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Lot 15
Solid fuel small combustion installations

Task 3: Consumer behaviour and local infrastructure

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Bio Intelligence Service - Scaling sustainable development
Industrial Ecology - Nutritional Health

Bio Intelligence Service S.A.S - bio@biois.com
1 rue Berthelot - 94200 Ivry-sur-Seine - France
Tél. +33 (0)1 56 20 23 98 - Fax. +33 (0)1 58 46 09 95

Contact Bio Intelligence Service S.A.S.
Shailendra Mudgal – Anne Turbé
☏ + 33 (0) 1 53 90 11 80
shailendra.mudgal@biois.com
anne.turbe@biois.com

Project Team

- **Bio Intelligence Service**

  Mr. Shailendra Mudgal

  Ms. Anne Turbé

  Ms. Ian Kuwahara

- **AEA Technology Energy and Environment**

  Mr. Robert Stewart

  Mr. Mike Woodfield

- **Institute of Thermal Technology of the Silesian University of Technology**

  Ms. Krystyna Kubica

  Mr. Robert Kubica

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3. Task 3 – Consumer behaviour and local infrastructure

Consumer behaviour directly affects the performance of solid fuel small combustion installations (SCIs) during use-phase and can therefore influence both the environmental impacts and the energy efficiency of these appliances. On the other hand, the infrastructure surrounding a solid fuel SCI often affects the choice, cost-effectiveness, and viability of these combustion systems. Consequently, the local infrastructure has an indirect influence on the environmental impacts and the energy efficiency associated with solid fuel SCIs.

- **Objective**

The aim of this task is to analyse how consumer behaviour and local infrastructure can affect the real-life performance of solid fuel SCIs. The importance of consumer behaviour is analysed for each life-cycle stage of a solid fuel SCI, from purchase, through the use-phase to the end-of-life. For the use phase, relevant parameters such as frequency and characteristics of use are quantified for use in later tasks (Task 5 onwards). Finally, possible barriers to eco-design measures for solid fuel SCIs (e.g. local infrastructure) are investigated.

3.1 APPLIANCE PURCHASE

3.1.1 FACTORS AFFECTING PURCHASE DECISIONS OF SCIS

The purchase of a heating system is the first step by which consumer behaviour can have an effect on the products covered by the Lot 15 preparatory study. Appliance functionality is usually the primary factor influencing the purchase decision of the consumer, but other factors may also be important and are discussed below.

➔ **Function of the appliance**

Solid fuel small combustion appliances can serve two different purposes in the domestic heating context, depending on their functionality. Solid fuel SCIs can either serve as the primary heating source for a dwelling, or as a secondary heat source. As previously described in Task 1, a primary heating appliance is the main source of space heating for the dwelling. Indirect heating appliances tend to be used exclusively for primary heating, whereas secondary heating involves the use of such appliances as a supplement to other sources of space heating in the dwelling. Direct heating appliances are typically used as secondary heating appliances, serving either as a supplementary heating source or for other purposes such as aesthetics.

Beside the function of an appliance, other factors like aesthetic pleasure usually matters for direct heating appliances, whereas for indirect heating appliances aesthetic issues are not important and it is the efficiency which counts. The implications of these different functions to the use phase and energy use of the appliances are discussed in Section 3.2.4 .

➔ Factors affecting the consumer purchase decision

Mahapatra (2007)[1] categorised the factors influencing consumer purchasing of indirect wood pellet heating systems into four main groups: technical factors, level of comfort, economic and environmental factors and fuel supply security issues. This categorisation can be applied to solid fuel SCIs and is discussed below.

Technical factors

- **Installation requirements:** when purchasing an indirect heating SCI as part of a central heating system, some form of distribution system to transfer the heat to different parts of the home is required, such as a 'hydronic' system. In addition, a chimney and space for fuel storage are necessary.
- **Functional reliability:** the performance of a new heating system affects the purchase decision of the consumer, as does its past experience. Breakdowns in (previous) systems due to low quality and/or mistakes in installation will tend to reduce the trust of the consumer in the reliability of the systems.

Level of comfort

- **System automation:** convenience influences the choice of heating system. People usually prefer a system that is automatic since it does not require manual work and saves time for the user. In Sweden, for example, retrofitting existing oil boilers with fully automatic pellet burners is common.
- **Indoor air quality:** direct heating appliances in particular can reduce the indoor air quality, due for instance to bad user habits. A dust problem could also arise with pellets heating systems, especially when the pellets are manually fed to the boiler/stove.

Economic factors

- **Investment costs:** affordability is one of the determining factors in the choice of a heating system. If the investment cost is higher than the consumer is willing or able to pay, then the system will lose its attractiveness. The purchase costs of solid fuel SCIs are analysed in Task 2 of this study (section 2.4.1). Moreover, for

[1] Mahapatra, K. (2007) Diffusion of innovative domestic heating systems and multi-storey wood-framed buildings in Sweden.

solid fuel appliances, first time installations usually require an additional investment for the fuel storage.

- **Annual costs of heating (excluding investment cost):** the availability and cost of solid fuels in comparison to other energy sources can be strong drivers of the market for solid fuel SCIs. Fuel prices are analysed in Task 2 (section 2.4.2).
- **Market value of the house:** the market value of a house may be another factor affecting the choice of heating system.

Environmental or supply security issues

- **Environmental impact:** biomass-based heating systems are considered to be environmentally friendly. Yet, some people may also believe that the use of forest resources to produce fuel disrupts the ecological balance of forests.
- **Security of fuel supply:** contrary to oil-based systems for which there is a risk of supply disruption and price fluctuation in oil-importing countries, biomass SCIs make use of local resources, such as wood residues. Using local resources improves supply security and reduces the dependence on global energy markets and their price fluctuations.

These factors often have important subsequent consequences on the operation and end of life phases of heating systems. System automation is a factor of particular importance relevant to the use phase of this study, and will be discussed in Section 3.2.3 Market value of the home is important to the end of life phase which is discussed in Section 3.3

Another important factor in the purchasing decision of a heating system is government policy intervention. Government policy intervention can be applicable to both direct and indirect heating systems.

➔ Government policy intervention

Governments can establish frameworks to provide financial and physical aid for supporting solid fuel SCI markets. These frameworks typically take the form of financial support to stimulate consumers to buy efficient appliances, through measures such as tax credits or reduced VAT.

Besides incentive programmes, governments also influence sales through legislative measures either directly or indirectly, with the effect of creating a favourable environment for solid fuel SCIs. In various European countries, builders are obliged to foresee the connection to a chimney for every dwelling[2]. In these countries, the switch to solid fuel heating is possible, as the structural requirement – the chimney – already exists. In other countries this is more difficult, because structural requirements in the buildings are not mandatory. Builders often do not include a chimney if it is not

[2] Haidlmair (2007) The Safety Chimney

obligatory, leaving the inhabitants without a choice. This applies especially to multi-family houses and single-family houses where the builder is not the inhabitant.

The market trends analysis of products covered by this study[3] shows that government actions through incentives programmes are an important driver of solid fuel SCI sales. Support schemes for biomass heating installations have been implemented in several Member States (MS) to increase the sales of these products. These direct government policy intervention schemes are a mechanism which influences consumer behaviour, since they directly reward the purchase decision with a financial compensation. In France for example, 50% of the costs of an individual wood heating appliance can be reimbursed to the taxpayer, if the appliance complies with pre-defined criteria (e.g. minimum energy efficiency of 65%). This tax credit was established in 2001 with a refund rate of 15%, and was further increased to 40% and 50% in 2004 and 2006 respectively. It was implemented by the government as one of the main measures to encourage the use of renewable energy sources (RES) in the household sector, with an overall objective to make RES reach 12% of primary energy consumed in France by 2010. These tax credit measures were supported by an important communication campaign at the national level. Results show that more than 450 000 people applied for this fiscal incentive in 2005 and 2006, resulting in a growth of the sales of individual wood heating appliances by approximately 26% in 2005[4].

In addition, some regions/cities require permits to install solid fuel installations and limitations may exist due to a priority for district heating, local air pollution concerns or for other reasons.

3.1.2 CONSUMER SURVEYS

Consumer surveys are often the only means to gain insight on how solid fuel SCIs are selected. The results from a stakeholder consultation conducted for this study are compared to those of two national surveys.

➔ Lombardy region of Italy

The reasons for preferring a wood combustion system were surveyed in the Lombardy region of Italy. Understanding consumer behaviour in this region is particularly important, since Lombardy has one of the highest local air pollutant concentration in Europe (NOx pollution in particular)[5] and wood fuel combustion systems represent approximately 17% of the domestic heating systems in this region. The main reasons respondents gave for purchasing a wood based combustion system are presented in Table 3-1. This table shows that besides economic savings, aesthetics are the most important factor. Economic savings arise largely from the fact that for over 30% of

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3 Section 2.3 of Task 2 report, available at www.ecosolidfuel.org

4 Observ'ER et al. Fact sheet - France, Refund + project: www.energies-renouvelables.org/refund/docs/neofactsheet/Fact%20sheet%20France.xls

5 Europen Environment Agency (2004) "NOx annual average map" http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=3404 , accessed Mar 4 2009

respondents to this survey, the wood used for fuel was self-made and thus represented little to no cost.

Table 3-1: Main reasons for using wood for domestic heating in Lombardy, Italy[6]

Main declared reason for using wood fuel for domestic heating	Percentage (multiple answers possible)
Economical	31.0%
Ecological	16.2%
Inherited (with property or other)	32.0%
It warms better	24.0%
I don't know	6.4%
Aesthetics	42.3%
Tradition	1.8%
It is better for cooking	1.1%
Other	0.9%
It is beautiful to see (sole answer)	17.0%

➔ Polish town of Tychy

Factors influencing the decision to purchase a solid fuel SCI in a Polish town are presented in Figure 3-1.

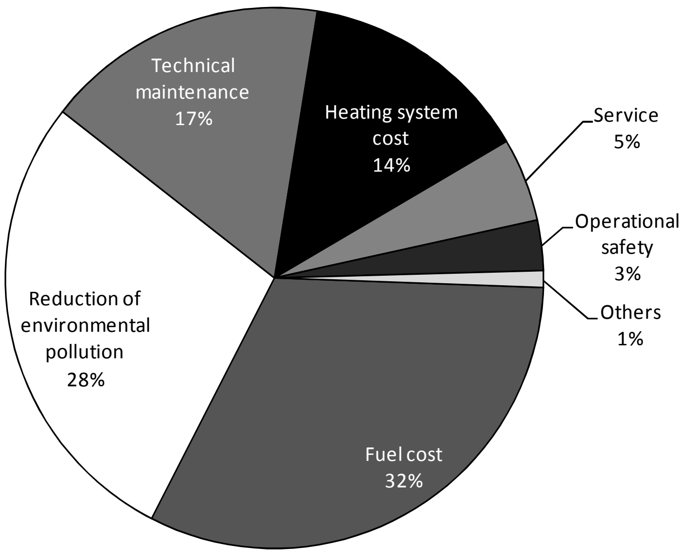

Figure 3-1: Factors influencing Polish consumers on heating equipment selection[7]

The decision process, including appropriate appliance selection, was mainly influenced by economical reasons (fuel cost and heating system cost), but environmental issues

6 Caserini, Fraccaroli, Monguzzi, Moretti, Angelino (2007) "New insight into the role of wood combustion as key PM source in Italy and in Lombardy region", ARPA Lombardia, Settore ARIA, presented at : 16th Annual International Emissions Inventory Conference "Emission Inventories: Integration, Analysis, and Communications"

7 Kubica, K., Kubica, R., Przybysławski, A. (2006) Ecological effects of a programme on low level emission reduction, in case of Tychy town, 5th International Scientific Conference 'Air protection in theory and practice', Zakopane 19-21st of October, 2006.

such as reduction of pollution were also important. In comparison, the maintenance, service, and safety of the appliances play a small role in the purchase decision of solid fuel SCIs.

In the same study, it was shown that the decision to change equipment was generally driven by the same set of parameters as the purchase decision, that is environmental considerations and financial benefits (The latter possibly reinforced by subsidies or tax credits in some countries).

➔ Stakeholder survey

In the context of the Lot 15 study, stakeholders were asked to assess consumer considerations when buying a new solid fuel SCI[8]. The results, based on 20 responses, are presented in Figure 3-2 and show that in general, stakeholders believe that the design/aesthetics of the SCI and the type of fuel used by the SCI are the most important criteria driving the purchase decision of the consumer. Functionality is also important, while the price and performance of the appliance rank lower in the decision-making process.

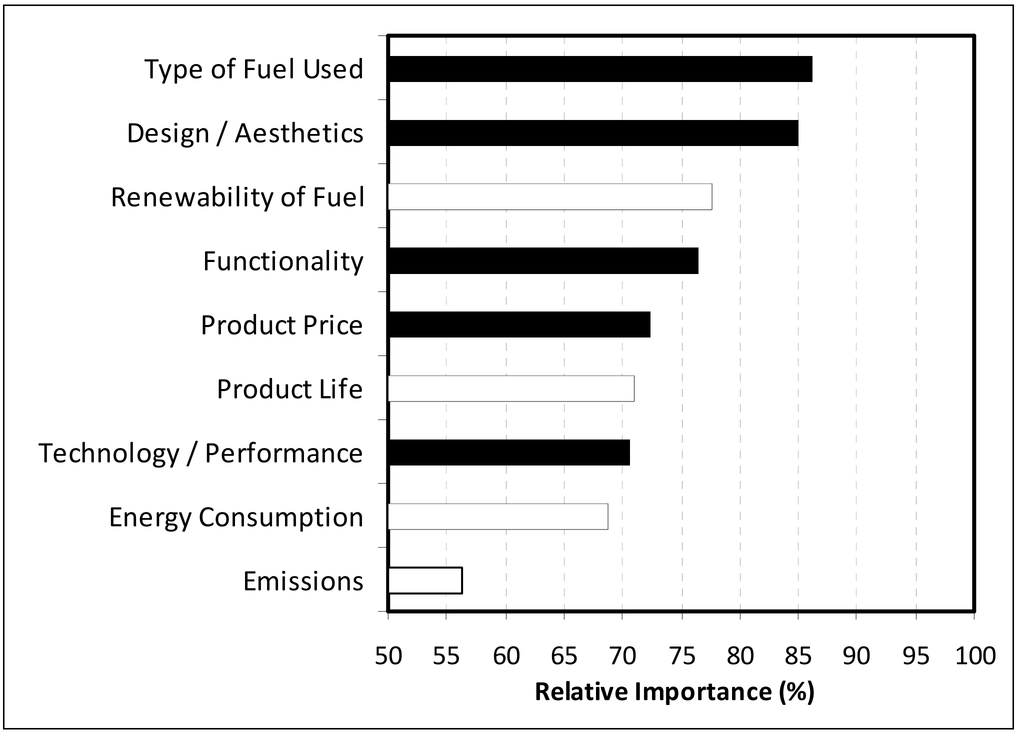

Figure 3-2: Factors influencing the purchase decision of an SCI[9]

But such general conclusions can be misleading. As previously discussed, the purchase criteria depend largely on the type of appliance. For example, for boilers, efficiency is often the main selection criteria because the buyer (who is owner and not only end-

8 Questionnaire on Task 2 and 3, sent to stakeholders in June 2008.

9 White bars represent environmental considerations, black bars represent other considerations.

user) is looking for economy and reliability. In contrast, the design and aesthetics are critical for fireplaces or stoves since these appliances are a visible part of the interior of the house. In this case, consumers wish not only to obtain heat from the appliance, but they also wish to enjoy the ambiance of the fire. These appliances can be considered a luxury product, especially when they are not used as the primary heat source. Price becomes less of a priority in the purchase decision of luxury products.

Among the environmental criteria (white bars in Figure 3-2), the renewability of the fuel was the main criterion considered in the purchase decision. Fuel availability, affordability and the ease with which fuel can be fed are also important drivers[10]. Although the lifetime of the appliance and its energy efficiency appear important, it is mostly because energy consumption is high on the list of consumers who use SCIs as the sole heating source in their house. On the contrary, the lifetime and energy consumption of the appliance are not really considered by consumers who only use their SCI occasionally. Customers are aware of the importance of emissions (local air pollution is an increasing concern), however according to manufacturers (who were the main respondents to this questionnaire), the emissions do not appear to be of major concern for the consumers. Consumers often believe that small combustion appliances are a “green” option and hence they rarely try to compare emission levels of different appliance/fuel types when purchasing them. In some MS, financial incentives linked to environmentally friendly products may encourage ‘green’ choices within these product categories.

Due to the long lifetime of SCIs, the purchase decision is also influenced by installation and maintenance services provided by the appliance manufacturer or dealer. Indeed, the consumer would like to be reassured of a proper after-sales service throughout the appliance life.

3.1.3 Best practice guidelines for purchase and installation

Best practices regarding the purchase of SCIs consist of[11]:

- Proper selection of the heating appliance with regards to the planned use and heat demand, preferably in consultation with professional advisors.
- Choice of a heating appliances that incorporates clean fuel combustion techniques, possibly awarded with an (eco)label.
- Proper installation of the heating appliance, with attention paid to the chimney system. Where relevant, use a central heating system with appropriate controls

10 Stakeholders have noted that in some Member States (e.g. Belgium and UK) consumers appreciate multifuel appliances as they offer greater flexibility to change fuel according to fuel prices and availability.

11 Projects “Clean energy for my house. Clean and cheap heat from coal” (2005/2006), “Coal and clean energy” (2007) financed by the Regional Fund for Environmental Protection and Water Management in Katowice, Poland. “Don’t release pollutants – protect your health. Individual Heating versus the Environment and Human Health – pilot programme for selected municipalities of the Upper Silesian Region” (2008) co-financed by the UE funds and by the Regional Fund for Environmental Protection and Water Management in Katowice, Poland. And stakeholder contributions.

and an accumulator tank (according to specification delivered by the manufacturer of the device or with the use of trained technician).

- Installation of a carbon monoxide (CO) detector. The detector sounds an alarm in case odourless carbon monoxide gas is released into the room. The CO detector is to be installed at or near ceiling level in the room in which the combustion appliances is located.

