INTERNATIONAL STANDARD

ISO 19869

First edition
2019-09

Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves

Fourneaux et foyers de cuisson propres — Méthodes d'essai sur site des fourneaux

Reference number
ISO 19869:2019(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 285, *Clean cookstoves and clean cooking solutions*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Field measurements of cooking systems are essential for providing metrics for impact evaluation and performance evaluation. Elements of the cooking system include cooking practice, fuel type, fuel quality, cooking device (cookstove) characteristics, and environmental conditions. Each can affect performance. Field tests provide measurements that capture elements of the system that are not able to be reproduced in a laboratory setting. The performance metrics in this document are considered more representative of cooking system performance than those described in ISO 19867-1. However, field testing results are generally only applicable to the study region. Guidelines for determining social impacts on individuals and communities from the cooking system are the subject of ISO/TR 19915[1].

Clean cookstoves and clean cooking solutions — Field testing methods for cookstoves

1 Scope

This document provides field testing methods to evaluate cooking system performance in real-world conditions.

This document is intended to:

a) Provide quantitative and qualitative measurements of cooking system performance. Requirements and guidance are provided for evaluation of usage, usability, fuel consumption, energy consumption, power, emissions, safety, and durability. These measurements include uncontrolled and controlled cooking tests.

b) Provide guidance for measurements of household air pollution and personal exposure to $PM_{2,5}$ and CO.

c) Provide guidance for field assessments that compare cooking system performance metrics either to defined performance levels or to a counterfactual scenario that enables assessment of whether the new cooking system is improved compared to what would have been observed without the implementation of a new cooking system.

d) Provide guidance for prioritizing measurements that balance comprehensiveness and feasibility.

The parts of the cooking system include the cookstove, cooking vessel, fuel, user practice, and additional cooking devices (such as pot skirts and retained heat cookers). Several measurements in this document are presented as measurements of "cookstoves" or "cooking devices" for simplicity, but are intended to be interpreted as measurements of cooking systems. Some measurements (usage, kitchen energy consumption, and pollutant exposure) pertain to household-level cooking systems that include all cookstoves, cooking devices, fuels, and user practices in a household. Cooking systems can also include other aspects of the cooking environment (such as ventilation when measuring exposure).

This document is applicable to cookstoves used primarily for cooking or water heating in domestic, small-scale enterprise and in institutional applications, typically with firepower less than 20 kW and cooking vessel volume less than 150 l. The provisions of this document are applicable to solar cookers. This document does not cover electric stoves or cookstoves used primarily for space heating. Although some parts of this document can be applicable to electric stoves (usage, usability, safety, durability, cooking power, and household energy consumption), specific considerations required for testing electric stoves are not provided.

This document is intended for manufacturers, implementing organizations, researchers, governments, or other entities that need to evaluate cooking system performance in the field.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19867-1:2018, *Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols — Part 1: Standard test sequence for emissions and performance, safety and durability*

ASAE S580.1, *Testing and reporting solar cooker performance*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1 Cooking system

3.1.1
cooking device
apparatus used for cooking (by heating)

Note 1 to entry: Cooking devices include such items as *cookstoves* (3.1.4), pot skirts, *cooking vessels* (3.1.3), and retained heat cookers.

3.1.2
cooking system
combination of *cookstove* (3.1.4), fuel, cooking equipment, cooking environment (including ventilation) and cooking practice

3.1.3
cooking vessel
pot or container in which food or water is heated and prepared

3.1.4
cookstove
device primarily employed for the cooking of food, but which can also be employed for space or water heating, or other purposes

3.1.5
improved cookstove
cookstove (3.1.4) proposed for a geographic region or *target community* (3.2.7), which has been shown to outperform a *baseline* (3.2.2) with respect to primary criteria that can include *emission factors* (3.4.5), *fuel consumption* (3.3.3), *thermal efficiency* (3.3.12), *durability* (3.5.2) and/or *safety* (3.5.7)

3.1.6
solar cookstove
solar cooker
device that delivers useful cooking heat from thermal energy received from the sun

3.1.7
traditional cookstove
type of *cookstove* (3.1.4) or three-stone open fire that has been in long existence in a region and has been established from generation to generation

3.2 Adoption

3.2.1
adoption
condition in which a user employs an *improved cookstove* (3.1.5) regularly and maintains it

3.2.2
baseline
status of a market, community, or *cooking system* (3.1.2) prior to intervention, determined by measurements and metadata

3.2.3
displacement
replacement of a *cookstove* (3.1.4) for major tasks with a different technology that is more efficient, safer, and/or produces fewer harmful emissions

3.2.4
initial acceptance
regular use of *improved cookstove* (3.1.5) by household when it is acquired

3.2.5
cookstove stacking
continued household use of one or more traditional biomass-burning *cookstoves* (3.1.4) in addition to *adoption* (3.2.1) of an *improved cookstove* (3.1.5) for some cooking tasks

3.2.6
sustained adoption
state in which there has been *adoption* (3.2.1) for an extended period of time

Note 1 to entry: The length of time for an *improved cookstove* (3.1.5) to be considered adopted is location and stove specific, but should be defined by the users' reliance on the stove, integration into regular cooking behaviour, and frequent use of the improved cookstove, as well as repair and/or replacement of the improved cookstove when it breaks or wears out.

3.2.7
target community
social group that regularly employs *cookstoves* (3.1.4) and has expressed a willingness to consider the use of *improved cookstoves* (3.1.5)

3.2.8
usability
extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use

[SOURCE: ISO 9241-210:2010, 2.13]

3.2.9
usage
action, amount, or mode of using a cooking device; often a quantitative measure of time that a *cookstove* (3.1.4) is used

3.3 Fuel consumption

3.3.1
as fired
condition of a fuel immediately before testing in a *cookstove* (3.1.4)

3.3.2
burn sequence
combustion of fuel in a *cookstove* (3.1.4) from ignition to an end point defined in a specified protocol

3.3.3
fuel consumed
mass of *raw fuel* (3.3.9) fed, see *fuel fed* (3.3.5), minus mass of *residual fuel* (3.3.10), if applicable, during a defined *burn sequence* (3.3.2)

Note 1 to entry: It is expressed in kilogrammes (kg).

Note 2 to entry: For applicability of *residual fuel* (3.3.10), see details in testing protocol.

3.3.4
fuel energy used
product of the *heating value* (3.3.6) of the *raw fuel* (3.3.9) and its mass as fired, less the product of the heating value of the *residual fuel* (3.3.10), if applicable, and its mass

3.3.5
fuel fed
fuel supplied to a *cookstove* (3.1.4) during the course of the *burn sequence* (3.3.2)

3.3.6
heating value
energy per unit mass released in the complete combustion of a sample of fuel

Note 1 to entry: The heating value shall be stated as either *higher heating value* (3.3.7) or *lower heating value* (3.3.8).

3.3.7
higher heating value
measured value of the energy of combustion of a fuel burned in oxygen in a bomb calorimeter under such conditions that all the water of the reaction products is in the form of liquid water at 15 °C, $MJ.kg^{-1}$

3.3.8
lower heating value
calculated value of the energy of combustion of a fuel burned in oxygen in a combustion bomb under such conditions that all the water of the reaction products remain as water vapour at 150 °C, $MJ.kg^{-1}$

Note 1 to entry: The *heating value* (3.3.6) at constant pressure is generally used when calculating lower heating value.

3.3.9
raw fuel
mass of the unburned fuel supplied to a *cookstove* (3.1.4) during the course of the *burn sequence* (3.3.2)

3.3.10
residual fuel
material that has a usable energy content that remains after a *burn sequence* (3.3.2) is completed

3.3.11
specific fuel consumption
amount of *fuel consumed* (3.3.3), on a mass or energy basis, per mass of food cooked

3.3.12
thermal efficiency
ratio of *useful energy delivered* (3.3.13) to *fuel energy used* (3.3.4)

3.3.13
useful energy delivered
energy transferred to the contents of a *cooking vessel* (3.1.3), including the sensible heat that raises the temperature of the contents of the cooking vessel and the latent heat of evaporation of water from the cooking vessel

3.4 Emissions

3.4.1
black carbon
particulate carbonaceous material containing mostly carbon by mass and measured by its high absorption of visible light

3.4.2
carbon emission ratio
ratio of a pollutant concentration to total carbon concentration

Note 1 to entry: Total carbon includes the CO_2, CO, CH_4, non-methane hydrocarbons, and PM.

3.4.3
carbon monoxide
toxic gas formed during the incomplete combustion of carbonaceous material

3.4.4
elemental carbon
particulate carbonaceous material emitted during combustion that demonstrates a refractory nature according to a defined thermal-optical protocol

3.4.5
emission factor
ratio of the mass of a pollutant emitted to a defined measure that quantifies the activity emitting the pollutant

3.4.6
emission rate
ER
mass of an air pollutant emitted per unit time, reported in units such as mg/h or g/s

3.4.7
fuel-based emission factor
EF_{mass}
mass of pollutant per mass of *fuel consumed* (3.3.3)

3.4.8
fuel energy-based emission factor
EF_{energy}
mass of pollutant per MJ of heat from the fuel

3.4.9
household air pollution
presence of air pollutants including solid particles or gases in air in both indoor and outdoor environments of living spaces

3.4.10
modified combustion efficiency
MCE
proxy for true combustion efficiency calculated as molar CO_2 over the sum of molar CO_2 and CO

3.4.11
organic carbon
carbonaceous material emitted during combustion in which the carbon is chemically bonded to hydrogen and possibly also oxygen, nitrogen, sulphur, or other elements

3.4.12
partial capture method
emission sampling method in which part of the exhaust plume is captured and a continuous sample is collected

3.4.13
particulate matter
PM
solids and liquids of a sufficiently small size to be suspended in air

3.4.14
$PM_{2,5}$
fine *particulate matter* (3.4.13) such that the aerodynamic equivalent diameter of the particles is less than or equal to 2,5 µm

3.4.15
pyranometer
instrument used for measuring global (all-sky) solar radiation

3.4.16
total capture method
emission sampling method in which all of the exhaust plume is captured and a continuous sample is collected

3.5 Safety and durability

3.5.1
acute hazard
hazard (3.5.3) that has immediate or short-term negative consequences

3.5.2
durability
ability of a *cookstove* (3.1.4) to continue to be operated for an extended period safely and with minimal loss of performance under conditions typical of those found in the *target community* (3.2.7)

3.5.3
hazard
potential source of harm

[SOURCE: ISO 7176-14:2008, 3.13]

3.5.4
kitchen
location where food is prepared and cooked

Note 1 to entry: The kitchen may be located indoors or outdoors.

3.5.5
likelihood of hazard
probability of occurrence of a *hazard* (3.5.3)

3.5.6
risk
product of the severity of the consequences of a *hazard* (3.5.3) and the likelihood that the hazard will occur

3.5.7
safety
ability of a *cookstove* (3.1.4) to be operated at an acceptable level of risk of harm

3.5.8
serious hazard
hazard (3.5.3) associated with outcomes that, if present, would lead to severe consequences, such as death or severe injury

4 Symbols, abbreviated terms, and units

NOTE Following ISO convention, decimal comma and thousand spacer in strings of numbers are used in this document.

Symbol/ Abbreviated term	Definition/ Meaning
BC	black carbon
C	carbon
C_C	total carbon concentration, g/m^3
C_{CO}	average CO concentration (background subtracted), g/m^3
$C_{CO,ppm}$	average CO concentration (background subtracted), ppm
$C_{CO,ppm,bkg}$	average background CO concentration, ppm
$C_{CO,ppm,bkg,realtime}$	real-time CO background data series, ppm
$C_{CO,ppm,postbkg}$	post-test background period average CO concentration, ppm
$C_{CO,ppm,prebkg}$	pre-test background period average CO concentration, ppm
$C_{CO,ppm,realtime}$	real-time CO data series, ppm
$C_{CO,ppm,realtime,n}$	measured CO concentration at time point index n, ppm
$C_{CO,ppm,test}$	test period average CO concentration, ppm
C_{CO2}	average CO_2 concentration (background subtracted), g/m^3
$C_{CO2,ppm}$	average CO_2 concentration (background subtracted), ppm
$C_{CO2,ppm,bkg}$	background CO_2 concentration, ppm
$C_{CO2,ppm,postbkg}$	post-test background period average CO_2 concentration, ppm
$C_{CO2,ppm,prebkg}$	pre-test background period average CO_2 concentration, ppm
$C_{CO2,ppm,realtime,n}$	measured CO_2 concentration at time point *n*, ppm
$C_{CO2,ppm,test}$	test period average CO_2 concentration, ppm
CCT	controlled cooking test
$C_{EC(or\ OC)}$	EC or OC concentration (background subtracted), mg/m^3
$C_{EC(or\ OC),back}$	EC or OC concentration measured by backup quartz filter, mg/m^3
$C_{EC(or\ OC),bkg}$	EC or OC background concentration, mg/m^3
$C_{EC(or\ OC),prim}$	EC or OC concentration measured by primary quartz filter, mg/m^3
$C_{EC(or\ OC),sample}$	EC or OC sample concentration, mg/m^3
$CFrac_{eff}$	effective fuel carbon fraction, g/g
$CFrac_{fuel,af}$	as-fired fuel carbon fraction, g/g
CO	carbon monoxide
CO_2	carbon dioxide
CoV	coefficient of variation; standard deviation/mean
$c_{p,p}$	specific heat of cooking vessel material, J/gK
$c_{p,w}$	specific heat of water, 4,186 J/g/K
C_{PM}	average PM concentration (background subtracted), mg/m^3
$C_{PM,bkg}$	average background PM concentration, mg/m^3
$C_{PM,sample}$	average PM concentration, mg/m^3
CSM	continuous stove monitor
D_{back}	backup quartz filter spot diameter, cm
D_{prim}	primary quartz filter spot diameter, cm
DTT	dithiothreitol
EC	elemental carbon
E_{cons}	energy consumed in past 24 h, MJ
$EF_{CO,energy}$	fuel energy based CO emission factor, g/MJ
$EF_{CO,mass}$	fuel mass based CO emission factor, g/kg
NOTE ppm = parts per million.	

