptions and sources, see the appendix.

	Water-to-water and geothermal	Air-to-water
Investment cost (EUR)[12]	> 12,000	6,000–13,000
Lifetime energy cost savings (EUR)	29,000	26,000
Annual energy savings (kwh)	11,300	10,000

In addition to the investment cost, there are costs associated to installation and maintenance not accounted for in the table above.

BLACK CARBON IMPACTS

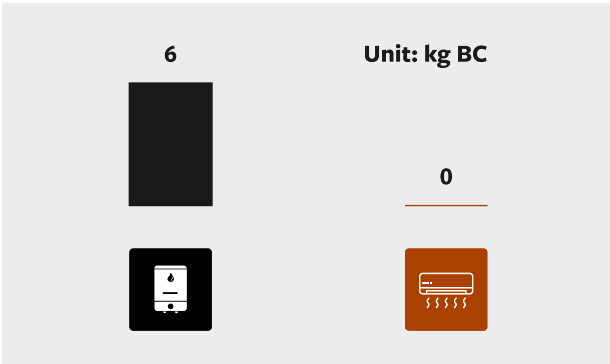


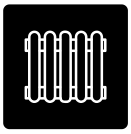
*Figure 6: Annual black carbon emissions of an **old boiler** and a **heat pump**. For assumptions and details about the calculation, please refer to the appendix.*

Heat pumps do not emit any particles directly, and from a black carbon perspective they are a preferred heating option (Figure 6).

11 SCOP value from EHPA (2018).

12 Enova (2019e) and Enova (2019d).

Central heating – Choice of boiler

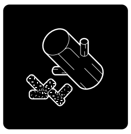


If a central heating system seems a feasible option for a given residential unit, the next step is to evaluate what type of boiler could be a preferred option. The boiler option should in turn be compared to the heat pump option, if relevant.

The residential units in question may already have a boiler in place, but there may be several good reasons to change an existing boiler to a BAT boiler: energy efficiency, emissions of black carbon, and greenhouse gas emissions. Evaluating whether changing the boiler to a BAT boiler is a good idea first requires a consideration of available boiler options.

Boilers are available in different sizes (heating capacities) and apply both to:


PELLET/WOOD CHIPS BOILERS



Pellets and wood chip boilers can replace electricity, gas or fossil fuel boilers. They are characterized by low particulate emissions and high energy efficiency. Pellets are a compact source of energy compared to, for example, wood logs. A pellet/wood chip boiler may be a good idea for a residential unit that:

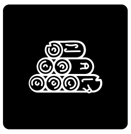
- Has a chimney.
- Has a boiler room, or there is space to build one.
- Has room to store fuel (pellets) in a dry area (there are storage solutions that keep the pellets/wood chips dry that can be installed outdoors, however, they cannot be located more than approx. 20 meters from the boiler with automatic feeding).
- Is located in an area where pellets/wood chips are available for purchase at a reasonable price (compared with the price of other energy sources).
- Is located in an area with very cold winters, down to -25 °C. Pellet/wood chips stoves can supply the entire demand for heat, also at peak times. This is normally when electricity/oil prices are at their highest.

A pellets/wood chip boiler is a good option for all residential units that already have a fossil fuel boiler.

There are many different pellets/wood chip boilers on the market. Most new models provided on the market will be BAT solutions, but make sure to check their properties. In particular, boilers (as well as stoves) may have ecological labelling, such as the Nordic Ecolabel in Nordic countries. A BAT boiler should have the following characteristics:

- Efficiency > 85% (which means that an amount of wood holding the equivalent of 100 kWh of energy, should give heat equal to or higher than 85 kWh).
- Automatic or semi-automatic operation. When there is a need for heat, the boiler is ignited automatically (this means a large heat accumulator tank is not necessary, however such a tank may increase efficiency and lower fuel costs). The fuel chamber must be manually filled from time to time, and some require manual emptying of the ash chamber.
- A programmable system so that the temperature can be pre-set to vary at different times of the day and different days of the week.

WOOD LOG BOILERS



Just like pellet boilers, wood log boilers can replace electricity, gas, fossil fuel boilers or old wood log boilers. Modern wood log boilers are significantly more efficient than old ones as they use a different combustion technology called *downdraft combustion*. This is slightly different to the technology used in pellet boilers but has the same effect: maximum heating and near-complete combustion, which means minimizing emissions of particulate matter.

Downdraft combustion means that the flame is below, and not above, the logs. This technology ensures that some of the chemical components in the wood, that under normal conditions would be incompletely combusted and emitted with the flue gas, are broken down to components that can be combusted in a similar way to natural gas. This gives high efficiency and very low emissions of black carbon.