3.2 APPLIANCE USE

In the existing test standards, efficiency and emissions of solid fuel SCIs are determined under steady-state conditions at nominal output, and sometimes also in low load conditions. However, real life conditions are often far from standard ones and can dramatically affect the actual efficiency and emissions of solid fuel SCIs.

In real life, efficiency and emissions of SCIs depend on a variety of factors. The discussion below focuses primarily on the behaviour of the consumer and how this affects the performance of solid fuel SCIs. The technical issues related to the appliance are discussed in Task 4.

3.2.1 SYSTEM PERFORMANCE

➔ Combustion effectiveness

In real life, efficiency and emissions of solid fuel SCIs depend on the extent to which "ideal" combustion conditions can be provided. The key factors of good combustion can be summarised by the rule of the "3Ts", Temperature, Turbulence and Time:

- Temperature has to be high enough to allow complete combustion
- Turbulence ensures a good mixing of the combustion gases with the air
- Time (or residence time) should be sufficient to ensure that volatile matter burns before escaping through the chimney

The "3Ts" of combustion are governed by the features of three key components which together comprise the combustion system (see Figure 3-3):

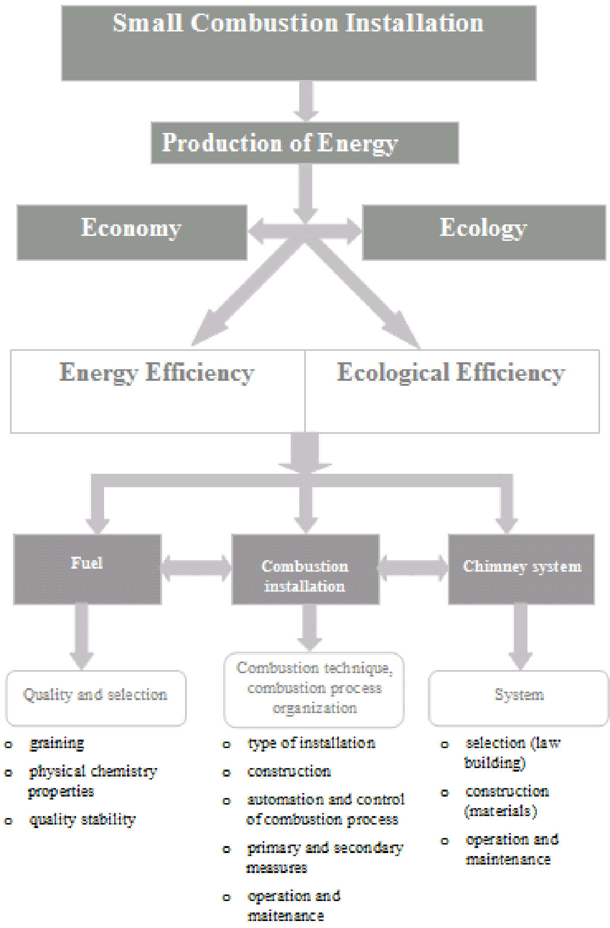

Figure 3-3: Parameters affecting the environmental impact of solid fuel SCIs[12]

- Appliance - its design and technical properties
- Fuel - its characteristics, such as moisture, content of pollutants, and its use (e.g. whether the fuel used is the one the appliance is designed for).
- Chimney[13] - its properties (correct dimensioning, insulation, etc.)

Users can affect all of the above parameters of the combustion system, either in their choice (e.g. choice of a fuel of adequate quality) or in their operating practices (e.g. overloading the solid fuel SCI).

➔ Parameters affecting the combustion system

Table 3-2 introduces the main factors affecting the real-life efficiency and emissions of solid fuel SCIs, their possible variability and their impact. The real-life efficiency of solid

[12] Kubica K. et al. (2004) Small Combustion Installations, Chapter for "Emission Inventory Guidebook"; UNECE TFEIP, 2004 (Updated by Kubica K., and Woodfield M. in 2006), B216-2, Techniques, emissions and measures for emission reduction.

[13] To keep the analysis short the chimney text has been retained despite the need for differentiation by product type

fuel SCIs can depend on technical parameters (discussed in Task 4), as well as on fuel characteristics (section 3.2.2) and user behaviour (section 3.2.3). Local infrastructure aspects, such as technical properties of buildings and chimneys, are also discussed (section 3.4).

Table 3-2 - Main factors influencing real life efficiency and emissions of solid fuel SCIs

Parameter	Possible influence on SCI efficiency and emissions
Appliance technical properties	
Size (capacity vs. heat demand of the building)	Appliance capacity and duty are correlated. If an appliance is not well adapted (e.g. over-dimensioned), it may result in non optimal efficiency.
System configuration	System performance can affect boiler performance. Proper system design to match operating parameters of boiler and duty cycle are important (i.e. Shunt loop if required).
Automatic (electrical) controls	Use of electrical energy in appliances or in the heating system is generally not considered in the standards for measuring appliance efficiency. Therefore, real life efficiency is in general lower than tested efficiency.
Air supply	Manual air control can cause high variations in the amount of air in the combustion chamber and consequently variations in term of efficiency and emissions. Properly controlled fan can help to ensure more stable and better air control. Sufficient secondary air supply to combustion can be ensured by proper design of the appliance which can significantly reduce the emissions by secondary combustion.
Fuel stoking: automatic or manual	With manual stoking, user has a large influence on the combustion and resulting efficiency and emissions through the load or the frequency of loading. Automation can help to optimise stoking, but to achieve proper results the feeding system needs to be properly configured and controlled.
Fuel	
Nature of the fuel	Chemical structure (e.g. elemental composition) and physicochemical properties (e.g. calorific value) of fuel influence both emissions and efficiency.
Use of fuel recommended by the manufacturer	Use of inappropriate fuel can be detrimental because it may lead to combustion problems and high pollutant emissions.
Fuel moisture	Too high moisture content leads to a significant quantity of water vapour. It reduces the efficiency of the combustion with an increase of the rate of unburned material which also leads to increased emission of pollutants (e.g. particulates in the case of wood).

Parameter	Possible influence on SCI efficiency and emissions
Dimension of wood pieces	Multiple wood pieces are needed to form a good geometry for combustion (forming a sheltered pocket reflecting heat toward each other and sustaining the fire). The number of pieces is dependent on the power output of the appliance and the size of fireplace area. Normally, it is better to have 2-3 medium size pieces than one big log. Correct size also assures sufficient but not too fast volatilisation of combustible gases.
Grain size distribution of coal	Appropriate grain size distribution contributes to good homogenisation of combustion air with fuel, higher efficiency and lower emissions from boilers and stoves.
Technical properties of building - chimney	
Dimensioning	The diameter of the cross-section influences the behaviour and real-life efficiency of an appliance. This complex calculation is laid down in the European standards EN 13384-1 and -2.
Air-intake	Chimneys with an air-intake shaft allow for a stable supply of combustion air, which is a pre-requisite for efficient room-independent appliances.
Insulation	Proper insulated chimneys with air-intake shaft increase the efficiency of appliances as combustion air for the appliance is pre-heated.
Sootfire-, water-, corrosion resistance	Pre-requisite for using high-efficiency, solid fuel appliances like condensing biomass boilers.
User behaviour	
Choice of fuel/ fuel quality	The user can choose the fuel quality when buying it or for example he has an influence on the fuel moisture through the time allocated to wood log drying and the fuel storage conditions. The presence of chemical residues (e.g. paints and varnishes) changes the chemical nature of the fuel and can lead to high emissions of toxic pollutants.
Way of operating: example of the load (real load vs. nominal output)	The performance of an appliance is sub-optimal if too much or too little fuel is used. Excessive fuel load leads to incomplete combustion, while using too little fuel quantity prevents the temperature to reach good combustion. In both cases, incomplete combustion causes high emissions.
Fuel residence time	The residence time has to be long enough to ensure a complete combustion. Especially in manually controlled appliances, user can affect the residence time (usually extending it) by manipulating air supply and/or draught increasing incomplete combustion. Appliance design and structure can also play a significant role in residence time.

Parameter	Possible influence on SCI efficiency and emissions
Air control	The output can be influenced in an unfavourable way if there is an excess of air (if the door of the appliance is open when heating, the draught of the stack is too important, much air is moved under the fuel, etc.). On the other hand, insufficient air supply will also compromise good combustion.
Maintenance	For direct heating appliances, insufficient cleaning of the grate (and of ashtray / box) may reduce energy efficiency by reducing draught and lowering combustion quality (especially when the appliance is fired with primary air supply). In general, neglecting maintenance operations leads to a reduction of the lifetime/durability of the appliance.

3.2.2 FUEL TYPES AND QUALITY

Solid fuel SCIs are designed for using one or several specific types of fuels, which meet minimum quality requirements. However, the quality of fuels available to the user may vary considerably based on geographic location and transportation networks. As a result the fuels used by consumers can differ from those required by the appliance, and from those used in the test standards. Several fuel characteristics influence the performance of an appliance during its use. The main characteristics of the different types of fuels and their possible effect on the combustion process are outlined below.

➔ Fuel characteristics

■ Fuel composition

A solid fuel can be characterised in an ultimate analysis by its chemical composition, or in a proximate analysis by its main constituents (Figure 3-4)[14,15]. In a proximate analysis, fuels can be broken down into four broad types of constituents:

- Moisture, the water content of the fuel
- Ash, the black, incombustible material remaining after complete combustion of the fuel
- Volatile matter, the quantity of organic matter which readily vaporizes.
- Fixed carbon, is the carbon found in the solid fuel after the volatile matter is driven off

14 Oravainen, H. Polttotekniikan perusteet ja päästöjen hallinta, VTT, Finland
15 Loo S. and Koppejan J.; Handbook of Biomass Combustion and Co-Firing; Twenty University Press, ISBN 9036517737

The composition of a solid fuel is normally analysed through four basis (Figure 3-4):

- ([d]) 'dry' basis – moisture not considered
- ([daf]) 'dry, ash-free' basis – moisture and ash not considered
- ([ar]) 'as received'
- ([a]) 'analytical state' – real test conditions, typically near 'dry' basis. The analytical state is the dried state which is technically feasible and which corresponds to the real conditions during the analysis. This may be different from 'dry' since there may be some moisture left even after drying.

An ultimate analysis gives the components of the dry, ash-free fuel in terms of the five main elements present in solid fuels, i.e. carbon, hydrogen, oxygen, nitrogen, and sulphur. These chemical components are the building blocks which recombine during combustion to liberate energy and produce different chemical products.

Mineral fuel and biomass fuels have different chemical compositions (Table 3-3). Solid biomass fuels roughly consist of the same elements as mineral fuels, but their relative quantities differ: for instance, while H-content is similar in both fuel types (5 – 6%), average C-content is 45% for biomass fuels compared to 80% for mineral fuels. As a result the volatile matter content of biomass fuels is about twice higher than that of mineral fuels, implying that biomass combustion requires special conditions of low-intensity combustion for optimal energetic and environmental efficiency. The proportion of elements such as sulphur, nitrogen, chlorine, and mineral matter (containing heavy metals) in biomass fuels is lower than in mineral fuels.

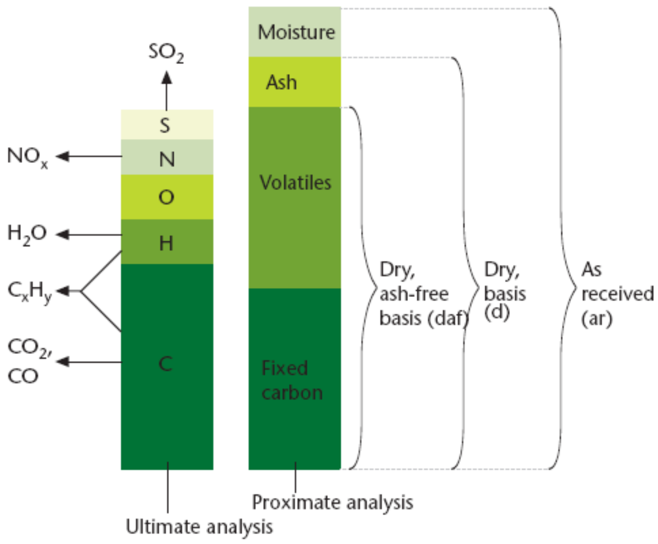

Figure 3-4: Illustration of how the different levels of fuel analysis and states of fuel (ar, d, daf)[16] relate to each other

16 Vapo and VTT (2006) Local fuels – Properties, classification and environmental impacts. Vapo Oy, Jyväskylä, Finland, http://www.vapo.fi/filebank/2035-local_fuels_in_finland.pdf

Table 3-3: Overview of the typical chemical properties of coal and biomass[17]

Property	Symbol	Unit	Biomass	Mineral
Main components				
Carbon	C^{daf}	%	44 - 51	75 - 85
Hydrogen	H^{daf}	%	5.5 - 7	4.8 - 5.5
Oxygen	O_d^{daf}	%	41 - 50	8.8 - 10
Sulphur	S_t^d	%	0.01 - 0.9	0.3 - 1.5
Nitrogen	N^{daf}	%	0.1 - 0.8	1.4 - 2.3
Other components				
Chlorine	Cl_t^d	%	0.01 - 0.7	0.04 - 0.4
Volatile matter	V^{daf}	%	65 - 85	35 - 42
Ash content	A^d	%	0.2 - 8	5 - 10

The symbols used in the table are consistent with the EN standards
($_d$) value calculated based on the determined other parameters. Usually oxygen content is determined in this way.
($_t$) total

Fuel properties can also vary significantly within the biomass and mineral fuel groups (Table 3-4, Table 3-5), but these differences remain minor in comparison with those observed between mineral and biomass fuels. However, the existence of such differences in fuel quality highlights the fact that standardisation is important for guaranteeing an even and adequate quality of fuel for the consumer.

Table 3-4: Chemical properties of some biomass fuels[18]

Property		Unit	Pine wood sawdust	Willow chips	Wood pellets
Carbon	C^a	%	47.4	43.9	49.1
Hydrogen	H^a	%	5.21	5.23	6.04
Sulphur (total)	S_t^a	%	0.10	0.08	0.12
Nitrogen	N^a	%	0.03	0.59	0.41
Chlorine	Cl^a	%	0.062	0.036	0.052
Volatile matter	V^a	%	57.5	69.6	80.6
Volatile matter	V^{daf}	%	64.3	80.5	84.6
Ash content	A^d	%	2.2	2.2	0.6

17 Krystyna Kubica, Boštjan Paradiž, Panagiota Dilara; Small combustion installations: Techniques, emissions and measures for emission reduction; Scientific Reports of the Institute for Environment and Sustainability, EUR 23214 EN – 2007; http://ies.jrc.cec.eu.int/365.html

18 Krystyna Kubica; Toxic organic pollutants from Small Combustion Installations and pyrolysis experiments, Procc. of the 2007 International Conference on Coal Science and Technology, The University of Nottingham,UK 28th – 31st August 2007.

Table 3-5: Chemical properties of different mineral fuels[19]

Property		Unit	Bituminous coal 1	Bituminous coal 2	Lignite coal	Anthracite
Carbon	C^a	%	74.1	78.5	58.8	90.1
Hydrogen	H^a	%	4.77	4.2	4.90	1.35
Sulphur (total)	S_t^a	%	0.42	0.64	1.49	0.83
Nitrogen	N^a	%	1.22	1.38	0.78	0.72
Chlorine	Cl^a	%	0.041	0.134	0.185	0.005
Volatile matter	V^a	%	34.0	32.8	42.10	1.68
Volatile matter	V^{daf}	%	37.6	35.0	54.3	1.77
Ash content	A^d	%	3.2	4.0	4.7	1.6

- **Ash content and ash composition**

Ash is the non-combustible residue left after the complete combustion of the fuel. Ashes represent the bulk of the inorganic (mineral) matter after carbon, oxygen, sulphur and water have been driven off during combustion. Ash mostly consists of oxides of sodium, potassium, magnesium and other alkali metals.

The quantity and characteristics of the ashes formed depend on the fuel composition (Table 3-6) and fuel type (Table 3-7), as well as on the combustion temperature. Greater amounts of ash particles are released at high temperatures than at low ones. Moreover, the temperature of ash fusibility (where the ash melts), defines how readily the ash can become entrained in the gas flow. This can contribute to slagging or creosote build-up in the appliances when the ash fuses (solidifies) on the heat exchangers or chimneys of the appliance. This decreases the performance of the equipment over time and contributes to increased safety hazards.

Table 3-6: Typical ash content of biomass solid fuels[20]

Biomass fuel type	Typical ash content
Clean wood	0.5%
Wood with bark	1.5%
Peat	1 – 10%
Energy plants	5 – 15%

19 Kubica K., Kubica R., Szlek A. (2007) Elaboration of low emission combustion technology of solid fuels - coal and biomass in small capacity boilers and strategy its implementation, PBR-16/RIE-6/2007, ITT Gliwice

20 Haaparanta S., Myllynen M. and Koskentalo T. (2003) Pienpoltto pääkaupunkiseudulla (Small-scale combustion in the Helsinki Metropolitan Area), YTV, Helsinki, Finland.

Table 3-7: Typical chemical properties of mineral and biomass ash content[17]

Ash chemical composition	Unit	Biomass	Mineral
SiO_2	%	26.0 - 54.0	18.0 - 52.3
Al_2O_3	%	1.8 - 9.5	10.7 - 33.5
CaO	%	6.8 - 41.7	2.9 - 25.0
K_2O	%	6.4 - 14.3	0.8 - 2.9
P_2O_5	%	0.9 - 9.6	0.4 - 4.1
Na_2O	%	0.4 - 0.7	0.7 - 3.8

- **Volatile matter content**

Volatile matter content is the quantity of organic matter which readily vaporises at high temperatures. While VOCs can encompass a broad range of chemical compounds, they are defined as "any organic compound having an initial boiling point less than or equal to 250°C measured at a standard pressure of 101.3 kPa"[21]. VOCs are typically a mixture of long chain and aromatic hydrocarbons and some sulphur. They are an important outdoor air pollutant contributing to global warming and ozone creation.

