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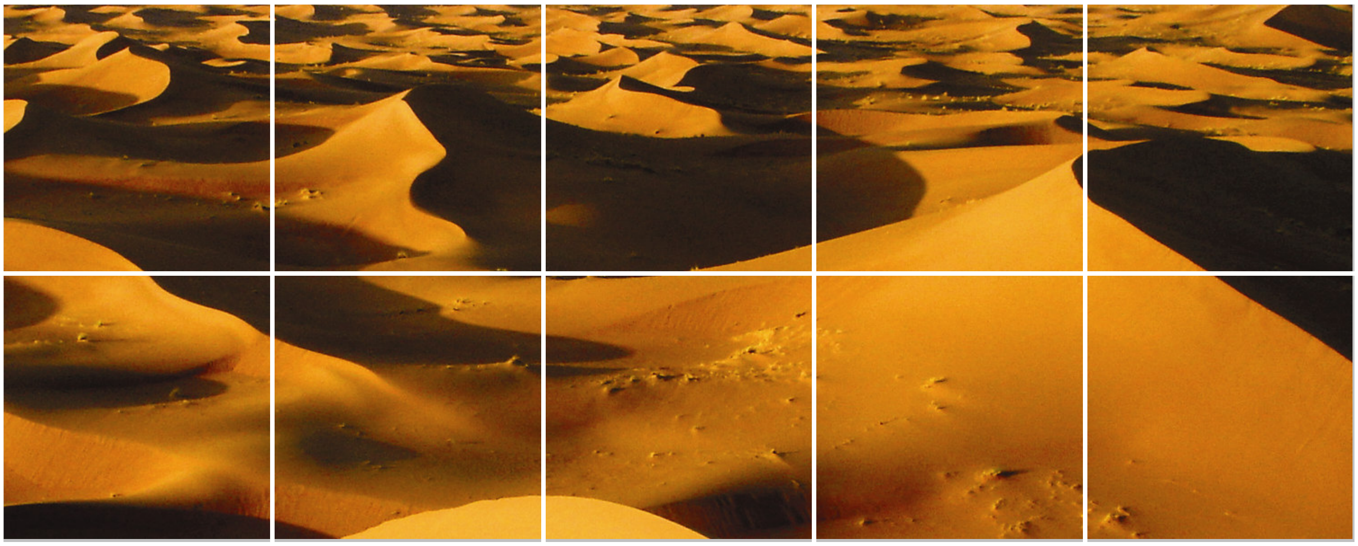

Support to Scottish Government on the Clean Air Act

A report to the Scottish Government

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Executive summary

AEA has undertaken a review on behalf of Scottish Government to assess the Clean Air Act 1993 and suggest measures which would protect air quality and allow more growth in biomass use. In addition, issues in the assessment of emissions from biomass combustion plant were examined.

1. A number of interim administrative measures have been suggested to enable protection of air quality and enable growth in biomass development. Consideration of a mechanism which does not require a Scottish Statutory Instrument (SSI) for appliance exemptions is recommended. The Scottish Government could also consider mechanisms for relaxation of smoke control areas to allow non-domestic biomass installations at specific developments where it has been demonstrated that biomass use will have little or no effect on air quality. Other suggested interim measures may have a potential impact on air quality.

2. A review of the Clean Air Act 1993 has identified a number of sections which could be updated, deleted or revised to recognise the changes in focus of air quality management and increase in biomass use.

3. We conclude that existing tools are suitable for assessing impacts of biomass appliances. Dispersion models such as ADMS4.1 and AERMOD are suitable for the assessment of the air quality impact of biomass combustion installations. However, in many cases, simpler screening modelling will be sufficient.

4. Scottish building standards may not be sufficient to meet the air quality objectives where a small (<50 kW) combustion appliance discharges below the height of attached or adjacent buildings.

5. The potential for revised testing procedures for Clean Air Act exemption have been considered and potential measures include a reduction in the number of replicate measurements, dropping the requirement for testing at intermediate output and dropping the requirement for misuse testing. These measures could be introduced without significant impact on compliance with the Clean Air Act.

6. Development of a protocol for assessment of air quality impacts needs to consider a variety of factors which can affect emissions from solid fuel appliances and reflect the move away from solid mineral fuel to biomass. However, any protocol designed to ‘type approve’ an appliance needs to balance the needs of defining the range of emissions possible from an appliance to achieving a reasonable test without applying an excessive burden to the manufacturer or importer.

7. Issues in different approaches adopted across the world for particulate measurement for a range of appliance types have been identified, particularly for domestic appliances. Suggested changes to allow the Clean Air Act exemption process greater use of test data from other test regimes include a reduction in replicate tests and a focus on emissions during normal operation (not misuse tests). However, use of data from other testing regimes requires data to allow correlations to be developed and hence development of evidence-based acceptance criteria. It is recommended that a measurement programme be undertaken on selected domestic appliance types to allow development of acceptance criteria.

8. It is recommended that NOx measurements should be based on existing EN and ISO Standards for NOx measurement; for domestic appliances and EN303-5 hot water boilers the measurements should be part of the existing efficiency and output measurement procedures.

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Appendices

1 Introduction

AEA has undertaken a review on behalf of Scottish Government to assess the Clean Air Act 1993 and suggest measures which would protect air quality and allow more growth in biomass use. In addition, issues in the assessment of emissions from biomass combustion plant were examined. In particular the study has examined :

- Interim administrative measures which would support the implementation of the Clean Air Act 1993 in the absence of Parliamentary time to alter the Act itself (Section 2).
- Sections of the Clean Air Act to identify where change may be desirable and to provide suggestions as to the types of change Scottish Government may wish to consider to reduce the barriers to biomass uptake while protecting public health (Section 3).
- Tools to assist Local Authorities, industry planners and other stakeholders in Scotland to implement biomass heating in an appropriate manner (Section 4).
- Measurement methods for particle matter; including a suggested test programme to explore the significance of differences in measurements. The aim here being to enable appliances tested to non-UK Standards to be assessed against objective criteria (Section 5.6)
- Measurement methods for oxides of nitrogen (Section 5.7).
- Measurement protocols for solid fuel appliances (Section 5).

In Section 6, we summarise the findings of this study in a series of recommendations for consideration by Scottish Government.

2 Interim administrative measures

A detailed review of the clauses of the Clean Air Act is provided in Section 3 and Appendix 1. In this section, we provide suggestions for interim administrative measures which would assist in the implementation of the current Act, by clarifying and simplifying administration of the Act. The proposed interim administrative measures could, to the best of our understanding, be implemented without requiring Parliamentary approval.

A number of measures are suggested in Table 1 for consideration as potential administrative measures that could be adopted to support Local Authorities in implementing the current provisions of the Clean Air Act (CAA).

Table 1 : Summary of suggested interim administrative measures

Recommendation	Description	Benefit and risks	Comment
Streamlining the process by which appliances are exempted under Section 21 of the Clean Air Act	A mechanism for exemption such that appliances could be exempted without an ongoing need for regular production of a regulation (Scottish Statutory Instrument - SSI) – perhaps a regulation declaring that exempt appliances are on a list maintained by/for Scottish Government which would, as now, also be publicly available on a website.	This list could be added to without requiring production of a regulation (SSI) listing the appliance. This would make the exemption process quicker (which would please manufacturers/suppliers) and also remove the administrative costs for Scottish Government of regularly producing new SSIs.	A variation to this may be to consider use of a UK-wide list. Manufacturers and suppliers have commented that different updating timescales of the regional exemption instruments can affect their access to support funding. A further option may be to use the approved energy technology list for the Enhanced Capital Allowance (ECA) scheme. However, the ECA scheme does not at present include particulate emission criteria for boilers or roomheaters equipment. Appliance efficiency is not an adequate surrogate for particulate emission and is not part of the CAA exemption review.
Review of smoke control areas.	A review with Local Authorities to determine if a complete or partial suspension of a Smoke Control Area (SCA) could be helpful for biomass development. This may be at specific locations or, perhaps more administratively helpful, a general suspension for non-domestic appliances. This would allow installation of non-exempt biomass appliances for a specific development if air quality is demonstrated to be at low or limited risk from biomass development and, in particular, low emission biomass installations.	A general modification to all SCAs perhaps restricted to those outside a declared Air Quality Management Area, to allow non-domestic appliances would be an easier administrative measure (a single regulation) but would have some risk to air quality if no emission criteria are included. A more area-specific approach may be difficult to administer if individual smoke control orders are modified for example around specific premises or areas.	The proposed biomass heating facilities would still need to meet agreed criteria to achieve planning consent but CAA exemption would not be needed. The removal of Smoke Control Area controls on domestic appliances is not recommended. The review needs to consider whether SCA includes or is part of an Air Quality Management Area.
Clarify acceptance and test criteria for non-domestic appliances in the Clean Air Act	The acceptance and test criteria for the appliances larger than 45 kW output are not formally defined in the CAA or associated documents. These could be aligned with EN303-5 classes or with emission limits under Pollution Prevention and Control guidance.	For hot water boilers this could be aligned to an EN303-5 class at limited risk to smokeless provisions for CAA Smoke Control Areas. For larger appliances an emission concentration limit aligned with emission limits for combustion plant under Pollution Prevention and Control regulations would also provide limited risk to smokeless provisions under the CAA.	To set emission limits to achieve a higher degree of protection than the CAA is more difficult. Emission levels such as proposed as good quality under the Renewable Energy Strategy or, as may be needed for air quality management are more stringent than for the CAA. Measurement methods differ across Europe such that achievement of emission criteria substantially lower than the CAA limits may be difficult to demonstrate under current emission testing (including EN303-5).

Recommendation	Description	Benefit and risks	Comment
Provide guidance to Local Authorities on what is smokeless and good quality biomass.	Smokeless is undefined in CAA and there is a need to raise awareness of EP UK/LACORS and other guidance. Also increasing awareness of CAA controls on combustion plant which are available to a Local Authority.	This could remove barriers caused by planning concerns over air quality impacts.	
Consider adopting non-UK ecolabelling schemes as mechanism for exempting domestic appliances.	Modify CAA requirements for domestic appliances to enable adoption of existing ecolabel emission limits (for example DINplus, Nordic Swan).	This could simplify administration of exemption and reduce testing costs for manufacturers. However, there would be a risk to air quality because the available ecolabel schemes are not designed to protect air quality and, for the CAA, do not demonstrate smokeless operation – they provide a test against a benchmark which is designed to provide a distinction between good and average or poor appliances.	In particular, DINplus testing does not cover the full operating range of appliances and has an emission measurement technique which has been demonstrated to underestimate particulate emission (see Section 5). The Nordic Swan test protocol adopts a particulate measurement technique which is more representative of air quality impacts and includes testing at different burn rates but only offers a single test at each and using an artificial firebed – the potential variability in real life burn cycles for manual appliances is not adequately represented
Develop criteria for acceptance of non-CAA test data.	Develop a test programme to assess differences between national test methods (and/or ecolabel criteria) to quantify differences between test methods and hence provide more robust criteria for acceptance of emission data from other test requirements in Europe.	This would ease the administrative hurdles for manufacturers. However, this would involve testing emissions from appliances and is unlikely to be a cheap solution.	At some stage a testing programme will be necessary to allow evidence-based decisions on whether standards for appliances in another country are acceptable in Scotland (and vice versa) without risk to air quality.
Develop harmonised European emission requirements and test methods.	A longer term objective would be to seek to harmonise European emission requirements and test methods.	CAA acceptance would be less protracted and cheaper for manufacturers and regulators – acceptance could potentially become a Notified Body function.	Could be very long-term. There are particular issues in that some countries (including the UK) have legislation and emission limits tied to national test methods. Fundamental differences are apparent in testing philosophies and hence methods. A potential mechanism may be to include test procedures which do not favour any particular Member State and require change to all Member States – particle number measurements and acceptance criteria.

3 Review of Clean Air Act 1993

A section by section review is provided in Appendix 1; potential changes to the Act can be divided into a number of areas :

- Updating – administrative modification of references to other instruments which have been superseded or revised, addition of references to other relevant instruments. Examples include replacement of elements of the Environmental Protection Act by the Pollution Prevention and Control Regulations, changes in nuisance regulations and a refocus on air quality objectives.

- Rationalisation – addressing inconsistencies, removing superfluous (unused) sections and incorporating associated regulations into the Act. Examples include consistent use of appliance thresholds, formalising ‘smokeless’ criteria, perhaps removing measurement provisions for Local Authorities and, bringing any associated regulations into the revised Act or providing direct reference to such regulations. For example, the permitted periods and exemptions for arrestment plant regulations.

- Revision of powers – amendments, deletions or additions to powers in the Act to focus on measures to achieve air quality objectives while allowing development of biomass for heating. Examples might include development of emission limits and other criteria which are more relevant to current and future air quality management requirements. The need for powers to designate new Smoke Control Areas (SCAs) should be considered – in the context of the current CAA smokeless criteria the need for powers to create an SCA may be largely irrelevant in addressing PM_{10} or $PM_{2.5.}$ However, if an increase in biomass does result in air quality issues, then there will be a need for a mechanism to address impacts. The existing CAA’s SCA measures could be developed to provide a mechanism to address exceedences in air quality objectives through designation of an updated or ‘super’ SCA. Removal of SCA powers is reasonable if an SCA will provide no benefit for air quality management and would restrict development. However a ‘super’ SCA may be a measure to allow targeted improvement of air quality from relevant sources where other powers/measures are not available.