Symbol/ Abbreviated term	Definition/ Meaning
$EF_{CO2,energy}$	fuel energy based CO_2 emission factor, g/MJ
$EF_{CO2,mass}$	fuel mass based CO_2 emission factor, g/kg
$EF_{EC(or\ OC),energy}$	fuel energy based EC or OC emission factor, mg/MJ
$EF_{EC(or\ OC),mass}$	fuel mass based EC or OC emission factor, mg/kg
$EF_{PM,energy}$	fuel energy based PM emission factor, mg/MJ
$EF_{PM,mass}$	fuel mass based PM emission factor, mg/kg
E_{fuel}	energy consumed, MJ
EHV	effective fuel heating value, MJ/kg
E_{percap}	daily per capita energy consumed for a fuel type, MJ
ER_{CO}	average emission rate CO, g/min
ER_{CO2}	average emission rate CO_2, g/min
$ER_{EC(or\ OC)}$	average emission rate EC (or OC), mg/min
ER_{PM}	average emission rate PM, mg/min
ERC_{CO}	CO carbon emission ratio, g/g
ERC_{CO2}	CO_2 carbon emission ratio, g/g
$ERC_{EC(or\ OC)}$	EC or OC carbon emission ratio, mg/g
ERC_{PM}	PM carbon emission ratio, mg/g
E_{tot}	total daily energy consumed for all fuel types, MJ
$E_{totpercap}$	total daily per capita energy consumed for all fuel types, MJ
FEPX	field emissions protocol
g	gram
H	hydrogen
HAP	household air pollution
HEPA	high-efficiency particulate arrestance
IQR	interquartile range
kg	kilogram
kJ	kilojoule
KPT	kitchen performance test
kW	kilowatt
l	litre
LHV	lower heating value, MJ/kg
LHV_{af}	lower heating value, as fired, MJ/kg
LOD	limit of detection
LOQ	limit of quantification
LPG	liquefied petroleum gas
MCE	modified combustion efficiency
mg	milligram
min	minute
MJ	megajoule
$m_{EC(or\ OC),back}$	EC or OC mass density on backup quartz filter, mg/cm^2
$m_{EC(or\ OC),prim}$	EC or OC mass density on primary quartz filter, mg/cm^2
$M_{EC(or\ OC),back}$	EC or OC mass on backup quartz filter, mg
$M_{EC(or\ OC),prim}$	EC or OC mass on primary quartz filter, mg
NOTE ppm = parts per million.	

Symbol/ Abbreviated term	Definition/ Meaning
M_{col}	new fuel mass collected in past 24 h, kg
M_{cons}	fuel mass consumed in past 24 h, kg
M_f	final mass of fuel, kg
M_{food}	mass of food cooked, kg
M_{fuel}	total mass of fuel consumed, kg
M_i	initial mass of fuel, kg
M_{lid}	mass of cooking vessel lid, g
M_{percap}	per capita fuel mass consumed, kg
M_{PM}	artefact-corrected PM mass on filter, mg
$M_{PM,filter}$	mass of PM collected on filter, mg
$M_{PM,filter,blank}$	average mass of PM collected on blank filters, mg
$M_{PM,filter,f}$	final PM filter mass, mg
$M_{PM,filter,i}$	initial PM filter mass, mg
M_{pot}	mass of cooking vessel, g
M_{prev}	fuel mass stock of the previous day, kg
M_{rem}	fuel mass remaining from the previous day's stock, kg
M_{stock}	mass of fuel stock, kg
MW_x	molecular weight of species x, g/mol
$n(x)$	data series point index for time x
N	nitrogen
OC	organic carbon
Pa	pascal
PAH	polycyclic aromatic hydrocarbon
P_{ave}	average firepower, W
P_{cook}	cooking power, W
P_{post}	post-test ambient pressure, Pa
P_{pre}	pre-test ambient pressure, Pa
P_{std}	standard pressure, 101 325 Pa
PE	personal exposure
PM	particulate matter
PM_{bkg}	average background PM magnitude from real-time sensor, arbitrary units
$PM_{postbkg}$	post-test background period average PM magnitude, arbitrary units
PM_{prebkg}	pre-test background period average PM magnitude, arbitrary units
$PM_{realtime}$	real-time PM data series, arbitrary units
$PM_{realtime,n}$	measured PM magnitude at time point n, arbitrary units
PM_{test}	test period average PM magnitude from real-time sensor, arbitrary units
$PM_{2,5}$	particulate matter with an aerodynamic diameter ≤ 2,5µm
PTFE	polytetrafluoroethylene
Q_{filter}	average volumetric flow across filter (standard conditions), l/min
$Q_{filter,post}$	post-test volumetric flow across filter (actual conditions), l/min
$Q_{filter,post,std}$	post-test volumetric flow across filter (standard conditions), l/min
$Q_{filter,pre}$	pre-test volumetric flow across filter (actual conditions), l/min
$Q_{filter,pre,std}$	pre-test volumetric flow across filter (standard conditions), l/min
NOTE ppm = parts per million.	

Symbol/ Abbreviated term	Definition/ Meaning
Q_{prim}	average volumetric flow through primary quartz filter (standard conditions), l/min
$Q_{prim,post}$	post-test volumetric flow through primary quartz filter (actual conditions), l/min
$Q_{prim,pre}$	pre-test volumetric flow through primary quartz filter (actual conditions), l/min
$Q_{prim,post,std}$	post-test volumetric flow through primary quartz filter (standard conditions), l/min
$Q_{prim,pre,std}$	pre-test volumetric flow through primary quartz filter (standard conditions), l/min
QFF	quartz fibre filter
R	ideal gas constant, 8,314 J/mol/K
RH	relative humidity
ROS	reactive oxygen species
s	second
SC_{energy}	specific energy consumption, MJ/kg
TCTT	time to complete tasks test
t	time between initial and final water temperatures for the cooking power test, s
$t_{postbkg,end}$	post-test background period end time, hh:mm:ss
$t_{postbkg,start}$	post-test background period start time, hh:mm:ss
$t_{prebkg,end}$	pre-test background period end time, hh:mm:ss
$t_{prebkg,start}$	pre-test background period start time, hh:mm:ss
t_{start}	start time of cooking power test, hh:mm:ss
t_{stop}	stop time of cooking power test, hh:mm:ss
t_{test}	test time length, min
$t_{test,end}$	test period start time, hh:mm:ss
$t_{test,start}$	test period start time, hh:mm:ss
T_{post}	post-test ambient temperature, K
T_{pre}	pre-test ambient temperature, K
T_{std}	standard temperature, 293,15 K
T_1	initial water temperature of cooking power test, °C;
T_2	final water temperature of cooking power test, °C;
UCT	uncontrolled cooking test
V_{back}	volume of air sampled through the backup quartz filter, m^3
V_{filter}	volume of air collected by the PM filter, m^3
V_{prim}	volume of air sampled through the primary quartz filter, m^3
VOC	volatile organic carbon
$w_{c,db}$	moisture content, dry basis, %
$w_{c,wb}$	moisture content, wet basis, %
°C	degrees Celsius
Δ	change
Δt_{burn}	burn sequence time for average firepower test, s
NOTE ppm = parts per million.	

5 Field study development

5.1 General

The purpose of this clause is to provide requirements and guidance for field studies intended to determine performance metrics of cooking systems. It links study design considerations to the metrics

and guidance provided in this document. Requirements are given for conducting a performance assessment.

Appropriate study design is critical for effective use of resources and ensuring research questions are answered. However, study design depends on numerous technical and practical considerations that can vary immensely across studies. This clause cannot practically address all potential considerations and solutions, but instead provides a framework for determining performance metrics to be measured and a testing strategy. Additional information for developing cooking system field studies is provided in Reference [2], including qualitative thinking tools, considerations and trade-offs, and example surveys for field studies of cookstove programs. In certain cases, specialist knowledge can be necessary to ensure appropriate and statistically valid study design.

The following clauses in this document provide methods for evaluating elements of cooking system field performance. Table 1 identifies common questions driving cooking system field evaluation. The second column of Table 1 refers to relevant metrics in Table 2 for addressing the specified question.

Table 1 — Field research question and suggested metrics for measurement

Field research question	Relevant metric number(s) in Table 2
How is the cookstove performing in terms of energy and fuel consumption?	Fuel use: 13 Power: 28 to 31
What are the potential hazards to health?	Emissions and usage: 15 to 27, and 2 to 9 Household air pollution and personal exposure: 35 and 36
How much is the cookstove influencing climate?	Emissions: 15 to 27
Is the cookstove likely to be used?	Usability: 12
How does the cookstove design relate to usage?	Usability: 12
How much is the cookstove being used?	Usage: 2 to 7
How is the cookstove changing time use patterns?	Usage: 9 to 11
How safe is the cookstove?	Safety: 32
How durable is the cookstove?	Durability: 33 and 34

5.2 Selection of testing strategy

5.2.1 General

Due to the time and resources required for conducting field tests, only cooking systems with reasonable potential for good performance and adoption rates in the targeted communities should be considered for the most rigorous testing. This subclause describes discrete evaluation levels to guide the user of this document to the appropriate measurement method and study design for the cooking system assessment. These evaluation levels are also reflected in Table 2 to guide the user toward the appropriate metric or metrics to measure.

The three evaluation levels of cooking system assessment are as follows and are described in 5.2.2 to 5.2.4.

1) **Preliminary assessment**: If no previous and/or relevant testing of a cooking system has been conducted, and performance is unknown, a preliminary assessment of the cookstove should be completed. This preliminary assessment includes measurements, observations, and surveys of usability, usage, safety, and durability. See 5.2.2 for more information on preliminary assessments.

2) **Performance assessment**: The performance assessment includes measurements, observations, and surveys of usage, fuel consumption, emissions, safety, and durability, and shall be employed to

evaluate cooking systems that have undergone a preliminary assessment (5.2.2). See 5.2.3 for more information on performance assessments.

3) **Outcomes assessment**: The outcomes assessment can be conducted to determine a change in metrics, such as emissions or household air pollution (HAP), due to use of the improved cooking system (i.e. compared to a baseline cooking system). See 5.2.4 for more information on outcomes assessments.

The metrics measured and the clauses in which to find guidance on these measurements are shown in Table 2.

Table 2 — Field-based metrics of cooking system measurements

Metric #	Metric name	Units	Clause	Preliminary assessment	Performance assessment	Outcomes assessment
1	Laboratory test results	several	5	optional	N/A	N/A
2	Average cooking events per day on a specific cooking device	events/ day	6	optional	required	N/A
3	Average cooking events per day on all cookstoves in a household	events/ day	6	optional	required	N/A
4	Average cooking duration per day on a specific cooking device	h/day	6	optional	required	N/A
5	Average cooking duration per day on all cookstoves in a household	h/day	6	optional	required	N/A
6	Displacement: fraction of cooking events on a specific cooking device	events/ events	6	optional	required	N/A
7	Displacement: fraction of cooking duration on a specific cooking device	h/h	6	optional	required	N/A
8	Number of stacked cooking devices		6	optional	required	N/A
9	Changes in cooking time	min/day	6	optional	optional	N/A
10	Changes in total cooking-related time	min/day/ household member	6	optional	optional	N/A
11	Changes in time-use patterns	qualitative	6	optional	optional	N/A
12	Usability assessment	qualitative	6	optional	optional	N/A
13	Percent difference specific energy consumption	% diff (MJ/kg)	7	N/A	required	N/A
14	Percentage difference of household energy consumption	% diff (MJ/ person/day)	7	N/A	N/A	optional
15	Modified combustion efficiency	mol/mol	8	N/A	required	optional
16	CO emission rate	g/min	8	N/A	required	optional
17	CO fuel energy-based emission factor	g/MJ	8	N/A	required	optional
18	CO fuel-based emission factor	g/kg	8	N/A	required	optional
19	$PM_{2,5}$ emission rate	g/min	8	N/A	required	optional
20	$PM_{2,5}$ fuel energy-based emission factor	g/MJ	8	N/A	required	optional
21	$PM_{2,5}$ fuel-based emission factor	g/kg	8	N/A	required	optional
22	OC emission rate	g/min	8	N/A	optional	optional
23	OC fuel energy-based emission factor	g/MJ	8	N/A	optional	optional

N/A Not applicable.

Table 2 *(continued)*

Metric #	Metric name	Units	Clause	Preliminary assessment	Performance assessment	Outcomes assessment
24	OC fuel-based emission factor	g/kg	8	N/A	optional	optional
25	EC emission rate	g/min	8	N/A	optional	optional
26	EC fuel energy-based emission factor	g/MJ	8	N/A	optional	optional
27	EC fuel-based emission factor	g/kg	8	N/A	optional	optional
28	Cooking power	W	9	N/A	optional	N/A
29	Average firepower	W	9	N/A	optional	N/A
30	Cooking power for solar cookstoves	W	9	N/A	required	N/A
31	Cooking efficiency for solar cookstoves	—	9	N/A	required	N/A
32	Safety assessment report	qualitative	10	optional	required	N/A
33	Fraction of non-functional stoves	—	11	optional	required	N/A
34	Fraction of stoves with particular failure	—	11	optional	required	N/A
35	$PM_{2,5}$ concentration 24 h average	$\mu g/m^3$	12	N/A	N/A	optional
36	CO concentration 24 h average	$\mu g/m^3$	12	N/A	N/A	optional
N/A Not applicable.						

5.2.2 Preliminary assessment

If no previous and/or relevant testing of a cooking system has been conducted, and performance is unknown, a preliminary assessment of the cooking system should be completed. The preliminary assessment includes qualitative and quantitative measurements within the study region, as well as any existing laboratory test results. The preliminary assessment can be used to assess adoption and basic performance of a cooking technology and should be conducted before either a performance assessment or an outcomes assessment.

5.2.2.1 Laboratory tests

Laboratory tests (see ISO 19867-1) are highly recommended to be conducted in conjunction with the preliminary assessment and before a performance assessment. Cooking systems that do not perform well under relatively ideal operating conditions of controlled laboratory testing are generally not expected to perform well under normal uncontrolled conditions in homes. Results of laboratory tests can be assessed using the thresholds defined in ISO/TR 19867-3[3].

5.2.2.2 Usage

Adoption and displacement measurements should be sensor-based by using continuous stove monitors (CSMs).

Displacement is a useful way to understand rates of use and adoption by determining the fraction of total cooking duration or events per day on an improved cookstove calculated by measuring cooking duration on all household cookstoves. Displacement can be calculated over a 24 h period and/or over a longer-term period (e.g. 1 year).

Optionally, observations and surveys may also be used to complement CSMs and determine changes in time use patterns (see 6.3.3).