- **Calorific value**

Calorific value (also called heating value) of a fuel is one of the major parameters related to appliance efficiency. The calorific value of a fuel is the quantity of heat produced by its combustion. It can be expressed either as a Net or Gross value.

Net calorific value (NCV; the lower calorific value) supposes that the products of combustion contain the water vapour, i.e. the heat contained in water vapour is not recovered. Gross calorific value (GCV; the higher calorific value) supposes that the water of combustion is entirely condensed and that the heat contained in the water vapour is recovered.

The calorific value differs among the different types of fuels, e.g. biomass and mineral fuels, as well as within biomass and mineral fuels available on the market. The commonly used value for wood is 19 MJ/kg. In fact, the heat content of the dry matter does not vary significantly across different wood species.

Table 3-8: Gross calorific value of coal and biomass fuel[17]

Property	Symbol	Unit	Biomass	Mineral
Gross calorific value	Q_s^a	MJ/kg	16 - 20	21 – 33

21 Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC, available at: http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&numdoc=32004L0042&model=guichett&lg=en

Table 3-9: Commonly used gross calorific values of commercial solid fuels[22]

Commercial fuels	Gross calorific value [MJ/kg]
Anthracite	29.3 – 33
Coke	25.1 – 29
Blind coke	26 – 30
Briquette to open fireplaces	26 – 32
Briquette to closed fireplaces	27 – 32.2
Bituminous coal	22.5 – 32
Brown coal briquette	18 – 21.3
Peat briquette	16.8 – 19.3
Wood log	17 – 20.3
Wood briquette	17.5 – 19.5
Pellet	16.6 – 20.5

- **Moisture**

Moisture is a measure of the water content in the fuel. Water content is a key parameter of the fuel, since it directly affects the lower or gross calorific value of the fuel, and thereby the heat which is available for extraction from the fuel, depending on the type of appliance.

Moisture content tends to be higher in biomass fuels than in mineral fuels (Table 3-10). Moreover, moisture content can vary significantly within a fuel type, especially for biomass fuels. The moisture content of solid fuels varies according their storage conditions, their physical state and their pre-treatment, if any.

Table 3-10: Typical moisture content of biomass and mineral fuels[17]

Property	Symbol	Unit	Biomass fuels	Mineral fuels
Moisture	W_t^{ar}	%	8 – 50	5 – 15

[22] Values derived from various sources such as:

- Krystyna Kubica, Boštjan Paradiž, Panagiota Dilara; Small combustion installations: Techniques, emissions and measures for emission reduction; Scientific Reports of the Institute for Environment and Sustainability, EUR 23214 EN – 2007; http://ies.jrc.cec.eu.int/365.html
- Elert, G. (2003), Energy Density of Coal, The Physics Factbook,
- http://hypertextbook.com/facts/2003/JuliyaFisher.shtml
- SGI Canada (2004) "Burning Wood Safely",
- http://www.sgicanada.ca/sk/residential/pdf/SLB011_BurnwoodsafelySK04.pdf

Fresh, non-seasoned biomass fuels can have high moisture content (>50%). The moisture in freshly cut firewood can range from 35 to 70 percent. For good combustion, the wood is to be properly seasoned: dry wood has less than 20% water content (by weight). When properly seasoned, each piece will have deep cracks in its end grain and will tend to have a dark grey colour. Table 3-11 presents commonly recommended drying times for wood (cut, split and stacked). However, exact drying time depends on the wood type, storage methods and weather conditions.

Table 3-11: Guidelines for drying times to obtain firewood of 20% moisture content[23]

Storage conditions	Size of firewood	Recommended drying time
Under shelter	33 cm wood logs in sections	15 months
	33 cm wood (rounded) logs	17 months
In the free air	1 m wood logs in sections	18 months
	1 m wood (rounded) logs	> 24 months

Inappropriate storage conditions may lead to very high moisture content for any fuel, and especially for wood pellets, which easily absorb moisture if stored in humid conditions.

➔ Effect of fuel characteristics on the operation of solid fuel SCIs

Comprehensive information on how solid fuels influence the combustion process, and therefore the efficiency and emissions of the SCI, is important to choose the right solid fuel selection for the appliance. Possible effects of different fuel characteristics on the combustion process and performance of SCIs are presented in Table 3-12.

Table 3-12: Main effects of fuel characteristics on appliance operation[19]

Parameter	Selection*	Effect of inappropriate fuel selection
Calorific value	E	Chimney loss
		Heating surfaces fouling
		Deformation of steel parts caused by overheating
	B	Power output below set point
		Decreased efficiency
Ash contents	E	Heating surface fouling
		Decreased efficiency
		Slag loss
	B	Insufficient insulation of grate elements
Moisture contents	E	Fly ash loss
		Slug loss
		Chimney loss (including increased emission of soot and heavy organic pollutants associated with PM)
		Decreased efficiency
	B	Chimney loss

23 ADEME (2008) Guide pratique « Le Chauffage au bois » http://www.ademe.fr/particuliers/Fiches/chauffage_bois/index.htm

Parameter	Selection*	Effect of inappropriate fuel selection
Volatile matter contents	E	Chimney loss
	B	Decreased efficiency
		Slag loss
Caking properties	E	Slug loss
		Chimney loss
	B	Inappropriate stoking (strict limitations by automatically stoked appliances)
		Fly ash loss
Grain size distribution	E	Inappropriate stoking (strict limitations by automatically stoked appliances)
	V	Chimney loss
		Slug loss
		Increased pollutants emission due to inappropriate combustion
	B	Fly ash loss
Ash melting point	B	Slug loss
		Heating surfaces fouling
Sulphur contents	E	Excessive emission of SO_2, corrosion
Chlorine contents	E	Excessive emission of HCl, corrosion

* E: values exceeding recommendation.
B: values below recommendation.
V: variable values.

Using fuels of inappropriate quality not only influences the combustion process (its energetic efficiency and environmental impact) but can also affect the mechanical operation of the SCI. For example, for retort boilers[24] which have an automatic fuel-feeding system, when poor quality of fuel is used (i.e. of high sintering ability) or if grain size distribution of the fuel is not suitable, the feeder safeguard cotter pin (Figure 3-5) is likely to break and the feeder will stop. In the first case this is due to the fact that the retort heart becomes blocked with sintered fuel, while in the second case the fuel is mechanically blocking the feeder.

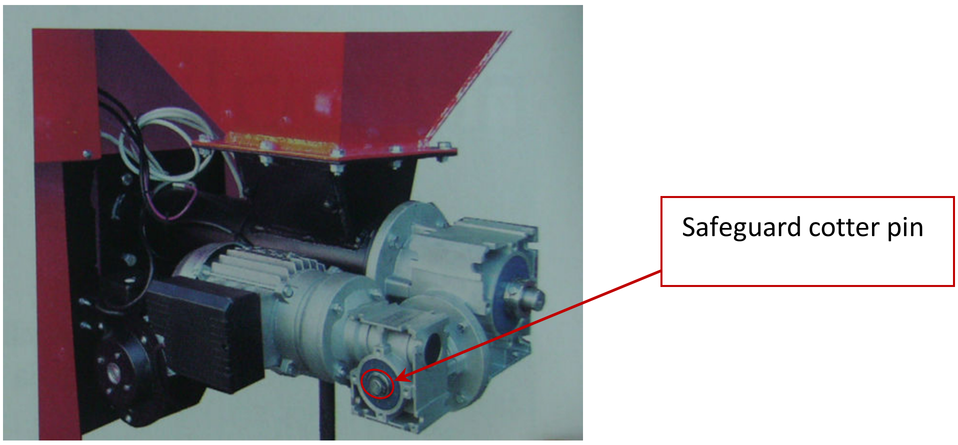

Figure 3-5: Safeguard cotter pin on the screw conveyer feeding the fuel

[24] Retort boiler structure and technology will be explained in detail in Task 4.

➔ Effect of fuel characteristics on the efficiency and emissions of solid fuel SCIs

Effect of fuel type on emissions

Fuel type is one of the key determinants of pollutant emissions from solid fuel SCIs, with different fuel types leading to different types and quantities of emissions. These differences are illustrated in Table 3-13 for a mineral fuel and wood pellets (burnt in a retort hearth boiler[24,25]). Similar differences between mineral fuels and biomass fuels can be observed in other types of appliances (i.e. chamber boilers and stoves[26]). Figure 3-6 shows how emissions differ between wood logs, manufactured wood pellets and bituminous coal (all burnt in a boiler) [27].

Table 3-13: Measured pollutant emission factors for selected fuels burnt in retort hearth boiler[28]

Emission factor	Symbol	Unit	Pea coal[3]	Wood pellets
CO	E_{CO}	mg/MJ	263	442
SO_2	E_{SO2}	mg/MJ	118	2
NO_2	E_{NO2}	mg/MJ	128	147
VOCs (C_3H_8)[1]	E_{C3}	mg/MJ	1.2	10.9
Dust	E_{dust}	mg/MJ	21.5	18.2
TOC	E_{org}	mg/MJ	22.0	19.6
16 PAHs	E_{PAHs}	µg/MJ	298.0	96.1
B(a)P	E_{BaP}	µg/MJ	7.3	9.1
PAHs[2]	E_{7PAHs}	µg/MJ	40.6	29.1
PCDD/Fs	I-TEQ	µg/MJ	0.055	n.a.

1 VOCs recalculated as the equivalent emission of propane C_3H_8 (C3).
2 benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthen together with benzo(g,h,i)perylene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene and dibenzo(a,h)anthracite.
3 Pea coal: certified fuel; special assortment of coal having narrow selected grain size distribution (size of grains between 5 and 25 mm) and other parameters appropriate for retort boilers.

25 Please note that this comparison seeks to illustrate the impact of fuels rather than present generally valid conclusions.

26 Ross A.B. et al. (2002) Measurement and prediction of the emission of pollutants from the combustion of coal and biomass in a fixed bed furnace, Fuel t. 81 no. 5 pp571-582

27 Log wood: Gross Calorific Value (GCV) 16.0 MJ/kg, wood pellet: GCV 19 MJ/kg. Coal based on bituminous coal with GCV of about 28 MJ/kg.

28 Kubica, K. (2007) Toxic organic pollutants from Small Combustion Installations and pyrolysis experimental, Proceeding of the 2007 International Conference on Coal Science and Technology, Nothingam 28-31st of August 2007.

Note that the CO_2 emissions are considered zero by political default for renewable fuels and hence only shown for coal. Indeed, as explicitly stated in the MEEuP[29] methodology, direct CO_2 emissions from biomass are not considered to be a greenhouse gas emission because forests and plants recycle carbon dioxide when growing.

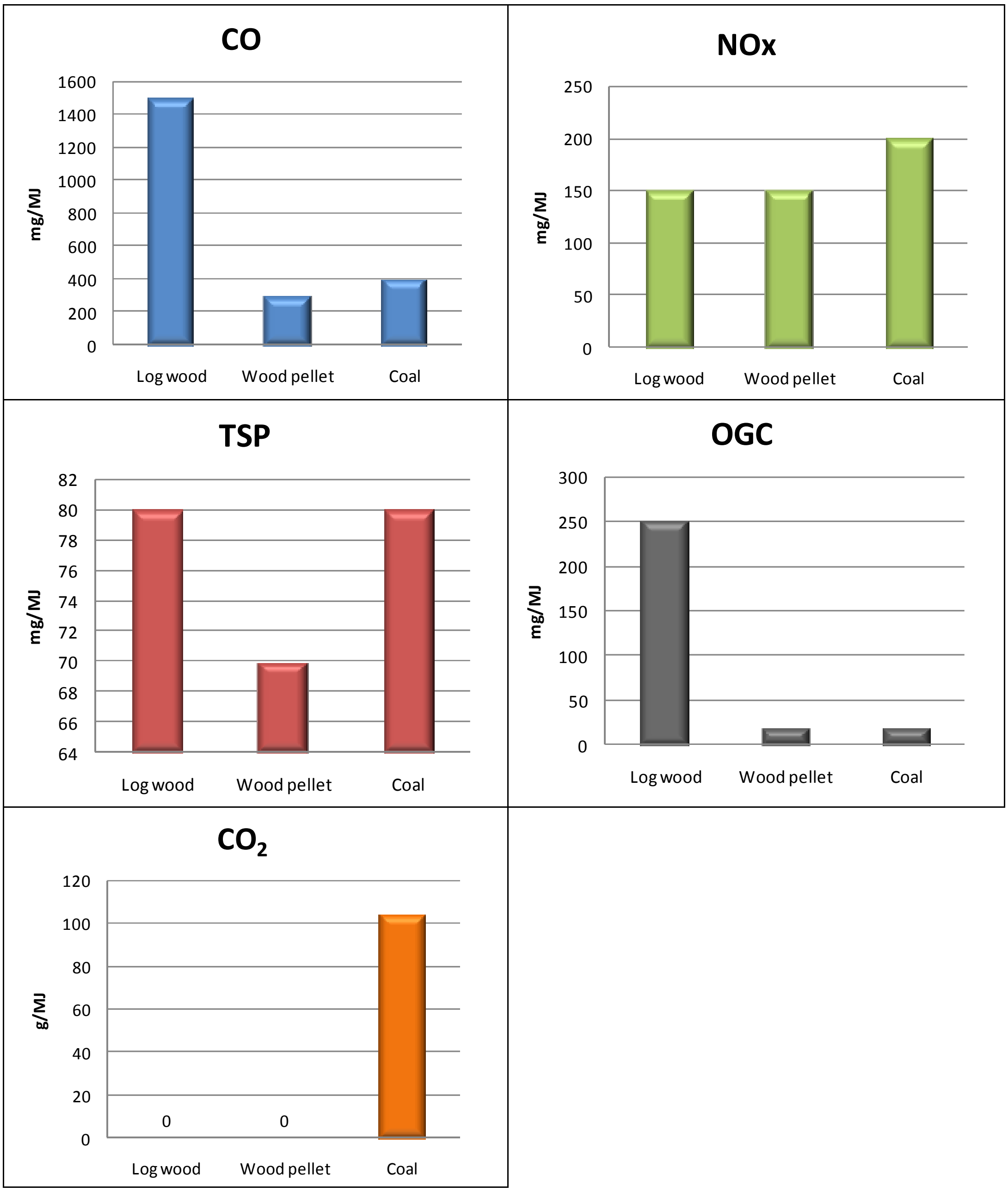

Figure 3-6: Examples of emissions from the combustion of different fuels[12],[30]

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[29] VHK (2005) Methodology Study Eco-design of Energy-using products. http://ec.europa.eu/energy/demand/legislation/doc/2005_11_28_finalreport1_en.pdf

[30] For CO_2, the source is: Wach E. (2004) Granulat drzewny. Wygodne paliwo do kominków, pieców i kotłów. Świat kominków 1 (3)/04

Effect of fuel moisture on efficiency and emissions

Burning a fuel with high moisture content affects combustion quality, and therefore efficiency and emissions of solid fuel SCIs. As moisture content increases, more energy is consumed in heating and evaporating the moisture rather than burning the wood. This reduces significantly the efficiency of the fire. Several studies suggest that high wood moisture content (> 30%) is one of the most important causes of performance loss[31,32]. Table 3-14 illustrates the resulting losses of calorific value and efficiency caused by a moisture content of 37.5% compared to 1.7% and 8.3% moisture (dry fuels).

Table 3-14: Net calorific value and efficiency losses due high moisture content[33]

	Unit	Dry wood (beech wood after 105°C drying)	Seasoned wood (air-dry seasoned beech wood)	Wet wood ("wetted" seasoned beech wood)
Moisture	%	1.7	8.3	37.5
Physical loss in the flue gas	%	30,91	29,99	45,21
Chemical loss in the flue gas	%	4,54	6,30	7,99
Chemical loss in the ash	%	2,2e-3	4,34e-3	7,19e-3
Efficiency	%	64,55	63,71	46,79
CELUS type D612 stove, of nominal power output equal to 5.6 kW.				

High moisture also leads to increased emissions of un-oxidised compounds and particles (above all carbon monoxide (CO), total organic carbon (TOC), and total suspended particulates (TSP)). For example, an increase of wood moisture content from 15% to 30% can lead to drastic increase in dust (TSP) emissions (Figure 3-7).

31 Bhattacharya et al (2002) Effects of selected parameters on performance and emission of biomass-fired cookstoves, Biomass and Bioenergy Vol. 23 pp387-395.

32 Johannsson et al (2004) Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Atmospheric Environment Vol. 38 pp4183-4195.

33 Kasprzyk, (2002) Influence of wood moisture on energy efficiency and pollutant emissions of burnt wood in a stove; MSc thesis ITT

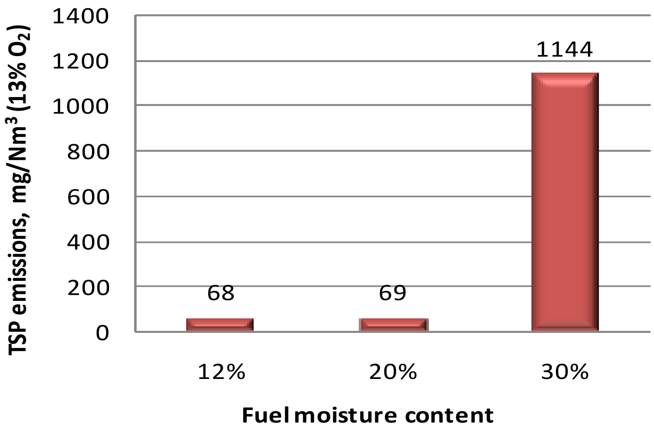

Figure 3-7: Effect of moisture content in wood (33 cm beech logs) on total dust emissions from a 30 kW chimney stove[34]

- **Effect of grain size distribution on efficiency and emissions**

Grain size distribution is important because the size and shape of the fuel affect how it can be fed or stoked into an appliance, as well as how it can be stored. While the optimum size of fuel pieces depends on the appliance, inappropriate grain (or wood log) size distribution can lead to sub-optimal combustion and cause losses or increase of pollutant emissions. For instance, Figure 3-8 shows how TSP emissions vary in a log wood stove (which operates in an updraft mode[35]) for three different quantities of beech wood logs (0.35, 0.7 and 1.4 kg), all of a similar length of 25 cm and fed at a constant fuel loading of 1.4 kg per fuel charge.