It is important to recognise that the current CAA provides powers to address emissions from domestic and other installations which fall outside Pollution Prevention and Control (PPC) or below PPC activity thresholds and, potentially, transport sources. Existing planning controls provide only limited controls for these activities and may offer little to remediate an emerging air quality issue from these sources. Other potential controls include the European Commission Ecodesign proposals for solid fuel appliances however, these will only address appliances up to 500 kW output and will not introduce EU-wide particulate emission limits on appliances due to the absence of an accepted measurement methodology.

The proposed ‘good quality’ low-emission criteria in the Renewable Energy Strategy (20 g/GJ for particulate and 50 g/GJ for oxides of nitrogen) were considered challenging for the industry and subsequent emission criteria in the proposed Renewable Heat Incentive (RHI) have been relaxed (see Section 5.8). Although there are appliances capable of meeting 20 g/GJ particulate emissions (some using abatement measures) the RES criterion for oxides of nitrogen is unlikely to be achievable without abatement measures and such measures are not proven on small biomass combustion plant.

An updated CAA could provide Local Authorities with a significant framework to tackle developing air quality issues from small combustion sources.

4 Tools for Local Authorities

4.1 Introduction

Biomass has the potential to provide a significant proportion of Scotland's and the UK's renewable heat and electricity demand. Consequently, it is anticipated that many new proposed developments may include provision for biomass combustion. However, emissions of particulate matter and oxides of nitrogen from biomass combustion may affect local air quality and this may become a material consideration for air quality, particularly in areas where Local Authorities have declared Air Quality Management Areas for these pollutants.

The impact of a biomass combustion installation on local air quality can be controlled primarily by limiting the emissions from the installation, by ensuring best practise in the complete heating system design and secondarily, by dispersing the emissions through a correctly-designed chimney stack. These factors and the height of the stack have a significant effect on local pollutant concentrations.

This note provides a summary of the tools available in Scotland for assessing whether the height of the proposed stack is sufficient to disperse the pollutant effectively. These tools will thus assist Local Authorities, industry planners and other stakeholders in Scotland to implement biomass heating in an appropriate manner.

The general approach to assessing the stack height is to use a dispersion model to predict the contribution of the proposed development to local pollution levels and then to assess the significance of that impact. The first requirement of the impact assessment is to establish whether the proposed development will lead to concentrations of particulate matter, PM_{10} or $PM_{2.5}$, or nitrogen dioxide exceeding the air quality objectives set out in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland. The air quality objectives are summarised in Table 2.

Table 2 : Air quality objectives for particulate matter and nitrogen dioxide for the protection of human health

Pollutant	Applies to	Objective	Concentration measured as	Date to be achieved and maintained thereafter
Particles (PM_{10})	UK	50 µg m^{-3} not to be exceeded more than 35 times a year	24 hour mean	31 December 2004
	UK	40 µg m^{-3}	annual mean	31 December 2004
	Scotland	50 µg m^{-3} not to be exceeded more than 7 times a year	24 hour mean	31 December 2010
	Scotland	18 µg m^{-3}	annual mean	31 December 2010
Particles ($PM_{2.5}$)	UK (except Scotland)	25 µg m^{-3}	annual mean	2020
	Scotland	12 µg m^{-3}	annual mean	2020
Nitrogen dioxide	UK	200 µg m^{-3} not to be exceeded more than 18 times a year	1 hour mean	31 December 2005
	UK	40 µg m^{-3}	annual mean	31 December 2005

For new developments, planners and regulators may wish to restrict the contribution from the development further, for example to maintain the headroom between ambient concentrations and the objective limits or to ensure that the development does not increase the ambient concentrations significantly.

A summary of the tools available for assessing impacts of biomass combustion is provided in Table 3. The tools vary from simple guidance on location and height of discharges (for domestic appliances) to detailed dispersion modelling tools

Table 3 : Summary of tools available for assessing impacts

Source	Type of tool	Range of application	Addresses Scotland AQ limits ?	Comment
Clean Air Act Memorandum	Stack height calculation	>150 kW gross heat input	No	Application of the Memorandum to wood burning appliances with thermal input greater than 1 MW may lead to exceedences of the air quality objective for nitrogen dioxide. The Chimney Heights Memorandum does not take account of particulate emissions from biomass combustion appliances..
HMIP (Environment Agency) 'D1'	Stack height calculation	Intended for PPC Part A installations	No	Developed for short-term impact assessment. It is not appropriate for assessing the impact of oxides of nitrogen and particulate matter emissions from biomass boilers.
Defra and the Devolved Administrations LAQM TG(09)	Screening for air quality review and assessment	Industrial emissions from stacks and low level/fugitive sources. Also biomass combustion sources	In part	Developed as a tool for determining whether an emission source would require more detailed investigation. Covers NO_2, PM_{10} and, through use of PM_{10} methodology, $PM_{2.5}$ Biomass nomographs have been added to LAQM TG(09)which include PM_{10} and $PM_{2.5}$
Scottish Government	Biomass screening tools	Biomass boilers	Yes	Developed as part of report into PM_{10} and $PM_{2.5}$ emissions from wood-burning boilers for Scottish Government
EPUK (NSCA)/ LACORS	Assesses significance of air quality impacts	Biomass boilers	In part	Provide contribution made by installation – to allow planning to assess impact on headroom to AQ limits. Tools for Scotland in development.
Various	Detailed dispersion model	Typically for PPC part A processes	Yes	Detailed assessment technique likely to be unnecessary for most sub-PPC activities
Building standards	Siting rules for chimneys	Domestic <50 kW).	No	May be issues where adjacent buildings/windows close and overlook discharge point.

The National Society for Clean Air (NSCA) provided guidance on the assessment of the significance of air quality impacts. The guidance "Development Control: Planning for Air Quality: 2006 update" is available from the NSCA successor organisation, EPUK. The guidance stresses the role of professional judgment in assessing significance: however, it provides a set of descriptors that are useful in assessing significance.

Many dispersion models are available for air quality assessment of biomass combustion plant. These can be broken down into two main types:

> **Screening tools** (Section 4.3). These are generic approaches based on a limited number of variables that are intended to assess whether an air quality problem exists and if a more detailed assessment is required. They are not suitable for application in complex situations for example where there is complex terrain with slopes greater than 1 in 10 within a distance of 10 times the stack height.

Detailed dispersion models (Section 4.2). Detailed dispersion modelling is usually appropriate for combustion appliances regulated under the PPC Regulations (Environmental Permitting Regulations in England and Wales). Screening modelling is usually applicable for smaller appliances. Screening modelling is intended to provide a conservative overestimate of ground level concentrations. Developers may use detailed dispersion modelling in some cases for smaller appliances in order to demonstrate that a proposed stack height will provide adequate dispersion in cases where the screening model has indicated that there is a risk of exceeding air quality objectives.

It may not be appropriate for local authorities and regulators to assess very small biomass combustion installations. Ideally, for small domestic or small commercial installations, regulators would be able to rely on the application of building regulations to ensure adequate dispersion. The implications for air quality resulting from reliance on building regulations for small biomass installations (less than about 50kW thermal output) are assessed in Section 4.4.

In some cases, a single biomass combustion installation will be proposed and the installation can be considered in isolation. However, in other cases, for example for a new estate of houses, many biomass combustion appliances may be proposed. Local authorities will then wish to consider the combined effects of the new installations.   Section 4.5 considers the available screening tools for assessing the combined air quality impacts of many installations.

4.2 Detailed dispersion models

There are many detailed dispersion models that can be used to assess the impact of biomass combustion emissions on local air quality. The European Environment Agency maintains a database of dispersion models[1]. The detailed dispersion models most widely used in the UK for assessing the impact of stack emissions on local air quality are ADMS4.1 and AERMOD.

ADMS4.1 is available from the developers, Cambridge Environmental Research Consultants[2]. It is a new generation air dispersion model, which means that the atmospheric boundary layer properties are described by two parameters:

- the boundary layer depth, and
- the Monin-Obukhov length rather than in terms of the single parameter Pasquill Class.

Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution.

The model takes account the plume rise resulting from the thermal buoyancy and upwards momentum of the discharge.

ADMS 4 has a number of model options including the ability to take account of hills and buildings. It includes an in-built meteorological preprocessor that allows the user to input a range of meteorological data.

AERMOD is available from the US Environmental Protection Agency[3].

AERMOD is also a new generation dispersion model. The model operates with a range of data preprocessors:

AERMET, a meteorological data preprocessor;
AERMAP, a terrain data preprocessor that incorporates complex;
AERSURFACE, a surface characteristics preprocessor; and
BPIPPRIME, a multi-building dimensions program.

1 http://pandora.meng.auth.gr/mds/mds.php
2 http://www.cerc.co.uk/environmental-software/ADMS-model.html
3 http://www.epa.gov/scram001/dispersion_prefrec.htm.

Various companies have integrated the AERMOD models in proprietary modelling packages[4].

Older models used a simpler representation of the atmospheric boundary layer. Examples of these models were ISC3 from the US EPA and various models based on the National Radiological Protection Board R91 model. These models are no longer widely used.

Technical Guidance prepared by Defra for Local Air Quality Management (LAQM.TG(09)) provides useful advice on carrying out detailed dispersion modelling assessments. Table 4 summarises the input data typically required for detailed dispersion modelling.

Table 4 : Input data typically required for detailed modelling

Data class	Input required	Units	Note
Emissions	Rate of emission of pollutant	g/s	From manufacturer's emission data, performance guarantees or other data.
Discharge characteristics	Stack height above ground	m	
	Stack diameter	m	
	Discharge temperature	°C	Needs to be estimated based on manufacturer's data for boiler and duct/stack details
	Discharge velocity	m/s	Needs to be calculated from manufacturer's data, temperature and stack diameter.
	OS grid coordinates	m	
Building characteristics	Height	m	
	Length	m	
	Width	m	
	Orientation wrt north	degrees	
	OS grid coordinates	m	
Terrain	Height above datum	m	Data usually required on a regular grid
	Surface roughness	m	Constant value usually applied, but possible varying across grid
Meteorological data	Wind speed	m/s	Hourly sequential data , typically for 5 years. Data is typically purchased from the Met. Office or other data suppliers
	Wind direction	degrees	
	Cloud cover	oktas	
	Boundary layer height	m	
Receptor grid	OS grid coordinates	m	Receptors on a regular grid or at specific locations

4 http://www.breeze-software.com/
http://www.lakes-environmental.com/
http://www.beeline-software.com/

4.3 Screening models

Several screening models are available that may be useful in assessing the impact of biomass combustion installations.

ADMS-Screen is available from the developers, CERC. It is based on the detailed ADMS model but makes use of a number of pre-defined meteorological datasets.

AERSCREEN is the screening model for AERMOD. The model will produce estimates of regulatory design concentrations without the need for meteorological data and is designed to produce concentrations that are equal to or greater than the estimates produced by AERMOD with a fully developed set of meteorological and terrain data. EPA is currently working on a beta version of the code that will be released to the public as soon as possible.

The third edition of the 1956 Clean Air Act Memorandum: Chimney Heights "The Clean Air Act Memorandum" provides simple numerical formulae for assessing chimney heights. It was developed based on a simple dispersion algorithm. Separate formulae are used for very low sulphur fuels (less than 0.04% by weight) and for other fuels i.e containing sulphur. Most forms of biomass may be considered to be very low sulphur fuels except where the biomass has been chemically treated. The method is applicable for fuel burning plant with gross heat input in the range 150 kW to 150 MW. The method seeks to determine the minimum height for a chimney that will ensure adequate dispersal of pollutants produced in normal combustion: these include oxides of nitrogen. It does not deal with grit and dust emissions. The calculations assume that an adequate efflux velocity for the flue gas will be achieved to prevent the plume of gas flowing down outside of the chimney. For boilers up to 2.2 MW input, the target velocity should not be less than 6 m/s at full load although it is recognised that many existing designs of small installations cannot achieve this. For boilers equipped with induced draught fans, higher velocities are required. The Chimney Heights Memorandum provides a simple algorithm for taking account of the effect of nearby buildings on dispersion.

The Chimney Heights Memorandum is widely used for assessing the height of discharge stacks for gas boilers. Abbott (2005) [5]reviewed the application of the Chimney Heights Memorandum for small gas boilers and concluded that chimney heights for conventional natural draught gas boilers determined by proper application of the third edition of the Chimney Heights Memorandum are likely to be sufficient to prevent local exceedences of the air quality objectives for nitrogen dioxide. That conclusion remains valid for gas boilers for the current air quality objectives for nitrogen dioxide in Scotland. For this study, we have reviewed the modelling carried out by Abbott taking account of the differences in oxides of nitrogen emissions and discharge velocities between gas boilers and wood burning appliances. Typically oxides of nitrogen emissions from wood burners are in the range 100-150 g/GJ compared to the emissions from gas boilers of typically 20 g/GJ for low NOx burners assumed by Abbott. Discharge velocities are also smaller. We conclude that chimney heights for wood burning appliances with thermal input less than 1 MW determined by proper application of the third edition of the Chimney Heights Memorandum are likely to be sufficient to prevent local exceedences of the air quality objectives for nitrogen dioxide. There is a risk that application of the Memorandum to wood burning appliances with thermal input greater than 1 MW may lead to exceedences of the air quality objective for nitrogen dioxide.

The Chimney Heights Memorandum does not take account of particulate emissions from biomass combustion appliances and so assessment of stack heights using the memorandum alone is not sufficient.