Wood log boilers are suitable for residential units that:

- Have the same characteristics that apply to pellet boilers, except that:
  - Instead of access to pellets/wood chips, have access to large quantities of reasonably priced wood, and
  - Have room to store wood in a dry place and an accumulator tank (storage tank for hot water)[13].

Unlike pellet boilers, most wood log boilers require manual feeding.

BAT wood log boilers should have the following characteristics:

- Downdraft combustion[14]:
- Efficiency > 80%[15].
- Very low particulate matter emissions.

13 As wood log boilers do not necessarily burn continuously, or ignite every time there is a need for heat, they are often installed with a large accumulator tank for storing hot water.

14 There are also other characteristics that are important, but these characteristics are most often present in modern 'underdraft' wood boilers. They include advanced combustion management (with lambda probe, weather and temperature control), fan assisted draft, combustion chamber and ceramic lining.

15 energismart.no.

ECONOMIC IMPACTS

Below is an example of the economic impact for a residential unit with an annual heat energy requirement of 15,000 kWh. The savings are based on an example where an old wood boiler is replaced by a new wood boiler of higher efficiency. It can be just as relevant to compare with the cost of energy if using a fossil-run boiler (this may be higher or lower than the price of bioenergy).

Table 2: Savings are relative to an old boiler with an efficiency of 70% as compared to 80% (with a new boiler). For assumptions and sources, see the appendix.

	Pellet/wood chips/ wood logs
Investment cost (EUR)[16]	5,000–20,000
Lifetime energy savings (EUR)	2,250
Annual energy savings (kwh)	1,500

The price of wood varies greatly across regions. The price of pellets, wood chips or logs and possible cost-savings are therefore not addressed in this report. The general advice is to check the price and availability of each of these fuel types and let this inform the choice of boiler.

In addition to the investment cost, there are certain installation and maintenance costs.

Checklist before purchase of any boiler:

- Get quotes from several providers.
- It may be wise to have a service contract with the boiler provider.
- Check the chimney (if it is old and has a wide diameter, improvements may be necessary). This is done only by professionals. Some municipalities or counties cover this service.

BLACK CARBON IMPACTS

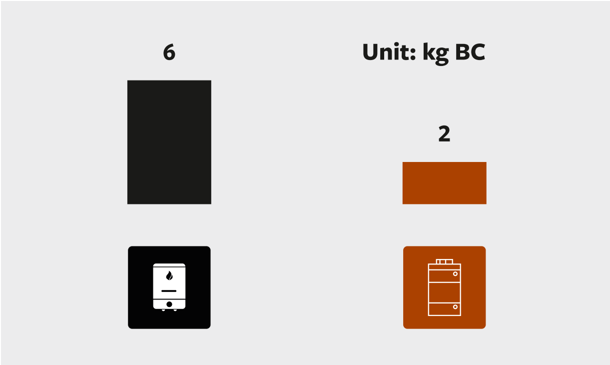


Figure 7: Annual emissions of black carbon of an ***old boiler*** *and a* ***BAT biofuel boiler****. For assumptions and details about the calculation, please refer to the appendix.*

Most of the particles that escape with the flue gas under less advanced conditions will be burnt in modern pellet and wood boilers. This ensures near-complete combustion and very low emissions of black carbon (Figure 7).

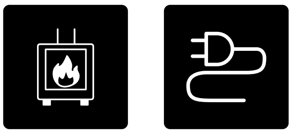
CONCLUSION – HOW TO CHOOSE BETWEEN PELLET, CHIP OR WOOD LOG BOILERS?

This decision largely depends on the following:

- The availability and price of these biofuel options.
- Storage requirements are a little different for each of the options – wood requires more space (for the wood and for the accumulator tank), and pellet/chip boilers require a tight container not too far from the boiler.
- The price of each of these options from technology providers in the area.

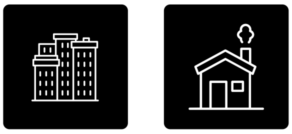
16 Enova (2019a) and Oljefri.no (2019).

Space heat – Air to air heat pump

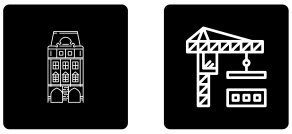


An air-to-air heat pump works in a very similar way to that of an air-to-water heat pump: it exploits heat from the outdoor air. Instead of using this heat to warm water for a central heating system, the hot air is pumped directly into the building.