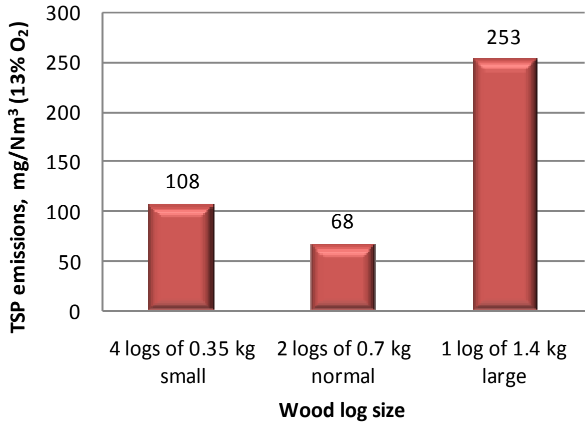

Figure 3-8: Effect of wood (beech) log size on total dust emissions from a 7 kW chimney stove[36]

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34 Measured from diluted flue gas. Source: Hartmann H. at al. (2008) Quantification and Characterisation of Particle Emissions from Residential Wood Stoves and Boilers, 16th European Biomass Conference & Exhibition, 2-6 June 2008, Valencia, Spain

35 This combustion technology is defined in Task 4.

36 Measured from diluted flue gas. Source: Hartmann H. at al. (2008) Quantification and Characterisation of Particle Emissions from Residential Wood Stoves and Boilers, 16th European Biomass Conference & Exhibition, 2-6 June 2008, Valencia, Spain

Contaminants

Solid fuels may contain contaminants, especially painted, treated and saltwater driftwood. These fuels may release toxic substances during the combustion and contribute directly to particulate emissions. Chlorine contamination, often present in the above-mentioned materials, leads to increased hydrochloric acid (HCl), polycyclic aromatic compounds (PAC), polycyclic aromatic hydrocarbons (PAH) and dioxin[37] emissions and can promote corrosion in ferrous components. The same applies to garbage, plastics or rubber, in the event that they are used as fuel.

3.2.3 USER BEHAVIOUR

Users can influence the effective operating performance of solid fuel SCIs in two ways:

- Directly, through the manual control of combustion parameters of the appliance
- Indirectly, through the maintenance of the appliance

→ Direct influence – operational practices

There are numerous manners by which users can directly influence the performance of their solid fuel SCI. This makes it difficult for users to achieve optimal combustion conditions. Optimal combustion may also not be reached simply because it is not aimed at. For instance in the case of solid fuel SCIs used for aesthetic pleasure, such as fireplaces, the main aim of the user is not necessarily combustion efficiency. Moreover, operator intervention is crucial for manually fuelled appliances whereas in the case of automatic appliances, intervention is limited to supervision and safety issues. The most important ways in which a user can influence combustion conditions are described below.

Ignition and kindling of the fire

The first stage of the fire, right after kindling or adding new fuel, creates most of the particulate matter emissions (smoke). This is because at the beginning, the fuel is still cool and water is evaporating from the fuel. Moreover, the inside of the stove is also cool and removes heat from the flames.

It is necessary to achieve a hot flame at this early stage by ensuring a sufficient air flow at the start-up (by opening air inlets). It might appear that this initial hot burn lets too much heat go up the chimney but it is a necessary part of an efficient fire. The extra heat "primes" the chimney to produce a strong draught and helps keep the flue liner clean by loosening creosote that might have been deposited by the previous fire. The

37 Dioxins comprise polychlorinated di-benzo dioxins (PCDD) and –furans (PCDF)

hot initial burn also drives moisture out of the firewood and gives an ignition source for the smoke that is released from the wood.[38]

Emissions can be reduced by modifying the ignition mode. Ignition from the top results in significantly lower emissions than conventional ignition from the bottom. In conventional ignition from the bottom, the whole fuel batch burns simultaneously and the flame is cooled by the logs above, resulting in incomplete combustion. In contrast, ignition from the top leads to a stepwise and more complete combustion, resulting in reductions of PM emissions by 50% to 80% compared to traditional ignition from the bottom.

- **Automatic fuel feeding**

Even in the case of boilers equipped with automatic fuel feeding and programmable electronic controllers, incidents of inappropriate user intervention have been observed. Improper controller setup can lead to serious malfunctions of the appliance. Such malfunctions can cause a decrease of both energetic and environmental effectiveness (e.g. increase of slug loss). Improper set points of the fuel feed system may lead to excess slagging and sintering of coal, for example causing reduction in appliance efficiency and also feeder malfunction (see Figure 3-9). For comparison, a well set up combustion process in the same appliance is presented in Figure 3-10. The excess slagging and sintering may also lead to increased convection from the combustion zone and hence to increased emissions.

Figure 3-9: Slagging of retort hearth

[38] Natural Resources Canada (1999) Getting the most out of your wood stove

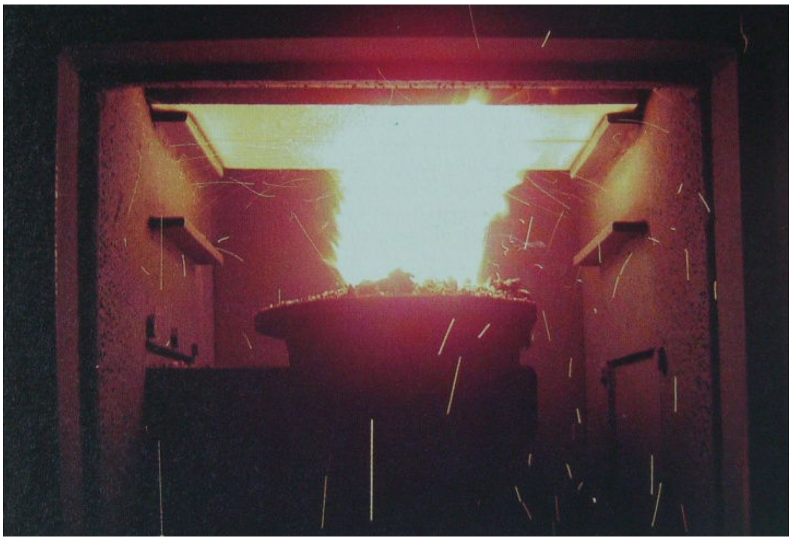


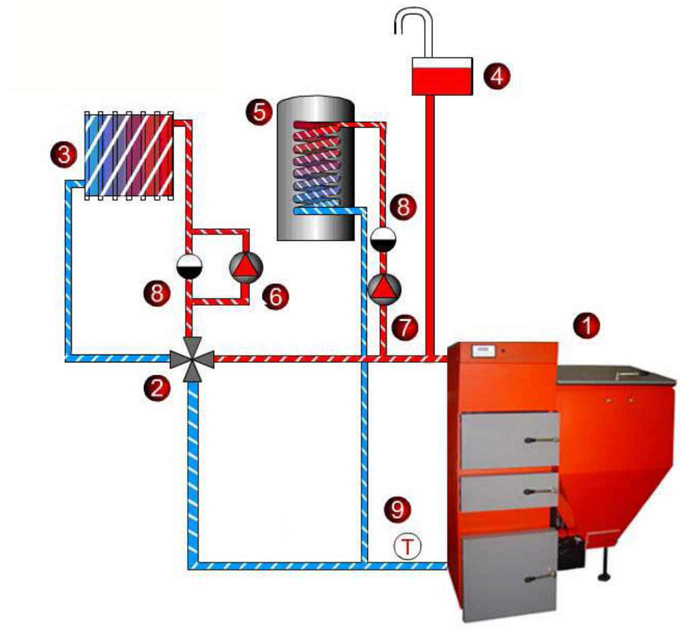
Figure 3-10: Well controlled combustion in retort boiler

- **Temperature control**

Temperature control for solid fuel SCIs is often achieved manually through the frequency and amount of fuel loaded. Automatically-fuelled and controlled appliances in contrast can have dynamic temperature controls, which adjust according to the outside temperature. Absence, incorrect location, or misuse of heating controls can reduce the energy efficiency of solid fuel SCIs. For instance, in many households, the central heating thermostat is set for comfort rather than for efficiency. One degree reduction in room thermostat set-point is often cited to reduce energy use for heating by up to 10% in the UK[39].

Indirect heating appliances also have secondary temperature set points (for the temperature of the heat exchanging fluid). If the user controls the warmth of radiators by means of the boiler temperature set point instead of using the mixing valve (Figure 3-11), the boiler will operate below recommended temperatures on both inlet and outlet. Such improper temperature operation can lead to low-temperature corrosion, inefficient heat exchanger operation and decrease the lifetime of the appliance.

[39] For example at the Energy Savings Trust http://www.energysavingtrust.org.uk/what_can_i_do_today/getting_started



1. boiler
2. four-way mixing valve
3. radiators
4. pressure vessel
5. buffer tank
6. circulating pump
7. circulating pump
8. non-return valve
9. thermometer

Figure 3-11: An example of a system equipped with 4-way mixing valve enabling water temperature control

- **Timer control**

Incorrect use of timer controls can lead to excessive operation of a heating system during periods when the dwelling is empty.

- **Air feed and distribution**

Air is a key component of the combustion process. Solid fuels require ample air in order to burn properly (7–10 m^3/kg of wood). Sufficient oxygen supply is the prerequisite for maintaining proper flames throughout the combustion cycle until the fuel is reduced to ashes. The turbulence in the flames creates good mixing between the combustion air and the gases that are released during pyrolosis of the fuel. The heat of the fire ignites and burns these mixing gases.

In contrast, insufficient air supply leads to incomplete combustion. The dense smoke from a slow, smouldering fire is potential heat energy that escapes up the chimney and either clings to the chimney flue as creosote or pollutes the outdoor air. In the worst case, the fire can go out if it is deprived of air. Therefore, air supply is one of the most important parameters affecting the efficiency of solid fuel SCIs, enabling to gain the maximum heat from each load of fuel. Closing the air inlet after start-up in a conventional stove to prolong the combustion time, can increase emissions (PM) by a factor of 10[40].

The air requirements depend on the type of fuel and on the combustion technology. To illustrate the differences, Table 3-15 presents air requirements specified for SCIs with relatively good energy efficiency and fuels. The table indicates the typical range of values for the excess air ratio "λ" for combustion of fuel in real life. λ is the ratio of actual air demand divided by the stoichiometric air necessary for combustion. Stoichiometric air demand depends on the chemical composition of the fuel (i.e. C, H, N, S and O content), whereas actual air demand for fuel depends on the combustion technology and design of the appliance.

Table 3-15: Examples of combustion air needs in different biomass fuel appliances[41]

Appliance	Power output	Efficiency	Fuel feed	Stoichiometric air demand	Excess air ratio	Actual air demand	
	kW	%	kg/h	Nm^3/kg	λ	Nm^3/kg	Nm^3/h
Automatic boiler	25	90	7.7	2.9	2.2	6.5	56.0
Hand stoked chamber boilers	25	80	8.7	2.9	2.5	7.4	63.6
Hand stoked chamber boilers with air distribution,	25	80	8.7	2.9	2.0	5.9	50.9
Cookers	10	60	2.9	2.9	2.0-3.5	10.3	47.5
Stoves	10	70	3.9	3.3	2.0-3.5	3.0	38.7
Fireplaces	10	75	3.9	3.3	2.0-3.5	3.5	45.2

40 Klippel et al (2007) Health relevance of particles from wood combustion in comparison to Diesel soot, 15th European Biomass conference , Berlin, May 2007.

41 The values have been calculated with net calorific value (NCV) of 13 MJ/kg.

Table 3-16: Examples of the combustion air needs in different coal fuel appliances[42]

Appliance	Power output	Efficiency	Fuel feed	Stoichiometric air demand	Excess air ratio	Actual air demand	
	kW	%	kg/h	Nm^3/kg	λ	Nm^3/kg	Nm^3/h
Automatic boiler	25	80	4.5	7.3	2.0-3.5	16.1	72.4
Hand stoked chamber boilers	25	80	4.5	7.3	2.0-3.5	18.3	82.3
Hand stoked chamber boilers with air distribution,	25	80	4.5	7.3	2.0-3.5	14.6	65.8
Cookers	10	60	2.4	7.3	2.0-3.5	25.6	61.4
Stoves	10	60	2.4	7.3	2.0-3.5	21.9	52.6

Air combustion may be supplied into the combustion chamber in either of two ways:

- **Natural draught (chimney draught control)**

Most manually fuelled appliances use natural draught, and chimney features therefore play an important role in the performance of these appliances[43]. The air supply/ draught can to a certain extent be controlled by means of a gate valve or damper, by varying the flue gas cross-section area (especially in case of cookers, fireplaces and some stoves). However, in practice it is difficult to control the efficiency or emissions in this way. Thus in these appliances, the combustion process is often far from optimum because of a high excess air ratio (ranges between 2 and 5).

- **Forced draught (fan-assisted air control)**

In some boilers, an additional fan for air supply is used. In such cases more precise control of power output and somewhat more constant efficiency and emissions are possible. Air demand decreases, falling below 2. Fan-assisted air supply is generally used in appliances with automatic fuel supply. Instantaneous control over fuel and air feed leads to optimum efficiencies, given that a proper control algorithm and controller is used. In such appliances, air demand can even reach a level below 1.5. However such control requires an electrical power supply.

An example of the differences in direct environmental emissions of selected pollutants of a boiler with and without fan assistance is shown in Figure 3-12. However, if designed properly, forced and natural draught SCIs can achieve similar results. Emissions from different types of appliances will be further assessed in Task 4.

42 The values have been calculated with net calorific value (NCV) of 25 MJ/kg.
43 The impact of the chimney will be discussed in more detail in Task 4.

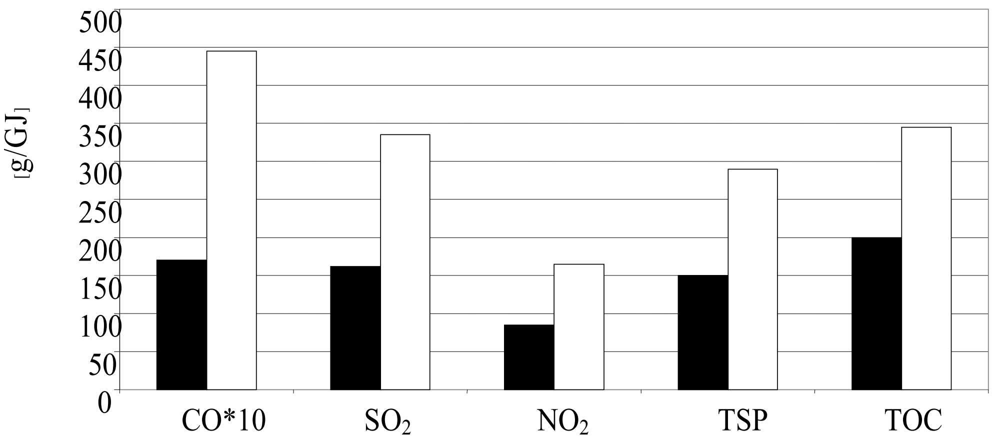


Figure 3-12: Emissions from a manually fuelled fixed bed coal boiler of 30 kW[44] under natural draught (in white) and under forced draught (in black)[45]

➔ Indirect influences - maintenance practices

For proper operation, solid fuel SCIs need regular maintenance. Necessary interventions, whether self-performed or professional (chimney sweeper or installer) are outlined in Section 3.2.5

Neglecting these maintenance operations may have a detrimental impact on the combustion process and on the emissions. The appliance itself can be damaged due to poor maintenance, resulting in a reduced lifetime. A common problem for solid fuel SCIs is the heat-exchanger part of a boiler may suffer from fouling with tar and soot (Figure 3-13). Such situations lead to resistance of flow on exhaust gases ducts, causing decreased efficiency (each mm of soot on the surface of the heat exchanger of the appliance reduces the efficiency of about 5%), increased fuel consumption and the risk of soot ignition.

Neglecting maintenance seems to be rather common and can compromise the performance of an appliance in real life to a varying degree. However, it has been impossible to quantify the extent or frequency of such user behaviour.

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44 Measurements carried out according to EN 303-5, at nominal capacity in laboratory conditions.

45 Kubica,K., Paradiz, B., Dilara, P. (2007) "Small combustion installations: Techniques, emissions and measures for emission reduction", JRC Scientific and Technical Reports, EUR 23214 EN – 2007, http://ies.jrc.ec.europa.eu/fileadmin/Documentation/Reports/Emissions_and_Health/EUR_2006-2007/EUR_23214_EN.pdf

Figure 3-13: Soot and tar fouling of heat exchange surfaces

Repair of the appliances

There are normally no or very few parts that need to be changed during the "normal lifetime" of a solid fuel SCI. Only wearing parts like grate, gaskets/joints, door, viewing glasses, etc, may need to be replaced according to the intensity of use and the frequency of maintenance of the appliance. For example, ceramic grates, or corresponding parts in wood log boilers with this technology, normally have to be retrofitted during the boiler lifetime. Changing these parts normally requires professional intervention.

→ Real life user practices

Given the number of factors which can affect the real-life efficiency and emissions of solid fuel SCIs, it is important to assess which are the most influential. This information can then be used in Task 8 for instance, to assess the sensitivity of the recommendations to these parameters. We discussed above how fuel and operational practices can affect the performance and emissions of solid fuels, in particular:

- For fuel: fuel moisture and fuel size
- For user behaviour: batch size, method of ignition (top or bottom), air control

Gap between real-life operational practices and test standard conditions

Standard experimental tests are generally finalised for testing appliances and do not always correspond to real wood burning procedures practiced by the public. This is particularly true for small-scale appliances in households, where fuel is manually fed, and new fuel amounts are added in an intermittent and discontinuous way.