HMIP Technical Guidance Note (Dispersion) D1 provides a simple set of formulae for assessing the short-term impact of pollutant emissions. It was developed by systematically running a dispersion model based on the NRPB R91 model for a range of discharge

[5] J A Abbott. Review of the Clean Air Act provisions for dispersion from small gas boilers, 2005. http://www.airquality.co.uk/reports/cat05/0605251503_Small_gas_boilers_Final.pdf

conditions. It is not appropriate for assessing the impact of oxides of nitrogen and particulate matter emissions from biomass boilers. D1 was developed in 1993 and addresses short term impacts, typically 15-30 minutes. Current air quality objectives for PM are associated with annual mean and 24-hour mean objectives. D1 is not applicable to the longer-term objectives. D1 should only be used where the discharge velocity exceeds 10 m s^{-1}: the discharge velocities for natural draught biomass boilers are often considerably less.

Environment Agency Guidance for estimating the air quality impact of stationary sources (GSS) was a chart-based system for calculating the maximum impact of pollutant releases from a process stack. It was developed using results from systematic application of the ADMS2 model for a range of geographical and discharge situations.

Industrial nomographs are provided in Technical Guidance for Local Authority Review and Assessment LAQM.TG(09) for the screening assessment of NOx and PM10 emissions against the Air Quality Strategy objectives for the purposes of Local Authority Review and Assessment.

The industrial nomographs provide a method for assessing the impact of combustion emissions from chimneys with effective stack heights greater than 10 m. These nomographs were based on the GSS charts. The method takes account of the effect of the height of nearby buildings using the approach adopted for the Chimney Heights Memorandum. The minimum stack height of 10 m usually limits the application of the method for biomass combustion to installations greater than 1 MW thermal input.

The following stack height nomographs from LAQM.TG(09) are relevant to the assessment of biomass combustion installations in Scotland:

> Figure 5.1: Emissions of nitrogen oxides (tonnes/annum) which will give rise to a 99.8th percentile hourly mean nitrogen dioxide concentration of 40 µg/m3;
>
> Figure 5.2: Emissions of nitrogen oxides (tonnes per annum) which will give rise to an annual mean ground-level nitrogen dioxide concentration of 1 µg/m3;
>
> Figure 5.7: PM_{10} emissions (tonnes per annum) from combustion source emissions (>100ºC) to give an annual mean ground-level concentration of 1 µg/m3.

LAQM. TG(09) also provides industrial nomographs for assessing the impact of low level and fugitive emissions:

> Figure 5.3: Emissions of nitrogen oxides (tonnes per annum) that will give rise to an annual mean ground-level nitrogen dioxide concentration of 1 µg/m3 at receptor locations up to 2 km from fugitive and low-level sources (stack <10 metres);
>
> Figure 5.9: PM_{10} emissions (tonnes per annum) that will give an annual mean ground-level concentration of 1 µg/m3 at receptor locations up to 2km from fugitive and low-level sources (stack <10m).

LAQM.TG(09) does not provide a nomograph for assessment against the objective for Scotland for PM10 of 50 µg m^{-3} not to be exceeded more than 7 times a year because the annual mean objective in Scotland of 18 µg m^{-3} is more stringent. Thus, it is assumed that if the screening assessment shows that the annual mean objective will be met it is assumed that the 24 hour mean objective will also be met.

LAQM.TG(09) does not provide a nomograph for assessment against the objective for $PM_{2.5}$ for Scotland of 12 µg m^{-3} because assessment against the objective is not required for local authority review and assessment. However Figures 5.7 and 5.9 of the guidance for PM_{10} are also applicable to $PM_{2.5.}$

The industrial nomographs have been implemented within a spreadsheet tool available for download from the Air Quality Archive[6]. The spreadsheet tool includes the provision to assess PM_{10} concentrations against the annual mean objective in Scotland of 18 µg m^{-3}.

Biomass nomographs were developed for inclusion in Technical Guidance for Local Authority Review and Assessment LAQM.TG(09) for screening assessment of biomass combustion installations. The nomographs were developed using results from systematic application of the ADMS4 model for a range discharge situations appropriate for biomass combustion installations. The development of the nomographs is described by Abbott[7]. The methods were developed further to take account of the different air quality objectives and meteorological conditions in Scotland in a separate report- Measurement and Modelling of Fine Particulate Emissions (PM_{10} and $PM_{2.5}$) from Wood-Burning Biomass Boilers[8].

The method takes account of the effect of the height of nearby buildings using the approach adopted for the Chimney Heights Memorandum.

The following nomographs from LAQM.TG(09) are relevant to the assessment of biomass combustion installations in Scotland:

> Figure 5.20: nitrogen dioxides emissions to give an annual mean ground-level nitrogen dioxide concentration of 1 µg/m3
>
> Figure 5.21: Emissions of nitrogen oxides that will give a 99.8th percentile of 1-hour nitrogen dioxide concentrations of 40 µg/m3

However, LAQM.TG(09) does not provide nomographs for assessing PM_{10} or $PM_{2.5}$ against the air quality objectives for Scotland. These nomographs and instructions for their use for local Authority Review and Assessment are available in Annex 3 of the measurement and modelling report.

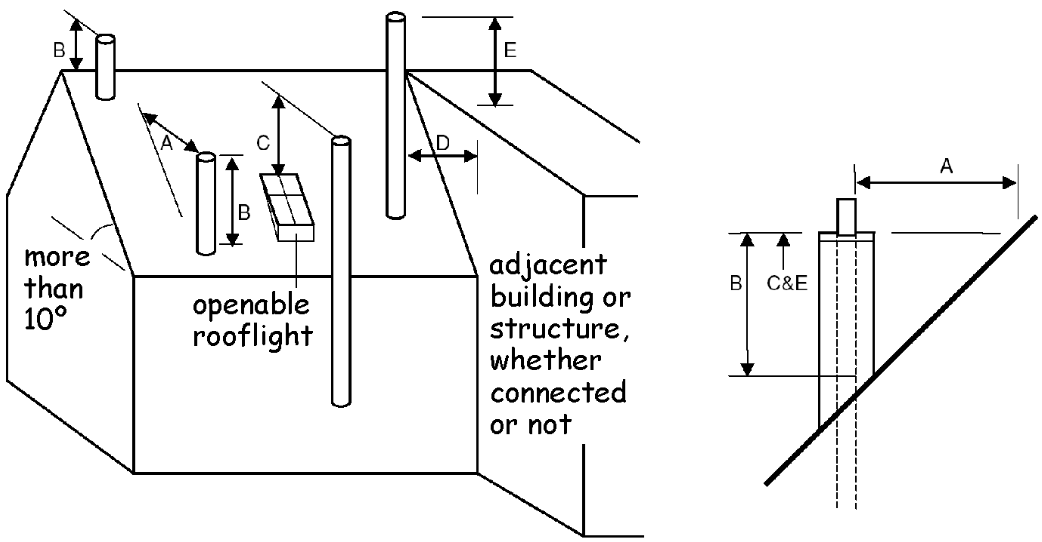
The biomass nomographs for UK and Scottish meteorological conditions have been implemented within a spreadsheet tool available for download from the air quality archive[9]. [Note. Users may have to activate macros when downloading the tool]. The spreadsheet tool includes the provision to assess PM_{10} concentrations against the annual mean objective in Scotland of 18 µg m^{-3} and to assess $PM_{2.5}$ concentrations against the annual mean objective in Scotland of 12 µg m^{-3}. The spreadsheet tool does not provide a nomograph for assessment against the objective for Scotland for PM_{10} of 50 µg m^{-3} not to be exceeded more than 7 times a year because the annual mean objective in Scotland of 18 µg m^{-3} is more stringent. Thus, it is assumed that if the screening assessment shows that the annual mean objective will be met it is assumed that the 24 hour mean objective will also be met.

The nomograph method was intended to identify biomass emissions sources that create a potential risk of locally exceeding the Air Quality Strategy objectives. The assessment criteria for planning and development control decision-making are different from those for Local Authority Review and Assessment. Local authorities may wish to limit the contribution to ground level concentrations from new developments so that the headroom between the ambient concentration and the air quality limit is maintained. In this case, it is desirable to estimate the contribution from the proposed development to ground level concentrations. The method has therefore been adapted as part of a joint Environmental Protection UK/LACORS project to develop Biomass and Air Quality Guidance for England and Wales (http://www.environmental-protection.org.uk/biomass/). The Scottish division of Environmental Protection UK intend to produce an amended version to cover Scotland and will consult on this at a later date. The adapted spreadsheet tool is available from the website. The spreadsheet tool calculates the contribution from the proposed installation to maximum annual mean ground level concentrations of oxides of nitrogen, PM_{10} or $PM_{2.5}$.

[6] http://www.airquality.co.uk/laqm/tools.php?tool=emission
[7] http://www.airquality.co.uk/archive/reports/cat18/0806261519_methods.pdf
[8] http://www.scotland.gov.uk/Publications/2008/11/05160512/10)
[9] http://www.airquality.co.uk/laqm/tools.php

4.4 Building regulations

It would be helpful if local authorities could assume that individual small biomass combustion appliances installed according to building regulations would not cause local exceedences of the Air Quality Strategy objectives. Scottish building regulations for domestic and non-domestic appliances are given in technical handbooks published by the Scottish Building Standards Agency[10]. The regulations apply for solid fuel appliances with less than 50 kW thermal output. The outlet from a flue should be located externally at a safe distance from any opening, obstruction or flammable or vulnerable materials. The outlets should be located in accordance with the following diagram:



Minimum dimension to flue outlets

A 2.3 m horizontally clear of the weather skin.
B 1.0 m provided A is satisfied; or 600 mm where above the ridge.
C 1.0 m above the top of any flat roof ; and 1.0 m above any openable rooflight, dormer or ventilator , etc. within 2.3 m measured horizontally.
D/E where D is not more than 2.3 m, E must be at least 600 mm.

Notes:
1. Horizontal dimensions are to the surface surrounding the flue.
2. Vertical dimensions are to the top of the chimney terminal.

Two cases can be considered depending on whether or not the chimney terminal is above the top of the building or adjacent building.

The biomass nomographs developed for Local Authority Review and Assessment are applicable in the case that the stack discharges above the building. Table 5 shows the maximum annual emission rate that could occur without exceeding the annual mean air quality objective for nitrogen dioxide for a 10 m high building with a stack 10.6 m high above ground and 0.2 m diameter for a range of annual average background nitrogen dioxide concentrations.

[10] http://www.sbsa.gov.uk/tech_handbooks/tbooks2009.htm

Table 5 : Maximum emission rates for screening assessment for the annual mean nitrogen dioxide objective

Background concentration, µg m^{-3}	Maximum annual emission rate, g/s
39	0.0013
35	0.0067
30	0.0133
25	0.020
20	0.0266

The oxides of nitrogen emissions depend on the nitrogen content of the wood and are usually less than 150 g/GJ thermal input. For a 50 kW biomass combustion installation operating at capacity throughout the year at 90% efficiency, the annual rate of emission would be 0.0083 g/s. Thus it is possible that the annual mean air quality objective would be exceeded locally if the background concentration was more than 34 µg m^{-3}. Annual mean background nitrogen dioxide concentrations in Scotland are generally less than 34 µg m^{-3} except near the centre of the largest towns and cities. Furthermore, the assessment has conservatively assumed that the combustion plant operates continuously and that all the oxides of nitrogen emitted is converted in the atmosphere to nitrogen dioxide. It is thus concluded that installations meeting the building regulations with stacks terminating above the building will generally not cause local exceedence of the annual mean air quality objective for nitrogen dioxide at background locations in Scotland.

Table 6 shows the maximum annual emission rate that could occur without exceeding the hourly mean air quality objective for nitrogen dioxide for a 10 m high building with a stack 10.6 m high above ground and 0.2 m diameter for a range of annual average background nitrogen dioxide concentrations.

Table 6 : Maximum emission rates for screening assessment for the hourly mean nitrogen dioxide objective

Background concentration, µg m^{-3}	Maximum annual emission rate, g/s
39	0.054
35	0.057
30	0.062
25	0.066
20	0.070

Comparing the maximum emission rates shown in Table 7 with the emission rate of 0.0083 g/s estimated for the 50 kW output installation indicates that local exceedences of the hourly mean objective for nitrogen will not occur.

Table 8 shows the maximum annual emission rate that could occur without exceeding the annual mean air quality objective for PM_{10} and $PM_{2.5}$ for a 10 m high building with a stack 10.6 m high above ground and 0.2 m diameter for a range of annual average background nitrogen dioxide concentrations.

Table 7 : Maximum emission rates for screening assessment for the annual mean particulate objectives

Background concentration, µg m^{-3}		**Maximum annual emission rate, g/s**
PM_{10}	**$PM_{2.5}$**	
17	11	0.0013
15	9	0.004
13	7	0.0067
11	5	0.0093
9	3	0.012

The particulate emissions depend on the design of the burner, the fuel and the operation of the burner. A well-operated modern boiler will emit typically 20 - 60 g PM_{10}/GJ thermal input. For a 50 kW biomass combustion installation operating at capacity throughout the year at 90% efficiency, the annual rate of emission would be in the range 0.001-0.003 g/s. Background PM_{10} concentrations in Scotland are typically less than 15 µg m^{-3} except in large urban areas. Furthermore, the assessment has conservatively assumed that the combustion plant operates continuously throughout the year. It is thus concluded that installations meeting the building regulations with stacks terminating above the building will generally not cause local exceedence of the annual mean air quality objective for PM_{10} at background locations in Scotland except in large urban areas. Limiting PM_{10} emissions to less than 20 g/GJ would allow biomass plant to operate in more urban areas without exceeding the objective.