5.2.2.3 Usability

Information on usability measurement methods is provided in 6.4.

Studies to establish levels of usability should be carried out in target communities where a cookstove type has not been previously tested. Culturally compatible and preferred cookstoves may be identified from a pool of those cookstoves meeting performance-related criteria, or cookstove designs may be created or adapted with these factors in mind. The evaluation of usability can be used to determine if certain cookstoves (and cooking systems) meet the cooking requirements of the target population in ways that provide benefits to the cooks and their families.

Usability metrics may include:

a) fuel cost and convenience: the expense and effort required to obtain and prepare fuel;

b) cooking performance: cooking speed, control, and versatility;

c) operability: ease of operation, ease of learning, and error-tolerance;

d) maintenance: expense and effort required for short- and long-term maintenance;

e) comfort: perceived comfort and aesthetic considerations; and

f) location-specific needs, including secondary uses besides cooking.

5.2.3 Performance assessment

The performance assessment produces quantitative performance metrics for a cooking system of interest that can be compared to existing performance results from comparable measurement methods in publications and resources such as Reference [4]. PM and CO emission rates and fuel-based emission factors can be compared to metrics reported in laboratory tests defined in ISO 19867-1.

Required and optional metrics for a performance assessment and the associated measurement methods are referenced in Table 2. The required metrics for the performance assessment assess fuel consumption, emissions, cooking system usage/adoption, durability, and safety (shown along with optional metrics in Table 2). Requirements shall include all required metrics to claim compliance with this document's performance assessment. Multiple metrics can be measured simultaneously during a performance assessment campaign.

The testing guidance presented in this document may also be used to assess a more limited list of metrics without claiming to have completed a performance assessment in accordance with this document. If baseline data from the study region of interest exists for a given metric, then a performance assessment for this metric can be appropriate for use in comparison against existing baseline data. Comparisons to test results published in the literature and in Reference [4] should only be considered meaningful if data are collected using the protocols described in this document and if sufficient detail regarding the test conditions [e.g. fuel type(s) used, fuel moisture content] is available.

5.2.4 Outcomes assessment

5.2.4.1 General

NOTE 1 This subclause provides guidance, rather than prescriptive direction, on procedures for assessing outcomes, and does not address all ethical and practical considerations of sample selection and study design.

The outcomes assessment evaluates the effect of the improved cooking system compared to a baseline cooking system. Thus, during an outcomes assessment, the baseline cooking system performance should be measured in addition to the improved cooking system performance.

NOTE 2 A cooking system can exhibit improved performance and yet not reduce levels of pollution to which a resident is exposed. For example, the stove might not be used regularly or could be moved into a less-ventilated cooking area.

Outcomes assessment addresses the question of whether a household cooking system yields improved performance and/or associated outcomes in the target community. Performance and/or outcome metrics can be measured using the study design elements presented in this clause. Refer to Table 2 for a list of the metrics that may be measured under the outcomes assessment study design framework.

5.2.4.2 General design issues

The outcomes assessment requires larger sample sizes or longer monitoring periods than the performance assessment, since both the improved and original cookstove systems are measured. This expansion can be achieved using a cross-sectional study design (greater sample size), described in 5.2.4.3.3.1, or a before-and-after/longitudinal study design (longer monitoring time), described in 5.2.4.3.3.2. The metrics included in the outcomes assessment may include emissions and fuel use, and can also include HAP and/or personal exposure (other potential metrics are shown in Table 2). Metrics listed as outcome metrics in Table 2 are measurements that require a comparative baseline measurement to contextualize the improved stove measurements. Multiple metrics can be measured simultaneously during an outcomes assessment campaign.

5.2.4.3 Study design options

5.2.4.3.1 General

There are several types of program evaluations that may be used as a framework for study design to answer outcomes assessment research questions. Each study design has advantages and disadvantages that should be considered in the planning of the study.

NOTE A common hypothesis for a outcomes-with-performance-metrics study takes the form of 'cooking system X uses less fuel than cooking system Y' or, for an outcomes-with-outcome-metrics study, 'a home with cooking system X has lower household air pollution than one with cooking system Y'. Cooking system X in these examples is typically some sort of improved cooking system and cooking system Y is typically an original cooking system.

5.2.4.3.2 Experimental study design

For an experimental study, randomization of study subjects into control and treatment groups is recommended.

NOTE 1 In randomized experiments, study subjects (or groups) are randomly assigned to a group that receives the program intervention (study or treatment group) or a comparison group that does not receive the intervention (control or non-treatment group). Data for each group are collected before and after the intervention. At the end of the experiment, differences between the intervention and comparison groups can be attributed to the effect of the intervention, if the sample is sufficiently large.

NOTE 2 Randomization, if the sample size is large enough, ensures that the intervention and comparison groups are equivalent with respect to all factors other than whether they received the intervention. The comparison group serves as the 'counterfactual' of what would have happened in the absence of the program—a key requirement in determining whether a program caused an outcome.

NOTE 3 Randomized experiments, also called experimental design, are the most rigorous evaluation design. Although considered the 'gold standard', randomized experiments often are not feasible in real-world scenarios. For more information on experimental, or randomized, studies, as well as other study design options, see Reference [5].

5.2.4.3.3 Observational study design

Observational study designs that do not alter the natural pattern of use and measure what is occurring naturally should be used.

NOTE Observational studies are generally more feasible in a real-world setting than experimental study designs. The two simplest and most commonly used observational study designs in cooking system trials are cross-sectional and before-and-after/longitudinal studies.

5.2.4.3.3.1 Cross-sectional study (independent samples)

In a cross-sectional study, a sample group of households using improved cookstoves are compared with a sample group of households not using the improved cookstoves, and outcomes are compared across these two groups. The cross-sectional measurement comparison is done on a population level rather than an individual level, which introduces variability and hence requires a larger sample size when implementing a cross-sectional outcomes assessment.

Theoretically, the main difference between the original and improved cooking system(s) measurement groups is the presence or absence of the improved cooking system. However, it can be difficult to ensure that this is the only meaningful difference between the two groups. Careful consideration should be made when selecting participants so that the two groups are well matched in demographic, socio-economic, behavioural, fuel availability, cooking behaviour, cooking location, family size, and other factors that may be specific to the study location, such as commercial cooking, smoking, or animal feed cooking.

These factors are especially important when implementing cross-sectional outcomes assessments as there can be important differences that influence the uptake of new cookstoves and also the reporting of outcomes. The factors should first be assessed with a survey prior to participant selection to understand which factors in the study region might influence uptake and outcomes. These factors need to be well matched or measured between the study groups.

Alternatively, randomized assignment to the original or improved cooking system for the study period can account for some differences. This similarity between the groups should be verified with a comparison between the two study groups and considered in the analysis of the results.

Cross-sectional measurements should be collected during the same time period for the independent study groups, so they are not influenced by temporal factors, such as seasonality or food/fuel availability. However, as the cookstove use and outcomes are measured at the same point in time, it will not necessarily be clear whether the cookstove use influenced the outcomes or vice versa (correlation does not imply causation).

5.2.4.3.3.2 Before-and-after/longitudinal study (paired samples)

In a before-and-after study, the samples for the original and improved cooking systems are collected from the same cooks or households. The sampling is conducted at two different time points, first with the original cooking system, and then after the introduction of the improved cooking system. An adjustment period of at least one month should be planned between 'before' cooking system distribution measurements and the follow-up 'after' cooking system measurements, to allow the users of the improved cooking system to become accustomed to their new technology. Since the monitoring periods are separated in time, temporal changes between the monitoring periods can influence the measurements. Changes such as fuel quality or moisture content, fuel and food availability, and participant schedules can have effects on measurements.

Before-and-after studies can also employ a 'control group', which does not receive the improved cooking system, in order to account for temporal changes observed by the improved cooking system study part. Use of a control group leads to a more robust study design and necessitates a larger sample size and more resources. If the improved cooking system demonstrates favourable performance in the field test, it is advisable to provide equal opportunity for households in the control group to obtain the improved cooking system at the end of the study period. Situations where improved cooking systems are made available in a phased approach can create a natural control group for this purpose.

5.2.4.3.4 Benefits and challenges of cross-sectional vs. before-and-after studies

The benefits and challenges of cross-sectional studies in comparison to before-and-after studies are presented in Table 3.

Table 3 — Benefits and challenges of study design approaches

Cross-sectional		Before-and-after	
Benefits	**Challenges**	**Benefits**	**Challenges**
— Requires least amount of planning — Can be conducted during a single field campaign without requiring a follow-up of study households at a later time	— Requires larger sample sizes — Improved cooking system users and original cooking system users should be carefully matched	— Smaller samples sizes possible — Samples from improved and original cooking systems are directly comparable	— Greater burden on participants due to the multiple visits required — Possible changes between the before-and-after monitoring (i.e. seasons) can affect measurements

There are many study design options for different research needs. If more complex study design options are required, such as randomized control trials, researchers should consult with a study design expert.

5.3 Sample selection guidance

5.3.1 General

The aim of a field study is to measure a subset of homes that represent the general study population and yield the same results as that the entire region of interest would yield if the full set of homes within the region was sampled. Guidelines for sampling are available from Reference [6], which outlines the various considerations for sample design and provides a sample size calculator.

Additional methods and considerations for sample selection are provided in Reference [2].

5.3.2 Efficacy versus effectiveness

For intervention studies, whether randomized or observational, it is important to define whether the study is an effectiveness trial (uncontrolled, i.e. measuring the performance or outcome of an intervention under real-world conditions) or an efficacy trial (controlled, i.e. measuring performance or outcome under near-ideal circumstances). This determination will frame the study and guide how participants are requested to participate. Some considerations are presented in Table 4.

Table 4 — Examples of factors to consider for effectiveness versus efficacy trials

Study development consideration	Training on use of an improved cooking system during cooking system dissemination	Participant instruction for personal exposure or household air pollution study	Will improved cooking systems be repaired or replaced for free during study period?
Effectiveness (real world)	Training should mirror the expectation for training in the scaled-up cooking system program	Participants should be instructed to cook as they wish with no specifications on which cooking systems to use during measurement period	Repair and replacement should mirror what the scaled-up program for the improved cooking system will employ
Efficacy (idealized)	Training should be as extensive as possible to ensure participant is fully clear on operation of the improved cooking system	Participants should be encouraged to use only the improved cooking system and discontinue use of the original cooking system	Cooking systems should be repaired and replaced as soon as needed in order to have the greatest number of optimally working cooking systems during the study

For more information on effectiveness versus efficacy trials, see Reference [7].

5.3.3 Uncontrolled cooking test (UCT)

An uncontrolled cooking test is a set of measurements performed when the meal is not constrained, and cooks are free to prepare what they want, how they want, using whatever cooking implements and fuels they choose. The UCT can be employed for the measurement of any cooking system, either original or improved. The UCT is applicable for measuring usage, power, and emissions.

5.3.4 Representative site selection

Selection of the study site is generally dictated by the focus area of the implementing organization. Assuming there is flexibility within the project area, several considerations can help guide the selection of the specific communities to ensure a successful field campaign.

5.3.4.1 Generalizability

Selection bias occurs when the participants selected do not represent the target population. When determining a study sample, researchers should consider the target demographic for the given study cooking system and should ensure the recruited participants match the target demographic based on key descriptors. Depending on the indicator measured, these factors can include socioeconomic status, primary fuel type, kitchen characteristics, family size, cooking practices, and original cooking system type. However, there are always potential influencing factors that cannot be predicted or measured, so within these constraints, randomization should be used.

5.3.4.2 Identifying representative communities

Cooking systems should be tested in communities that are representative of the cooking and fuel use practices of the potential customer/users, considering socio-economic and agro-climatic traits. Local cuisine, fuel types/mixing, and other energy demands, such as heating, should be carefully considered to ensure that the measurements are taken in communities that typify the larger geographic region and the location where the cooking system program will be scaled up. The samples should be selected from households that represent the potential customers/users, with care taken to represent the relevant socio-economic and agro-climatic conditions. If large and distinct differences in these conditions exist within a given region, then sampling across these conditions will be necessary to provide representative performance estimates.

5.3.4.3 Obtaining data on representative practices

If information on the cooking and fuel use practices to guide the study site designation is not formally available through prior surveys or census data such as Reference [4], it can often be provided by local partners or contacts with knowledge of the target area.

5.3.4.4 Representative household selection

Within each of the sampling approaches, selection criteria can further guide recruitment of households. Selection criteria are designed to identify study participants that are representative of the target population of interest and have the necessary characteristics to answer the research question. Participant selection criteria will vary depending on the performance or outcome metric measured. Exclusion and inclusion criteria are specified during study design to decide who will take part in the study. In selecting representative samples, the factors mentioned in 5.2.4.3.3 are unlikely to be matched.

NOTE Reference [2] provides an example of a short selection criteria survey used in the field to screen potential participants for an uncontrolled cooking test.

5.4 Selection of representative sampling times

Selection of representative sampling days is particularly important because it is usually impractical to randomize the sampling days across seasons. There can also be specific days or times when

sampling is not representative due to factors such as cultural events and household work schedules (e.g. harvest times).

5.4.1 Seasonal

There are likely to be seasonal differences in emissions. If a before-and-after study design is carried out with the baseline and follow-up data collection periods occurring in different seasons, there is a risk that the results will be confounded by seasonal changes in cooking and fuel use behaviour. Although some of the confounding effects of seasonal behaviour can be explored and controlled for, if possible, the before-and-after sections of the study should be conducted in the same season.

5.4.2 Events

Consultation with the local team should be carried out to identify any religious or cultural festivals/events occurring during the proposed study timeline in the target population. These events can often cause the communities to be unavailable to participate in the study or can influence them to cook in ways that are not reflective of normal behaviour. Such events can also limit the availability of the field staff.

5.4.3 Harvest

If conducting the study in an agricultural community, care should be taken to ensure that the harvest and/or planting season will not complicate sampling due to participants' time demands. The influx of migrant workers and use of harvest-specific crop residues for cooking can also alter the normal cooking patterns and performance.

5.4.4 Weather constraints

In geographical areas with extreme climatic seasons, possible constraints imposed by the weather should to be considered. For example, physical access to the study site can be limited during the rainy season.

5.5 Sample size

Sample sizes should be determined following the guidelines in Reference [6].