Operating conditions are often related to individual behaviour but also to cultural habits and energetic or environmental aspects of the living area, that can differ considerably from country to country[46]. Operational practices also change with time. In the past the houses were poorly insulated and there was always somebody at home that could take care of the fire. Nowadays, nobody takes care of the fire through the night and houses are well insulated but often empty during the day. Therefore, to get a comfortable temperature at home, less heat output is needed. The tendency is then to fill the stove with a big load of wood and nearly close the air supply so that the average wood consumption is low and the fire lasts longer. This results in low efficiency, high pollutant emission and coating of the chimney with risks of chimney fire[47]. This is the main reason why emissions from residential solid fuel combustion have become an increasing problem.

To date, no EU-wide information regarding the manner in which real consumers operate their solid fuel combustion appliances has been compiled. However, studies published in other states can provide indications on the type of user practices. Recently, Environment Australia conducted a survey[48] on a sample of Australian residents using biomass (wood log) fireplaces, stoves or cookers to assess how much consumer behaviour deviates from the national standard test procedures. The findings from this study are summarised in Table 3-17 and indicate that in real-life users overload their appliance, and use improper air control and lighting procedures. While the test standards referred to in this study are the Australian standards (AS/NZS 4013:1999. Domestic solid fuel burning appliances), the implications of the differences are expected to be similar in a European context. This study provides one of the best insights into the magnitude of variation in the practices of users. Surveys similar to this one in Europe could help modify emission testing procedures to better represent the habits of users, and accordingly to improve solid fuel SCI designs, and to direct implementing measures.

46 Angelino, Bertagna, Caserini, Giudici, Hugony, Marengo, Mascherpa, Migliavacca (2005) "An extensive survey on wood use for domestic heating in Lombardy: implication for PM emission inventory", ARPA Lombardia – Environmental Protection Agency of Lombardy Region, ITALY

47 Karlsvik et al (1994). Emissions from wood stoves and fireplaces. In Advances in Thermochemical Biomass Conversion, pp 690-707.

48 JJ Todd, (2008), Woodheater Operation and Firewood Parameters: Australian Department of the Environment, Water, Heritage and the Arts, Australia, Available at: http://www.environment.gov.au/atmosphere/airquality/publications/pubs/wooheater-operation.pdf [accessed Feb 16 2009]

Table 3-17 – Results of user behaviour survey of 80 wood heated households[48]

Variable	Findings
Wood moisture	40% of firewood used has 12% - 16% moisture. 7% of firewood was very wet (>30% moisture)
Log weight	Twice that used in standard conditions (but there is a large variance).
Log loading geometry	33% of users load logs properly, 25% load logs in a way that blocks combustion air Rest inconsistent log loading
Number of logs added	60% added only one log when refuelling
Lighting the appliance	The most common lighting practice was to use newspaper and kindling, adding more substantial logs once the kindling was well alight. 1/3 of users used firelighters 50% of the users left the fuel-loading door ajar during lighting for 15 minutes average and 50% closed the door immediately
Overnight burning	> 50% of users operated their appliance overnight to the next day at least once during the survey 25% kept the appliance burning overnight half the time. In about 33% of the overnight burns, the user had to re-establish the fire the next day. Maximum unattended burning times averaged about 8 hours.
Air control settings	Appliances were frequently operated with air controls fully open. It was common practice to load wood and immediately set air controls to low burn rates. This occurred 17.5% of the time fuel was added. Some households follow best practices and run the appliance with maximum air for 10 minutes or more before turning the air control to low, but the proportion is small.
Fan control settings	1/3 of appliances used fans. 50% used fans correctly throughout the survey period 50% used fans badly, either running the fan too high when burning the appliance slowly, or too high when lighting the appliance.
Time intervals between refuelling	On average, householders refuelled their appliance every two hours. They adjusted air controls slightly more frequently, but usually at the same time as refuelling.

Impact of the gap between user practices and test standard conditions

Differences between standard laboratory test conditions and actual operating habits of users are known to be significant[49], but the extent of this difference can only be determined through real-life surveys of SCIs emissions and performance. It is important to understand these differences because in the context of the Lot 15 study, the actual emissions from domestic solid fuel SCIs can be more relevant to any subsequent implementation measures than the emissions under standard test conditions.

49 Klippel et al (2007) Health relevance of particles from wood combustion in comparison to Diesel soot, 15th European Biomass conference, Berlin.

Standard test methods generally reflect general solid fuel combustion operation in steady-state. As a result, several variables that influence real-life emissions cannot be included in standard tests. For instance transient phases, such as when the fuel temperature is locally raised up to several hundred degrees during kindling and refilling procedures (that are likely to be repeated several times per burning session) are not simulated by the standard methods used for testing small combustion devices[50]. Yet, clear spikes in certain emissions can be observed at transition moments such as refuelling or kindling (Figure 3-14). It has been shown that up to 30% of the cumulative total PM emissions from an 8 hour burn cycle and 50% of VOC can be emitted during transient burn phases. Type test conditions also tend to be under constant draft, which leads to lower emissions in the ignition phase than under natural draft conditions (up to 50% PM emission reduction)[51]. This is because natural draft is low during the start-up, which leads to an extended ignition phase with rather low temperature in the combustion chamber, resulting in incomplete combustion.

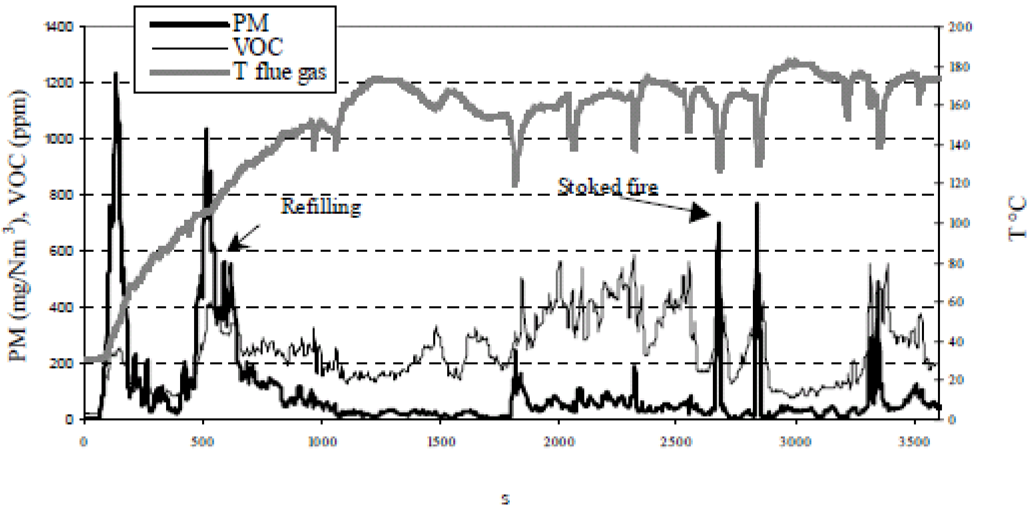

Figure 3-14: Variations of emissions over time after loading a closed fire place with beech wood[50]

In one of the few comparative studies, Bhattacharya et al compared the role of fuel moisture, fuel size, and ignition procedure on the performance and emissions of cook stoves[52]. Fuel moisture was found to have the most significant effect on the efficiency and performance of the stoves, with increasing moisture resulting in a decrease in stove efficiency and double the production of CO depending on the stove type and fuel type used. The effects of fuel size were less pronounced than those of moisture, however increasing the fuel size was found to slightly increase the production of CO

50 Angelino, Bertagna, Caserini, Giudici, Hugony, Marengo, Mascherpa, Migliavacca, "Experimental investigations of the influence of transitory phases on small-scale wood combustion emissions" ARPA Lombardia – Environmental Protection Agency of Lombardy Region, Italy.

51 Nussbaumer et al (2008) Influence of ignition and operation type on particle emissions from residential wood combustion. 16th European Biomass Conference Exhibition, Spain.

52 Bhattacharya et al (2002) Effects of selected parameters on performance and emission of biomass-fired cookstoves. Biomass and Bioenergy Vol 23 pp387-395.

and NOx. Top ignition slightly decreased CO and NOx emissions compared to bottom-up emissions. In a conventional stove operated under typical heating conditions, with the fuel chamber filled to more than 50%, PM emissions can increase by a factor 5 to 10 due to incomplete combustion[51], presumably as a consequence of insufficient mixing and too short residence time in the hot zone[53]. Improper air control, such as closing the air inlet after start-up to prolong the combustion time can increase emissions by another factor of 10. But top ignition enabled PM reductions of 50-80% in comparison to traditional ignition from the bottom[50].

Real-life surveys of SCIs performance and emissions are also scarce. But results from a residential survey conducted in Poland do indicate wide variations in real-life conditions compared to test standard conditions (Table 3-18). In the case of the automatic pea coal boiler, all emissions except dust are lower in real life than in test standards. This may indicate that the measurements in real-life conditions were conducted for an output well below the nominal one. The results for dust may indicate that the quality of the fuel used was not far from the test fuel parameters, maybe because the users were somehow obliged to buy a certified fuel (e.g. participants of a program on low emission abatement). In the case of the automatic fine coal boiler, NOx and SO_2 emissions are also lower in real-life measurements than in test standard conditions, which may indicate that these measurements were also conducted for an output well below the nominal one. The higher CO emissions in real-life conditions may indicate that the combustion process was carried out under inappropriate conditions (e.g. insufficient air supply). The high values for dust, could result from low quality fuel – far from the test fuel parameters (especially taking into account grain size distribution) and/or from inappropriate combustion conditions.

Similar differences between real-life emissions and those measured under test standards can be observed for biomass solid fuels, where fuel composition is particularly variable according to the type of biomass (e.g. coniferous or deciduous wood) and where moisture can also vary significantly.

[53] But more modern appliances (e.g. with two-stage combustion) can be operated with a fully filled fuel chamber without compromising the combustion efficiency.

Table 3-18: Comparison of emissions between real life and test[54]

	CO [mg/m3]	SO2 [mg/m3]	NOx [mg/m3]	Dust [mg/m3]
Automatic boiler (pea coal)				
Certification test	**425**	**510**	**305**	**135**
Real life use	260	160	240	110
	250	170	260	95
	250	180	270	100
	270	200	280	110
	190	220	140	100
	200	240	160	110
	180	220	150	95
	170	210	150	90
	210	180	170	85
	230	200	130	90
	220	180	140	100
	200	160	120	95
	240	180	160	100
	200	200	110	95
	210	180	100	85
Automatic boiler (fine coal)				
Certification test	**260**	**510**	**290**	**95**
Real life use	410	190	100	315
	410	160	85	340
	410	140	70	230
	320	150	75	210
	380	180	105	220
	480	95	80	480
	430	110	70	270
	410	160	85	340
	410	140	70	230
	380	180	90	200
	310	170	85	180
	330	200	95	190
	350	190	70	230
	380	180	90	200

54 K. Kubica, R. Kubica, A. Przybysławski (2006) Ecological effects of programme on low lewel emission reduction, in case of Tychy town (Efekty ekologiczne wdrażania programu redukcji niskiej emisji (pone), na przykładzie miasta Tychy) V Międzynarodowa Konferencja Naukowa *„Ochrona Powietrza w Teorii i Praktyce”*, Zakopane 19-21 październik.

3.2.4 FREQUENCY AND INTENSITY OF USE

The frequency and intensity of use for the different types of appliances are crucial issues because they determine to a large extent the environmental impacts caused by Lot 15 products.

➔ **Factors affecting the characteristics of use of solid fuel SCIs**

The parameters affecting the frequency and characteristics of use of these appliances include:

- Climate conditions
- Appliance type (e.g. direct vs. indirect heating appliance; automatically vs. manually fuelled)
- Appliance function (e.g. primary vs. secondary heat source)

There is clearly a link between the type of the appliance and its role. For example, a boiler is normally a utility appliance which is installed as a primary heat source. Thus, it is likely to be continuously operated over the heating season. At the other extreme, an open fireplace is likely to be installed to create atmosphere or as a decorative element rather than as a primary heat source (exceptions of course exist). Accordingly, it may only be lit a few times in the year. However, between these two extremes, appliances such as traditional or slow heat-release stoves can play either role. Even open fireplaces may serve as the main heat source in some cases.

The interaction between the above-mentioned parameters and the frequency and characteristics of use are shortly discussed below. This analysis is not exhaustive and in real-life there many other use patterns are possible. Nevertheless, it is necessary to develop certain assumptions for the purpose of the study.

■ **Climatic conditions**

The external climate has an impact on heating needs, with the geographical location effectively fixing the duration of the heating season. One way to assess climate differences between MS is the calculation of the number of heating degree days and of the length of the heating season[55]. Figure 3-15 indicates the mean number of heating degree-days over the period 1980 – 2004 in the EU 27. This indicator reflects the outdoor coldness, and thus the heat load of dwellings in each country (see Annex 2-2 of Task 2 report for the exact values).

[55] Calculation method is presented in Annex 3.1

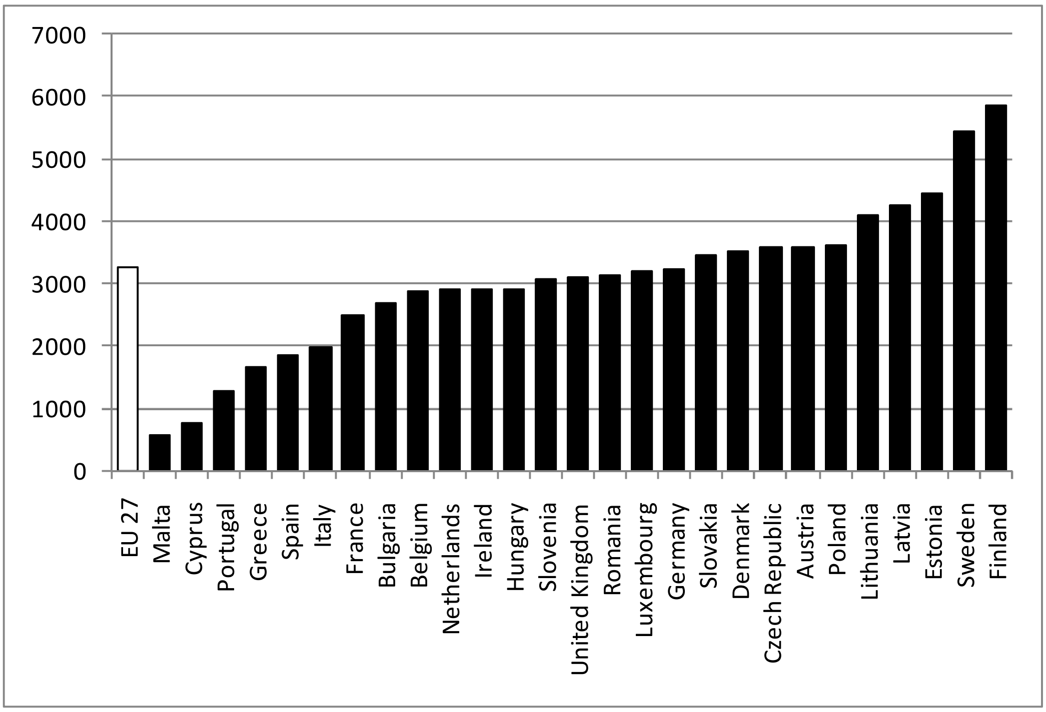

Figure 3-15: Heating degree days per country (Eurostat)

The corresponding heating seasons for EU-27 are between 3 and 10 months (representing the difference between Malta and Finland), with 70% of EU-27 having a heating season between 6 and 8 months.

Appliance type and function

While central heating appliances can be assumed to operate continuously during the heating season, direct heating appliances are mainly used as a secondary heat source and may not be operating frequently. Thus, an estimation of the share of secondary appliances, as well as their typical frequency of use, need to be made.

For example in Germany, it has been estimated that in 2007:

- 55% of the appliances are the only heat source
- 45% of appliances are auxiliary heating sources. Out of these, 43% of the appliances are "regularly" used, 46% are "occasionally" used, and 11% are not used[56].

According to a Dutch[57] study, in 1996, most people used direct heating appliances as a secondary heat source.

- 61.2% of the people use it to create an atmosphere

[56] Struschka, M. et al. (2007) Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung (Efficient provision of updated emission data for air quality control), Institute of Process Engineering and Power Plant Technology (IVD), University of Stuttgart, for the German Federal Environmental Agency

[57] Handboek Sfeerverwarming (based on a report of Hulskotte et.al)

- 21.4% use the appliance as a secondary heat source
- 17.4% use it on a daily basis as a primary heat source

For heavy users, the appliance is used (when necessary) between 3 and 8 hours per day. In contrast occasional users, use the appliance on average 4 hours per day, 10 days per year. These estimations lead to an average use of appliances of 460 hours per year.

In France, the use of wood fuels has been assessed as follows[58]:

- 67% of the people who use wood, use it as the main energy for heating
- 31% of the people who use wood, use it as an auxiliary heating system, but regularly
- 2% of the people using wood, do so occasionally for the pleasure of a chimney fire.

In a Swedish study conducted in 2004[59], the frequency and characteristics of use for wood-fired room heaters of different types was studied in a one-family house area of a Swedish town. A questionnaire was sent to 152 households, of which 72 % answered. The main results were the following:

- 40 % of the households had a stove, 27 % a slow heat release appliance (tiled stove, soapstone stove etc.) and 25 % had a fireplace with an insert.
- Nearly all households used their appliance only in winter.
- 54 % of the households only use their appliances for “cosy comfort reasons”. 19 % only use them at weekends and 27 % every day or on demand.
- 58 % only use hardwood as fuel, 41 % use a mixture of hardwood and softwood.
- According to the questionnaire, 65 % use the appliance at a constant heat output. In the other cases, the appliance is initially operated at high heat output and then turned down to slow combustion.