A well-operated modern boiler will emit typically 10 - 50 g $PM_{2.5}$ /GJ thermal input. For a 50 kW biomass combustion installation operating at capacity throughout the year at 90% efficiency, the annual rate of emission would be in the range 0.0005-0.003 g/s. Background $PM_{2.5}$ concentrations in Scotland are typically less than 9 µg m^{-3} except in large urban areas. Furthermore, the assessment has conservatively assumed that the combustion plant operates continuously throughout the year. It is thus concluded that installations meeting the building regulations with stacks terminating above the building will generally not cause local exceedence of the annual mean air quality objective for $PM_{2.5}$ at background locations in Scotland except in large urban areas. Limiting $PM_{2.5}$ emissions to less than 20 g/GJ would allow biomass plant to operate in more urban areas without exceeding the objective.

The building regulations allow discharge through chimneys below the top of attached or adjacent buildings provided that the building is more than 2.3 m horizontally from the chimney. The dispersion from these chimneys will be affected to a significant extent by the buildings. The low level industrial nomographs and spreadsheet tool are applicable in this case. Table 8 shows the maximum PM_{10} emission rates calculated using the spreadsheet tool for a range of background concentrations and distances to the nearest relevant receptor (e.g. the house next door) assuming a discharge height of 5 m above ground. Comparing these emissions with the rate of emission for a 50 kW installation calculated above (0.001-0.003 g/s) indicates that the annual mean air quality objective might be exceeded even where background concentrations are 14 µg m^{-3} or less if neighbouring houses are close. It is therefore recommended that small (<50kW thermal output) biomass combustion installations should be considered on a case by case where the chimney discharges below the height of attached or adjacent buildings.

Table 8: Maximum emission rates for screening assessment for the annual mean PM_{10} objective for low level emissions

Background PM_{10} concentration, µg m^{-3}	Distance of nearest receptor, m	Maximum emission rate, g/s
14	10	0.0012
	20	0.0026
	30	0.0043
	40	0.0062
	50	0.0084
15	10	0.0009
	20	0.0020
	30	0.0032
	40	0.0047
	50	0.0063
16	10	0.0006
	20	0.0013
	30	0.0022
	40	0.0031
	50	0.0042
17	10	0.0003
	20	0.0007
	30	0.0011
	40	0.0016
	50	0.0021

4.5 Combined effects

LAQM.TG(09) provides simple nomographs to assess the combined effects of the installation of many biomass boilers in an area against the annual mean objective for PM_{10} in Scotland for the purposes of local authority review and assessment. The nomograph (Fig. 5.23 of the guidance) enables the user to calculate a screening emission limit for a 500m by 500m area that depends on the background PM_{10} concentration and the nature of the surrounding area (village, small town or large town). The estimated annual emission from biomass combustion appliances in the area can then be compared with the screening emission limit: more detailed assessment would be required if the emissions from the area exceeded the screening emission limit.

The Scottish Government report-Measurement and Modelling of Fine Particulate Emissions (PM_{10} and $PM_{2.5}$) from Wood-Burning Biomass Boilers- provides examples of detailed modelling of the combined effect of potential biomass combustion installations in Dundee and Edinburgh.

5 Emission testing protocols for solid fuel appliances

5.1 Overview of emissions

An introduction to the range of solid fuel appliances, appliance standards and combustion processes is provided in Appendix 2.

In any combustion process, a range of typical pollutants is usually formed, but their amount differs depending on fuel and appliance type, and on operational mode. Relevant emissions from solid fuel appliances include pollutants with transboundary and/or local impacts including particulate, oxides of nitrogen, oxides of sulphur, carbon monoxide, carbon dioxide, heavy metals, polynuclear aromatic hydrocarbons, hydrogen halides, volatile organic compounds and persistent organic pollutants. The formation of particulate matter, oxides of nitrogen and carbon monoxide (a key indicator of combustion efficiency) are described below.

Particulate matter

Particulate Matter (PM) in flue gases from combustion of solid fuels includes ash (mineral matter) and carbon and other products of incomplete combustion. There are different types or groups of particulate matter :

1. Products of Incomplete Combustion (or PICs) including soot and organic carbon particles formed during combustion as well as from gaseous precursors through nucleation and condensation processes (secondary organic carbon). Condensed organic compounds (tars) are an important, and in some cases, the main contributor to the total level of particles emission in small, manually-fed, domestic appliances such as fireplaces, stoves and cookers.

2. Mineral ash particles or cenospheres that are largely produced from mineral matter in the fuel, they contain oxides and salts of Ca, Mg, Si, Fe, K, Na, P, and heavy metals. Biomass combustion can give rise to volatile chloride salts which can condense on boiler heat exchanger surfaces

3. Carbon from incomplete combustion of carbonaceous material is also present in ash particles.

The particulate matter emission from small combustion is typically a mixture of all groups with PICs associated and/or adsorbed onto particulate. Size distribution depends on combustion conditions. Optimisation of the solid fuel combustion process (for example by introduction of continuously controlled conditions such as automatic fuel feeding and distribution of combustion air) leads to a decrease of particulate emission.

Several studies have shown that the particulate emissions from modern and ‘low-emitting’ residential biomass combustion technologies are dominated by submicron particles (< 1µm) and the proportion of the mass concentration of particles larger than 10 µm is normally < 10% (however in some instances this conclusion may be derived from inherently limited particle measurements). For larger appliances, entrainment of fuel and ash material, and the presence (or absence) of abatement measures will dictate size distribution.

Oxides of nitrogen

Oxides of nitrogen (NOx) are the sum of nitric oxide (NO) emissions (typically >90% of the NOx emission) and nitrogen dioxide (NO_2). The emissions of NOx increase with increasing nitrogen contents in the fuel, as well as with increasing excess air ratio, and higher combustion temperature. Nitrogen content in solid fuels vary both among and within fuel types. Nitrogen levels in coals are generally higher than for wood fuels.

Additional NOx may be formed under high temperature conditions (>1300ºC) as "thermal NOx". However, the combustion temperatures in small appliances is generally too low for formation of significant levels of thermal NOx and formation is not usually important (especially for domestic roomheaters).

Carbon monoxide

Carbon monoxide (CO) is found in the gaseous combustion products of all carbon-based fuels, as an intermediate product of the combustion process and in particular in sub-stoichiometric (insufficient air for complete combustion) conditions. CO is the most important intermediate product of fuel combustion; it is oxidised to CO_2 under appropriate temperature and oxygen availability. Hence CO is considered as a good indicator of the combustion quality. The mechanisms of CO formation, thermal-NO, VOCs and PAH are in general similarly influenced by the combustion conditions. The emissions level is also a function of the excess air ratio as well as of the combustion temperature and residence time of the combustion products in the reaction zone.

5.2 Issues in the measurement of particulate material

There are a number of issues in assessing emission data for appliances including differences in the sampling methods (capture of semi-volatile components and particulate capture efficiency) and, differences in testing protocols (how many tests and at what output). Overall, the lack of harmonisation between methods for particulate emission testing makes meaningful comparison difficult.

Air Quality is assessed in terms of PM_{10} and $PM_{2.5}$ concentrations however, most emission measurement data are for total particulate matter and do not consider post-discharge transformation and transport – so comparability between emission and exposure to PM_{10} and/or $PM_{2.5}$ is difficult. Modelling of discharges and determination of size-specific emissions can be undertaken but sampling to determine PM_{10} and $PM_{2.5}$ emission requires more specialised equipment and test protocols.

Although total particulate is not the same as PM_{10}/$PM_{2.5}$, total particulate provides a reasonable indicator of PM_{10} and $PM_{2.5}$ emission. The main issue is whether the sampling procedure adequately captures the particulate - especially the semi-volatile components and whether the test protocol adequately represents actual use of the appliance.

The differences in measurement approaches largely reflect appliance types :

- Domestic appliances - although efficiency and heat output Standards for domestic appliances are harmonised across Europe for defined product types, emission tests depend on national regulations and there are wide regional variations which makes comparison with UK limits difficult. Due to different testing conditions, tests to the Norwegian Standard (a dilution tunnel method) can give emission results twenty (20) times higher than the German test procedure (direct sampling of flue gases). The largest differences are seen when testing batch-fed, manually-stoked, natural draught appliances (that is fireplaces, insert appliances, cookers and standalone roomheaters – except pellet stoves). These appliances can have high flue gas temperatures (>300ºC) coupled with combustion efficiency issues which result in the potential for substantial emissions of semi-volatile components which generally form an aerosol in the plume following exit from the chimney – the differences in measured emissions are largely related to how well a methodology can collect such material.

- Boilers <300 kW output – these appliances are covered by a non-harmonised EN Standard which includes particulate measurement but doesn't specify a common method of measurement. The measurement issues are not as extreme as for domestic appliances because combustion efficiencies are higher and there is much less potential for emissions of semi-volatile organic components. The most common test protocol may underestimate emissions due to use of packed wool (low efficiency) filters and non-recovery of material deposited in sampling systems – perhaps by more than 50% of the true emission. In addition, depending on filter temperature and sample recovery, semi-volatile inorganic salts may not be captured.

- Larger appliances are not covered by EN Standards but can be tested using 'industrial' stack monitoring EN Standards (or other recognised Standards) however, much testing is based on national methods which, as with smaller boilers, can underestimate emissions.

The UK Clean Air Act test procedure requires more tests and at more output conditions than other national procedures on domestic appliances. Other key differences between national procedures for domestic appliances include use of standardised artificial firebeds made from cribs or lattices of square cut timber. The UK particulate test method also differs from those in other countries and there are limited recent data to compare data from UK and other sources.

The issues for particulate emission measurements on domestic appliances are well known. Order of magnitude differences in measured emissions have been reported[11] between various national and regional methods particularly as applied to residential manually-fired wood roomheaters. Similarly, differences between methods for measuring emissions for wood-fired boilers have been reported. Recent work[12] to assess test methods for non-wood biomass has indicated that simpler approaches underreporting by up to 50% compared to more rigorous measurements.

CEN Technical Committee 295 (domestic solid fuel appliances) prepared a Technical Specification for particulate measurement which included input from UK (provided through Defra and Devolved Administration support) based on a dilution tunnel method but this was not published as agreement could not be achieved with countries using different methods – partly because of the lack of comparative data between test methods.

5.3 Development of UK emission limits and measurement methods

The current Clean Air Act fuel Authorisation and appliance Exemption system is based around the Beaver Commission report of 1954 which required that the smoke emissions from authorised fuels be set at 20% of those of bituminous coal when burnt in a domestic open fire. As smoke emission is a strong function of burn rate this led to several years of technical investigations at the Fuel Research Station which led to the 5g/hour limit for Authorised fuels at defined burn rates on an open grate measured according to BS 3841.

This also was used to define the minimum performance standard for exempt appliances; domestic appliances are allowed 5g/hour plus an allowance of 1g/hour for every 3kW of heat

[11] Nussbaumer et al. Particulate Emissions from Biomass Combustion in IEA Countries – A survey on measurements and emission factors. 2008. ISBN 3-908705-18-5. Produced for IEA Bioenergy Task 32 and Swiss Federal Office of Energy. Available from www.ieabcc.nl

[12] ERA-NET Bioenergy project. Development of test methods for non-wood small-scale combustion plants. Final report, 2008. Austrian BioEnergy Centre Report 302 TR nK I-1-23.

output (BS PD 6434)[13]. The test method is BS 3841 (Part 2) and uses the same methodology to collect the smoke emission as for the Authorised fuel test.

BS 3841 incorporates two methods :

1. The first method involves passing the entire exhaust gas flow (with addition of some dilution air) through an electrostatic precipitator[14] which is weighed before and after use to give a mass emission over the sampling period.
2. The alternative procedure uses a dilution tunnel approach and conventional stack monitoring gravimetric filtration method.

The electrostatic precipitator method is unique to the UK but several other countries have test methods based on dilution tunnels including USA, Canada, Australia, New Zealand and Norway (and many Scandinavian countries have adopted the Norwegian method including the Nordic Swan ecolabel).

There is no formal guidance on smokeless emission standards for Clean Air Act exemption of appliances above 45kW. Regulations define emission limits for grit and dust from furnaces larger than about 250 kW; these limits are for all furnaces outside a smoke control area and are higher than extrapolated values from BS PD 6434. Criteria for exemption under Section 21 of the Clean Air Act have been developed based on extrapolated limits from BS PD 6434, visual assessment (Ringelmann) and most recently a particulate concentration limit.

Use of extrapolated BS PD 6434 limits on particulate emission for appliances larger than 45 kW now appear high in terms of the need for minimising the impact of large-scale biomass uptake on the achievement of air quality objectives for $PM_{2.5}$ and PM_{10}. Increased biomass use may also impact on the achievement of air quality objectives for nitrogen dioxide.

The UK Renewable Energy Strategy (RES) suggested a blanket CAA exemption for appliances with emissions below 20g/GJ PM_{10} and 50g/GJ NO_x; these emissions criteria were derived from modelling of various biomass uptake rates and emission performance levels. The RES proposals are expressed in terms of energy input and not directly equivalent to emission rate limits in BS PD6434 (for domestic appliances) however, calculations indicate that the RES proposals are considerably more stringent than provided in BS PD 6434. The subsequent consultation on the Renewable Heat Incentive (RHI) proposed a relaxation of the RES thresholds following feedback from stakeholders and manufacturers (see Section 5.8).

5.4 Outline of current particulate measurement methods

5.4.1 Domestic appliance particulate emission sampling methods

Particulate emission concentrations differ significantly according to the measurement method used. Methods used for assessing regulatory compliance are:

- Direct (whole exhaust) gravimetric electrostatic precipitator method (UK only)

[13] BS PD 6434 defines the testing protocol for assessing smoke emissions from solid fuel appliances; it references BS 3841 as the test method but defines a testing programme for manually-fired appliances. The protocol was designed to demonstrate that an appliance will operate smokelessly over its entire operating range. It incorporates tests at rated output, low output and a medium output (if necessary) as well as misuse tests. It also sets out the acceptance criteria for appliances up to 45 kW output

[14] Electrostatic precipitators are commonly used to abate particulate matter from exhaust gas flows at power stations and industrial processes such as cement and steel works. It works by passing flue gas through an electrical field. Particles become charged and are collected on an oppositely-charged or grounded plate. In the emission test facility this is achieved by passing the exhaust gases through a honeycomb of grounded metal tubes with a charged wire running through each tube.