When determining the difference in performance between an improved and an original cooking system, the sample size or number of tests required to support or refute a hypothesis is a function of the expected variability in the measurements and the expected or desired difference in performance of the improved and original cooking systems. Any study reliant on repeated measures is at risk of participant fatigue or drop out. Fatigue and dropout occur when participants begin a study but are unable or unwilling to participate in follow-up visits. It is often advised to oversize a study to mitigate the impacts of participant dropout by approximately 10 %.

Key sample size concepts and conventions can be found in Reference [2].

NOTE Cross-sectional studies necessitate more samples because the comparison is between two independent groups, which results in more variability. A before-and-after study, in contrast, directly compares the results of a paired sample, which reduces the variability.

Tables 3 and 4 in Reference [2] provide a guide for determining sample sizes for a field study. The tables assume the standard conventions: *p*-value of 0,05, power of 80 %, and a two-tailed statistical test. Given the assumed conventions, the remaining factors to consider are study design, expected/desired difference in the means, and expected variability.

EXAMPLE If the detectable difference for the performance metric of interest is targeted to be 40 % and a CoV of 60 % is expected, then the researcher would need 36 test samples in each group for cross-sectional study, or 18 in a before/after study (sampled once with the original cooking system and once with the improved cooking system). Adding an additional 10 % for potential drop-out would yield 40 test samples in the cross-sectional study or 20 in a before-and after study. For a study in which the outcomes relate to health or the sample is clustered, a larger sample is likely to be needed.

With large detectable differences and small CoV, it is theoretically possible to measure statistically significant differences with very small sample sizes; however, sample sizes less than 15 for uncontrolled field testing should be avoided to maintain a reasonable level of confidence in the results.

5.6 Field technician capacities

Field technicians should have experience with instrument handling and following protocols. Collecting quality data will be aided by having conscientious, well-trained, independent, and motivated field staff. The technicians should be sensitive to local cultures and customs and be able to communicate fluently, preferably in the same language as the participants. These individuals should not have any vested interested in the outcome of the study, nor be supervised by personnel responsible for the promotion of any fuel or technology.

In-field responsibilities include correctly completing consent forms; filling out survey forms legibly, completely, and consistently; and setting up/running the test equipment according to set protocols. The team should pay close attention while taking detailed notes during tests.

Post-field procedures can include downloading data from instrumentation, calibrating and cleaning instruments, gathering supplies for the following day, and possibly data entry, depending on the arrangement with the field supervisor and project manager.

5.7 Measurement statistics

5.7.1 General

All aggregated measurements should be reported as a sample mean or proportions, median, standard deviation, and CoV. Confidence intervals should also be included.

Further information on statistical analysis can be found in Reference [8].

5.7.2 Reporting guidelines

Written consent of the cook should be obtained for all test methods and metrics in this document along with photographs and records of test conditions.

When reporting aggregated data, measures of spread (such as the range, interquartile range, variance, and standard deviation) should be reported to help contextualize test results and to help others when designing similar studies. One way to characterize uncertainty is to report the 95 % confidence interval, which indicates that in repeated identical experiments, there is a 95 % probability that the confidence interval will include the true mean value.

For more information on statistical analysis for calculating uncertainty and variability of a data set, see Reference [8].

5.7.3 Mitigating bias and managing uncertainty

Mitigating bias and managing measurement uncertainty are critical for controlling the quality of the data collected during a field measurement campaign. Systematic bias can be minimized with good quality assurance and quality control practices. See Reference [2] for more information. See Annex C for guidelines on reporting measurement uncertainty.

6 Usage and usability

6.1 General

Cookstove use and adoption rates, which relate to the potential impact of a cooking system, can be assessed through usage measurements. The cookstove user's cooking needs and attitudes towards

a cookstove, which may impact usage decisions, can be understood by the assessment of cookstove usability.

An example cookstove usage and usability survey can be found in Reference [2].

6.2 Sample selection and timing

Guidelines for sample selection are provided in 5.3 and contain provisions for selecting a representative sample of households in a target community. Additional considerations important in study design for cookstove usage measurements can be found in 5.2. These considerations include determining relevant baseline use and time required to adjust to an improved cookstove, which need to be determined before representative measurements can be taken.

6.3 Cookstove usage

Intended outcomes of an improved cooking device can only be realized if it is used. Usage measurements include how much and how often a cooking device is used, as well as savings in time use attributed to a cooking device. This subclause describes sensor, observation, interview, and survey-based usage measurements.

6.3.1 Usage reporting metrics

The quantitative measurement of changes in time use due to a new cooking system relative to the old cooking system does not necessarily provide a complete picture of the impact on time use. Qualitative investigations of the changes in time use patterns for all household members are also recommended, as tasks may shift from one family member to another or take place simultaneously after the introduction of a new cooking system. Similarly, perceptions of drudgery and quality of time may also evolve.

Reporting metrics for cooking events in usage studies can be used to assess changes in time use due to a new cooking system compared to the original cooking system. These metrics include:

a) changes in time use, measured relative to time to complete a standard cooking task;

b) changes in time use of other activities related to cooking, such as

   1) fuel gathering (walking, chopping, carrying);

   2) fuel preparation (chopping, splitting, stacking);

   3) food preparation (peeling, chopping, grinding, mixing);

   4) fire tending (fanning, blowing, adding fuel);

   5) fire starting (lighting, adjusting, maintenance);

   6) food tending (mixing, stirring, flipping); and

   7) clean-up (extinguishing fire, removing ashes, washing pots); and

c) total changes in time use, measured as the sum of the time savings for the cooking task and all other related activities.

The following reporting metrics are determined by using continuous stove monitors as described in 6.3.3.3:

— average cooking events per day on a specific cooking device;

— average cooking events per day on all cooking devices in a household;

— average cooking duration per day on a specific cooking device;

— average cooking duration per day on all cooking devices in a household;

— displacement as a fraction of cooking events on a specific cooking device;

— displacement as a fraction of cooking duration on a specific cooking device; and

— number of stacked cooking devices.

NOTE Displacement is a useful way to understand rates of use and adoption by determining the fraction of total cooking duration or events per day on an improved cookstove calculated by measuring cooking on all cooking devices in a household including both improved and traditional cooking devices.

6.3.2 Usage claims

6.3.2.1 Performance assessment

To claim compliance with this document's performance assessment, requirements for usage shall use sensor-based measurements. The measurement period shall last one month or more. The sample of households shall be determined following the provisions of Clause 5, with a minimum sample size of 20 households if the sample guidelines result in a lower sample size.

NOTE Studies have shown that self-reported cookstove usage is not correlated with sensor-based measures of cookstove usage (see References [12] and [10]).

6.3.2.2 Sustained adoption

Claims regarding sustained adoption should be based on long-term sensor-based monitoring in order to track how usage has changed over time (see References [9] and [10] for more information). To achieve an accurate understanding of sustained adoption, measurements should be made over 8 months or more[11]. Daily measurements of all cooking events should be taken by placing sensors on the cookstove to continuously monitor for the duration of 8 to 9 months. This length of time might not reflect seasonal variation. Sensors should be used to calculate average daily usage per month, and data should be plotted on a histogram to assess how usage has changed over time.

6.3.2.3 Changes in time use

While it is possible to make claims of cooking time savings of one cooking system relative to another using the approach described in 6.3.3.2, claims based on this methodology should be presented very specifically in relation to technology and fuels only. Any claims of outcomes for users based on time-related metrics should focus on labour time and reflect a more nuanced investigation. Such claims should take into consideration the ways in which changes in cooking technology, fuel, or practices (alone or in combination) affect household time use, whether through time savings, increased time expenditures, or balance-neutral transference of time among activities and/or household members, as well as changes in the user's perceptions of the changes in time use, such as the increase or decrease of perceived drudgery.

6.3.3 Measurement methods

6.3.3.1 General

Measurement methods can be observational, interview, and/or sensor-based (see Reference [2]).

6.3.3.1.1 Observational-based usage measurements

Observational-based methods include local observation during individual cooking events, allowing for notes to be taken regarding cooking time, exposure time, tending time, and clean up time associated with a specific event.

Observational forms reduce recall bias by the participant and allow the surveyor to make objective observations of use. Quick observations can include spot-checking cookstove presence, absence, or

condition. Observations of all cookstoves in the home are recommended. Structured observations may be used in which certain key behaviours are counted.

EXAMPLE The inspector might count the number of times the stove was relit during a cooking event or the number of refuellings.

These methods can facilitate collecting observational data efficiently across larger samples sizes. These approaches also provide insights into how intensively the cook participates in the cooking across the duration of the event.

Longer-term observations can include physically observing behaviours associated with cooking by keeping a record of activities performed by the cook before, during, and after cooking times. When conducting this type of observation, it is important to limit intrusiveness to avoid observational bias (i.e. changes in behaviour due to the researcher's presence).

In some cases, longer-term observations can be partially automated using time-lapse video cameras to record cooking behaviours (i.e. 'video ethnography'). Informed consent of the cook and family members will be necessary for such studies, and these studies should be approved by an ethics review committee.

6.3.3.1.2 Interview/survey-based usage measurements

Interview and survey methods rely on recall by the participant on typical behaviour patterns. These methods yield information on subject demographics, characteristics, and factors associated with cookstove use behaviour.

Interview-based usage measurement can be conducted using questionnaires designed to investigate usage patterns, cookstove and fuel preferences, effects on use due to seasonal or other external factors, and drivers for adoption. Questionnaires should be piloted before use to ensure cultural appropriateness and clarity of the questions. Surveyors should be trained in the use of the surveys before administering them.

An example cookstove usage and usability survey can be found in Reference [2].

NOTE There are disadvantages to interview and survey methods. Responses do not necessary reflect reality, but instead an interviewee might try to satisfy the interviewer's expectations. Imperfect human recall can also lead to errors in responses. This effect increases with the time gap between an event and the interview.

6.3.3.1.3 Sensor-based usage measurements

Sensor-based methods allow direct, objective measures of cookstove heat output using temperature as a proxy for cooking. These methods can be used to measure use across many households using multiple cookstoves. Sensor-based methods cannot necessarily distinguish between cooking time, energy output time, heating time, and other associated applications that increase the temperature of cookstoves without necessarily increasing the cooking time. Sensor-based methods can be used to quantify sustained use over time. Study design for sensor-based methods can vary.

6.3.3.1.4 Combining measurement approaches

Sensors and survey forms can be used independently or together. Combining the methods can allow contextual information from surveys to inform sensor-based measurements.

EXAMPLE 1 An observation of a broken cookstove explains why a sensor-based measurement yields a "no-use" status.

EXAMPLE 2 A completed questionnaire reveals that the festival season is responsible for the higher than normal sensor-based usage measurements, which show cooking for 6 h per day for 3 days in a row.

Reference [2] compares the data measured by observational, interview, and sensor-based methods and also discusses their associated protocols, data analyses, and limitations. It is recommended that interviews or surveys be completed as close to the event as possible.

6.3.3.2 Observation, interview, and survey-based time measurements

Time measurements are listed in 6.3.1 and can be separated into cooking time and labour time.

6.3.3.2.1 Potential constraints of observational and interview measurements

The use of observational methods can require significant time investment by observers to obtain appropriate sample sizes.

These data can also be subject to biases such as the Hawthorne effect, whereby study participants change their behaviour due to the presence of an observer.

EXAMPLE Study subjects might use the improved stove for a larger portion of cooking than they normally would or might load fuel in a manner that more closely follows the training they received than they would when not under observation.

Similarly, interview methods are subject to recall bias by the participant.

6.3.3.2.2 Cooking time

Cooking time refers to the total time spent cooking a dish; it is the time difference between the finishing time and the starting time of cooking (in minutes), which is referenced within the CCT protocol[13]. Cooking time can be measured by sensor-based, observational, or interview methods (see 6.3.3.1).

Observational methods allow for single events to be observed.

Interview methods can also be used to investigate cooking time for different tasks on different cookstoves.

6.3.3.2.3 Labour time

Labour time includes cooking-related times that are not measures of the actual cooking period. These time periods consist of:

a) fuel gathering (walking, chopping, carrying);

b) equipment maintenance (axe sharpening, knife sharpening, fixing);

c) fuel preparation (chopping, splitting, stacking);

d) food preparation (peeling, chopping, grinding, mixing);

e) fire starting (lighting, adjusting, maintenance);

f) fire tending (fanning, blowing, adding fuel);

g) food tending (mixing, stirring, flipping); and

h) clean-up (extinguishing fire, removing ashes, washing pots).

Observations allow for records to be kept regarding cooking-related behaviours, such as gathering and preparing fuel, preparing food, starting a fire, cookstove tending time, and clean up after cooking that cannot be captured by sensor-based methods.

Interview methods can also be used to investigate the cooking-related behaviours listed above.

6.3.3.2.4 Time to complete tasks

For a time to complete tasks test (TCTT), the time to prepare a controlled meal should be monitored for the traditional cookstove and improved cookstove of interest. The full cycle of food and fuel preparation, cookstove lighting, cooking, and any cookstove cleaning tasks should be recorded during a timed event for each cookstove. A minimum of three traditional cookstove events and three improved cookstove

events should be conducted on the same meal type that is applicable to the local context. Multiple meal types can be chosen, as needed in the local context. Refer to ISO/TR 19915[1], for more context and qualitative guidelines. See also the CCT protocol[13].

6.3.3.3 Continuous (cook)stove monitoring (CSM) measurement method

6.3.3.3.1 General

A number of commercially available continuous stove monitors (CSMs) can be purchased, which log temperature data or other indicators of cookstove use. Deciding which one works best for a given project depends on the cookstove type, budget, and study design, with respect to the availability of appropriate data analysis alternatives. The main components to consider when selecting among device options are memory and battery life of the device, cost, data processing and analysing, and size/placement requirements. Each cookstove use monitor will come with more explicit instructions for use, which are not covered in this document. A comparison of several cookstove use monitors can be found in Reference [2]. Accuracy of CSM devices vary, but the accuracy of cookstove usage measurements (in hours per day) is more strongly affected by other factors such as CSM placement and the algorithm used to translate raw CSM output to hours of usage.

Calibration of the algorithm for the sensor to translate temperature into cooking duration shall be performed before sensors are used to compare usage across different stoves.

NOTE For sensor-based methods, it is important to understand how the cookstoves are used. Fuel left in the cookstove to burn out after cooking is done can lead to a misinterpretation of 'hot cookstove' time as 'cooking' time.