To contrast this, information on direct heating appliances collected again in Sweden regarding 286 house owners in two Swedish towns which use wood log boilers to heat their houses were asked to fill out a questionnaire[60]. 59 % answered. The main results were the following:

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58 ADEME (2008) Enquête sur le prix des combustibles bois en 2006 et 2007

59 Cooper, D., Jöborn, I., Sjödin, Å, Munkhammar, I. and Gustavsson, L.: Kartläggning av användningsmönster för lokaleldstäder (Survey of use patterns for wood-fired room heaters), Report from IVL Swedish Environmental Research Institute Ltd to the Swedish National Energy Board, Göteborg 2004

60 Johansson, L. et al.: Fältstudie av metan och andra viktiga komponenter från vedpannor (Field study of emissions of methane and other important components from wood log fired oilers). Report of research project 21826 to the Swedish National Energy Board, Borås 2006

- 57 % consumed 15 - 25 m3 of wood per year. Most of the other used more than 25 m3.
- The mean moisture content of the fuel was estimated to about 15 %
- Assuming an energy efficiency of 50 % and 70 % for conventional boilers and modern boilers with an accumulator tank, this indicates that 84 % has an energy demand of more than 19 000 kWh per year.
- 82 % say that they use the boiler the year around, 17 % that they use it in the winter och just a few only in the summer.
- 62 % stated that they had an accumulator tank
- During winter, 37 % stated that they fire once a day and 4 % that they fire more seldom. This indicates a correctly dimensioned accumulator tank. 36 % stated that they fire two times a day and 23 % that they fire more than two times a day. The latter most probable use smaller fuel charges, adapted to the meat demand.
- Of those who fire two times a day, 44 % have no accumulator tank, and among these 29 % say that they fill up the fuel chamber. This may lead to risks for incomplete combustion when the control system turn down the air supply.

➔ Energy use by solid fuel SCIs

There is little data available regarding the use patterns of solid fuel SCIs in Europe, which makes it hard to estimate their overall energy consumption. Detailed data on the use of solid fuel SCIs as primary or secondary heat source and user habits are hard to define, and tend to exhibit high regional variability (e.g. the amount of time a fireplace is used may depend on the latitude and altitude of the dwelling, but also on the insulation and size of the building, on the fuel availability and price). Hence, indirect estimates of the energy consumption of SCIs have to be made.

Methodology used for estimating energy use

Two main approaches are possible to make such estimates. The first is the bottom-up approach, whereby use patterns and technical specifications of an SCI (per appliance) are modelled based on data and/or assumptions. Alternatively, a top-down approach can be used, whereby the total direct energy consumption of solid fuel in the residential sector is split among the different appliances according to their stock and, possibly, weighing factors. Ideally, both approaches should be used in combination, so that one can validate the findings in a dynamic way.

Here, a bottom-up approach was used to estimate energy consumption of non-domestic indirect heating appliances. In contrast, a top-down approach was used for domestic heating appliances, since this is the approach for which the most comprehensive and reliable data could be obtained.

The structure and relationships between different types of appliances is shown in Figure 3-16.

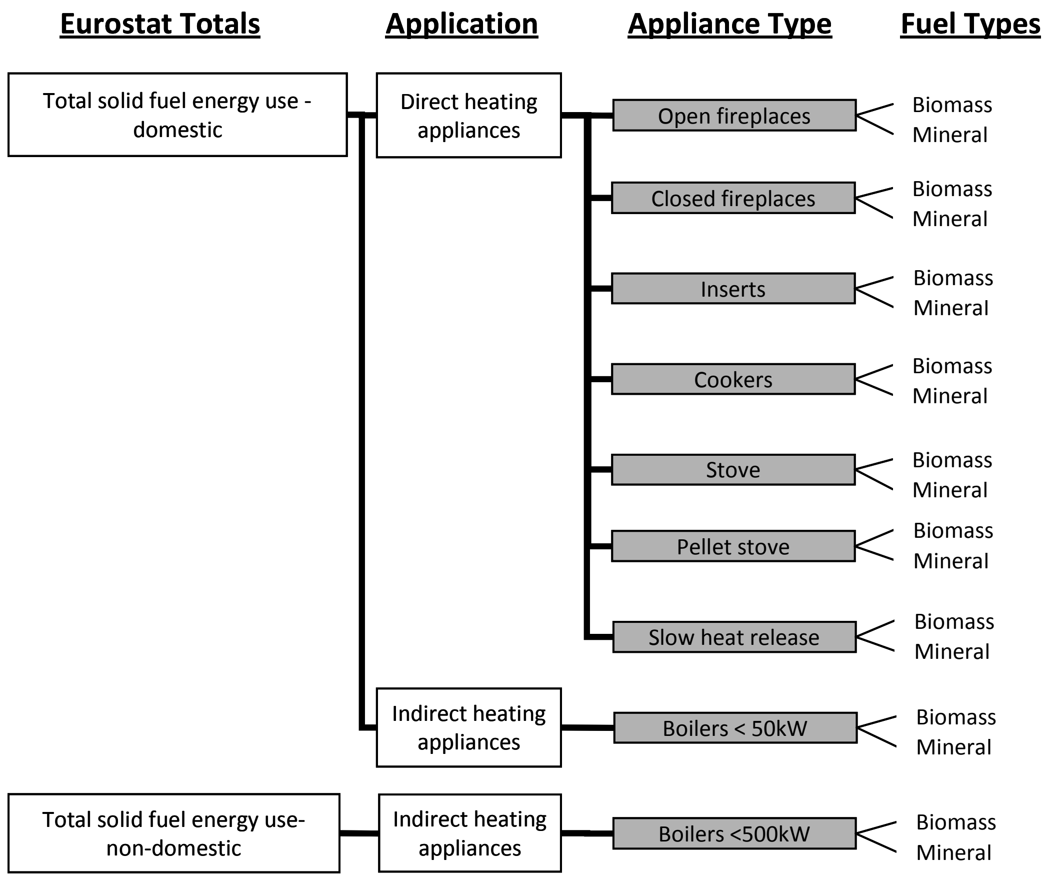

Figure 3-16: Tree diagram showing the top-down approach used for calculating the solid fuel energy use for each appliance[61] (and eventually for each fuel type)

Each numerical data to be estimated or calculated in the above figure is defined with the following nomenclature:

$E_{dom\ tot}$ =	***Total solid fuel energy use – domestic***
$E_{non\text{-}dom\ tot}$ =	***Total solid fuel energy use – non domestic***
$H_{non\text{-}dom}$ =	***Heating energy of indirect appliances – non domestic***
$H_{dir\ tot}$ =	***Heating energy of direct appliances- domestic***
$H_{indir\ tot}$ =	***Heating energy of indirect appliances- domestic***
h_x =	***Heating energy of an appliance type, x***
$h_{x,y}$ =	***Heating energy of appliance, x, country group, y***
h_x^* =	***Heating energy appliance x, scaled to Eurostat***

61 Note that 'stove' refers to stoves other than heat retaining/tiles stoves and pellet stoves

Total non-domestic solid fuel use

Non-domestic solid fuel appliances within the scope of this study represent a small share of the total non-domestic solid fuel use in Europe. According to Eurostat data, industrial solid fuel use was 1799 PJ in 2006.

$E_{non\text{-}dom\ tot}$ ***= 1 799 PJ / year*** ***(Total non-domestic solid fuel use)***

Since it is difficult to estimate the proportion of this fuel which is used in medium sized indirect heaters as defined in this study, a bottom up approach is taken to estimate the total solid fuel use. This approach is based on the stakeholder reported market share of small to medium sized boilers. This market share ratio is multiplied by the stock estimated in Task 2 to give the medium sized boiler stock applicable to non-domestic indirect heating fuel use (628 000 units). The total energy use is determined by multiplying this stock by the energy use per year.

$H_{non\text{-}dom} = n_{med.boiler}\ h_{med.\ boiler}$

Where:

$H_{non\text{-}dom}$ = ***Heating energy used – indirect (non-domestic)***

$n_{med.\ boiler}$= ***Medium boiler stock***

$h_{med.\ boiler}$ = ***Energy used by medium boilers per year***

For consistency purposes, the scenarios estimated in the Lot 1 study are used. The scenario most appropriate for non-domestic indirect heating SCIs corresponds to the heating demand for an appliance with a nominal heat output of 70-150 kW. The yearly fuel energy consumption of such an appliance, in the scenario developed by the Lot 1 study is estimated to be 89492 kWh/a[62], or 322.2 GJ/a.

$H_{non\text{-}dom}$ ***= 628000 x 322,2***

$H_{non\text{-}dom}$ ***= 202.2 PJ / year***

Total domestic solid fuel use

Total domestic solid fuel use (in terms of energy) in the domestic sector is very difficult to estimate, because many wood fuels do not enter the market or are not properly accounted for in the national energy balances. This is because wood can enter the market either directly, as wood logs cut from forests, or indirectly, as waste, recycled or re-used products from the forest industry.[63]

Several sources of data exist for the total energy use of solid fuel in the residential sector, including a recent improved enquiry carried out by UNECE-FAO, the Joint Wood

[62] See table 3-5 in "Task 3 Report, final - Consumer Behaviour & Local Infrastructure", VHK, (2007), available at www.ecoboiler.com

[63] UNECE-FAO (2008) Wood resources availability and demands

Energy Enquiry (JWEE), to monitor the wood energy situation[64]. This may currently represent the most accurate data on solid fuels, with a detailed breakdown per wood fuel type (e.g. wood logs, pellets, wood chips). Unfortunately, as yet, it is only available for 10 MS, and only for wood fuels. In contrast, the Eurostat energy balance[65] data provides energy data for all MSs, for biomass, coal, and other non-wood solid fuels (see Table 3-19).

According to Eurostat data, the total energy use in the domestic sector (Edom tot) amounts to 1 743 PJ per year. Since this data is consistently and regularly collected by the Commission, it was preferred over other sources, such as EurObserver wood energy barometer[66], where the sources and methods used for estimation are not clear. However, the comparison between Eurostat energy balance data, EurObserver and JWEE data (Key points to note from this table include:

- Poland has by far the largest contribution to the overall coal consumption in domestic heating in Europe, approximately 59% of the total. Of this contribution, 98% is hard coal. Polish hard coal for domestic heating is hence the best candidate for a representative mineral fuel for the base cases. This will be furthered in Task 5.
- French and German biomass fuel consumptions in domestic heating are the largest contributors, making up 40% of biomass fuel consumption in Europe. Together these will be considered in Task 5 as representative fuel supplies for biomass fuel types.

Table 3-20) confirms the fact that currently there is a large uncertainty in the solid fuel energy use estimates.

Thus, the following figure is used for calculations.

$E_{dom\ tot}$ = 1743 PJ / year   (Total domestic solid fuel use)

The nomenclature used here highlights the difference between total solid fuel energy use (*E*) and the energy used specifically for indoor heating (*H*). Since there is insufficient data to estimate how much domestic solid fuel is used by appliances which are outside the scope of this study (e.g. outdoor barbeques, braziers, sauna stoves), and since it is reasonable to assume that the solid fuel consumption of these appliances is negligible compared to that of solid fuel SCIs falling within the scope of the study, it assumed that all the solid fuel energy reported in Eurostat is consumed by appliances applicable to this study. Therefore, the assumption is taken the total domestic solid fuel use presented in Eurostat is entirely used for indoor space heating; that is to say the sum of direct and non-direct heating energy equals total solid fuel use:

$$E_{dom\ tot} = H_{dir\ tot} + H_{indir\ tot}$$

64 UNEVE-FAO (2007) Joint Wood Energy Enquiry (JWEE)

65 Eurostat (2008) Energy balance sheets 2005-2006

66 EurObserver (2005) Wood energy barometer, Systèmes solaires n°169

Table 3-19: Energy balance for the year 2006 (Eurostat)

Country group	MS	Hard Coal	Patent Fuels	Coke	Total Lignite	Coal Briquettes	Total Mineral fuels	Total Biomass fuels	TOTAL
		TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
1	Finland	153	-	-	479	-	632	41 240	41 872
1	Sweden	0	-	-	-	-	0	24 952	24 952
1	Estonia	625	-	-	0	144	769	12 107	12 876
1	Latvia	813	-	-	0	0	813	31 647	32 460
1	Lithuania	1 608	-	-	164	375	2 147	18 096	20 243
1	Denmark	0	-	0	-	0	0	30 829	30 829
2	UK	13 563	7 935	627	-	-	22 125	7 182	29 307
2	Ireland	7 378	1 431	-	8 349	3 691	20 849	703	21 552
3	Netherlands	205	59	0	0	0	264	9 586	9 850
3	Belgium	5 363	234	257	-	201	6 055	8 777	14 832
3	Luxembourg	0	-	-	-	20	20	650	670
3	France	12 480	2 304	114	0	0	14 898	318 829	333 727
4	Germany	4 400	1 727	1 425	17	17 900	25 469	221 760	247 229
4	Austria	954	31	3 249	55	791	5 080	63 861	68 941
4	Slovenia	0	-	-	0	-	0	13 573	13 573
5	Poland	236 664	-	3 216	2 168	-	242 048	104 500	346 548
5	Czech Rep.	2 677	-	1 050	27 460	3 139	34 326	40 138	74 464
5	Slovakia	26	-	113	1 824	23	1 986	1 290	3 276
5	Hungary	8 923	-	0	1 377	540	10 840	18 751	29 591
5	Romania	0	0	-	420	-	420	107 639	108 059
5	Bulgaria	5 571	-	-	2 179	3 811	11 561	26 587	38 148
6	Italy	292	-	0	-	-	292	68 400	68 692
6	Greece	52	-	0	9	0	61	29 393	29 454
6	Portugal	0	-	-	-	-	0	48 600	48 600
6	Spain	8 176	0	0	-	-	8 176	85 034	93 210
6	Cyprus	-	-	-	-	-	0	214	214
6	Malta	-	-	-	-	-	-	-	0
	EU-27	**311 342**	**12 290**	**10 051**	**44 503**	**30 260**	**408 446**	**1 338 650**	**1 747 096**

Key points to note from this table include:

- Poland has by far the largest contribution to the overall coal consumption in domestic heating in Europe, approximately 59% of the total. Of this contribution, 98% is hard coal. Polish hard coal for domestic heating is hence the best candidate for a representative mineral fuel for the base cases. This will be furthered in Task 5.
- French and German biomass fuel consumptions in domestic heating are the largest contributors, making up 40% of biomass fuel consumption in Europe. Together these will be considered in Task 5 as representative fuel supplies for biomass fuel types.

Table 3-20: Comparison among the total biomass energy use from Eurostat energy balance, the Joint Wood Energy Enquiry (JWEE) and EurObserv'ER wood energy barometer

Country group	MS	Eurostat (2006)	JWEE (2007)	Eurobserv'ER (2004)
		PJ*	PJ	PJ
1	FI	41.2		302.8
1	SE	25.0		345.8
1	EE	12.1	59.5	0
1	LV	31.7		54.4
1	LT	18.1		0
1	DK	30.8	8.7	46.6
2	UK	7.9		51.5
2	IE	0.7		0
3	NL	9.6		0
3	BE	8.8	2.7	0
3	LU	0.7		0
3	FR	318.8		384.3
4	DE	221.8	486.0	262.2
4	AT	63.8	0.1	146.5
4	SI	13.6	88.5	0
5	PL	104.5	47.2	164.4
5	CZ	40.2		42.2
5	SK	1.3	11.9	0
5	HU	18.8	18.0	0
5	RO	107.6		
5	BG	26.6		
6	IT	70.0		45.3
6	GR	29.4		0
6	PR	48.6		111.6
6	ES	85.0		172.0
6	CY	0.2		0
6	MT	-		0

* Petajoule (1 PJ = 10^{15} J).

In Table 3-20:

- France and Germany are major consumers of biomass energy for domestic heating across all data sources.
- Scandinavian countries, including Finland and Sweden have a much larger contribution to biomass consumption in Eurobserv'ER data than Eurostat.
- Spain, Poland and Austria have more significant contributions in Eurobserv'ER data than in Eurostat
- Germany is the most significant contributor in JWEE data

These points will be considered when developing the fuel types in Task 5 for the base cases.

Indirect solid fuel use

Domestic indirect solid fuel heating appliances can be assumed to be used exclusively as the primary heating source of the building. Accordingly, the energy used by domestic indirect heating solid fuel appliances can be estimated from central heating energy requirements. The average EU-27 central heating energy consumption was estimated in a previous EuP study on boilers (Lot 1)[67]. For consistency purposes, ($H_{inditot}$) in this study is estimated based on the baseline scenario estimated in the Lot 1 study, for an existing house. This scenario seems the most appropriate for domestic indirect heating SCIs, since it corresponds to the heating demand for an appliance with a nominal heat output of 26-32kW. The yearly fuel energy consumption of such an appliance, in the baseline scenario developed by the Lot 1 study is estimated to be 18 490 kWh/a[68], or 66.6 GJ/year. In the Lot 15 study, the total stock of solid fuel domestic boilers is estimated at 7.846 million[69]. Accordingly, in the Lot 15 study, the total domestic indirect heating energy used by solid fuel SCIs ($H_{indir\ tot}$) amounts to 480 PJ[70].

$H_{in\text{-}dir\ tot}$ = 480 PJ / year (Domestic indirect heating fuel use)

Direct solid fuel use

The total energy used by direct heating appliances is calculated as the difference between ($E_{dom\ tot}$) and ($H_{indir\ tot}$). Consequently, ($H_{dir\ tot}$) equals 1263 PJ.

$$H_{dir\ tot} = E_{dom\ tot} - H_{indir\ tot} = 1743 - 480$$

$H_{dir\ tot}$ = 1263 PJ / year (Domestic direct heating fuel use)

Energy use by appliance type

To derive the energy consumption for the different types of direct heating appliances, (h), the relative energy consumption of each appliance type has to be estimated. Detailed energy consumption data per appliance is scarce, but the results compiled from five different studies, scattered around Europe[71], made it possible to evaluate the energy consumption per type of appliance in the EU. Remarkably, except for pellets stoves, the variability among the different estimates is relatively small (Table 3-21).

67 VHK (2007) Eco-design of boilers, available at: http://www.ecoboiler.org

68 See table 3-5 in "Task 3 Report, final - Consumer Behaviour & Local Infrastructure", VHK, (2007), available at www.ecoboiler.com

69 See Task 2 report, section 2.2.2

70 H_indir_tot = total stock of boilers X yearly energy use of a boiler in an existing house

71 Finland: Pienpoltto pääkaupunkiseudulla (2003) (in Finnish) ; Tissari et al (2007) Emissions from residential wood combustion, air quality and health, University of Kuopio (in Finnish).
Germany: Handboek Sfeerverwarming (based on a report of Hulskotte et.al)
Italy: Caserini et al (2007) New insights into the role of wood combustion as key PM source in Italy and in the Lombardy region, Conference proceedings
Denmark and Sweden: Sternhufvud et al (2004) Particulate matter emissions and abatement options in residential wood burning in the Nordic countries

This suggests that the European average energy consumption by appliance type captures the regional variations in energy consumption reasonably well.