- Dilution tunnel gravimetric filtration method (Norway/Scandinavia, USA, Canada, Australia, New Zealand, UK)
- Direct gravimetric filtration only method, (Germany/central Europe)
- Direct gravimetric filtration and condensable method (USA, Canada)

Research work has also included measurement of particle numbers (and size).

The UK precipitator methodology was developed over forty years ago to meet the needs of testing primarily mineral fuel domestic appliances but is only used in the UK and by only one testhouse. Validation records of the methodology are limited due in part to the period of time since development. Limited validation data with a dilution tunnel shows reasonable agreement for a mineral fuel.

The dilution tunnel methods (and the electrostatic precipitator method) give significantly higher particulate emissions than the direct gravimetric filtration method. A dilution method is likely to allow formation of secondary aerosols which is likely to be more representative of total emissions to atmosphere (and hence impact on air quality). A key benefit of a dilution tunnel approach is a more homogenous exhaust gas flow which can be characterised using Standard stack sampling methods. However, true replication of post-discharge plume processes would also include use of an 'aging' chamber with the dilution tunnel to allow plume/air interactions to come to equilibrium[15].

The direct gravimetric filtration measurement method is subject to a large number of uncertainties including non-uniform concentration distribution in the stack, losses of particles in the sampling system, inefficient capture of particles (particularly fine particles when using a packed wool sampling media) and variable capture of condensable material.

The US Environmental Protection Agency (USEPA) certification scheme for wood heaters includes methods for both dilution tunnel and direct measurements – the USEPA methods include a correlation function and can hence be considered equivalent. The differences between the German and USEPA direct methods provide an insight into the likely reasons for discrepancy between the dilution tunnel and direct gravimetric filter only method. The USEPA direct Method :

- recovers material which collects in the sampling system upstream of the primary filter
- employs a high efficiency primary filter at a fixed temperature
- includes capture of condensable material
- employs a secondary low temperature filter

The German approach has been developed for ease of use (including application in the field which is difficult for a dilution tunnel) and variants on the method can employ a low efficiency packed wool filter. No provision is made for recovery of condensable particulate or of material deposited in the sampler.

5.4.2 Comparison of domestic appliance sampling protocols

A summary of the key features of the various protocols adopted for testing domestic roomheaters and other appliances is provided at Table 9 .

Key differences beyond the physical collection of the particulate emission are :
- the range of outputs tested;
- numbers of tests (replicates);

[15] The 'aging' chamber allows more time for volatile components which may have condensed or adsorbed onto particles on cooling to re-evaporate. Dilution tunnel studies in the US on apparent condensable emissions from gas-fired combustion sources including gas turbines has indicated that direct measurements can overestimate PM due largely to measurement errors in the direct measurements. http://www.nyserda.org/programs/environment/emep/11_PMVarConceptModel_R1-V3.pdf Solid fuel combustion processes (particularly in domestic appliances with high potential for emission of products of incomplete combustion) generates far more semi-volatile organic compounds than a gas fuel so an aging chamber may be relatively unimportant.

- fuel bed preparation.

The UK test procedure requires the largest number of replicate tests, covers misuse conditions and uses a normal or natural firebed. Note that the UK procedure was intended to show that an appliance would operate smokelessly over the full range of operating conditions – other schemes are also for regulatory or other compliance but are generally a simple pass/fail criteria at a specific condition or range of conditions. Other test procedures are based on fewer measurements and in some case, an artificial firebed, fewer output conditions and differing test methods.

5.4.3 Recommendations for reducing the scope of testing for domestic appliances for compliance with the Clean Air Act

The following changes to the CAA measurement protocol are recommended to align the test procedure more with practise in other countries. Note that the changes do not align fully with the other test protocols used in Europe so are unlikely to match manufacturers' desires but, the other testing protocols are not designed to address the CAA requirements.

Output range : In general, particulate emission increases with output and some of the test protocols (USEPA and Norway) require burn rates higher than the rated output of the appliance. However, for a batch-fed appliance, emissions can also be relatively high at low output. The output of a manually-stoked domestic appliances depends on the availability of air (because the fuel is all available in the fireplace). If air flow is restricted to reduce burn rate then this can impact on emissions of particulate and particulate precursors. Modern stoves are small (often less than 5 kW) and wood burns relatively quickly so some appliances have a very limited capacity for the user to control output. However, many appliances available on the market can be 'throttled' to some degree and if the design is inadequate then smoky operation is a likely consequence.

All of the test procedures except the German method include testing at a range of outputs. Consequently it seems reasonable to require tests at rated and a low output in a measurement protocol. An intermediate output test is probably redundant but, there is potential for introducing a 'maximum' output test (as is done in the USEPA/Norwegian Standards). The use of misuse tests in the CAA test protocol could be replaced by clear instruction to the user that common misuse conditions (overfuelling, fuel onto a low firebed, keeping primary air controls open) will result in smoke emission.

Misuse tests were intended to assess how well an appliance could cope with foreseeable mis-operation of the appliance. User behaviour is a key parameter in the effective control of an appliance but, it is impossible to account for all aspects of user (mis)behaviour in a test protocol and the need for such tests could be removed from the scope without significantly weakening the test.

Replicates : The UK requirement is for 5 tests at each output condition and this is more than any other test protocol in use. Indeed BS 3841 Pt 2 has criteria which may increase the actual number of tests to achieve 5 'good' tests. The need for 5 replicate tests is due to the inherent variability in performance of a manual appliance and perhaps in the measurement uncertainties achievable during development of the method.

However, use of single tests at a burn rate to demonstrate compliance seems optimistic given the likely variability between burn cycles.

It is considered likely that the number of tests could be reduced to 3 at each output without loss of protection to air quality.

Fuel bed : the use of artificial uniform fuel beds (fuel is cut into oblongs and arranged to form a uniform lattice) by some test methods (the USEPA and Norwegian Standard) is likely to aid repeatability of measurements and consistency of assessment but does not reflect real-life use. The EN Standards for output and efficiency determination do not use artificial firebeds so, the CAA procedure should retain use of a real firebed.

5.4.4 Particulate emission measurements for EN303-5 appliances

This Standard applies to solid fuel hot water boilers up to 300 kW output (potentially up to 500 kW output after the current review of EN303-5). It includes particulate emission measurement at rated output only. Up to four measurements are required for manual and automatic boilers.

The main issue is that the emission measurement methodology is not specified so testing at one laboratory may not match testing at another. Testing procedures range from comparatively low efficiency packed glass wool filters and similar 'quick and dirty' methodologies to test protocols based on ISO 9096 or EN 13284-1 (applied to installations which fall within the scope of the Waste Incineration Directive and Integrated Pollution Prevention & Control Directive).

The high combustion efficiency of these appliances means that emission of semi-volatile organics is generally not a major issue and recent comparative testing on automatic boilers indicates the range of results is less extreme than for manually-stoked domestic appliances with natural draught. However, a recent assessment for the ERA-NET Bioenergy programme indicates that the simpler, low efficiency packed wool filter methods can underreport emissions by about 50%.

The current UK CAA requirement is based on BS PD 6434 and an EN303-5 test programme extended to include emission tests at low output. A reduced number of tests from BS PD 6434 is permitted for automatic appliances (3 tests at rated output and 3 at low output) and no misuse tests unless a potential issue is determined from the operating manual. It is recommended that this requirement is not changed.

5.4.5 Particulate emission measurements on larger appliances

Larger boilers or non-boiler appliances can be tested to a variety of stack monitoring standards. These can range from international Standards such as EN13284-1 or ISO 9096 to national or in-house methods. The national and other methods range from the packed wool filtration methods to methods that are consistent with the EN or ISO Standards.

The main issue with the methods is that a minimum number of measurements is not usually stated.

The UK CAA requirement is based on BS PD 6434 but with a reduced number of tests required (3 tests at rated output and 3 at low output) and no misuse tests on the presumption that automatic appliances larger than 300 kW should be subject to operational and maintenance controls that avoid misuse conditions.

Table 9 : Key features of domestic appliance particulate emission testing

Country	Standard	Test outputs & tests					Fuel bed	Test Method	Expression of emission	Comment
		>Rated	Rated	Medium	Low	Other				
UK	BS3841-2, PD BS 6434	-	5	(5)	5	misuse	Natural	Electrostatic precipitator or Dilution tunnel	g/hr	Requires output of appliance for assessment against limits. Also requires continuous indicative monitoring of opacity to assess peaks. Electro-static precipitator is unique to UK but methodology allows dilution tunnel approach and includes some validation of EP against dilution tunnel (for mineral fuels). Dilution tunnel approach not as defined as USEPA, Norwegian or Australian methods.
Germany	VDI, DINplus	-	3	-	-	-	Natural	Stack	mg/Nm3	Requires output of appliance for assessment against limits. Out of stack filter with no filter specification and, no collection of material collected in probe , Vapour phase material in stack may condense in probe or pass through filter. Near-isokinetic sampling, fixed volume of exhaust gas collected.
Norway	NS3058/3059	1	1	1	1	-	Test crib	Dilution tunnel	g/kg	Very similar to USEPA procedure and test facility. Up to 4 burn rates (defined by appliance output/size) aggregated into a single emission factor. Dual high efficiency filters held at constant temperature to capture PM. Different criteria for catalytic and non-catlytic stoves , criteria also cover aggregate and individual factors. Nordic Swan criteria are at low and high output and can be assessed from individual burn rates. Use of standard crib of fuel unlike 'natural' fuel beds used in UK/Germany.
USA Canada	USEPA Method 5G, Method 28	1	1	1	1	-	Test crib	Dilution tunnel	g/hr	Up to 4 burn rates aggregated into a single emission rate. Dual high efficiency filters held at constant temperature to capture PM. Use of standard crib of fuel unlike 'natural' fuel beds used in UK/Germany.
	USEPA Method 5H, Method 28	1	1	1	1		Test crib	Stack	g/hr	Method uses high efficiency filter at fixed temperature external to stack backed up by chilled condensable sampling train and final low temperature high efficiency filter. Material in probe also recovered.
Australia New Zealand	AS/NZS 4013, 4012	-	3	3	3	-	Natural	Dilution tunnel	g/kg	Multiple tests at 3 burn rates. Dual high efficiency filters held at constant temperature to capture PM.

5.5 Developing a methodology to assess emissions for air quality impact

A key issue is the characterisation of the emissions to enable modelling of air quality impacts of PM_{10} and $PM_{2.5}$. Operation of the appliances needs to be understood; some appliances can operate automatically either at fixed or modulating output; emissions from such appliances tend to be more consistent than for manually-stoked appliances. Manually-stoked appliances may operate intermittently or continuously[16] and have potential for significant smoke emission at stages of the combustion cycle (refuelling and ignition). The impact of these factors on air quality will vary along with other factors such as user behaviour and fuel quality.

A test protocol for assessing air quality impacts should assess emissions over a range of operating conditions likely to be encountered in normal operation of the appliance.

AEA considers that there are effectively two main groups of appliance which can be distinguished by likely emission characteristics. The different appliance categories are key to assessing the emission .

- Manually-stoked appliances without fan-assisted air supply.
- Appliances with fan-assisted air supply.

A further distinction could be to separate those appliances larger than 300 kW (larger than EN 303-5). The first group of appliances encompasses most domestic appliances (except some boilers and pellet stoves) but also may cover some larger, simpler boiler appliances which rely on natural draught for air supply. The test protocol for these appliances could follow the BS PD 6434 used for assessing Clean Air Act – that is testing at rated output and reduced output, with additional testing at other conditions as appropriate. These could include ignition and refuelling tests and misuse tests.

However, BS PD 6434 was designed to assess mineral fuel appliances and these have different characteristics from wood stoves. In particular, many mineral fuel appliances are designed for continuous operation and to allow slow combustion whereas modern wood fired stoves are generally classed as intermittent appliances – potentially emissions from the ignition phase will be far more significant for such appliances.

For appliances with fan-assisted air supply, and particularly those with an automatic fuel supply, the variation in combustion efficiency and hence particulate emission is generally much lower than for natural draught appliances. However, the operating characteristics of the appliance still need to be considered in developing a test protocol as there may be periods of smouldering fuel or other conditions which lead to poor combustion. However, the measurement of emissions should be comparatively straightforward for these appliances. Table 10 lists the features that need to be considered for development of an emission test protocol for assessing air quality impacts.

Table 10 – Features of an emission assessment methodology

Protocol Parameter	Manual appliances, natural draught	Appliances with fan-assisted air supply	Comment
Fuel type, condition	'Standard' fuel, range of fuel quality	'Standard' fuel, range of fuels or fuel quality	'Standard' fuel types. Type of fuel (wood logs, chips, pellet, physical/chemical characteristics of fuel). Whether a reproducible fuel crib is preferred to natural firebed
Test load conditions	Rated output and other conditions to verify no substantial smoke	Rated output and other conditions to verify no substantial smoke	BS PD 6434 requires rated output, low output and intermediate output (if necessary). Other test regimes are rated output only or at a range of burn rates
Other test	Ignition, misuse	Ignition, misuse,	BS PD 6434 recommends misuse

[16] An intermittent roomheater is one which cannot achieve a minimum refuelling interval of 4 hours and which cannot sustain 'slow' combustion.

conditions		slumber/standby	tests
Replicate tests	5(3)	3	Needs to address consistency of results, test repeatability.
Particulate test methodologies	BS 3841 Pt 2, dilution tunnel, filter only, filter and condensables	Filter approach	How representative of emission/air quality impact. Practicalities of sampling from small appliances.
Sampling location	Test laboratory	In situ	Defined by methodology
Verification of test load	By EN Standard	By EN303-5 or other appropriate Standard	Additional measurements needed (fuel used, stack temperature, CO/CO_2/OGC emission).
Minimum reporting requirements			To define content of test report, reporting of emissions and aggregation of emissions

These features would allow definition of an emissions measurement methodology which could then be used with modelling techniques to assess air quality impacts.