6.3.3.3.2 Piloting placement of temperature sensors

Protocol for CSM placements varies with choice of device for the study. Placement of the sensors should be piloted with all cookstove types seen in the field to decide on a standardized placement protocol for each cookstove type that will yield strong signals and will not break sensors from frequent overheating and burn out. Potential places suitable for CSM placement can be determined using a data logging thermocouple with a real-time screen interface.

While the cookstove is in use, a location should be identified that shows a strong heat signal but not higher than that for which the CSM is rated. After identification of this location, the CSMs should be placed according to the user guide and data should be logged over at least 24 h in a home that is using the cookstove. The data should then be assessed to determine if the signal is both clear and safe for the CSM's temperature threshold. For some CSMs, insulation, such as high temperature silicone, can be added to protect the CSM from high heat.

6.3.3.3.3 Installing CSMs during a study

Once a standard location for CSM placement has been determined for all cookstoves, CSMs should be placed in homes. If displacement metrics are intended to be reported, CSMs should be placed on all cookstoves in homes. Those cookstoves may include traditional cookstoves, advanced cookstoves, gas cookstoves, electric cookstoves, electric rice cookers, or electric kettles.

Manufacturers' usage guides should be followed when handling CSMs. Additionally, CSM placement should not be in direct sunlight, and should not interfere with participants' normal activities. Participants should be informed of the purpose of the CSMs and should be instructed not to tamper with CSMs.

When installing CSMs, surveyors shall fill out a tracking form for each house that documents the location of all CSMs. The placement of each CSM shall be documented with a photograph that includes a visible ID number for each cookstove. Reference [2] provides an example of a tracking form. Using identifiers such as label stickers or barcodes will help to track CSMs in the field when handling many sensors for many households.

When using temperature-based CSMs, additional CSMs shall be deployed to measure ambient temperature. Ambient CSMs shall be located out of direct sunlight. A minimum of three ambient CSMs shall be used within a sample region.

6.3.3.3.4 Analysing CSM data

A standardised algorithm shall be used to determine the time periods when each stove is being used and the daily stove usage (in hours per day) from the raw CSM data. For temperature-based CSMs, ambient temperature data series shall be subtracted from stove CSM data series. Output data from CSM analysis software should be inspected for erroneous results and cross-checked against a subset of observational data.

Cookstove stacking is determined by identifying all cooking devices that are used in a household. Cooking devices that are not used (determined by analysing CSM data) shall not be counted.

6.3.3.3.5 CSM usage reporting

A usage reporting template should include:

a) average and standard deviation of:
   1) average cooking events per day on a specific cooking device,
   2) average cooking events per day on all cooking devices in a household,
   3) average cooking duration per day on a specific cooking device,
   4) average cooking duration per day on all cooking devices in a household,
   5) displacement as a fraction of cooking events on a specific cooking device,
   6) displacement as a fraction of cooking duration on a specific cooking device, and
   7) average number of stacked cooking devices per household; and
b) description of:
   1) sample location,
   2) household sample size,
   3) cooking devices measured and frequency of use of each cooking device,
   4) CSM type and features, and
   5) algorithm and/or software used to analyse raw CSM data.

6.4 Cookstove usability

Usability measures the degree to which a cooking system is able to meet the needs of a cook in a given context and can be understood in terms of effectiveness, efficiency, and user satisfaction. The usability of a cookstove can depend on each end user; therefore, measurements should be taken across diverse ranges of target populations. Usability criteria include:

a) fuel cost and convenience: the expense and effort required to obtain and prepare fuel;

b) cooking performance: cooking speed, control, and versatility;

c) operability: ease of operation, ease of learning, and error-tolerance;

d) maintenance: expense and effort required for short- and long-term maintenance;

e) comfort: perceived comfort and aesthetic considerations; and

f) location-specific needs, including secondary uses besides cooking.

While usability-focused design criteria can sometimes conflict with design criteria that improve emissions, fuel consumption, and other technical performance aspects, an acceptable level of usability is necessary for initial acceptance and sustained adoption by a cook.

Usability can be evaluated most effectively by triangulating results from a variety of methods, given the subjective nature of the measurements. Valid methods include observation, interviews, surveys, and physical measurements of the cookstove and cooking system. While quantitative methods should be employed whenever possible to reduce subjectivity, many criteria will need to be evaluated qualitatively.

A protocol for the evaluation and analysis of usability characteristics based on observation, measurement, survey, and interview data are available from Reference [14]. Results for each individual aspect of usability are reported as quantitative performance tiers, from 0 to 4, with supplementary qualitative data provided where applicable.

7 Fuel measurement

7.1 General

This clause includes fuel measurements to determine:

a) relative difference in fuel consumption between two cooking devices (7.6),

b) relative difference in household fuel consumption caused by a cooking intervention (7.7), and

c) emission reporting metrics using the carbon balance method.

The metrics presented in this clause are not applicable to solar thermal cookstoves.

7.2 Output metrics

Table 5 lists fuel consumption communication metrics. Table 6 lists additional fuel measurements that are used for determination of emissions by carbon balance.

Table 5 — Fuel measurement reporting metrics

Metric	Units	Subclause	Assessment level
Relative difference specific energy consumption	%	7.6	Performance
Relative difference daily per capita kitchen energy consumption	%	7.7	Outcomes

Table 6 — Fuel measurements for emission measurements by carbon balance

Metric	Units	Subclause	Assessment level
Energy consumed	MJ	7.8	Performance
Effective fuel heating value	MJ/kg	7.8	Performance
Effective fuel carbon fraction	kg/kg	7.8	Performance

7.2.1 Specific energy consumption

Specific energy consumption is the energy consumption per mass of food cooked measured for a single cooking event. The specific energy consumption depends on the following variables: cookstove, fuel, cooking vessel, cooking task, and cookstove operation by the cook. It is not a direct measurement of

cooking device performance because it is also dependent on the cook and cooking task. When the cook and cooking task are controlled, the metric can be used to compare the relative difference in fuel consumption between one cooking device and another. Additionally, the fuel variable may be controlled to measure a relative difference in cookstove performance, or the cookstove variable may be controlled to measure a relative difference in fuel performance, or both the cookstove and fuel can be varied to measure the relative difference in cookstove/fuel combinations.

7.2.2 Kitchen energy consumption

Per capita kitchen energy consumption is the household cooking energy consumed per person per day. It is a measurement of the following variables: all of the cooking fuels in a household, all of the cooking technologies in a household, and the daily cooking tasks. Per capita energy consumption is not a direct measurement of cooking device performance because it is also dependent on other variables besides the cooking device. However, the metric can be used to compare the relative difference of household energy consumption with and without a cookstove intervention.

7.2.3 Comparison between specific energy consumption and kitchen energy consumption

The relative difference of specific energy consumption is a measure of potential fuel reduction caused by a cooking intervention for a typical cooking event. The relative difference of kitchen energy consumption is a measure of actual fuel reduction caused by a cooking intervention in a household, acknowledging that the introduction of a new cooking intervention in a household may also cause a change in cooking appliance use patterns.

7.2.4 Energy consumed

Energy consumed is calculated from the total fuel consumption during a cooking task. The metric is used for determination of emission rates by carbon balance method and for determination of average firepower.

7.2.5 Effective fuel heating value

Effective fuel heating value is the energy content of the fuel consumed during a cooking event. This metric is required for the determination of fuel energy-based emission factors using the carbon balance method (see 8.5).

7.2.6 Effective fuel carbon fraction

The effective fuel carbon fraction is the mass-based proportion of carbon in the fuel that was consumed. This metric is required for determination of energy-based emission factors by carbon balance (see 8.5).

7.3 Equipment

A mass balance is required for fuel consumption measurement. The mass balance shall have a resolution, accuracy, and precision of at least 0,1 % of the reading or better. One or more mass balances can be necessary to meet this requirement depending on the fuel mixture and the length of the test.

EXAMPLE A hanging type mass balance with a 10 kg range and 0,01 kg resolution can be necessary to measure wood fuels. A top loading mass balance with a 1 kg range and 0,001 kg resolution can be necessary to measure reused fuel and food.

Mass balances shall be calibrated once per year using standard reference weights and checked against reference weights regularly. Deviation from the reference value may be used to estimate measurement uncertainty.

Optional equipment items for measuring specific energy consumption, kitchen energy consumption, and/or emissions by carbon balance are listed in Table 7. Examples for equipment calibration and frequency are provided in ISO 19867-1.

Table 7 — Optional fuel measurement equipment

Optional equipment item	Specific energy consumption	Kitchen energy consumption	Emissions by carbon balance	Notes
Metal tongs for handling hot fuel	x		x	
Metal spoon or spatula for scooping hot fuel and/or small fuel pieces	x		x	
Heat-resistant gloves	x		x	
Metal container for collecting and weighing small fuel pieces, char, ash	x		x	
Hand-held moisture meter for measuring moisture content of solid wood fuels	x	x	x	See 7.4
Fuel sample storage bags or other sealed container for transporting fuel samples for laboratory analysis	x	x	x	Shall be non-permeable to air and moisture
Cord for bundling wood	x	x	x	
Bomb calorimeter to determine the lower heating value of the fuel samples	x	x	x	See 7.5. Not required if the lower heating value is instead taken from a published data source.
Measuring scale for cookstove, pot, and fuel dimensions	x	x	x	
Electricity meter (kilowatt-hour meter) for measuring energy consumption of electric appliances		x		
Gas flow meter for measuring piped gas fuel		x		

NOTE "x" indicates that the equipment item may be used for the measurement.

7.4 Moisture measurement

7.4.1 Hand-held moisture meter

A hand-held moisture meter is only appropriate for wood fuels and shall not be used for non-wood fuels unless it is calibrated for the specific fuel being measured. The moisture meter should meet the requirements in 7.3.

The procedure is as follows.

a) Select a minimum of three pieces of wood from the pile.

b) For each piece of wood, measure the moisture content at three equally-spaced points along the length of the piece.

c) Calculate the average of all single-point measurements using Formula (1).

$$w_{c,av} = \frac{\sum_{i=1}^{n} w_{c,i,1} + w_{c,i,2} + w_{c,i,3}}{n \times 3} \quad (1)$$

where

$w_{c,av}$ is the average moisture content of the fuel, in %;

$w_{c,i,1}$ is the moisture content at point 1 for the *i*th piece of wood, in %;

$w_{c,i,2}$ is the moisture content at point 2 for the *i*th piece of wood, in %;

$w_{c,i,3}$ is the moisture content at point 3 for the *i*th piece of wood, in %;

n is the total number of pieces of wood measured (at least three).

The moisture content shall be reported on a wet-basis. If the moisture meter outputs moisture content on a dry basis, then the average shall be converted to a wet basis.

$$w_{c,wb} = \frac{w_{c,db}}{1 + w_{c,db}} \quad (2)$$

where

$w_{c,wb}$ is the moisture content, wet basis, in %;

$w_{c,db}$ is the moisture content, dry basis, in %.

An example moisture meter reporting template is provided in Figure 1.

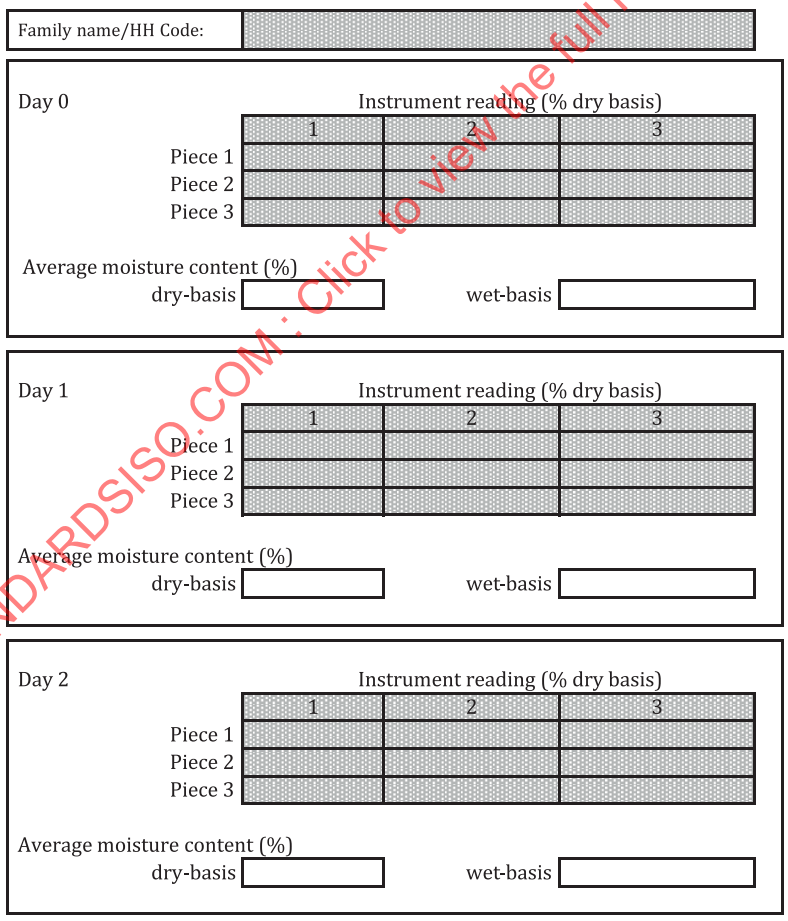


Figure 1 — Example moisture meter reading report template

7.4.2 Oven dry method for wood and other non-wood solid fuels

The oven dry method is appropriate for all solid fuels. A representative fuel sample shall be collected. As soon as practicable, its mass shall be measured and recorded. The sample shall be placed in an air-tight container for moisture content determination in the laboratory using the oven dry method (see EN 14774-3[15]). The time between collection and moisture determination should be minimised.

The difference in mass immediately after the sample was collected and immediately before its moisture content is determined is an indication of the reliability of the measurement.

7.5 Fuel heating value measurement

For solid biomass fuels, determination of the heating value as specified in ISO 19867-1:2018, 5.5 shall be followed to determine the lower heating value as-fired. For fuel types other than solid biomass (coal, liquid, gas), a standard method appropriate for the fuel type shall be used and a reference to the method shall be provided along with the results. Alternatively, if the fuel heating value has been previously measured and published, then the value may be taken from that published source. If so, the value shall be adjusted to the lower heating value as-fired using the formulae in ISO 19867-1:2018, 5.5.