Air-to-air heat pumps are quite common, as they are quite reasonably priced and do not require a central heating system. They apply to apartment buildings and stand-alone houses.



The installation is simple and well suited to existing buildings (and buildings under construction).



Air to air heat pumps may be suitable for residential units that:

- Have an energy consumption of above 15,000 per year.
- Are located in an area with relatively mild winters or have an optional source of energy for energy consumption peaks.
- Currently use panel heaters.
- Have an open design for free distribution of the heat.
- Cannot be insulated further.
- Are newer and/or have not been declared protected (when installing a heat pump, one part of the installation has to be on the façade of the building).
- (Applicable to apartment buildings) necessary permissions are granted centrally by the apartment building's owner or condominium association. It may be a coordinated decision to install heat pumps.

It should be noted that air-to-air heat pumps do create some noise. The level of noise varies across models.

ENERGY EFFICIENCY GAINS

In terms of energy efficiency gains, air-to-air heat pumps are similar to other heat pumps: They typically run on electricity and they deliver more energy than they need to run. The SCOP (Seasonal Coefficienty of Performance) is used to measure their efficiency. If a heat pump gives 40,000 kwh and needs 10,000 kwh of electricity to run, it has a SCOP of 4. SCOP values for different types of air-to-air heat pumps are shown below, and the '...to water' heat pumps discussed previously are included for comparative purposes.

From	Water	Geothermal	Air	Air
To	Water			Air
SCOP[17]	> 4	> 4	> 3	> 3

ECONOMIC IMPACTS

Below is an example of the economic impacts for a residential unit with a heat-related energy consumption of 15,000 kwh annually.

Table 3: Impacts of switching to an air-to-air heat pump. For assumptions and sources, see the appendix.

From →	Old wood stove	Open fireplace
Investment cost of heat pump (EUR)	2,000–3,000[18]	
Lifetime energy cost savings (EUR)[19]	19,000*	137,000*
Annual energy savings (kwh)	16,000	95,000

**A caveat of this calculation is that it is most likely not realistic to cover an entire household's heat related energy consumption with a fireplace or wood stove, as is assumed here. The figures are kept this way to keep calculations consistent with other estimates of energy savings. Please take into consideration what share of the household's heat requirement will be covered by a stove/fireplace when interpreting these figures.*

The cost estimate includes installation but not maintenance. The energy savings can be seen as relative to a panel heater.

17 COP requirements from EHPA (2018).

18 Enova (2019c).

19 Based on the difference between energy costs of an open fireplace/old stove multiplied by the price of biomass, and energy costs of producing the same amount of energy with an air-to-air heat pump. For values and sources, see appendix.

BLACK CARBON IMPACTS

Heat pumps do not emit any particles directly, and from a black carbon perspective they are a preferred heating option. If they are replacing biomass heating options, they will have a significant direct impact on reducing black carbon, see figure 8 below. If an air-to-air heat pump is an electricity efficiency measure, to replace the need for panel heaters for instance, there will not be a direct effect on black carbon, but it will give energy savings.

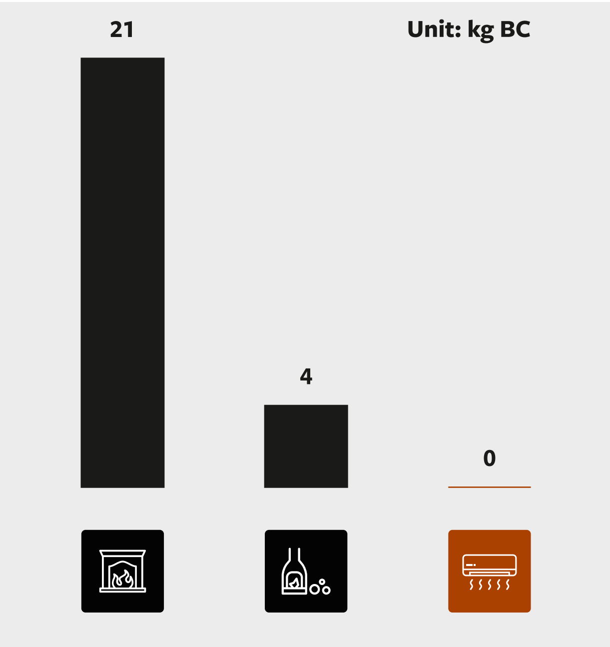
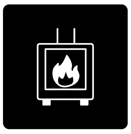