However, any protocol designed to 'type approve' an appliance for air quality needs to balance the needs of defining the range of emissions possible from an appliance to achieving a reasonable test without applying an excessive burden to the manufacturer or importer. This is a particular issue where different test protocols are applied across Europe. The UK Clean Air Act testing protocol already places more requirements on manufacturers than test requirements in Germany, Austria and Scandinavia. A review of how these test requirements differ (in implementation and in reported emissions) is a key phase to understanding air quality impacts and how to develop a good protocol.

5.6 Proposed testing programme to assess and quantify differences between national testing requirements for particulate

5.6.1 Domestic appliances

The key testing regimes for UK consideration are the Norwegian, German and UK Standards – the Norwegian testing regime is very similar to the USEPA regime. However, applications to the CAA for appliances tested to North American or Australia regimes are rare. A staged process is suggested.

As a **first stage**, a relatively simple comparative exercise may be achieved by inviting manufacturers (perhaps through the UK Stove Industries Alliance, CEFACD, CEN TC 295 and Notified Bodies) to provide output, fuel and emission test data for a range of appliances which have been tested under two or three different test regimes. This will provide fairly limited appliances which have been tested to the UK Standard (perhaps only one or two) but this could then provide a basis for identifying where Scottish Government and industry could undertake additional testing to complete a basic set of data on wood-burning appliances. Such appliances could include :

- Inset fireplaces (open)
- inset fireplaces (closed)
- Roomheaters (stoves)
- Pellet stoves
- Cookers
- Slow heat release stoves

For roomheaters and perhaps inset appliances, there is a need to cover both older appliances and those which are new to the market (because efficiency and emissions are likely to be different).

Industry involvement is considered essential as this would enable access to full testing results.

The **second stage** would be to undertake additional testing on selected appliances to complete the suite of three methods. As this could give the manufacturers exemption (or equivalence under the other test procedures) the manufacturers could be expected to provide support by (at least) providing appliances for testing. An elaboration of this process would involve doing tests on each method using a common appliance and fuel.

The **final stage** would be to review the emission data and determine if emission test data from non-UK protocols can be accepted with no additional testing or, identify the minimum additional testing requirements to assure protection of air quality. This will depend on being able to correlate data between the test regimes. It is unlikely that overall results from different protocols can be correlated because they represent entirely different approaches. However, selecting elements of each protocol (tests at particular burn rates) may provide a more realistic foundation for correlating the procedures.

Note that if this proves that there is no correlation then the CAA criteria and testing regime will need to continue.

5.6.2 Non-domestic appliances (including automatic domestic boilers)

Recent work under the ERANET programme has suggested that significant under reporting of emissions using (in particular) sampling procedures including packed wool filters. Consequently the benefit of an additional test programme to assess such methods – which appear to vary depending on test house and country – would be limited. There may be benefit in developing a test programme which assessed how real-life emissions compared to type-testing measurements.

This is the type of appliance which could be targeted by RHI funding and hence there will be a need to be assured that ‘good quality’ criteria are being addressed to ensure limited impact on air quality.

The potential measurement issues for these are less significant than for domestic manually-stoked appliances. But there is a need to determine that reported emissions are representative of actual emissions. The key issue is that an appropriate measurement approach and method has been adopted – this can be done by review of the report and retesting if required.

The use of packed wool filters is inappropriate unless used as a pre-filter and supported by a backup high efficiency filter. Although EN303-5 incorporates particulate measurements at rated output only, it is reasonable that particulate emission testing should be at rated output and low output with a minimum of three or four individual measurements at each load. Emission testing should be in accordance with ISO 9096 or, if concentrations are low, EN 13284 Part 1 – these methods incorporate isokinetic sampling, recovery of probe deposits and high efficiency filtration. The measurement of oxygen, TOC (OGC), CO and related parameters is needed to normalise data and assure combustion efficiency

5.7 Outline of current NOx measurement methods

Methods range from international Standards EN 14792 or ISO 10849 (intended for monitoring NOx at industrial installations) to the CEN TC 295 Technical Specification 15883 which includes NOx measurement (although NOx measurement is not required by any of the TC 295 Standards). In addition there are international standards/protocols for determining NOx emissions from gas boilers, engines and other appliances in addition to various national standards and in-house methodologies.

The EN and ISO Standards provide full details and performance criteria for determining NOx emission concentrations in flue gases. TS 15883 provides useful information on measurement techniques but lacks comprehensive calibration and routine performance checks.

The TC295 domestic solid fuel appliance Standards have no requirement to monitor NOx emissions and there is no UK requirement so there is no pre-existing method however, testing could be adapted to the existing TC295 efficiency and output Standards either incorporating the EN or ISO reference methods for NOx or other appropriate methods.

A test programme for domestic appliances should ideally be incorporated with TC295 Standard tests on output and efficiency to allow emissions to be related to output.

EN303-5 includes a recommendation for NOx measurement but it is not a requirement and no acceptance criteria or measurement techniques are specified.

For EN303-5 and larger appliances it is recommended that the EN or ISO Standards for NOx measurement are applied alongside performance and particulate measurements.

As NOx emission generally increases with thermal input the determination of NOx emission could be done at rated output only (although the additional work to monitor at part load would be minimal).

5.8 Renewable Heat Incentive criteria for air emissions

The consultation by DECC on the proposed Renewable Heat Incentive (RHI)[17] sets emission criteria with a view to minimising the impact of increased biomass use on air quality. The current (April 2010) RHI proposals for maximum acceptable emissions for eligibility for RHI support are 30g/GJ PM and 150g/GJ NO_x.

Although the RHI's particulate emission thresholds remains lower than permitted under the Clean Air Act, no criteria are specified for assessing the emissions (the methodology is in preparation) and therefore achieving of RHI criteria may not be sufficient to demonstrate Clean Air Act exemption.

[17] Available here : http://www.decc.gov.uk/en/content/cms/consultations/rhi/rhi.aspx

6 Recommendations

A review of the Clean Air Act and associated issues concerned with regulation of small scale biomass combustion indicates the following :

1. A number of interim administrative measures have been suggested to enable protection of air quality and enable growth in biomass development. Consideration of a mechanism which doesn't require an SSI for appliance exemptions is recommended. The Scottish Government could also consider mechanisms for relaxation of smoke control areas to allow non-domestic biomass installations at specific developments where it has been demonstrated that biomass use will have little or no effect on air quality. Other suggested interim measures have potential for impact on air quality.

2. A review of the Clean Air Act 1993 has identified a number of sections which could be updated, deleted or revised to recognise the changes in focus of air quality management and increase in biomass use.

3. We conclude that existing tools are suitable for assessing impacts of biomass appliances. Dispersion models such as ADMS4.1 and AERMOD are suitable for the assessment of the air quality impact of biomass combustion installations. However, in many cases, simpler screening modelling will be sufficient.

4. Scottish building standards may not be sufficient to meet the air quality objectives where a small (<50 kW) combustion appliance discharges below the height of attached or adjacent buildings.

5. The potential for revised testing procedures for Clean Air Act exemption have been considered and potential measures include a reduction in the number of replicate measurements, dropping of the requirement for testing at intermediate output and dropping the requirement for misuse testing. These measures could be introduced without significant impact on compliance with the Clean Air Act.

6. Development of a protocol for assessment of air quality impacts needs to consider a variety of factors which can affect emissions from solid fuel appliances and reflect the move away from solid mineral fuel to biomass, However, any protocol designed to 'type approve' an appliance needs to balance the needs of defining the range of emissions possible from an appliance to achieving a reasonable test without applying an excessive burden to the manufacturer or importer.

7. Issues in different approaches adopted across the world for particulate measurement for a range of appliance types have been identified, particularly for domestic appliances. Suggested changes to allow the CAA exemption process greater use of test data from other test regimes include a reduction in replicate tests and a focus on emissions during normal operation (not misuse tests). However, use of data from other testing regimes requires data to allow correlations to be developed and hence development of evidence-based acceptance criteria. It is recommended that a measurement programme be undertaken on selected domestic appliance types to allow development of acceptance criteria.

8. It is recommended that NOx measurements should be based on existing EN and ISO Standards for NOx measurement; for domestic appliances and EN303-5 hot water boilers the measurements should be part of the existing efficiency and output measurement procedures.

Appendix 1: Review of Clean Air Act 1993

Table 1.1 Review of Clean Air Act 1993 provisions

Part	Section	Provision	Comment
1		*Dark smoke*	*Measures to control dark smoke emissions – some key provisions from associated regulations could be incorporated in a revised Act.*
	1	Dark smoke prohibition from building chimneys and chimneys attached to fixed furnaces or plant. Exclusions for start-up and other specified exclusions allows Secretary of State (SoS) to define allowable periods	Regulations from SoS e.g. permitted periods instrument could be incorporated into single instrument.
	2	Dark smoke exclusion from industrial/trade premises. Except for chimneys as set out in section 1, specific exemptions as allowed by SoS	Regulations from SoS could be incorporated into single instrument.
	3	Dark smoke definition. Ringelmann 2 or darker (or equivalent method)	No change proposed
2		*Smoke, grit, dust and fumes*	*Measures to control smoke/ particulate emissions – effectiveness not clear as some measures operate in virtual absence of guidance. Emission limits in associated regulations out of step with air quality management requirements and modern emission control.*
	4	Prior notice to Local Authority (LA) for installation of a furnace. New furnace to be smokeless when burning design fuel. LA approval deemed to provide compliance	Potentially a very substantial power for air quality as it applies to all non-domestic appliances. However, it is not clear where the notification would fall in an LA (presumably planning) and potentially burdensome. A key issue is that LA officers no longer have direct experience and very limited information on whether equipment is smokeless (no definitive guidance on smokeless is provided except in BS PD 6434 for domestic appliances). Indeed smokeless could be considered to be an exempt appliance – which would imply that the intention was that new appliances at all locations should match criteria for a smoke control area. Type-approval, compliance with Standards or general appliance exemption (such as provided by the use of mechanical stokers) may be helpful to EHOs but, there are few available Standards which allow a readily available means to assess performance. EN303-5 could be used to cover hot water boilers up to 300kW output. There are no Standards for other plant or appliances up to 20 MWth but consideration is needed whether to develop formal emission criteria which could be applied by an LA (perhaps adopting PPC limits such as in PG1/12 or formalising the biomass guidance).
	5	Grit and dust limits on non-domestic furnaces. Best practicable means for emission control.	The limits are set out in a separate regulation. Grit is particulate matter >75µm and dust is greater than about 3 µm. The test method for this (BS3405:1983) has been withdrawn in favour of total particulate measurement so there is a technical issue regarding demonstration of compliance (although this is only relevant if the measured total PM exceeds the limit because the grit and dust could conceivably be below the limit). The emission limits are very much higher than should be achievable by application of modern abatement measures. Emission limits are also well in excess of what would be considered acceptable for air quality management purposes and likely to impact on visual amenity. There is scope to move to a total particulate limit and to reduce limits to a level more consistent with modern technology. Best practicable means could be replaced by Best Available Techniques but in any event there needs to be guidance on what should represent BPM (or BAT) for operation of these plant.