However, such a limited number of case studies cannot be considered to be representative of appliance energy use at the EU-level. But since the studies use a similar methodology, they are comparable among themselves. So while these individual studies cannot be used to determine the total energy use of appliances, they can be used in a comparative manner, to estimate the relative energy use between each type of appliance. In order to compare energy use between appliances, a use factor, or the relative energy use of a direct heating appliance compared to that of a reference, can be calculated. This use factor can then be used to calculate the energy use of each appliance (h_x), by weighing the total stock of each appliance by its relative energy use. Here, the reference appliance has been arbitrarily chosen to be a stove. The energy use of the reference appliance (h_{stove}) is first averaged over the three sources of data available for stoves[71]. This figure is then used to normalise other appliance's energy use, which is also averaged over the available data sources for that appliance. The normalised energy use then becomes the use factor for the appliance (uf_x). Then the energy use of the appliance (h) is simply h_s*uf_x. The equation below describes the relationship.

$$H_{dir\_tot} = \sum_x h_{stove} \cdot uf_x \cdot n_x$$

Where:

$H_{dir\ tot}$ = total energy used by direct heating solid fuel appliances

h_s = Energy used by the reference appliance (stove)

uf_x = use factor for the appliance x

n_x = stock for the appliance x

Table 3-21 displays the average energy consumption of each of the direct heating appliances and the resulting use factor.

Table 3-21: Average energy consumption per direct heating solid fuel appliance in the EU-27, and relative consumption of each direct heating appliance type compared to a 'stove'[61]

Direct heating appliances	Average energy consumption (GJ/yr/appliance)	Standard deviation	Use factor Reference = stove
Stove	12.27	4.89	1.0
Slow heat release stove	17.09	5.44	1.4
Pellet stove	17.63	19.32	1.4
Open fireplace	6.66	2.51	0.5
Closed fireplace and inserts	7.70	0.30	0.6
Cooker	3.66	0.19	0.3

These numbers represent the average energy consumption for each type of appliance and the standard deviation found between the data. These use factors (*uf*) allow one to subdivide the data given by Eurostat to specific appliance types across Europe in a manner approximately proportional and consistent to the independent data found.

For indirect heating appliances (both domestic and non-domestic) there is only one appliance type for the energy use calculated, thus that appliance type can be assumed to consume all the energy.

- **Energy use by country group and appliance**

Unfortunately, the method described above for determining energy consumption by appliance type for direct heating effectively suppresses any accounting for the geographical variations in energy use. While the data remains consistent across appliance types, the factors do not allow for further investigation into regional differences. For instance in Germany, the energy consumption of pellet stoves and stoves is much higher than in other EU countries, even Nordic ones (Table 3-22). In contrast, in Italy, stoves consume half the European average, but closed fireplaces are used 20% more than in other MS (Table 3-22). This reflects the fact that in the Mediterranean countries, less heating is needed, and fireplaces can suffice to fit these (occasional/short-term) heating needs. Table 3-22 shows the limited data found for the variations in energy consumption of each appliance type in reference to the established reference case (stove) by country group, as can be seen, no data was found for country groups 2, 3 and 5.

Table 3-22: Energy consumption per country group relative to the EU average consumption

Appliance type	Country group					
	1	2	3	4	5	6
	FI,SE,DK	na	na	DE	na	IT
Open fireplace	1.08	na	na	1.12	na	0.72
Closed fireplace or insert	na	Na	na	0.97	na	1.19
Cooker	1.13	Na	na	0.96	na	na
Stove	1.17	Na	na	1.29	na	0.54
Pellet stove	na	Na	na	1.77	na	0.23
Slow heat release	0.96	Na	na	1.04	na	na
na = no data available						

In absence of complete regional data of energy consumption, assumptions have to be made to estimate the energy consumption of each appliance by country group. Here, the simplest assumption was taken, by assuming that the energy consumption of each appliance (based on the use factor previously developed) is proportional to the distribution of stocks throughout Europe (as estimated in Task 2). The energy consumption for each appliance can then be calculated based on this new scale. The relationship developed can be expressed as shown below.

$$h_x^* = \frac{n_x uf_x H_{tot\_dir}}{n_{tot}}$$

Where:

h_x^* = Energy used by the appliance (* is scaled to Eurostat data)

$H_{tot\ dir}$ = total energy used by direct heating appliances

uf_x = use factor for the appliance

n_x = stock for the appliance

n_{tot} = total stock of all appliances in Europe

These scaled energy consumption values per appliance allow the total energy consumption per appliance type to be calculated by country group. The expression is shown below.

$$h_{x,y} = \frac{h_x^*\left(E_{dir\_tot,y} - H_{indir\_tot,y}\right)}{\sum_x h_{x,y}^*}$$

Where:

$h_{x,\ y}^*$ = Energy used by the appliance, x

$^{(*)}$ denotes scaled to fit Eurostat data

$_{(y)}$ denotes country group

h_x^* = Energy used by the appliance x,

$^{(*)}$ denotes scaled to Eurostat data

$H_{tot\ dir}$ = total energy used by direct heating appliances

uf_x = use factor for the appliance x

n_x = stock for the appliance x

n_{tot} = total stock of all appliances in Europe

The total energy use for the stock of appliances in each country group is presented in Table 3-23.

Table 3-23: Total energy consumption (PJ) by the EU-27 stock of appliances according to country group

Appliance type	1	2	3	4	5	6	EU Total
Open fireplace	6.85	5.86	121.14	23.53	46.11	40.07	243.56
Closed fireplace	7.91	6.78	139.99	27.20	53.29	46.30	281.47
Stove	30.97	3.86	79.66	125.31	245.53	73.09	558.42
Cooker	3.75	0.58	11.89	5.06	9.92	24.47	55.66
Pellet stove	0.24		4.13	0.71		23.67	28.76
Slow heat release	20.35			74.46			94.81
Domestic boilers	62.33	33.79	33.10	73.46	245.24	32.57	480.49
Non-domestic boilers	26.23	14.22	13.93	30.92	103.21	13.71	202.22

Accordingly, the energy used per appliance in each country group is presented in Table 3-24. This value depends on the stocks of appliances, estimated in Task 2. An under-estimation of those stocks would lead to an over-estimation of the energy consumption per appliance and vice versa.

Table 3-24 – Energy consumption per appliance (GJ/yr/appliance)

Appliance type	1	2	3	4	5	6	EU Total
Open fireplace	4.61	2.56	31.21	6.83	17.20	17.03	15.09
Closed fireplace	5.32	2.95	36.07	7.89	19.88	19.69	17.44
Stove	8.48	4.71	57.48	12.58	31.67	31.37	21.56
Cooker	2.53	1.41	17.15	3.75	9.45	9.36	7.33
Pellet stove	12.19		82.57	18.07		45.06	45.30
Slow heat release	11.88			17.61			15.96
Domestic boilers	66.56	66.56	66.56	66.56	66.56	66.56	66.56
Non-domestic boilers	322.17	322.17	322.17	322.17	322.17	322.17	322.17

By dividing the above totalled values with the average power input of each appliance, an approximation of the hours per year can be determined. This approximation can help to ensure that the numbers calculated agree with reality. The estimated efficiency of the appliances and power output is based on market research of stock and will be refined further in Tasks 4 and Task 5 for the base cases. Table 3-25 shows the calculated average hours per year of appliance operation at nominal load.

Table 3-25: Hours of operation per year of appliances for EU-27 countries based on Eurostat data scaled to appliance types and country groups

Appliance type	Average Power Output (kW)	Estimated Efficiency (%)	Hours of operation per year
Open fireplace	15	15%	42
Closed fireplace	10	55%	266
Stove	8	45%	337
Cooker	10	55%	112
Pellet stove	25	80%	403
Slow heat release	10	85%	377
Domestic boilers	29	75%	478
Non-domestic boilers	110	80%	651

In contrast, the German Federal Energy Agency compiled national data to determine hours of use for several appliance types applicable to the Lot 15 study. This compilation of data represents reliable external estimates. They are included below in Table 3-26.

Table 3-26: German hours of use for appliances applicable to Lot 15[72]

Solid fuel combustion installations in Germany 2005	Output (kW)	Annual use at full load
Manually fuelled boilers (wood and coal)	4-25	1020
	> 25 – 50	928
	> 50	930
Pellet boilers	4 – 25	980
	> 25 – 50	920
	> 50	920
Stoves	< 15	596 - 750
Cookers	< 15	154

The limitation associated with the data in Table 3-25 is that the mineral fuel data is that the fuel is not necessarily limited to use in solid fuel heating appliances in the scope of the study (appliances outdoors etc.). It therefore does not properly estimate the hours of use, especially for boilers based on what has been presented by stakeholders and experts (ie. Table 3-26).

Furthermore, the EuP preparatory study Lot 1 (CH boilers) assumed to operate on the 'bin' method and operated on various regimes of cycling or part load operation with multiple heat generators possibly included in the heating system depending on the climate assumed and heating controllers. Figure 3-17 shows an example of the bin method temperature spread whereby a boiler is assumed to supply heat over the heating season to at various temperature 'bins' and associated cycling or part-load operating regimes result for various portions of the year.

[72] Struschka et al.: Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung; UBA-Texte 44/2008, Umweltbundesamt Dessau, 2008

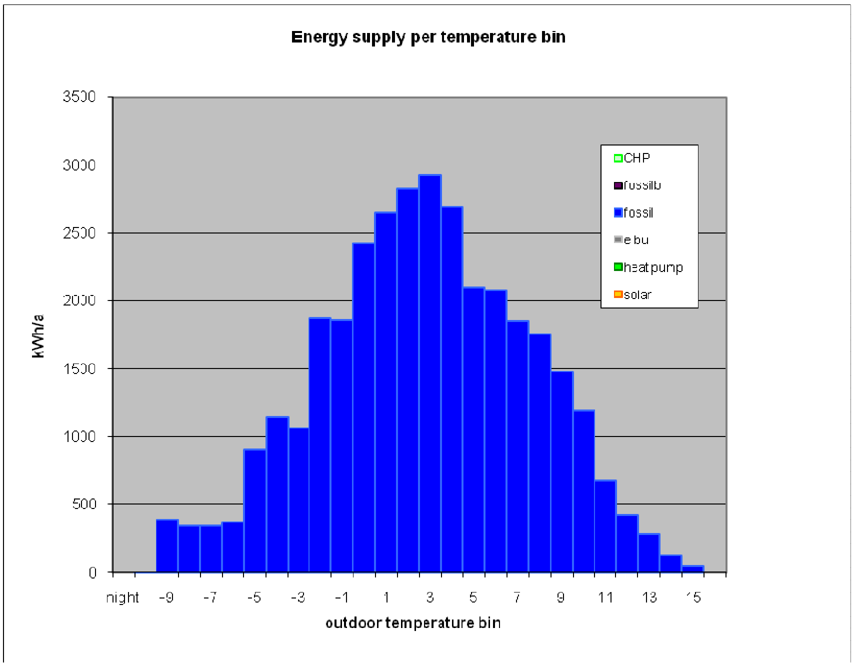

Figure 3-17: Example calculation for estimating energy consumption in Lot 1 boilers

As a result, the following numbers will be used to accommodate information provided by stakeholders for the inherent shortcomings in Eurostat estimates.

Table 3-27: Hours of use per year for Lot 15 appliances

Appliance Type	Hours of Use Per Year	Source
Open fireplace	42	Eurostat est.
Closed fireplace, insert	266	Eurostat est.
Wood stove	337	Eurostat est.
Coal stove	337	Eurostat est.
Cooker	112	Eurostat est.
Slow heat release (SHR) stove	337 (fired)	Eurostat est.
Pellet stove	403	Eurostat est.
Dom. Conv. Boiler	1000	Lot 1 / UBA*
Dom. Dd. Gas. Boiler	1000	Lot 1 / UBA*
Retort coal boiler	1000	Lot 1 / UBA*
Pellet boiler	1000	Lot 1 / UBA*
Industrial chip boiler	1000	Lot 1 / UBA*
*UBA numbers as referenced from source 72 is in approximate agreement with Lot 1 number of 1000 hours / year however are not exactly the same and are not based on the same assumptions. These two sources are completely independent and were not necessarily in collaboration when developing their data. They have been presented together here merely because they are approximately in agreement for the purposes of this study.		

These hourly figures will be used with base case data in Task 5 to create the Ecoreports for the base cases of the Lot 15 study.

- **Energy use by fuel type**

Solid fuel SCIs usually support several variants of solid fuel, but tend to be specific to one solid fuel type (e.g. wood logs or anthracite). Therefore, the energy use per appliance needs to be divided among the most likely fuel types used by this appliance. Unfortunately, while Eurostat data is available for different types of mineral fuels used for domestic purposes, a similar split among different types of biomass fuels is not available. Thus estimations of energy use by specific fuel type are not possible, and at this stage the distinction can only be made between 'mineral fuels' and 'biomass fuels'.

The distribution of biomass and mineral fuel is done based both on and some regional differences and on the functionality of solid fuel SCIs (indirect heating SCIs, assumed to be used exclusively for central heating vs. direct heating appliances, which can be used both as secondary and primary heat source). The assumptions used are detailed below.

- **Country groups 1, 3, 4 and 6**

For these country groups, it was assumed that:

- **Indirect heating appliances**: both domestic and non-domestic appliances are assumed to be fuelled by mineral fuels. This is because it is assumed that most indirect heating applications take first preference to this kind of fuels, although it is acknowledged that this is not true for all applications. Biomass fuel makes up for any shortcoming of mineral fuel.
- **Direct heating appliances**: these appliances are assumed to consume primarily biomass fuels. Any remaining mineral fuel resources are distributed among direct heating applications, proportionally to the stock of each appliance (as estimated in Task 2 of this study). Biomass fuel is then assumed to fill the rest of the needs.

These assumptions have resulted in 100% of domestic coal reported by Eurostat being consumed in indirect domestic heating applications for these country groups, and biomass being used in all direct heating applications, and some indirect heating applications.

- **Country groups 2 and 5**

Based on stakeholder feedback and commercial evidence, it was determined that these country groups tend to use mineral and biomass fuels for both indirect and direct heating applications. As a result, the fuel is distributed proportionally to its availability among the different types of appliances:

- **Indirect heating appliances**: non-domestic indirect heating appliances are assumed to be fuelled by exclusively mineral fuel. Domestic indirect heating applications consume both mineral and biomass fuel resources, proportionally to their share in the total domestic energy use of that country group. Non domestic appliances use the same ratio of mineral to biomass fuels.
- **Direct heating appliances**: consume mineral and biomass fuels proportionally to their share in the total energy use of that country group, except for pellet stoves which use only biomass fuel.

These assumptions have resulted in a mix of both fuels being used both in direct and indirect heating appliances for domestic appliances.

Summary

Figure 3-18 and Figure 3-19 show a summary of the estimated energy use by fuel type in each country group, calculated according to the assumptions previously described.

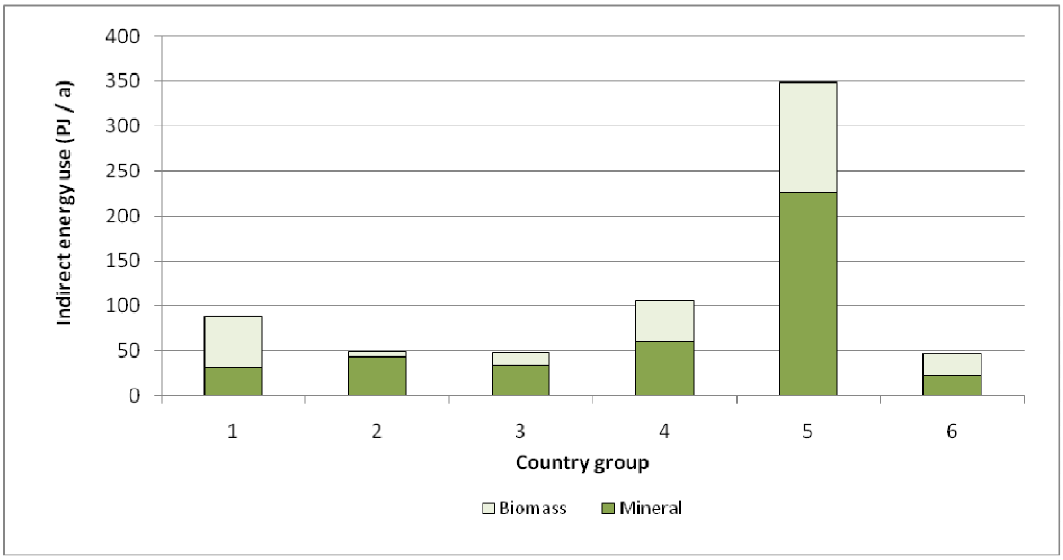

Figure 3-18: Estimated indirect energy use by country group and fuel type in Europe

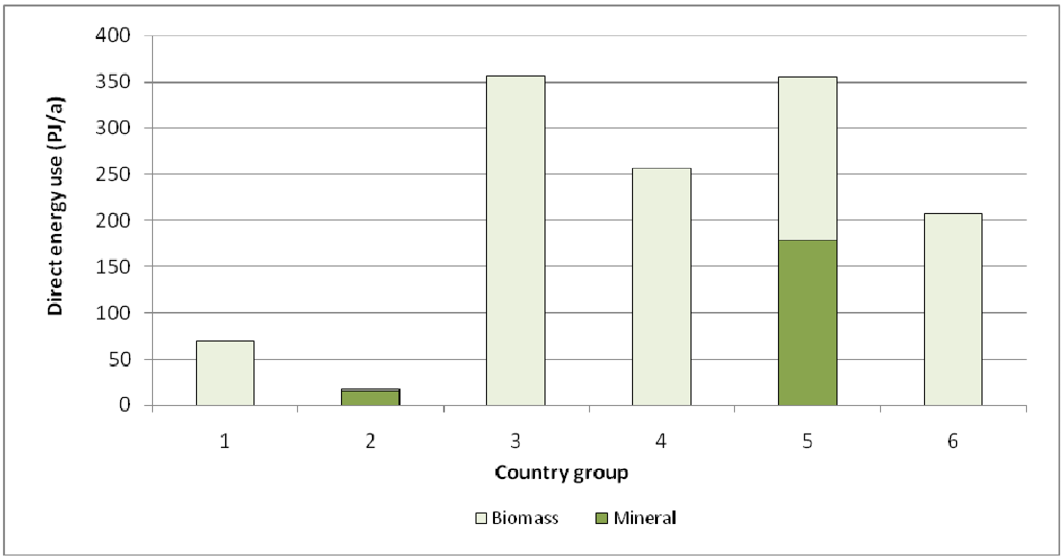

Figure 3-19: Estimated direct energy consumption by country group and fuel type in Europe

At the EU-27 level, the total estimated energy use by appliance and fuel type is shown in Figure 3-20 and indicates that biomass energy use is much more prominent than mineral fuel energy use, for all SCIs except boilers. Stoves and boilers are responsible for most of the solid fuel energy consumption, while cookers, slow heat release stoves and pellet stoves only represent a small share of the domestic solid fuel energy use.