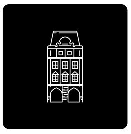
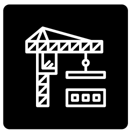
Figure 8: Annual emissions of BC of an ***open fireplace****, an* ***old stove,*** *and a* ***heat pump****. For assumptions and details about the calculation, please refer to the appendix.*

Space heat – Biomass stoves and inserts

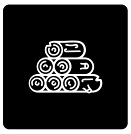


Fireplace inserts and stoves are heaters that run primarily on biomass (most commonly on wood) but there are options that run on gas as well. BAT options for such heaters are described in this section. BAT stoves can replace older and more polluting/inefficient models, typically open fireplaces. Modern stoves are well suited to apartments and to stand-alone houses


Existing buildings with a chimney and of course buildings under construction.

WOOD FIREPLACES AND STOVES



Wood log fireplaces have a long tradition and are still a very common source of emissions, but not really for regular heating. Instead, fireplaces are often used for the 'comfort factor' by modern humans, but produce very high emissions compared to heat, with only 10% efficiency and 90% of the heat lost through the chimney. Given their occasional use, those operating fireplaces often build fires in a manner not considering best 'burn right' practices, which leads to low efficiency and higher emissions. Open fireplaces also produce far larger amounts of indoor emissions, leading to poor air quality. As such, they have been banned in new construction some places, most notably in urban areas. An open fireplace, however, might be replaced by either a fireplace insert or a freestanding wood stove.

There is a significant difference between modern log stoves and inserts compared to older models in terms of efficiency and emissions of particulate matter: BAT stoves are what are referred to as 'clean burning'. An improvement in technology called 'secondary combustion' ensures a second round of oxygen is let into the combustion chamber that burns some of the hydrocarbons in the wood, that would not be combusted in older stoves. Some of what was previously emitted as particles with the flue gas is now burned and used as energy.

Wood stoves may be suitable for households that:

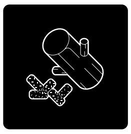
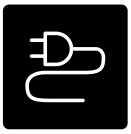
- Have an open design, or alternatively, can place the stove in the room where the need for heating is the greatest.

- Have high peak energy needs.
- Are located in an area where one can access reasonably priced wood.
- (Applicable to existing buildings): Modern stoves are well suited to replace existing stoves.

BAT solutions should have the following properties:

- They should be clean burning, usually reverse combustion. As a reference, the Nordic Ecolabel (2014) sets the limit for PM (particulate matter) at 40 mg/m^3 of flue gas; other measures specify emissions for weight or volume of wood burned. In a clean-burning stove there are some holes on top or inside the fireplace that are meant to pump air around and recycle the flue gas. With this recycling, most of the flue gas that would not have been combusted in an older stove is now burned and not emitted as flue gas. This means more energy and lower emissions for each wood log or pellet[20].
- They typically have an efficiency > 80%. This level of efficiency (or above) is commonly reported by technology providers. For black carbon purposes however, stoves must aim for 95% efficiency or above (see more below).

PELLET STOVES

Pellet stove technology is similar to that of pellet boiler technology. They must, however, be manually filled, typically once a day. They are more sophisticated in temperature management than wood stoves: the temperature can be managed by a thermostat that can be pre-programmed to the desired temperature level, just like panel heaters. Pellet stoves sometimes have a fan that spread the heat from the panel stove more evenly in the building. This, and additional integrated fans that are needed for operation, is why they require electricity to run, in addition to wood chips/pellets.

They apply to households that:

- Are located in an area where pellets can be accessed at a reasonable price, and from a sustainable wood source.
- Have an open design, or alternatively, can be placed in the room where the need for heating is the greatest.
- Have high peak energy needs where the pellet stove may serve as an additional supply of heat.

For some pellet stove models, there is a moderate noise that should be taken into consideration when choosing a model or deciding on purchasing one.

BAT solutions should have the following properties:

- Unlike wood stoves and fireplaces, most pellet stoves are quite advanced as it is a reasonably modern technology. They should, however, meet certain limits of emissions. As a point of reference, the 'Nordic Swan Ecolabelling of Stoves' sets the limit for PM (particulate matter) at 20 mg/m^3 of flue gas.
- They typically have an efficiency > 90%, and preferably above 95%. This level of efficiency (or above) is commonly reported by technology providers.

ENERGY EFFICIENCY GAINS

There are energy efficiency gains from replacing an old stove or open fireplace The BAT solutions for heating using wood logs as a fuel is a fireplace insert or a modern stove with reverse combustion, and for pellets, a pellet stove. For an explanation on how this has been calculated, and for assumptions and sources, see the appendix.