Part	Section	Provision	Comment
	6	Arrestment plant for new non-domestic furnaces burning pulverised fuel, solid matter >45.4 kg/hr, liquid or gaseous fuel >366.4 kW. Arrestment plant to be approved by local authority and to be properly maintained and used.	The scope of control offered by this section may have been significantly reduced by the 1969 exemption SI. The need for arrestment on oil or gas boilers (as opposed to melting or other process furnaces) is questionable and such plant appear to have been exempted under the 1969 SI. The relationship between this section and the appliance exemptions and grit and dust emission limits isn't clear. Section 7 allows generic exemptions. Note mix of criteria as weight of solid fuel but energy threshold for liquid/gaseous fuel. The energy threshold is undefined (gross/net, input, output). Consideration to harmonise on thermal output ?
	7	Allows Secretary of State to provide generic exemptions to Section 6 and also Local Authorities to provide specific exemptions to Section 6.	Local Authorities have limited guidance or resources to determine such an application. If a duly made application isn't determined by an LA within 8 weeks then the exemption is deemed to have been granted.
	8	Domestic furnace not to be used to burn pulverised fuel or 1.02 tonne/hr or more of soild fuel or solid waste without grit and dust (particulate) arrestment approved by Local Authority.	The target of this section is unclear and may reflect a mismatch in definition of a domestic furnace or an unknown specific circumstance/technology. Exclusion of pulverised fuel from a domestic appliance without arrestment is clear. But, the throughput for other solid fuels is not consistent with the domestic furnace definition in the Act. A domestic furnace is defined later (Section 63) as a furnace for domestic purposes or for heating a boiler of less than 16.12 kW heating capacity. Given the fuel type and throughput, then this section was presumably intended to mean non-industrial heating but the boiler capacity limit is for a single household/dwelling and would exclude any multiple occupant-type building's hot water system (eg a community heating boiler, residential care home boiler). It could be applied to hot air generators but a tonne per hour would be over 4 MW capacity and highly unlikely. Consideration of need for section or revise to focus on larger throughput appliances.
	9	Provision for appeal by applicant to Secretary of State if approval under Section 7/8 refused.	
	10	Provision for Local Authority to require measurement of grit dust and fumes from a furnace by occupiers of furnace building if the furnace burns pulverised fuel, 45.4 kg/hr or more of solid matter or 366.4 kW or more of gaseous or liquid matter.	Not clear if this power is usable as requirements need to have been prescribed by Secretary of State –regulations made under CAA do not appear to cover this. Grit, dust and fume is total particulate.
	11	Provision for occupier to request Local Authority to measure of grit dust and fumes from a furnace by occupiers of furnace building if the furnace burns 45.4 kg/hr or more but less than 1.02 tonnes/hr of solid matter (not pulverised fuel) or between 366.4 kW and 8210 kW or more of gaseous or liquid matter	In effect the operator can refer Local Authority request under Section 10 back to the Local Authority. The occupier still has obligation to provide sampling facilities but measurement obligation reverts to Local Authority. However, given that Section 10 may not be usable then this may not be enforceable.
	12	Provision for Local Authorities to request information from building occupiers on furnaces and fuels.	This has been gathered by some local authorities but on an ad hoc basis.
	13	Provision of previous sections to outdoor furnaces	
	14	Provision for Local Authority approval of chimney heights where a furnace burns pulverised fuel, 45.4 kg/hr or more of solid matter or 366.4 kW or more of liquid or gaseous matter.	Except where exempted through Section 15. Note that stack/vent requirements for smallest (domestic) appliances are covered by building regulation provisions.
	15	Requires Local Authorities to approve chimney heights if satisfied that it will be sufficient to prevent (as far as practicable) particulate and gaseous emissions from becoming prejudicial to health or a nuisance. Note that failure to grant approval within defined period means that approval shall be treated as granted without conditions.	One of the most common supervision tasks carried out by Local Authorities under the CAA. However note that guidance on chimney heights has evolved to recognise air quality management aspects. See separate comments on Tools for Local Authorities.

Part	Section	Provision	Comment
		Includes provision for appeals where approval is not provided.	
	16	Local Authority planning approval for non-furnace chimneys on proposed buildings or extensions outside Greater London or in an outer London Borough except office, shop or residence buildings/extensions	Extends approval to include other types of discharge – ie approval required for all discharges. Not clear why there is an exclusion for parts of London but this exclusion is irrelevant to Scotland . Difference in legal instruments and planning approval terminology in Scotland referenced.
	17	Smoke nuisance in Scotland	Different legal instrument for nuisance enforcement referenced. CAA provision superseded by other legislation ?
3		*Smoke control areas*	*Powers to designate smoke control areas (SCAs) and provision to support adaptation work. Support for adaptastion largely defunct in absence of new SCAs but could be of relevance if seeking to use a modified SCA as a mechanism to encourage biomass uptake.*
	18	Powers for Local Authority to declare a smoke control area through a smoke control order.	Defines all or part of the area within a Local Authority as a smoke control area with conditions or exemptions as needed. Areas and conditions can be varied. Key issue is what supervisory or enforcement powers the smoke control area provides which other parts of the CAA, an air quality management area or industrial pollution control (PPC permit) cannot and whether these remain relevant. The ability to control the types of appliance and fuels to those meeting minimum criteria is relevant, as is ability to require adaptation within the SCA but, declaration of an SCA would place burdens on LA. The benefits of declaring an SCA with current CAA criteria for appliances and furnaces may be limited.
	19	Secretary of State approval/rejection or variation of a Local Authority proposal. Secretary of State can also direct Local Authority to propose a smoke control area.	
	20	Prohibition of emission of smoke in an SCA. Secretary of State powers to designate Authorised fuels	This section includes the use of Authorised ('smokeless') fuel in an SCA as a defence from smoke emission. Authorised fuels based on passing criteria for smoke emission when tested on a traditional open fireplace (that is a worst case test) – BS3841 pt 1. Tests on biomass (wood) fuels in the past have not been able to achieve satisfactory emission performance so wood is not an authorised fuel. Perhaps if an AQMA is declared due to solid fuel combustion there may be a need to have a new 'super' SCA which specifies more stringent conditions – no solid fuels in domestic appliances and/or only high quality low emission larger appliances.
	21	Secretary of State powers to exempt fireplaces for use with non-Authorised fuels in an SCA	The numbers of appliances put forward for exemption has increased dramatically in recent years. Virtually all for biomass-fuelled appliances. Initially for hot water boilers as manufacturers have been able to access grant funding but unable to install appliances in SCAs. Increasing applications for domestic roomheaters are now being received. This indicates that the CAA requirements are still being addressed. Streamlining the process to avoid the need for a regulation to confer/confirm exemption status would be advantageous. Consideration of whether a mechanism suitable for implementation by notified bodies (or perhaps even self-declaration) may also provide benefits but the absence of harmonised test methods would make such a move difficult at present.
	22	Secretary of State powers to suspend or relax Section 20 in all or part of an SCA	It would be hard to conceive a situation where complete suspension would be acceptable to public or Local Authority – it effectively allows any fuel. A partial suspension may be reasonable if a non-exempt boiler is to be installed which meets air quality criteria at a specific location. The concern would be uptake of non-authorised fuels in domestic furnaces which could lead to visible

Part	Section	Provision	Comment
			plume intrusion and increased particulate emission.
	23	Acquisition and sale of unauthorised fuel in smoke control area	In practise it would appear to be difficult to assure that only authorised fuels are not burned in non-exempt appliances/buildings and that unauthorised fuels are only burned in exempt appliances/buildings.
	24	Local Authority powers to require adaptation of appliances in private dwellings in (or proposed for) an SCA. If the work has to be arranged by the Local Authority then a maximum level of recovery of expenses from the owner is provided.	It isn't clear whether the costs of adaptation fall on the owner or occupier. The recovery of expenses is unclear, it seems to be beneficial to the owner/occupier to get the Local Authority to undertake the work. If it is unlikely that a new SCA will be created then this Section may be redundant. In the event that a new SCA is declared to address emissions from wood-burning then funding for adaptation will be an important consideration. Reference is made to differences relevant legal instruments for appeals in Scotland.
	25	Age of private dwellings eligible for adaptation support	Dwellings older than 15/8/1964 – an updated Act if used as a mechanism to develop more smoke control areas may wish to consider more recent eligibility dates to reflect changes in Building Standards/ Regulations since 1964. Adaptation could encompass energy efficiency measures as well as appliance replacement.
	26	Power of Local Authority to make grants toward adaptations in places of worship, buildings used by charities	Allows a Local Authority *if they think fit* to reimburse all or part of expenditure incurred. The range of organisations is fairly wide but there is no absolute commitment for funding.
	27	Scope of adaptations eligible for funding	This is fairly wide ranging but recognises that changing an appliance is only part of the issue. If the Act were to be used to encourage both energy efficiency and residential biomass over coal or oil appliances then a range of activities would be needed.
	28	Expenses incurred in adaptation works	Terms for estimating expenditure
	29	Interpretation of Sections in Part 3	Meanings of terms used
4		*Control of certain forms of air pollution*	*Concerned with fuel oil, motor fuel and cable burning. Largely superseded by other instruments.*
	30	Regulations about motor fuel – power to Secretary of State to make regulations on fuels of a kind used in motor vehicles for the purpose of limiting or reducing air pollution	A number of potential powers and linkages to other legal instruments and regulatory authorities – but presume these are largely superseded.
	31	Sulphur content of oil fuel for furnaces and engines	Not clear if these powers were exercised. If regulations were developed these would have been replaced by Sulphur Content of Liquid Fuels (for non-vehicle sources) and transport fuel limits.
	32	Provision to apply exemptions to Sections 30 and 31	
	33	Cable burning	Reference to EPA Part 1 valid ?
5		*Information about air pollution*	*A key aspect as public knowledge/experience of solid fuel combustion in 2009 is much lower than previously – and very limited experience of best practise for wood combustion.*
	34	Research and Publicity – provision for Local Authority to contribute funding into air pollution research/investigation and for information dissemination.	Wide-ranging and unspecified - superseded by air quality management responsibilities ?
	35	Obtaining information. Specific powers to obtain information by issue of notices (Section 36) and, for premises other than private dwellings, undertaking or arranging measurement of emissions.or inspection. If information is requested then the Local Authority also has to contact local interested groups/individuals with an interest in local amenity and trade associations	It is considered unlikely that the powers for measurement of emissions are used.
	36	Notices for information on air pollution. Content, response times, maximum frequency.	Covers premises other than private dwellings and could be wide-ranging. Reference to EPA 1990 now out of date. Information on Part A/B processes limited to what is required by (now) PPC regulation.
	37	Appeals to Secretary of State against providing information requested at Section 36.	Essentially allows appeals where private/commercial interest is affected or, unreasonable expense to gather information. Appeals also allowed on grounds that disclosure of information may be 'contrary to the public interest'.
	38	Regulations by Secretary of State to prescribe Local Authority functions; consultation with	Relevant information for air quality management and inventory development including Public Register provision.

Part	Section	Provision	Comment
		relevant parties before making regulations.	Not clear if regulations developed ?
	39	Secretary of State powers to direct a Local Authority to obtain and operate apparatus for measuring and recording air pollution and passing information. Also provides funding for purchase and installing equipment.	This would have been originally for daily smoke and SO_2 sampling but not explicitly limited to such.
	40	Clarification of emissions to atmosphere and measurement	Essentially covering emissions in gaseous, solid or liquid form and sample-based measurement – perhaps to avoid indicative or secondary measurements of air pollution parameters ?
6		*Special Cases*	*Relation to EPA 1990; needs to reflect PPC regulations. Also colliery bings, railway engines and vessels, crown premises.*
	41	Exclusion of Parts 1 to 3 to prescribed processes.	Part A/Part B processes
	42	Prevention of combustion of colliery spoil	Reference to difference in nuisance provision in Scottish legal instrument
	43	Dark smoke provisions also apply to railway locomotives	
	44	Dark smoke provisions also apply to vessels. In all waters not navigable by sea-going ships and waters navigable by sea-going ships within the seaward limits of UK territorial waters but contained within areas where certain charges can be made in respect of vessels entering or using facilities.	Action outside Local Authority boundaries depends on empowerment to make charges under other regulations.
	45	Exemption for research into air pollution	Allowed subject to application and conditions.
	46	Crown premises and vessels	Mechanism for Local Authorities to register issues regarding dark smoke and smoke.
7		Miscellaneous and General	
	47	Provision for regulations to extend provisions of Act to fume and gases.	Not clear if regulations were ever prepared
	48	Provision to develop regulations to International Agreements	Not clear if such regulations have been made under the CAA provision.
	49	Unjustified disclosure of confidential information	
	50	Cumulative penalties for contuance of offences	
	51	Period for notification of offences to occupiers/owners relating to dark smoke, smoke and smoke in an SCA.	Reference also made to nuisance smoke in Scotland.
	52	Offences by companies/organisations	Provides for action against organisation and directors/individuals of the organisation where event is attributable to their actions/consent/neglect
	53	Offences due to act or default of another	
	54	Authorising adaptation works and expenditure by owner of a building.	Where the occupier is not the owner and believes that the owner should undertake the work. This section covers power of a court to make an order against the owner.
	55	General enforcement provisions	Note provision to allow a Local Authority (in England & Wales) to institute proceedings for dark smoke or smoke in an SCA where chimney/premises are outside the district. Reference to different arrangement for instituting proceedings in Scotland but this also implies that Authorities in Scotland can only action offences in their own districts.
	56	Rights of entry for authorised Local Authority officers	Significant powers available to a Local Authority officer.
	57	Requirement to produce evidence of authority to gain entry; notice of entry for certain property; security of property and damages; obstruction.	
	58	Provision of information and offences for failing to provide information or providing false information.	
	59	Provision of powers for Secretary of State to require a local inquiry relating to air pollution or a provision in the Act	Reference to different instrument in Scotland
	60	Powers available to Secretary of State to address a defaulting Local Authority	Can direct Authority, placing conditions on improvements, ultimately can take over powers.
	61	Joint exercise of local authority functions – port health authorities and joint declarations of an SCA - across the boundary of two or more authorities.	
	62	Provisions in other Acts	References to instruments in Scotland
	63	Powers of the Secretary of State to make regulations	By Statutory Instrument/SSI.
	64	General provisions as to interpretation	Some definitions are difficult.

Part	Section	Provision	Comment
			Domestic is undefined but domestic furnace is defined in contradictory terms – it is either for domestic purposes with no size constraint but, if it has a boiler, is effectively for only a single family dwelling. Smoke is defined as including soot, ash, grit and gritty particles. Fume is defined separately.
	65	Isles of Scilly	
	66	Transitional provisions relating to Alkali, &c Works Regulation Act provisions until repeal by EPA 1990.	EPA 1990 has itself been replaced now.
	67	Transitional provisions and appeals.	
	68	Citation.	
Schedule 1		Coming into operation of smoke control orders	Publication in London (Edinburgh) Gazette and a newspaper local to SCA; notices in area, objection procedure, postponement of order
Schedule 2		Expenditure on old private dwellings	Sets out grants where relevant expenditure is incurred. Also sets out exclusion for grants eg where fuel resources may be inadequate. Sets out level/provision of Central Govt support
Schedule 3		Interim provisions relating to Alkali &c Act	Transitional – should now be superfluous.
Schedule 4		Amendments to other instruments	Note that a number of these have themselves been superseded
Schedule 5		Older provisions, application to older smoke control orders .	Sections 6 & 8 – fitting arrestment plant – derogations for plant installed before 1/10/1969 (S 6.1) and 15/11/1958 (S 8 in Scotland). Section 14 – chimney height – derogations for plant prior to 1/4/1969. Section 18 – confirmation of smoke control orders. Section 42 – spoilbanks – derogation for spoilbanks no longer in use before 5/7/1956. Publication of confirmed smoke control orders and provision for objection to confirmation..
Schedule 6		Repeals	

Appendix 2: Combustion in solid fuel appliances

Overview of appliances

The range of solid fuel appliance types and models is very wide[18] but a general categorisation is provided in Fig. 1.