7.6 Specific fuel consumption

The specific fuel consumption measurement is adapted from the controlled cooking test[13]. Compared to the controlled cooking test, the measurement in this document:

a) provides more prescriptive requirements and less informative guidance,

b) has terms and definitions consistent with ISO/TR 21276[16],

c) prescribes an explicit step-by-step measurement procedure, and

d) has a different calculation of specific energy consumption.

The purpose of the test is to measure the relative difference in fuel consumption between two cooking technologies, such as cookstoves, fuels, or cookstove/fuel combinations. A standard cooking task is determined and then performed using each of the two cooking technologies. The cooking task is performed by multiple cooks, with multiple repetitions by each cook in order to prevent bias.

7.6.1 Test conditions

The test shall be conducted in a home setting that has adequate ventilation and is protected from ambient wind. The cookstove system that is tested in this procedure includes the cookstove, cooking vessels, fuels, cooks, and cooking task. In order to test a part of this system (such as the cookstove, fuel, cookstove/pot combination, cookstove/fuel combination, or cookstove/fuel/pot combination) all variables shall be controlled except the test variable(s). The cooking task is controlled by choosing a standard cooking task. The cooks are controlled by having the same cooks use each cooking technology. The fuels shall be prepared and the stove shall be operated and cleaned following normal practices in the region. The combinations of cooks and cooking technologies shall be tested in random order. Each type of fuel stock shall have consistent moisture content and energy content for all test replicates.

7.6.2 Sample selection

The standard cooking task used for the test should be typical to the region where the test is performed and typical for the cooking technologies being tested.

The particular cooking devices that are used during the test should be functioning correctly.

The cooks should be selected locally in the region where the test is performed and should have knowledge and experience in using the cooking technologies and performing the standard cooking task.

The cooking task shall be performed by at least three cooks. Each cook shall perform at least three repetitions of the cooking task. When performing more tests than the minimum requirement, it is recommended to increase the number of cooks rather than increasing the number of repetitions per cook.

7.6.3 Measurements

The following measurements shall be taken:

a) mass of each type of fuel consumed;

b) energy content of each type of fuel (lower heating value);

c) moisture content of each type of fuel;

d) initial empty mass of each cooking vessel;

e) initial mass of uncooked food; and

f) final mass of each cooking vessel with cooked food.

7.6.4 Equipment

In addition to the equipment described in 7.3, an adequate supply of fuel, food, and water shall be provided based on the selected cooking task and number of test repetitions. Dishes, utensils, cutting boards, and knives may also be needed to prepare the ingredients.

7.6.5 Protocol

7.6.5.1 Determining the standard cooking task

Cooks shall be interviewed in the region to determine an appropriate cooking task that is typical of the region for the cooking technologies being tested. The cooking procedure shall be recorded in detail, with the recorder remaining as objective as possible. A list of ingredients and the mass of each ingredient shall be recorded. An example ingredient list from the CCT[13] is provided in Table 8.

Table 8 — Example ingredient list used in a CCT

Dish	Ingredient	Quantity (g)
porridge	water	4 000
	millet flour	1 000
sauce	oil	100
	meat	450
	tomatoes	300
	water	2 500
	onions	70
	spices	50
Taken from Reference [13].		

7.6.5.2 Conducting the test

The procedure for conducting the test is as follows.

a) Prepare the fuel and cooking ingredients. Prepare twice as much fuel as is expected to be used. Measure and record:

   1) the initial mass of each cooking vessel,

2) the initial mass of uncooked food, and

3) the initial mass of each fuel type.

Fuel types shall be distinguished by their heating value. Examples of fuel types include biomass species or other fuel materials such as kerosene. Reused fuel in shall also be treated as a separate fuel type in addition to raw fuel.

b) Collect a representative sample of each fuel type in sealed containers for laboratory analysis of moisture content and heating value. If using a hand-held moisture meter for wood fuels, measure and record the moisture content (see 7.4.1).

c) Instruct the cook to begin cooking and record the start time of the cooking event.

d) When the cook indicates the cooking task is finished, record:

1) the end time of cooking, and

2) the mass of each cooking vessel with cooked food.

b) Instruct the cook to separate reused fuel from the remaining solids following normal practices. If the separation process happens after the remaining solids have cooled, then wait until the separation has been performed to measure the reused fuel. Record:

1) the final remaining mass of each raw fuel type,

2) the final mass of reused fuel, and

3) the time of the final fuel measurement.

7.6.6 Calculations

7.6.6.1 Energy consumption

Energy consumed is defined as the total fuel energy in (raw and reused fuel in) less the reused fuel remaining. In Formula (3), reused fuel in and reused fuel remaining can be treated as one fuel type if they have the same heating value, otherwise they should be treated as separate fuel types.

$$E_{\text{fuel}} = \sum^{\text{type}} \left[\left(M_{\text{type,i}} - M_{\text{type,f}} \right) \times LHV_{\text{type,af}} \right] \quad (3)$$

where

E_{fuel} is the total energy consumed, in MJ;

$M_{\text{type,i}}$ is the initial mass of each fuel type;

$M_{\text{type,f}}$ is the final mass of each fuel type;

$LHV_{\text{type,af}}$ is the lower heating value of each fuel type, as fired, in MJ/kg.

7.6.6.2 Mass of food cooked

The total mass of food cooked, M_{food} (kg), is the initial mass of uncooked food.

7.6.6.3 Specific energy consumption (as fired)

$$SC_{\text{energy}} = \frac{E_{\text{fuel}}}{M_{\text{food}}} \tag{4}$$

where

SC_{energy} is the specific energy consumption, in MJ/ kg;

E_{fuel} is the total energy consumed for all fuel types, in MJ;

M_{food} is the total mass of food cooked, in kg.

7.6.6.4 Aggregated results

The specific consumption metric shall be tabulated for all test replicates performed on each cooking technology. There should be a minimum of 9 test replicates for each cooking technology (3 cooks × 3 replicates per cook).

The mean, standard deviation, and coefficient of variation of the specific energy consumed SC_{energy} shall be calculated for the cooking technology #1 and cooking technology #2 test replicates.

To calculate the percent difference of the two sample means, Formula (5) shall be used:

$$\%\text{diff} = \frac{\text{mean}\left(SC_{\text{energy},2}\right) - \text{mean}\left(SC_{\text{energy},1}\right)}{\text{mean}\left(SC_{\text{energy},1}\right)} \tag{5}$$

where

$SC_{\text{energy},1}$ is the specific energy consumption of cooking technology #1;

$SC_{\text{energy},2}$ is the specific energy consumption of cooking technology #2.

This calculation provides the percent difference in fuel consumption of cooking technology #2 compared to cooking technology #1. A negative value indicates technology #2 had a reduction in fuel consumption compared to technology #1.

A two-tailed *t*-test shall be performed on the cooking technology sample groups to determine the probability that the samples are from the same population. The *p*-value of the *t*-test shall be reported along with the percent difference.

7.6.7 Reporting

All measured and reported quantities shall include uncertainty estimates (see Annex C for uncertainty guidelines). In addition to the reporting requirements of 7.8.9.1, the following should also be reported:

a) initial uncooked mass of each type of food;

b) empty mass and material of each cooking vessel;

c) final mass of each cooking vessel with cooked food; and

d) the reporting metric of specific energy consumption.

An example specific energy consumption reporting template is provided in Figure 2.

Specific energy consumption reporting template

Specific energy consumption (MJ/Kg)

	sample size	mean	stdev	CoV
cooking technology #1				
cooking technology #2				
difference (%)				
t-Test p-value				

description of cooking technology #1
description of cooking technology #2
description of standard cooking task:
description of other controlled variables [fuel, stove, cooking vessel, etc.]:

Figure 2 — Example specific energy consumption reporting template

7.7 Kitchen energy consumption measurement

See Reference [17].

The primary purpose of this test protocol is to demonstrate differences in consumption of cooking fuels between households using baseline cooking technologies and households using improved cooking technologies by measuring the rate of daily fuel consumption per person in the normal household environment over an extended period of time (typically 3 to 7 days). It is a prolonged test conducted with the willing cooperation of individual families.

7.7.1 Considerations

Field technicians should not provide fuel. Households should use their own supply of fuel and store the fuel following their regular practice.

The minimum sample size is 20 households.

7.7.2 Reporting

All measured and reported quantities shall include uncertainty estimates (see Annex C for uncertainty guidelines).

Copies should be kept of all datasheets and spreadsheets used to determine individual household results and final aggregated results.

An example kitchen energy consumption reporting template is provided in Figure 3.

Kitchen energy consumption reporting template

Daily per capita energy consumption (MJ/person/day)

	sample size	mean	stdev	CoV
baseline sample group				
intervention sample group				
difference (%)				
t-Test p-value				

description of study design (how samples were selected):
description of baseline sample group (location, cooking appliances, fuels):
description of intervention sample group (location, cooking appliances, fuels):

Figure 3 — Example kitchen energy consumption reporting template

7.8 Fuel measurements for emissions by carbon balance

The energy consumption, effective fuel heating value, and effective fuel carbon fraction are determined in this subclause. The output metrics are not a direct measure of cooking system performance. The metrics are used to determine emission factors and emission rates by carbon balance method in 8.5. Limitations to the carbon balance method, and these associated fuel measurements, are discussed in A.3.2. The energy consumption E_{fuel} may also be used to calculate average firepower (see 9.3).

7.8.1 Test conditions

This fuel measurement procedure is applicable for uncontrolled and controlled cooking tasks in any setting. The measurement procedure is for one full burn sequence. The burn sequence starts upon ignition and ends when combustion is extinguished or left to burnout naturally. If left to burnout naturally, the end of the burn sequence is defined at the time when the plume CO_2 concentration (after subtracting the background concentration) has diminished to 10 % of the average value during the cooking sequence.

7.8.2 Equipment

In addition to the equipment listed in 7.3, laboratory fuel analysis equipment described in ASTM E870[18] may be used to perform the ultimate analysis of the fuel samples (unless the carbon fraction value is instead estimated from a reference source).

7.8.3 Required measurements

The following measurements are required for each fuel type:

a) initial fuel mass;

b) final fuel mass;

c) moisture content (wet basis);

d) lower heating value (as-fired); and

e) carbon fraction (as-fired).

7.8.4 Determination of moisture content

See 7.4.

7.8.5 Determination of lower heating value

The lower heating value LHV_{af} may be determined according to ISO 19867-1:2018, 5.5 or by referencing a published value that was determined following the method specified in ISO 19867-1:2018, 5.5.

7.8.6 Determination of fuel carbon fraction

The fuel carbon fraction $CFrac_{fuel}$ may be determined by referencing a published data source, or by obtaining a representative fuel sample and performing an ultimate analysis in a laboratory following ASTM E870[18].

7.8.7 Protocol

a) Measure and record the initial mass of each fuel type. Fuel types shall be distinguished by their heating value. Examples of fuel types include biomass species or other fuel materials such as kerosene. Reused fuel in shall also be treated as a separate fuel type in addition to raw fuel.

b) Collect a representative sample of each fuel type in sealed containers for laboratory analysis of moisture content (see 7.4.2), heating value (see 7.5), and carbon fraction (see 7.8.6). Mark and catalogue each sample. If using a hand-held moisture meter for wood fuels, measure and record the moisture content (see 7.4.1).

c) Record the start time of the burn sequence when the cookstove is ignited.

d) Determine the end time of the burn sequence when combustion is extinguished, or when the cooking sequence is finished and combustion is left to burnout naturally. If left to burnout naturally, the end of the burn sequence is defined at the time when the plume CO_2 concentration has diminished to 10 % of the average value during the cooking sequence. Instruct the cook to separate reused fuel from the remaining solids following normal practices.

e) Measure and record:

   1) end time of burn sequence;

   2) final remaining mass of each raw fuel type;

   3) mass of residual fuel; and

   4) final mass of reused fuel.

7.8.8 Calculations

7.8.8.1 Energy consumption

Refer to 7.6.6.1.

7.8.8.2 Effective fuel heating value

The effective heating value *EHV* (MJ/kg_{fuel}) is an expression of fuel heat energy per unit mass that relates the fuel mass consumed to the fuel energy contained in it. (See further guidelines for determining

effective heating value in Annex A.) For the simple case of a single fuel type that burns homogeneously, the effective heating value is equal to the lower heating value, as-fired LHV_{af}:

$$EHV = LHV_{af} \tag{16}$$

where

EHV is the effective heating value, in MJ/kg;

LHV_{af} is the lower heating value as-fired, in MJ/kg.

Formula (16) is valid for liquid and gas fuels as well as biomass fuels that burn to completion with no net change in reused fuel. For more complex cases of multiple fuel types and/or a net change in reused fuel, the effective fuel heating value can be calculated as:

$$EHV = \frac{\sum^{type}\left[\left(M_{type,i} - M_{type,f}\right)\times LHV_{type,af}\right]}{\sum^{type}\left(M_{type,i} - M_{type,f}\right)} \tag{17}$$

where

EHV is the effective heating value, in MJ/kg;

$M_{type,i}$ is the initial mass of each fuel type, in kg;

$M_{type,f}$ is the final mass of each fuel type, in kg;

$LHV_{type,af}$ is the lower heating value of each fuel type, as fired, in MJ/kg.

Formula (17) is the total energy consumed divided by the total net change in fuel mass (summed over all fuel types where each fuel type is denoted with the subscript "type"). In this case, reused fuel in and reused fuel remaining can be treated as one fuel type if they have the same heating value, otherwise they should be treated as separate fuel types.

7.8.8.3 Effective fuel carbon fraction

The effective fuel carbon fraction $CFrac_{eff}$ is a conversion factor between carbon released and fuel mass consumed. (See further guidelines for determining effective fuel carbon fraction in Annex A.)

For the simple case of a single fuel type that burns homogeneously, the effective fuel carbon fraction is equal to the fuel carbon fraction:

$$CFrac_{eff} = CFrac_{fuel,af} \tag{18}$$

where

$CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;

$CFrac_{fuel,af}$ is the as fired fuel carbon fraction, in g/g.