	Conventional		**BAT solution**	
	Old stove	Open fireplace	Wood	Pellet
Efficiency (%)[21]	70	15	80	80
Energy requirement (kWh)*[22]	21,400	100,000	18,800	18,800

**A caveat of this calculation is that it may not be realistic to cover an entire household's energy consumption with a fireplace or wood stove, as is assumed here. The figures are kept this way to keep calculations consistent with other estimates of energy savings. Please take into consideration what share of the household's heat requirement will be covered by a stove/fireplace when interpreting these figures.*

20 There are different standards and legislations that define what is meant by 'clean-burning', and these definitions vary across countries. In the EU, the European Ecodesign Directive sets the legal limitations on emissions from stoves and for closed inserts the limit is set at 40 mg particulate matter/m^3 of flue gas (20 mg/m^3 for pellet stoves).

21 Based on an efficiencies from an article from Statistics Norway (2006).

22 Calculation based on a heating need of 15,000 kwh annually and the efficiencies shown in the table.

ECONOMIC IMPACTS

In addition to energy efficiency gains of replacing old technology by modern technology, there can be economic gains from replacing some of the electricity consumption with wood log/pellet consumption. These gains, along with economic impacts of the energy efficiency gains, are shown in the table below. For an explanation on how this has been calculated, and for assumptions, see the appendix.

	Pellet stove	Wood stove/ insert
Investment cost (EUR)[23]	1,500–4,000	1,500–10,000[24]
Lifetime savings if replacing electricity (EUR)	11,000[25]	
Lifetime savings if replacing an old stove (EUR)	4,000[26]	
Lifetime savings if replacing an open fireplace (EUR)*	120,000[27]	

**A caveat of this calculation is that it is not realistic to cover an entire household's energy consumption with a fireplace or wood stove, as is assumed here. Please take into consideration what share of the household's heat requirement will be covered by a stove/fireplace when interpreting these figures. If the heat requirement covered by a fireplace is a quarter, the energy savings will be reduced by four. However, a pellet stove may replace another heat source in addition to the fireplace. In reality, the energy savings will be a result of replacing a mix of heat sources.*

BLACK CARBON IMPACTS

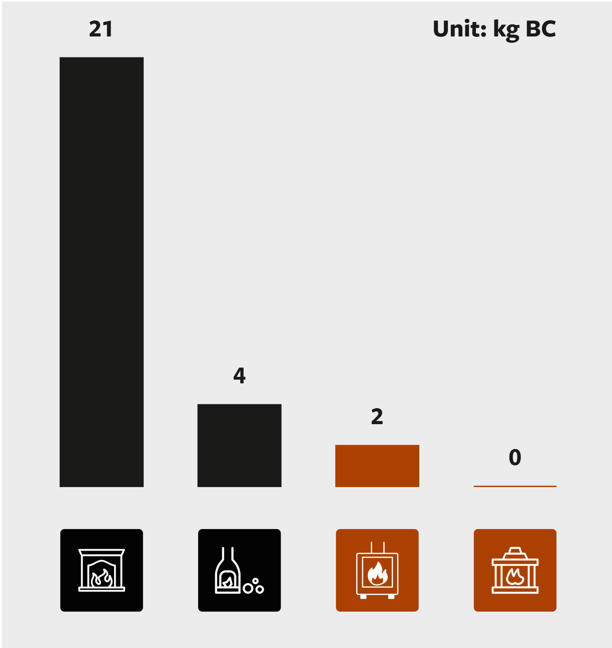


*Figure 9: Annual emissions of BC emissions of an **open fireplace,** an **old stove** a **BAT wood stove** and a **pellet stove**. For assumptions and details about the calculation, please refer to the appendix.*

Reverse combustion and pellet stoves emit an almost negligible amount of black carbon and other particles compared to older technologies, as shown in Figure 9. However, many purported 'clean-burning' stoves at current efficiency requirements (of 80%) often produce similar, or even higher amounts of black carbon, especially as a factor of fuel used. This is because some 'clean' technologies involve combustion at relatively low temperatures, with longer periods of smouldering during which very high levels of black carbon are emitted, while the heat output continues.

In order to address this BC portion of wood smoke, emissions as well as efficiency need to be considered directly, since PM2.5 and BC are not always interchangeable. Going forward, it will therefore be important to measure improved stove emissions specifically both for PM2.5, and black carbon. Thus far, the BAT that specifically decreases BC emissions is either pellet stoves (with automated feeding), or reverse combustion stoves with similar automaticity, preventing operator errors. While other 'improved' stoves may decrease fuel use, they do not always adequately address BC emissions. Creators of subsidy programs should keep this in mind.