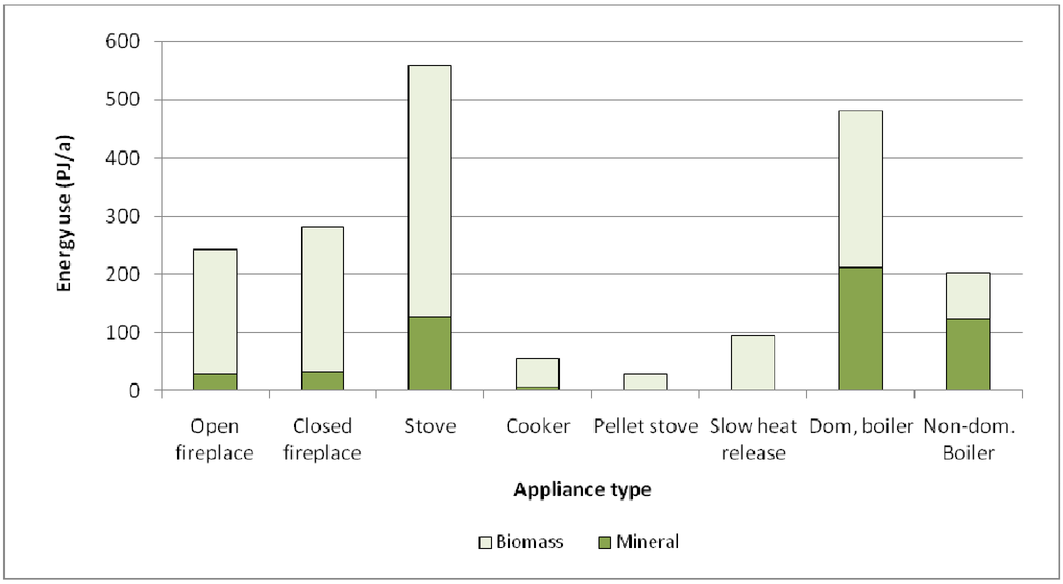

Figure 3-20: Total estimated energy use by appliance type and fuel type in Europe

The general trends shown in the graphs above will be used in task 5 for establishing base cases which are the most representative of the current EU stock levels.

The following table summarizes the stock data based on the information presented in Figure 3-20 and will adapted for use in Task 5.

Table 3-28: Estimate for appliance stock by fuel type for Europe

Appliance Type	Mineral	Biomass
Open fireplace	1 861 829	14 277 141
Closed fireplace	1 861 829	14 277 141
Stove	5 866 845	20 034 451
Cooker	745 656	6 848 567
Pellet stove	-	634 900
Slow heat release stove	-	5 941 867
Domestic boiler	3 171 928	4 046 487
Non-domestic boiler	380 571	247 118

While it is understood that this information is based on wide estimations in a top-down approach, it is useful for the purposes of this study and provides insight as to where the major of solid fuel SCIs are installed, which types and approximately how much they are used.

For comparison, Table 3-29 shows the stock and sales information complied for direct heating appliances by CEFACD in 2009.

Table 3-29: Sales and stock data as provided by CEFACD for direct heating appliances

Name	Fuel	Sales	Stock
Open fireplaces	Wood Logs	748 000	16 000 000
Traditional closed fireplace	Wood Logs	254 730	13 056 645
Modern fireplace/insert	Wood Logs	551 915	2 759 575
Closed fireplace with boiler	Wood Logs	42 455	322 780
Traditional woodstove	Wood Logs	625 000	14 941 220
Modern woodstove	Wood Logs	562 500	3 937 500
Boiler stove	Wood Logs	62 500	385 280
Cooker	Wood Logs	278 520	4 556 400
Cooker with boiler	Wood Logs	185 680	3 037 600
Slow Heat Rel.Stove	Wood Logs	110 000	6 000 000
Pellet Stove	Pellets	155 000	605 150
Pellet stoves with boilers	Pellets	21 000	31 850

The estimates for the stock of appliances are not significantly different between the CEFACD data and the estimate in Table 3-28 except that the CEFACD data is has a greater precision for appliances types and has not considered a distinction between mineral fuel appliances and wood fuelled appliances.

Overall, the ratio of fuel use for solid fuel combustion installations as calculated with the above calculations is 77% biomass fuels and 23% mineral based fuels based on total energy consumption. This information will also be adapted for use in Task 5 when representing the fuel types of the base cases.

3.2.5 BEST PRACTICES

➔ Best Practices for use

Best practice regarding product use consists of:

- Using recommended/certified fuels (according to user manual of the device) having appropriate quality certificates. In Austria and Germany, it is illegal to burn other types of fuels than those for which the appliance is certified for[73].
- Never burning waste, plastics or contaminated or treated fuel (e.g. painted wood or ocean driftwood).
- Burning seasoned (not "green") wood, and dry solid fuels in general.
- For wood log appliances, using firewood cut shorter than the firebox to make loading easier; and pieces of a diameter between 75 mm and 150 mm for most modern wood stoves.
- Burning small, hot fires (they produce much less smoke than ones that are left to smoulder).

[73] The chimney sweeper is responsible for controlling this.

- Burning wood in cycles (in most appliances, the wood burns best in cycles): a cycle starts with loading some wood onto a bed of charcoal and is completed when abut the same size charcoal bed remains.

Regarding safety, it is recommended[74] to equip every house equipped with a SCI with smoke detectors and/or carbon monoxide detectors as outlined in best practices of appliance purchase. It is advised to install one on the ceiling of the room in which the appliance is located, or in the other major living area and another near the entrance to the bedroom area.

➔ **Best practices for maintenance**

Best practices regarding product maintenance consist of[75]:

- Emptying the combustion chamber before it is full (the frequency depends on the use pattern of the appliance). The removed ashes should be placed in a metal container with a cover and stored outdoors (if stored indoors, they may smoulder, creating a risk of fire)
- Always cleaning the grate before use (for open fireplaces) so the combustion air can flow unobstructed through the air holes of the grate, and around it
- Cleaning the smoke conduit, heat exchanger surfaces and flue pipes at appropriate intervals
- Checking electrical parts regularly
- Replacing door gaskets and other seals when necessary

Further, it is important to take care of the inspection and cleaning of the chimney system by a professional chimney sweeper at appropriate intervals (depending on the fuel and frequency of use). This is a legal requirement in some countries.

3.3 END-OF-LIFE OF THE APPLIANCES

At the end-of-life, appliances made of metal (e.g. cast iron, steel) are typically recycled due to the value of the raw materials contained in the appliances (steel, iron). Installers usually collect them when replacing the installations.

For appliances with an aesthetic value (e.g. old decorative stoves and cookers) second-hand markets are known. Other solid fuel SCIs rarely have a second-life, since in most cases an appliance stays where it is originally installed, even if the dwelling changes

74 In some MS (e.g. Finland) it is obligatory to have a smoke detector in every dwelling regardless of the existence of SCI.

75 Projects “Clean energy for my house. Clean and cheap heat from coal” (2005/2006), “Coal and clean energy” (2007) financed by the Regional Fund for Environmental Protection and Water Management in Katowice, Poland. “Don’t release pollutants – protect your health. Individual Heating versus the Environment and Human Health – pilot programme for selected municipalities of the Upper Silesian Region” (2008) co-financed by the UE funds and by the Regional Fund for Environmental Protection and Water Management in Katowice, Poland. And stakeholder contributions.

owners. Thus the responsibility of the disposal of the equipment is transferred to a different person than the original buyer.

It should be noted that resale of second-hand appliances is not recommended because often they have not been maintained properly. Safe, efficient and environmentally effective operation cannot be guaranteed.

3.4 LOCAL INFRASTRUCTURE AND BARRIERS TO ECO-DESIGN

In the case of small solid fuel SCIs, the infrastructure factors are normally very difficult and expensive to change in comparison to the size of the heating system. This is why the infrastructure surrounding a solid fuel SCI purchase is significant; it imposes constraints or facilitating the various needs of solid fuel SCI systems. Essentially, infrastructure plays a key role in determining which solid fuel SCI systems are feasible and economical in a particular location.

Stakeholders' consultation[76] allowed identifying the most important infrastructural factors that may hinder the installation or the use of eco-designed SCIs.

- **Fuel supply:** there are wide differences between and within MS. While firewood markets exist in every MSs, there are not always developed markets for chips and pellets. For instance, there are no country-wide markets for chips supply to small-scale customers, but lots of locally developed markets. Supply infrastructure has been identified as the most important brake to pellet market development, even in countries whose market is well-developed. New markets for biomass heating systems in Eastern Europe would require the supply infrastructure to be reinforced.
- **Fuel quality:** constant and adequate quality of fuel are important, either for "natural" fuel (e.g. wood logs dried long enough so to have a low moisture) or for manufactured and commercial fuels (e.g. fuel compliant with established standards).
- **Availability of maintenance services:** professional care as well as professional installation is crucial for optimal performances. Lack of qualified craftsmen (installers and chimney sweepers) can be detrimental for both market development and environmental performances of appliances.
- **Quality of information given to consumers:** lack of knowledge or lack of independent reliable information on products, and on their energy and environmental performance
- **Local regulations**: in areas where district heating system is installed, independent domestic heating appliances may be forbidden. Local regulations may also impose limitations for air pollution concerns (e.g. forbidding all solid

[76] Via questionnaire sent in June 2008.

fuel installations independent of their performance) or for aesthetics (e.g. limiting the installation of chimneys in certain districts).

- **Lack of local regulations:** in countries where it is not mandatory to equip dwellings with a chimney, it is often not foreseen, and hence discourages installation of SCIs.
- **Type of buildings and storage requirements:** the limited space for fuel storage may limit the propensity of consumers to buy a solid fuel appliance. This barrier may be difficult to overcome especially in case of retro-fits e.g. when changing from oil to solid fuels (Figure 3-21). In some cases, more frequent deliveries may be possible to overcome this barrier, but this is likely to increase costs. Furthermore, with automatic fuel feeding systems, the fuel store must also be next to, or connectable to, the boiler. This may again pose a problem with some retro-fit cases.

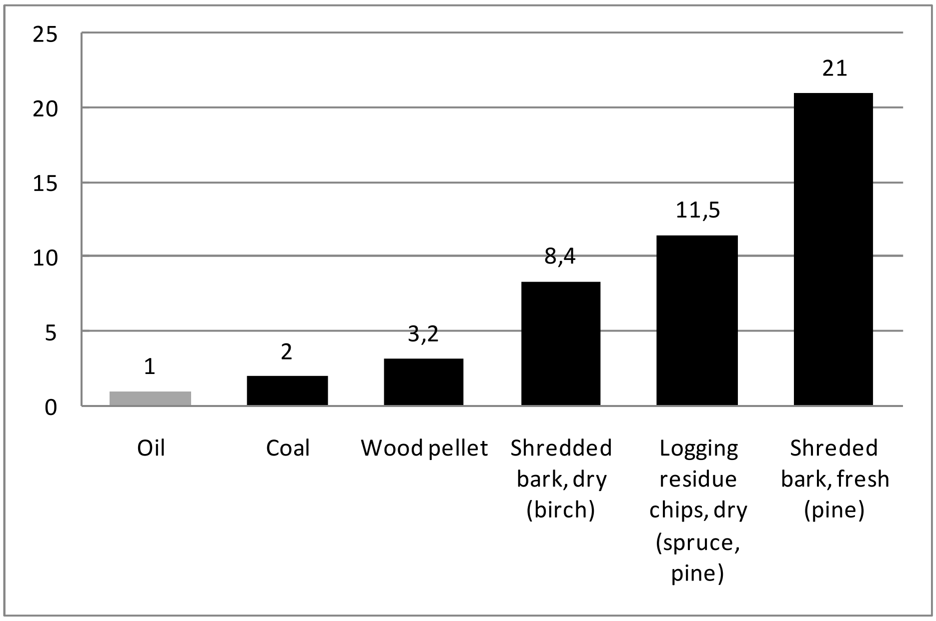

Figure 3-21: Relative fuel storage space requirement per unit of heat [16]

- **Fuel availability:** there are wide differences between MS. Shifts towards more environmentally-friendly fuels or technologies may be hindered due to convenience reasons and the negative environmental impacts associated with transporting fuels.
- **Existence of chimneys:** chimneys are a structural requirement and therefore they are a pre-requisite for customers being able to install (new) SCIs. Without one, the usage of solid fuel SCIs is not possible. Unlike other fuels like gas, where it is possible (but not advisable) to install the appliance exhaust simply through-the-wall, solid fuel SCIs require a proper chimney to safely convey flue gases. Due to the special characteristics of solid fuel burning, a proper chimney has to feature resistance to soot fire, vapour diffusion and corrosion. Efficiency is even higher if the chimney is equipped with an insulated air-intake shaft.

- **Type of chimney:** the usage of high-efficiency condensing solid fuel SCIs is only possible if the chimney is suitable and meets the already mentioned criteria of resistance to soot fire, vapour diffusion and corrosion. In countries, with high usage of biomass, like Austria and Germany, a special approval has been developed by authorities to classify these products – GW3. This topic has also been taken up by EOTA , developing a European wide technical approval for this characteristic.

Note that factors related to consumers' frame of mind (e.g. preference for stabilised technologies, fear of complexity, etc), as well as financial factors (e.g. reduced budget, relative high investment costs) appear not to be the most important barriers to eco-design. Political actions, which lead to both information campaigns and subsidies program, and rising of environmental awareness, have already helped to reduce these two potential barriers.

3.5 CONCLUSIONS

Task 3 focused on the user/consumer as the central player concerning the environmental impacts and performance of solid fuel SCIs in real-life. Overall, due to the inherent nature of solid fuel combustion, the behaviour of consumers has a significant and unavoidable impact on the performance of solid fuel SCIs. This will need to be strongly considered in the sensitivity analyses in Task 8. The parameters affecting real-life efficiency of appliances, the frequency and characteristics of use and consumer behaviour information will be used for the evaluation of base cases in Task 5 and in later tasks. While the importance of the infrastructure surrounding the solid fuel SCI is acknowledged, it is not analysed in detail, since the focus of the Lot 15 study is on the products.

A first attempt at summarising consumer behaviour regarding solid fuel SCIs has been made. To date, there is little data on real-life consumer behaviour at the EU-level. Yet, it is clear that real-life operating conditions differ widely from test standard conditions. Accordingly, real-life emissions and performance of solid fuel SCIs differ significantly from those measured in test labs, in large part due to differences in fuel quality (moisture content) and incorrect operational practices (overloading of the appliance and improper kindling and air control). This difference is to be expected since the purpose test standards is to establish the performance of the appliance, rather than the determination of actual emissions of the appliance under normal operation. This becomes a problem when these standard appliance tests are used as a platform for emissions testing. It has been suggested to establish specific test standards for emissions testing of appliances, which would better represent typical emissions during normal operation of domestic users than product tests[77].

Regarding the frequency and intensity of use of solid fuel SCIs, no information has been compiled at the EU level. Accordingly, we use a top-down approach to derive domestic solid fuel use by appliance and fuel type based on the total solid fuel energy used in the EU (Eurostat data), data from independent but consistent studies, the stocks of appliances, and a few stated assumptions regarding the distribution of fuels and energy among appliances. The analysis does not consist in a thorough consumer behaviour analysis, and has not been cross-referenced with any bottom-up analysis. Yet, with the currently available data, it is considered to provide the best possible EU-wide estimate for solid fuel energy use patterns across the different country groups and appliances relevant to this study. The assumptions used are made transparent, and as better data becomes available, e.g. on solid fuel use in the residential sector or on regional energy consumption of different appliances, it can be replaced to update the calculations.

[77] Jokiniemi J. (2007) Aerosol sampling and measurement techniques with a special focus on small-scale biomass combustion systems, IEA Bioenergy Task 32: Biomas Combustion and Cofiring, Jyvaskyla, Finland, September 2007.

3.6 TASK 3 ANNEXES

3.6.1 CALCULATION METHOD FOR DEGREE-DAY AND HEATING SEASON

Consumption of energy depends strongly on weather conditions. If the temperature decreases below a certain value (”heating threshold”), more energy is consumed due to increased need for space heating.

Actual heating degree-days express the severity of the cold in a specific time period taking into consideration outdoor temperature and room temperature.

To establish a common and comparable basis, Eurostat defined the following method for the calculation of heating degree days:

- (18°C - Tm) x d if Tm is lower than or equal to 15°C (heating threshold)
- nil if Tm is greater than 15°C

Tm is the mean (Tmin + Tmax / 2) outdoor temperature over a period of d days. Calculations are to be executed on a daily basis (d=1), added up to a calendar month - and subsequently to a year- and published for each Member State separately.

Using the degree day parameter, it is also possible to estimate the heating season:

- Heating season in hours = (degree-days + 2000)
- Heating season in months = rounded (12*heating season in hours/ 8760).