Formula (18) is valid for liquid and gas fuels as well as biomass fuels that burn to completion with no net change in reused fuel and no residual fuel. For more complex cases of multiple fuel types and/or a net change in reused fuel or residual fuel, the effective fuel carbon fraction can be calculated as:

$$CFrac_{\text{eff}} = \frac{\sum^{\text{type}} \left[CFrac_{\text{fuel,af,type}} \times \left(M_{\text{type,i}} - M_{\text{type,f}} \right) \right]}{M_{\text{fuel}}} \tag{19}$$

where

$CFrac_{\text{eff}}$ is the effective fuel carbon fraction, in g/g;

$CFrac_{\text{fuel,af,type}}$ is the as fired fuel carbon fraction for each fuel type, in g/g;

$M_{\text{type,i}}$ is the initial mass of each fuel type, in kg;

$M_{\text{type,f}}$ is the final mass of each fuel type, in kg;

M_{fuel} is the total mass of fuel consumed, in kg.

Formula (19) is the total net change in carbon in the fuel consumed divided by the total fuel consumed (summed over all fuel types where each fuel type is denoted with the subscript "type"). Residual fuel shall be included as a fuel type. Reused fuel in and reused fuel remaining can be treated as one fuel type if they have the same heating value, otherwise they should be treated as separate fuel types.

7.8.9 Reporting

A report shall be prepared for each cooking event and shall contain the following information. All measured and reported quantities shall include uncertainty estimates (see Annex C for uncertainty guidelines).

7.8.9.1 General fuel measurement report

a) administrator information:
   1) organization/company;
   2) contact information;
   3) technician names;
b) location:
   1) home (country, district, village, address, house ID, GPS coordinates);
   2) cookstove (indoor/outdoor, location in home, photograph);
c) date;
d) weather conditions;
e) description of cooking system (note if any factors are controlled):
   1) cookstove (make, model, serial number, description, materials, dimensions, photograph);
   2) food cooked/cooking task [description, quantity (number of people fed), flavour, photograph];
   3) cooking vessels (shape, size, mass, materials, description, photograph);
   4) fuels (species, shape, dimensions, quantity, photograph);

5) stove operator (who);

f) description of equipment:

1) scales (make, model, range, resolution, accuracy);

2) moisture measurement equipment;

g) cooking test data sheet for each fuel type:

1) moisture content;

2) moisture content measurement method;

3) initial mass of fuel;

4) final mass of fuel;

5) fuel mass consumed;

6) lower heating values as fired;

7) method of determination of lower heating values;

8) energy consumed;

h) additional notes; and

i) copies of raw test data sheet.

7.8.9.2 Carbon balance fuel report

If emissions are measured using the carbon balance method described in 8.5, in addition to the reporting requirements of 7.8.9.1, the following shall be reported:

a) carbon fraction as-fired for each fuel type;

b) method of determination of carbon fractions;

c) effective heating value; and

d) effective fuel carbon fraction.

7.9 Limitations

Researchers should limit their subjects to participants willing to cooperate with the study. Households should understand the requirements that are placed on them. Long-duration tests can necessitate regular visits to households; these visits can be seen as a nuisance if subjects are not fully informed of the study parameters.

8 Emission measurement

Cookstove emissions contain pollutants that affect health and climate. The pollutant composition and emission rate can vary greatly with cooking technology and fuel type and condition. Emission measurements are used to compare cooking system technologies, observe changes in performance under different conditions, and provide input for health and climate relevant research questions. This clause provides guidance for measuring and reporting cooking system emissions of $PM_{2,5}$, CO, CO_2, EC, and OC. The methods and metrics covered in this clause are applicable for field measurements of emissions during controlled and uncontrolled cooking tests for chimney and non-chimney cookstoves.

Owing to their lack of combustion-based emissions, this clause does not apply to solar cookstoves. Emission factor and emission rate values are not prescribed for solar cookstoves.

8.1 Emission species measured

This protocol provides guidance for measuring $PM_{2,5}$, CO, elemental carbon (EC) and organic carbon (OC). $PM_{2,5}$ and CO are required, while EC/OC are optional measurements. Additional species may also be measured. In general, the same procedures to measure $PM_{2,5}$ and CO can also be used to measure additional species. However, additional species analysis can require a unique sampling matrix, such as quartz fibre filter for EC/OC analysis, and can be sensitive to method detection limits and overloading.

8.2 Emission output metrics

Emission reporting metrics are shown in Table 9. All reporting metrics in Table 9 are part of the performance assessment. Justifications, considerations, and relative importance of each metric are discussed in Annex A.

Table 9 — Emission reporting metrics and units

Reporting metric	Units by species		
	CO	$PM_{2,5}$	EC/OC (optional)
Fuel energy-based emission factor	g/MJ	mg/MJ	mg/MJ, mg/MJ
Fuel-based emission factor	g/kg	mg/kg	mg/kg, mg/kg
Emission rate	g/min	mg/min	mg/min, mg/min
Modified combustion efficiency	mole/mole		

8.3 Sample selection

The sample of households shall be determined following guidelines in 5.3 to 5.5, with a minimum sample size of 20 households if the sample guidelines result in a lower sample size.

8.4 Sampling methods

The partial capture sampling method with carbon balance calculations is described in 8.5. The sampling and calculation method in 8.5 may be adapted, or a different method may be used to determine reporting metrics listed in Table 9. If a different method is used, changes shall be clearly reported, proper justification shall be provided, and potential measurement biases and uncertainties shall be identified and propagated to the confidence interval of the reported results.

It is possible to perform field emission measurements using the total capture method by adapting the laboratory-based total capture measurement described in ISO 19867-1. However, there are many considerations and practical challenges associated with performing total capture measurements in the field, and therefore the partial capture method described in 8.5 is recommended as the most practical and effective option for field measurements. A general description of partial and total capture sampling methods is provided in A.3.

8.5 Emission measurements using partial capture sampling with carbon balance

This subclause details the equipment and procedure for CO, EC/OC, and $PM_{2,5}$ emissions sampling using partial plume capture and carbon balance. CO_2 is also simultaneously measured because it is essential for calculation of emission metrics. Emission output metrics are calculated using the carbon mass balance method. Biases and limitations of the method are described in A.3.2.

8.5.1 Test conditions

This method is intended primarily for uncontrolled cooking tests, in which the technician does not specify cookstoves, fuels, meals, cooking practices, location of the cookstove in the household, or any

other factors that may affect emissions. However, this method is also applicable for controlled cooking tests in which one or more of these factors are specified by the protocol. The type of cooking test, the test protocol, and any controlled factors shall be reported with the results.

Emissions should be measured continuously for a complete cooking event, including pre-lighting background, lighting, cooking, burnout, and post-burnout background. Alternatively, in the case where the cookstove is used continuously, as in heating cookstoves, a representative burn cycle should be chosen.

8.5.2 Required measurements

Measurements shall be taken for:

a) average concentration of CO_2 in the sampling event plume;

b) average concentration of CO in the sampling event plume;

c) average flow rate through the $PM_{2,5}$ gravimetric filter;

d) mass of $PM_{2,5}$ collected on the gravimetric filter;

e) background concentration of CO_2 in the sampling environment;

f) background concentration of CO in the sampling environment;

g) background concentration of $PM_{2,5}$ in the sampling environment;

h) temperature and humidity in the sample train;

i) ambient (atmospheric) pressure;

j) mass of dry fuel burned during sampling event;

k) effective carbon fraction of fuel burned during sampling event;

l) effective heating value of fuel burned during sampling event; and

m) duration of the sampling event.

Optional measurements for EC and OC are:

o) average flow rate through the primary and backup quartz filters;

p) mass of EC and OC on the primary quartz filter;

q) mass of EC and OC on the backup quartz filter; and

r) background concentration of EC/OC in the sampling environment.

8.5.3 Equipment specifications

8.5.3.1 Emission sampling system

An emission sample shall be collected from a free plume or chimney with one probe and drawn through a sample train. The sample stream may be diluted with dry, clean air. The sample stream shall be size-segregated using a flow through a particle separator (such as a $PM_{2,5}$ cyclone) to remove particles larger than 2,5 µm in diameter, and then passed through a PM filter for gravimetric analysis. CO and CO_2 gas sensors shall sample from the sample stream after removal of particulate matter.

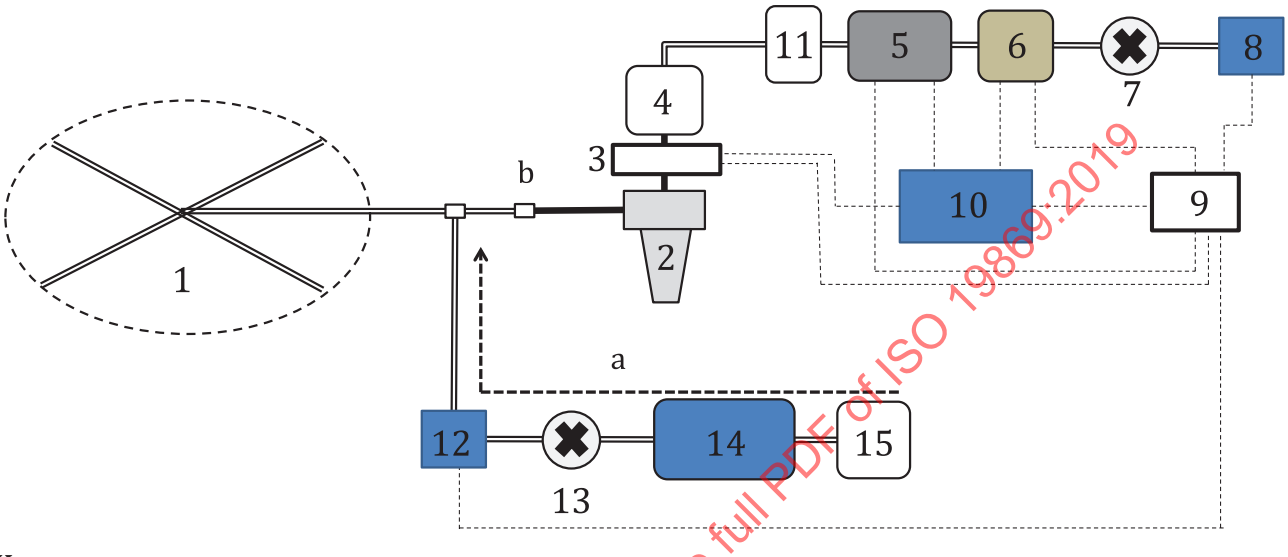
The sample train shall have only one sample probe to ensure all measurement instruments are exposed to the same emission sample. Using separate sample probes for separate instruments is not permitted.

An example sample train is shown in Figure 4. Other configurations that meet the component requirements given in this subclause may be used. The sample train may be split into parallel flows

to meet the flow criteria when combining sub-assemblies into one sampling system. All sample train components shall seal to pass the sample train leak test described in 8.5.9.

EXAMPLE 1 Arrangements meeting the requirements of this subclause can include gas sensors packaged into subassemblies that include a data logger and multiple sensor-specific data loggers along the sample train.

EXAMPLE 2 Arrangements meeting the requirements of this subclause can include pumps, flow control mechanisms, and batteries packaged into a subassembly such as a personal sampling pump.

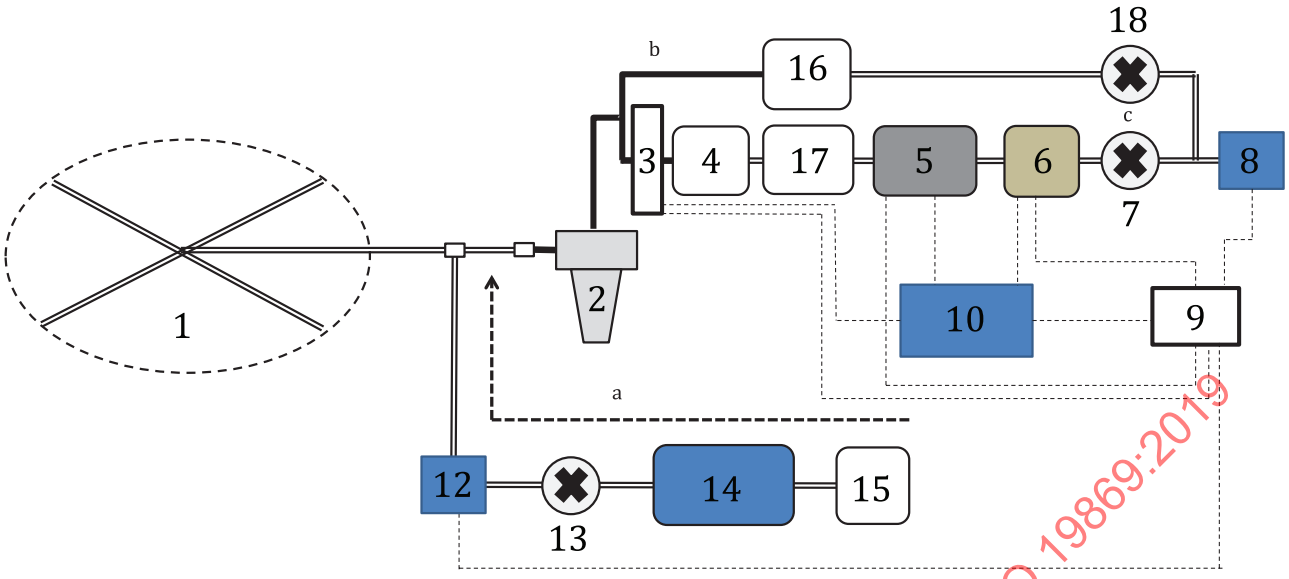


Key

1 sampling probe
2 particle size separating device (cyclone)
3 temperature and relative humidity sensors
4 $PM_{2,5}$ gravimetric filter and filter holder
5 carbon dioxide sensor
6 carbon monoxide sensor
7 flow control device
8 vacuum pump
9 power supply
10 data acquisition system
11 backup HEPA filter
12 dilution pump
13 dilution metering valve
14 dilution desiccator
15 dilution HEPA filter
a Forced dilution.
b Conductive tubing.

Figure 4 — Sampling system diagram for CO and $PM_{2,5}$ emissions from an open plume

To measure EC and OC in addition to CO and $PM_{2,5}$, the sample train shall have two quartz filters in parallel (see Figure 5). The primary quartz filter is in parallel with the gravimetric PM filter. The backup quartz filter is located downstream of (behind) the gravimetric PM filter for measuring of volatile OC artefact. The sample train shall also have additional flow control for the primary quartz filter flow train.



Key

1-15 see Figure 4
16 primary quartz filter holder
17 backup quartz filter holder
18 primary quartz metering valve
a Forced dilution.
b Conductive tubing.
c Flow control.