23 Enova (2019b).

24 Prices vary across technology providers and models.

25 A calculation based on a difference between efficiencies and differences in energy prices of biofuel and electricity. For assumptions and sources, see appendix.

26 Based on the difference between the energy use of a new pellet stove and an old stove shown in the table above, multiplied by the price of biomass, and the lifetime of the heating device. For sources and values, see appendix.

27 Based on the difference between the energy use of a inserts/stove and an open fireplace shown in the table above, multiplied by the price of biomass, and the lifetime of the heating option. For assumptions used and sources, see appendix.

What to do – Policy instruments

This section presents available policy instruments for tackling black carbon from residential heating, at both the national and local levels in Arctic countries, both Arctic Council and EU/EEA member states, especially those in the northern tier or in mountain regions where current use of wood for heating is high.

POLICY MEASURES CURRENTLY USED IN THE ARCTIC COUNTRIES[28]

- **Financial support schemes, such as subsidies or reduced taxation (VAT, installation costs, etc.).** Residents may be granted the full cost or a share of the cost of installing a BAT solution. This is currently the case in some municipalities of Norway, and has been used at both local (state/provincial) and national levels in other Arctic and EU/EEA countries such as the U.S., Germany and Sweden; and applies to most of the BAT solutions presented here.
- **Information on technology and heating options.** Just as this document aims to convey information, information on different BAT solutions and the types of residential units to which these apply may be provided to consumers or construction firms. This may be combined with financial support.
- **Information on 'burn right'.** Such information campaigns have been launched or are continuing at different levels of intensity in Sweden, the U.S., Canada, Norway, Finland, Austria, Belgium, Denmark, France and Germany (UN Economic and Social Council 2019) (ICCI 2020).
- **Regulations that apply to manufacturers.** Today, there are limits on particulate matter emissions in flue gas in many countries. In the EU, new regulations under the EcoDesign directives will come into effect on Jan. 1, 2022 (though these standards are actually weaker than some previously existing in Nordic countries and North America). These apply to technology providers.
- **Regulations on the selling and buying of non-BAT solutions.** Today, many countries and some local municipalities (such as Bergen and Montreal) require that all stoves purchased today be clean-burning, although old stoves may be sold privately. No countries, however, currently have regulations that match the higher demands required to decrease black carbon emissions specifically.
- **Regulations, often at the municipal urban level, banning use of wood stoves and fireplaces during conditions of high pollution**. This is the case for example in Bergen and in Los Angeles.

EXPERIENCE WITH THESE POLICY INSTRUMENTS

Experience with the described policy instruments has been mixed. This is, however, often due to different ways of implementing these measures.

At the lowest-cost end, **burn right information campaigns** often appear attractive as they can decrease emissions at relatively low cost. However, experience over the past two decades with such campaigns indicate that simply making information available has little or no impact (ICCI 2020). When surveyed, most consumers do not even remember seeing materials that were mailed directly to them, let alone reported any change in behavior. The most successful burn right campaigns however have the following characteristics:

- One-on-one instruction on fire lighting and fuel guidelines, especially by a trusted provider such as a stove retailer, chimney sweep or firefighter, and preferably in the consumer's home using their actual stove.
- Stringent guidelines on fuel use, especially banning any burning of trash or processed wood products in stoves.
- Backed up by monitoring and regulation: a highly successful effort in Canada had local officials monitoring the chimneys of so-called 'super polluters' in their community, who often burned trash; and in some cases, only hefty fines caused behavior change.

Subsidies also have a mixed record, and no record at all concerning black carbon specifically. All efforts thus far have aimed at 'better' stoves generally. No subsidies have been specifically targeted at the highest-performing stoves with regards to black carbon emissions. In some cases, it appears that most of the surveyed consumers planned to replace their stoves in any case. A study in Norway found

28 This is a brief summary of the policy measures currently in place. For a more comprehensive overview, please refer to The Expert Group on Black Carbon and Methane (Arctic Council 2019).

that recent emissions may have increased in urban areas due to a higher use of stoves overall, even though a greater proportion of those stoves were clean burning. Other factors such as higher electricity prices may also be at play ((ICCI 2018) and (Lopez-Aparicio and Grythe 2020)).