A key difference with regard to emissions is in the degree of automation of appliances; boilers and pellet stoves can be fully automatic offering near continuous operation with matching of fuel and air using induced or forced draught (combustion air fans) and combustion sensors whereas wood log roomheaters (stoves, fireplaces or inset appliances) are batch fed operating under natural draught with a high degree of manual control.

These extremes of operation have an impact on combustion quality and hence emissions. While emissions from modern closed batch fed, manually-controlled appliances are much improved compared to traditional open fireplaces, they have higher emissions of products of incomplete combustion (including potential contributors to particulate matter emission) than automatic appliances.

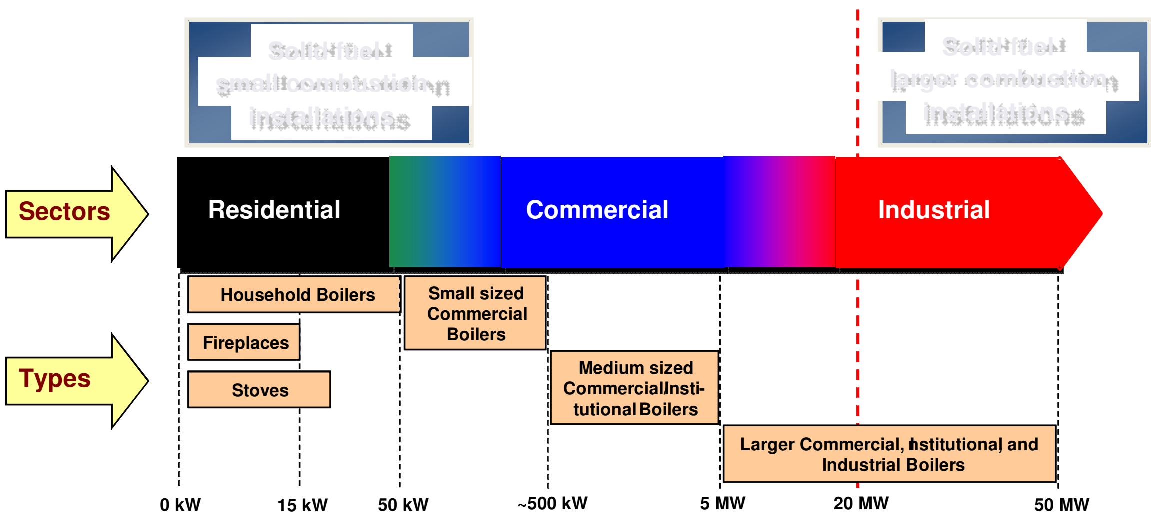


Figure 1 Types of solid fuel appliance [EuP Lot 15, 2009]

Standards for residential solid fuel appliances

CEN Technical Committee 295 produces Standards for residential solid fuel appliances and the current range of Standards represents the broad classifications of appliances in the market (Table 2.1). Residential heating devices, as defined by CEN TC 295, either heat a single room or a single dwelling. The TC295 Standards address output, efficiency, carbon monoxide emission and appliance safety. None of the Standards includes measurement of particulate emission. TC 295 has produced a Technical Specification (TS 15883:2009) for measurement of selected gaseous emissions and provides information on the most common particulate sampling approaches.

Particulate emission thresholds/limits are set in some but not all Member States and, where required, national measurement requirements are applied.

The appliances are a mixture of boilers (indirect heaters), roomheaters (direct heating) cooking appliances, sauna stoves. A number of direct heating products are also fitted with boilers to provide indirect heating capacity. In general residential appliances are less than 50 kW output and most direct heating appliances (stoves, fireplaces) have an output of <10 kW.

[18] See Energy using Products (EuP) Lot 15 preparatory study reports www.ecosolidfuel.org produced by Bio IS, AEA Group and ITT for the European Commission.

There is a wide variety in roomheater design and appliances with similar external appearance can have very different internal arrangements for air supply with impacts on efficiency and emissions [EuP Lot 15, 2009].

Most wood-burning roomheaters burn wood logs except for pellet stoves which have a growing but relatively minor market share at present; boilers are either suitable for wood logs or pellets. In the UK market, there are mineral fuel appliances and a small number of stoves can burn wood or mineral fuels : 'multifuel' appliances.

While roomheaters and cooking appliances require are natural draught and have fairly basic controls, boilers and pellet stoves can be very sophisticated and many offer virtually fully automatic operation.

Table 2.1 : CEN TC 295 Residential solid fuel appliance Standards

Standard reference	Title	Harmonised
EN 12809	Residential independent boilers fired by solid fuel - Nominal heat output up to 50 kW - Requirements and test methods	Yes
EN 12815	Residential cookers fired by solid fuel - Requirements and test methods	Yes
EN 13229	Inset appliances including open fires fired by solid fuels - Requirements and test methods	Yes
EN 13240	Room heaters fired by solid fuel – Requirements and test methods	Yes
EN 14785	Residential space heating appliances fired by wood pellets - Requirements and test methods	No
EN 15250	Slow heat release appliances fired by solid fuel - Requirements and test methods	Yes
prEN 15281 (under development)	Sauna stoves fired by solid fuel - Requirements and test methods	No
prEN 15544 (under development)	One off tiled/mortared stoves – Dimensioning	No

In addition to Standards there are a number of national and regional ecolabelling and biomass support schemes which set efficiency and, in some instances, emission thresholds. For example Nordic Swan (Scandinavia), DINplus (Germany and central Europe), Flamme Verte (France). The UK Microgeneration Certification Scheme sets performance criteria but does not (at present) require better energy efficiency performance than specified in the relevant EN Standard or better smoke emission performance than specified by the Clean Air Act (that is, exemption where appliance is installed in an SCA).

Note that the CEN TC295 Standards do not cover traditional UK open masonry fireplaces with small cast iron grates or simple open devices such as firebaskets, or, appliances intended for use outside such as barbecues or chimineas.

Standards for larger solid fuel appliances

Larger indirect heating appliances are typically hot water boilers but there are also solid fuel air heaters. Steam boilers tend to be larger than 1 MW capacity. Hot water boilers are used for community heating, larger residential heating (multi-occupancy), schools, commercial and similar applications. These are typically smaller than 300 kW output although larger hot water boilers are available including appliances up to 5MW output. Larger boilers used for industrial heating, Combined Heat & Power applications and larger district heating boilers tend to be steam boilers.

Boilers up to 20 MW (thermal input) can fall within the scope of the Clean Air Act as the threshold for LA-PPC regulation is 20 MWth (although a lower threshold applies if the appliance is burning a fuel derived from solid waste).

CEN TC57 produces Standards for central heating boilers (Table 2.2) and EN 303-5 includes a particulate measurement requirement but doesn't define how measurements should be undertaken.

Fuels for larger wood-burning appliances include wood logs (typically less than 150 kW output), wood pellet (<500 kW) and, most commonly, wood chip (all sizes of appliance).

Table 2.2 : CEN TC 57 Standards

Standard reference	Title	Harmonised
EN 303-5:1999	Heating boilers - Part 5: Heating boilers for solid fuels, hand and automatically stocked, nominal heat output of up to 300 kW[19] - Terminology, requirements, testing and marking	No
EN 15270:2007	Pellet burners for small heating boilers - Definitions, requirements, testing, marking (applies to burners applied to non-integral boiler)	No

Note that there are no UK, European (or ISO) Standards covering emission performance of larger appliances although other countries within Europe operate national emission and efficiency performance criteria. In addition a number of national biomass support schemes incorporate emission and performance standards.

Combustion of solid fuel

Further details can be found in the recent preparatory study for the Energy using Products Directive (Ecodesign) on small solid fuel combustion installations. Appliances can use a variety of fuels and combustion techniques, but in most cases the combustion process occurs on a fixed-bed. The combustion techniques vary a lot between manually-fired, natural draught appliances (typically roomheaters, cookers and fireplaces) and automatic appliances with forced draught (most boilers and pellet stoves).

The combustion techniques, fuel properties (and quality) and operational practices define the performance and emissions from a solid fuel appliance. Solid fuels are far more variable in quality and composition than refined gas and oil fuels and, the physical characteristics and chemical composition of a solid fuel have a considerable influence not only on the combustion technology and the method of fuel stoking, but also on the emissions of pollutants. To achieve consistent combustion most appliances are designed for a specific type and quality of fuel.

The type and properties of the fuel affect the design and combustion techniques of an appliance, solid fuels include a range of mineral fuels (e.g. hard coal, manufactured solid fuels, anthracite, coke), peat and wood fuels (soft and hard woods, pellets, chips). Fuels can be in a raw form (e.g. lump coal, wood logs) or be processed into uniform size, briquettes or pellets, having different grain sizes and properties. Wood logs are often 20-50 cm long, whereas wood pellets are typically 1 cm long.

Wood fuels have a relatively high volatile matter content (twice that of a hard coal), and a higher reactivity and velocity of combustion than solid mineral fuels. However, there are significant differences within different wood and mineral fuel types.

Although almost any solid fuel can be burnt on an open grate, this requires significant user input and will achieve only low combustion efficiency and poor emission performance.

Solid fuel combustion is a complex process which involves four main steps: drying (moisture evaporation), devolatilisation (with instantaneous pyrolysis inside the fuel grain, and gasification), char combustion, and gas phase oxidation.
The combustion process consists of phases that can occur simultaneously at different places in the appliance. The time used for each phase of the process depends on fuel size and properties,

[19] The proposed upper limit in the revised EN303-5 is 500 kW.

temperature, and combustion conditions. Usually the phases of the process overlap, because their physical and thermal boundaries are not rigid.

1. Drying – fuel is heated up and moisture is driven off, with the water vapour passing to the exhaust gases. A high moisture content in the fuel reduces heat absorption, and thus the temperature of the whole combustion process.

2. Devolatilisation (or pyrolysis) – once the fuel has dried, the fuel is heated and at high temperatures (up to 900ºC) volatile matter begins to vaporise. The devolatilisation involves the release of carbon dioxide and chemically-bound water, followed by hydrocarbons and tars at higher temperatures, and finally by hydrogen and carbon monoxide (which will be burnt in the gasification phase). Char, consisting of carbon and ash (mineral matter), is part of the solid residues of the pyrolysis.

3. Gaseous phase combustion (and gasification) - volatile matter and some of the char react with oxygen to form carbon monoxide (CO), carbon dioxide (CO_2) and water (H_2O). Combustable gaseous products from devolatilisation and char combustion (step 4) are consumed in homogenous gaseous phase combustion reactions, which occur in the zone above the fuel bed. In well-controlled combustion processes, these reactions can help reduce the emission of gaseous products arising from devolatilisation and incomplete combustion.

4. Char combustion – As devolatilisation proceeds, the ratio of C/H in the fuel increases, and the combustion of residual char starts. This takes place on the surface of char particles and produces heat, slag, fly ash and gases (mainly CO and CO2). The process depends on the rate of the chemical reaction and on the rate of diffusion of oxygen to the surface. As temperature increases, the rate of chemical reaction increases, and the reaction is limited by the oxygen diffusion process (the transfer of oxygen to the particle surface).

Three key conditions are necessary for achieving complete combustion (often referred to as the 'three Ts'): Temperature, Turbulence, and Time. Achieving the three conditions is dependent on the design of the appliance, as well as on appropriate fuel use and appropriate user behaviour.

- Temperature: At higher temperatures, oxidation reactions are faster and more complete than at lower temperatures. The combustion temperature is affected by the material used in the combustion chamber, as well as by the temperature of the combustion air. For example pre-heating the combustion air can considerably increase the temperature inside the combustion chamber. Enclosed and insulated combustion chambers minimise heat loss to the surroundings.

- Turbulence: good mixing also allows lower air requirement and higher combustion temperatures. Avoiding local air deficiency is key to combustion quality. Measures to improve turbulence include distribution of air around the combustion chamber, draught control (natural draught appliances) or use of mechanical ventilation (forced draught appliances).

- Time (residence time): wood fuels have high volatile matter contents and this requires provision for increased residence time to ensure complete combustion of devolatilisation products. Some appliances use a divided combustion chamber to achieve this.

If the three Ts are not achieved, combustion is not optimal and the emissions of Products of Incomplete Combustion (PICs) will be significant. The PICs include pollutants such as carbon monoxide (CO), particulate matter (PM), particulate matter of less than nominally 10/2.5 µm size (PM_{10} /$PM_{2.5}$), volatile organic compounds (VOC)), semivolatile organic compounds (SVOC) which contain polycyclic aromatic hydrocarbons (PAHs), and dioxins/furans (PCDD/Fs).

In most instances combustion efficiency in automatic boilers and stoves (pellet stoves) is better than for manual appliances with manual stoking and natural draught – typically these are residential roomheaters or cooking appliances. The air control in batch-fed appliances cannot provide the same degree of combustion control throughout the burn cycle as can be achieved in the automatic appliances. Hence emission of PICs is usually far lower for automatic appliances than for manual appliances – this is significant for the particulate emission and measurement methods.

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