Regulation at the level of manufacture has in the past appeared to have the greatest effect, by stimulating growth in cleaner technologies such as reverse combustion stoves, or those with a high level of automation to eliminate operator error. Voluntary standards, such as the Nordic Swan or German Blue Angel have also been relatively successful. However, efforts at regulation have lagged in the 2000's, with new EU regulations at times less strict than national regulation already in place, as well as in some instances industry's own desires for regulation. For example, the latest Ecodesign emission standards of the EU were actually lower than the national standards already in place in most of northern Europe; and they do not at all address black carbon emissions. Recent studies tying wood stoves to health impacts, as well as climate concerns (including sustainable wood fuel sources) have led some municipalities in Europe and Canada to ban stoves and open fireplaces almost entirely (in Montreal, only stoves with very low emission rates under 2.5g/hr can be used; residents who do not declare their stoves may be fined or even have chimneys plugged). This has led some progressive manufacturers to demand, and even themselves begin designing new and more stringent stove standards, including standards for PM2,5 and BC emissions.

SUGGESTIONS FOR NEW POLICY INSTRUMENTS

There is a recent change in the sentiment and willingness to address black carbon: a number of guidance documents have been issued recently outlining potential next steps to reduce BC emissions from wood stoves and boilers, specifically under the LRTAP Convention (UN Economic and Social Council 2019), as well as various guidance and advisory documents from the Arctic Council working groups (AMAP, ACAP) and the Climate and Clean Air Coalition (ICCI,2018). These suggestions include:

- Put in place emission limits and efficiency standards for black carbon (in addition to particulate matter). In the Arctic region, the United States, Canada, and the European Union have limits on emissions of particulate matter on certain heating devices, but not for black carbon.
- Agree on a harmonized methodology to measure black carbon from residential heating. There is no such methodology in place today, although several have been suggested and remain under development, including for the Nordic Council's Swan Eco-label.
- Consider strengthening the incentives to replace old heating devices with BAT solutions that specifically decrease black carbon and putting in place incentives in countries/regions where this is not in place.
- Consider much higher standards for the eco-labelling of stoves, including emission limit values for black carbon, specifically in relation to consumer demand for stoves that are more climate friendly. This could also take the form of a second tier of standards for climate purposes. Such a 'tiered' system has been put in place as regards standards for cook stoves in developing countries.
- Consider policy methods that address the tendency of consumers to use wood when district heating or electricity-based heating become more expensive, including banning households from disconnecting from district heating.
- More information on 'burn right' campaigns, including how to conduct these effectively to motivate measurable behavior change.
- Fund 'household energy efficiency programs' that allow efficiency measures such as increasing insulation, or the installation of heat pumps.
- At a national level: fund R&D programs helping manufacturers develop even cheaper versions of cleaner burning stoves that employ reverse combustion and/or automated fuel delivery systems.

Given the importance of residential heating as a source of black carbon for both the Arctic, and snow-based mountain ecosystems, as well as its health and biodiversity impacts, these measures should be integrated into national and international climate and health action plans as a matter of urgency. This should happen in a pre-2030 timeframe as an additional approach to reducing greenhouse gas emissions, especially to slow warming in the Arctic.

Appendix – Assumptions

Table A1: Assumptions

Description of assumption	Value and/or unit	Source/comment
Global warming potential of BC	900	Bond et. al (2013)
Energy savings of heat pumps	kWh	Based on the different SCOP values. The sources of these are listed in connection with the SCOP value.
Energy savings of switching to a more effective bio-run heater (fireplace, boiler etc.)	kWh	Based on efficiencies listed below
Efficiency of an old boiler	70%	Assumption
Efficiency of a pellet boiler	85%	Enova (2019b). Efficiencies up to 90% are reported in literature.
Efficiency of a modern wood log boiler	80%	Energismart.no
Efficiencies of different stove and fireplace inserts	%	Statistics Norway (2006). The different efficiencies are shown in a table in the relevant chapter.
Price of electricity	0.13 EUR/kWh	Eurostat (2019), average since 2014.
Price of biofuel	0.075 EUR/kWh	Enova (2019a)
Lifetime of a heating device	20 years	Assumption used for lifetime energy savings.
BC emission factors	mg BC/MJ	Different emission factors used for different heating sources. See the figure and table below for specific emission factors. Emission factors used in the main body of the report are from ACAP (2014).
Energy content in one kg of wood	15 MJ/kg	Assumption used for calculating BC emissions of one evening in front of the fireplace. Source: (Valter Francescato, Bergomi, and Antonini 2008).
Consumption of wood in one evening	10 liters of wood (1/4 of a bag)	Assumption used for calculating BC emissions of one evening in front of the fireplace
Weight of wood	0.5 kg/liter	Assumption used for calculating BC emissions of one evening in front of the fireplace. Based on the assumption that air makes up 50% of the volume of a bag of wood.
CO_2 emissions of driving a car	0.18 kg/km	Thune-Larsen et. al (2014)
Price of a BAT boiler	EUR 12,000	Enova (2019a) gives a range of 10,000 to 15,000 EUR.
Price of air-to-water heat pump	EUR 9,000	Enova (2019d) gives a range of 6,000 to 13,000 EUR.
Price of a geothermic and water-to-water heat pump	> EUR 12,000	Enova (2019e)
Price of a pellet stove/insert	EUR 2,500	Enova (2019b) gives a range for a pellet stove of 1,000–4,000 EUR. Different technology providers give different prices, especially for inserts where there does not seem to be an upper limit.
Price of an air-to-air heat pump	EUR 2,500	Enova (2019c) gives a range of EUR 1,800 to 3,000
Conversion rate NOK/EUR	10	Norway's Central Bank (exchange rate on 27 January 2020)

How energy savings (EUR) are calculated

Energy savings of changing from t to i (EUR) = Annual energy need of household (kWh) × 1/Efficiencyt × Cost of energy source (EUR/kWh)t × Lifetime of heating device – Annual energy need of household (kWh) × 1/Efficiencyi × Cost of energy sourcei (EUR) × Lifetime of heating device

Where

t = old heating solution, such as old boiler, old wood stove etc.

i = new heating solution that can replace t, such as pellet boiler, new wood stove etc.

Annual energy needs of household (kWh) = 15,000

Efficiencyt = Efficiency of heat source t, see relevant chapters for values and sources

Cost of energy source = varies across biofuel and electricity, see table for values

Lifetime of heating device = assumed to be 20 years for all heating devices

How emissions of BC are calculated

Annual emissions of BC of heat source$_{kg}$ (kg BC) = Energy need of household (kwh) × 1/Efficiency$_t$ × Emissions of BC$_t$ × MJ/kwh

Where

t = heat source (stove, panel heater, boiler etc.)

Energy need of household (kwh) = 15,000

Efficiency$_t$ = Efficiency of heat source t

Emissions of BC$_t$ = emission factor of BC of heat source t in mg/MJ, see table below

Efficiency$_t$ = Efficiency of heat source t, see relevant chapters for values and sources

MJ/kwh = 3.6

Table A2: Underlying emission factors. An average of the emission factors shown above has been used for each of the heating devices in the first column in this report. What seems to be outliers have been left out. For a full review of emission factors and more details, see ACAP (2014).

Heat source	Heating device and BC emission factor in brackets (mg/MJ)
Conventional boiler	Canada: Central furnaces/boilers[29] (102) EMEP/EEA: Conventional boilers < 50kW (75)
BAT wood boiler	Finland: Manually fed boilers with accumulator (26) Denmark: New boilers with acc. Tank (52) Denmark: New boilers without acc. Tank (90)
Pellet/wood chip boiler	EMEP/EEA: Pellet stoves and boilers (4) Denmark: Pellet stoves/boilers (12)
Heat pumps	NA (heat pumps do not have any direct emissions)
Old wood stove	EMEP/EEA: Conventional stoves (74) Canada: Wood stoves (conventional – airtight) (42) Canada: Wood stoves (conventional – not airtight) (72) Finland: Iron stoves (conventional) (28)
Open fireplaces	EMEP/EEA: Open fireplaces (57) Finland: Open fireplaces and other stoves (35) Norway: Open fireplaces (86)
New stove/inserts	Canada: Fireplace inserts/advanced tech. fireplaces (15) EMEP/EEA: Energy efficient stoves (59) Canada: Wood stoves, advanced tech. (15) Finland: Iron stoves, modern (18)
Pellet stove	EMEP/EEA: Pellet stoves and boilers (4)

Table A2 shows underlying emission factors used for all presentations of potential emission reductions when switching from one technology to another. These emission factors are taken from ACAP (2014). Another important factor determining emission reductions is the efficiency assumed for the different heating solutions and those are presented in table A2.

There are many possible emission factors that s could have been used, as there is a large collection of emission factors in the European Environment Agency's database for emission factors (2019). One reason why ACAP (2014) was chosen as the preferred source, is that the authors have confirmed that these emission factors relate to consumed energy from fuels and not to produced heat (taking into account the efficiency of the heating device).

29 In ACAP (2014) there were other boilers with higher emission factors but they were treated as outliers and thus these emission factors have not been used.

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