Figure 5 — Sampling system diagram for EC and OC emissions from an open plume

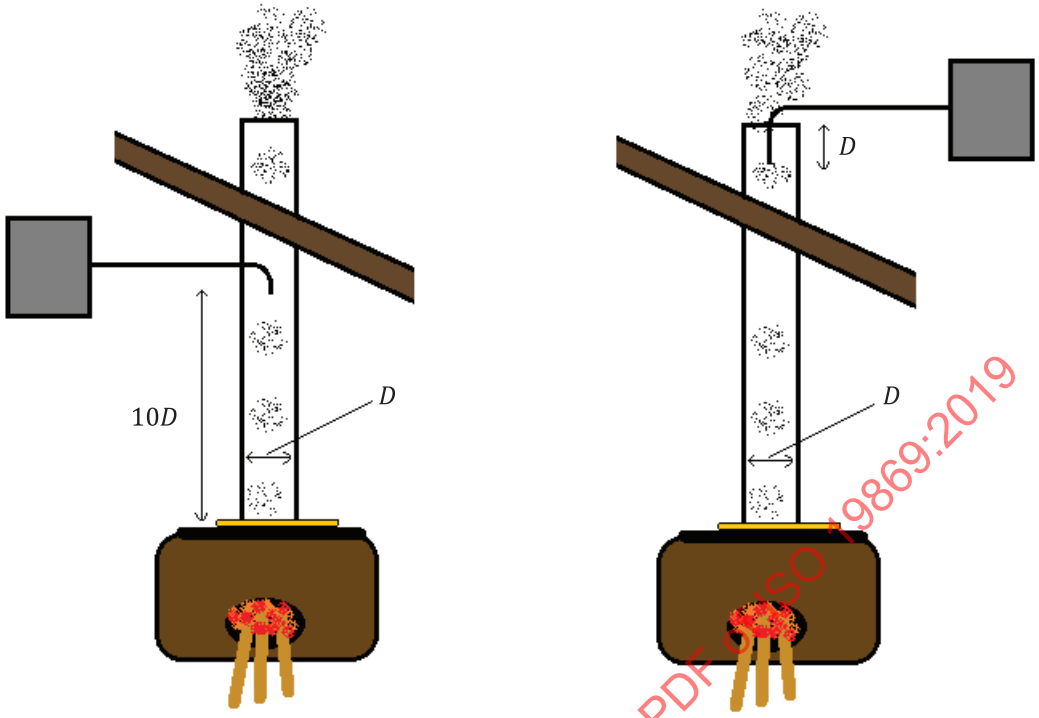
8.5.3.1.1 Sampling probe

A sampling probe is tubing that is placed in the plume from which the emission sample is drawn into the sampling system. The probe should be made of stainless steel (or similar) tubing. A multi-point sample probe can be used for sampling naturally diluted plumes in free air above a cookstove or chimney outlet. The number, size, and positioning of inlets should be chosen to capture a representative sample of the plume. The inlets need not be isokinetic (the nozzle inlet velocity need not match the plume velocity), since cookstove plumes in free air usually meet calm air sampling criteria. The probe should intersect a cross-section of the plume perpendicular to the direction of cookstove exhaust flow. The sample shall be fully mixed before it reaches the particle separator in the sample train.

A collection hood may be used to capture the plume and channel it to the probe. Considerations and potential biases of collecting a representative sample are discussed in A.3.2.1.

For chimney cookstoves, a single point emission sample should be drawn from a port in the chimney where the emission flow is fully mixed. As a guideline to locate fully mixed flow, the port should be located downstream of the cookstove at a distance greater or equal to 10 times that of the inside chimney diameter (Figure 6). Ideally, the sample probe should be located at the chimney outlet, if it is accessible, to avoid adding a hole in the chimney wall. The probe end may be extended into the chimney opening at a depth greater than the pipe diameter to minimize variability associated with ambient mixing (Figure 6). The probe diameter should be sized to approximate isokinetic sampling conditions.

NOTE Sampling at the chimney outlet avoids drilling a hole in the chimney and prevents the sampling equipment and operator from intruding into the cooking space.



Key

D inside chimney diameter

Figure 6 — Chimney cookstove sampling probe configurations

8.5.3.1.2 Particle size separating device

The particle size separating device removes particles larger than 2,5 µm from the sample stream. A cyclone or impactor can be used to remove particles larger than 2,5 µm from the sample stream. The flow rate through the particle separator shall be set to match the $PM_{2,5}$ cut point of the device (1 l/min to 5 l/min is common for portable field sampling equipment).

8.5.3.1.3 Temperature and relative humidity sensors

The temperature sensor and humidity sensor shall transmit a continuous or semi-continuous reading that is logged to a data file. The temperature sensor shall have a range of 0 °C to 100 °C or larger, with a resolution of at least 1 °C, and an accuracy to within 2 °C or better. The relative humidity sensor shall have a range of at least 10 % RH to 90 % RH, a resolution of at least 1 % RH, and an accuracy of 10 % RH or better.

8.5.3.1.4 $PM_{2,5}$ gravimetric filter and filter holder

$PM_{2,5}$ mass shall be collected on a filter for gravimetric analysis. The filter shall be PTFE, glass fibre, or PTFE coated glass fibre, with a collection efficiency of at least 99,95 % for 0,3 µm dioctyl phthalate smoke particles. The filters shall be transported between the analysis laboratory and field site in air-tight Petri dishes or filter holders. Petri dishes or filter holders should be clearly labelled with a permanent marker or bar code. Care should be taken to ensure filters remain in the same container before and after sampling. After sampling, the filters should be kept at −4 °C or lower during transportation and storage. The filter shall be pre-weighed and post-weighed according to the gravimetric analysis procedure in 8.5.5.

8.5.3.1.5 EC/OC filter holders

EC/OC mass shall be collected on a filter for thermal optical analysis for carbonaceous species. The filter shall be quartz fibre filter (QFF), with an aerosol retention efficiency of at least 99,9 % for 0,3 µm dioctyl phthalate smoke particles. The filters shall be transported between the analysis laboratory and field site in sealed, baked aluminium-lined Petri dishes or sealed filter holders. The filters shall be kept at −4 °C or lower during transportation and storage. QFF shall be pre-baked to remove organic carbon contamination by placing the sample filter in a muffle furnace at 550 °C for a minimum of 15 h. Two filter holders are required to correct for volatile organic carbon artefacts developed on the primary quartz filter during sampling. The secondary (backup filter) collected downstream of the gravimetric $PM_{2,5}$ filter can be used to correct for the volatile carbon artefact. In lieu of a backup filter, flow through activated carbon denuders can be used to scrub VOC from the EC/OC sample line prior to the QFF holder. One filter holder with two stages in series may be used to hold the gravimetric $PM_{2,5}$ filter and backup quartz filter.

8.5.3.1.6 Carbon dioxide sensor

The carbon dioxide sensor shall be located in the sample train downstream of a particulate matter filter. The sensor shall transmit a continuous or semi-continuous reading that is logged to a data file. The sensor shall have a T90 response time of 60 s or less, a resolution of 1 ppm or less, and accuracy of 10 % or less. The sensor shall be calibrated prior to collecting a set of measurements, and the calibration shall be checked before and after a set of measurements following the procedure in 8.5.7.

8.5.3.1.7 Carbon monoxide sensor

The carbon monoxide sensor shall be located in the sample train downstream of a particulate matter filter. The sensor shall transmit a continuous or semi-continuous reading that is logged to a data file. The sensor shall have a T90 response time of 60 s or less, a resolution of 1 ppm or less, and accuracy of 10 % or less. The sensor shall be calibrated prior to collecting a set of measurements, and the calibration shall be checked before and after a set of measurements following the procedure in 8.5.7. Electrochemical type CO sensors shall be hydrogen compensated if coal or other hydrogen emitting fuel is used during a measurement.

8.5.3.1.8 Flow control

The flow rate in the sample train should remain constant for the correct particle size separation to minimize bias and uncertainty of the measured $PM_{2,5}$ concentration and to maintain a constant dilution ratio. A sample flow rate of 1 l/min to 5 l/min is common. The flow can be controlled with an adjustable metering valve, critical orifice/venturi, automated control valve (such as mass flow controllers), or pump speed controller. The flow rate shall be set and checked according to 8.5.10. If the sample train has parallel filter flows for OC/EC measurements, the flow across the primary and backup quartz filters should be set equal to each other.

NOTE A critical orifice maintains a constant flow rate as the pressure downstream fluctuates so long as the pressure drop across the orifice is sufficient to maintain sonic velocity (choked flow); however, if the pressure upstream changes (e.g. due to filter loading), the flow rate will change.

8.5.3.1.9 Vacuum pump

The vacuum pump shall be located in the sample train downstream of the particulate filter. The pump shall provide the required flow rate for the $PM_{2,5}$ cut point of the particle separator.

8.5.3.1.10 Data acquisition system

Sensor readings (CO, CO_2, temperature, RH) shall be logged at a rate of once every 10 s or faster to a data file with time stamps.

8.5.3.1.11 Dilution train

A forced dilution train is recommended, but not always required. Cookstove exhaust shall be diluted before sampling to condition the PM sample and to prevent condensation from forming inside the sample train. An emission plume will dilute naturally as it rises above the cookstove and mixes with the surrounding air. If natural dilution is adequate, forced dilution is not required. Subclause 8.5.11 provides guidance for determining adequate dilution and adjusting the amount of dilution.

The forced dilution flow train draws in ambient air, dries it, and forces the air into the sample probe to dilute the exhaust sample. The dilution flow train contains a HEPA filter, desiccator, flow control device, and pump as shown in Figure 4. The HEPA filter removes particles from the dilution air. The desiccator is a chamber of desiccant that removes moisture from gases that pass through it. Colour-changing silica gel or anhydrous calcium sulfate are recommended desiccants, because they provide a visual indication of saturation. The flow control device may be an adjustable metering valve, critical orifice/venturi, automated control valve (such as mass flow controllers), or pump speed controller. The pump shall be located in the dilution train downstream of the particulate filter. The pump and flow control device combination shall produce a constant flow rate for the duration of the sampling event. See 8.5.11 for guidelines to set the dilution flow and 8.5.10 for guidelines to check the dilution flow. The dilution train shall connect to the sample train near the sample probe, far enough upstream of the particle separator to ensure thorough mixing of emission sample and dilution air. The dilution train inlet shall be located to capture representative background air. Gas sensors can be added to the dilution train for more accurate background CO and CO_2 concentration measurement. See 8.5.12 for background air considerations.

8.5.3.1.12 Tubing

All tubing that transports the particle-laden sample shall be electrically conductive to dissipate static charge to minimize electrostatic particle accumulation on the tube walls. Particle-laden tubing can be made of stainless steel, copper, or conductive silicone (soft tubing). To minimize particle loss, the particle-laden tubing shall be as short as possible and shall not have sharp bends.

8.5.3.2 Additional equipment

8.5.3.2.1 Primary flow calibrator

A primary volumetric flow calibrator, such as a bubble meter or other thin film flow calibrator, shall be used to measure the in-line volumetric flow rate of the sample train before and after each sampling event. The primary flow calibrator shall measure the volumetric flow rate at actual conditions with an accuracy of 5 % or better.

8.5.3.2.2 Ambient pressure, temperature, and RH measurement device

Sensors to measure ambient pressure, temperature, and RH shall be used to measure ambient conditions. The sensor outputs need not be measured continuously or logged but shall be displayed to record a single point measurement. The pressure sensor shall have a resolution of 100 Pa, and accuracy of 3 % of reading or better. The temperature sensor shall have a resolution of 1 °C and an accuracy to within 3 °C or better. The RH sensor shall have a resolution of 1 % RH and an accuracy of 5 % RH or better. Many hand-held devices exist with ambient sensor assemblies that meet these requirements.

8.5.3.2.3 Vacuum gauge

A vacuum gauge shall be used to leak test the sample train before a sampling event. The gauge shall be able to measure a vacuum pressure equal to the highest vacuum pressure that occurs in the sample train. The gauge can be combined in an assembly with a hand pump in order to draw a vacuum on the sample train. If a hand pump is not included, then a vacuum can be applied to the sample train by cycling the sample pump on and off.

8.5.3.2.4 Fuel measurement equipment

Fuel measurements are required to calculate emission reporting metrics. Refer to 7.8 for the required fuel measurement equipment.

8.5.3.3 Laboratory equipment

Required equipment to perform gravimetric analysis of PM filters is described in 8.5.5. Required calibration gases and calibration equipment are described in 8.5.7. Optional laboratory equipment to measure the fuel composition and energy content may also be used to reduce uncertainty of output metrics. The optional laboratory equipment for fuel analysis is described in Annex A.

8.5.4 Sampling protocol

8.5.4.1 Onsite preparation

a) Load the filter into the filter holder at the sampling site, or in a clean location prior to arriving at the sampling site. Check the filter for damage when loading.

b) Set up the equipment. Position the probe 0,5 m to 1 m above the cookstove or in the chimney (8.5.3.1.1). If the cookstove is already burning, then set up the probe but do not place it in the plume or chimney until the start of the test period.

c) Leak test the sample train (8.5.9) and dilution train.

d) Turn on all sensors and pumps. Set sample flow rate for the particle separator to ensure the appropriate size cut point will be obtained, and then set the dilution flow rate following the guidelines in 8.5.11.

e) Measure and record the sample and dilution flows with a primary calibrator (8.5.10).

f) Measure and record ambient pressure, temperature and RH.

g) Sample background air for at least 10 min (8.5.12). Record the start time and end time of the background period.

h) Collect fuel samples for laboratory analysis if necessary, weigh the initial fuel load, and test the fuel moisture content, according to 7.4 and 7.8.

8.5.4.2 Sampling event

a) Record the start time of the cooking event (when the cookstove is lit or when the probe is moved into the plume).

b) During the cooking event, record observational notes such as observations of what is cooked, who cooks, and what fuels are used. Record observations of other emission sources that contribute to the background emissions. Record observations if wind moves the plume off the probe for an extended period of time.

c) Record the stop time of the cooking event when the cooking is finished, the time when the cookstove is extinguished (naturally or forced by the cook), and the time when the plume CO and CO_2 concentrations are near or at background air concentrations.

8.5.4.3 Onsite post-sampling

a) Sample background air for at least 10 min (8.5.12). Record the start time and end time of the background period.

b) Measure and record ambient pressure, temperature, and RH.

c) Measure and record the sample and dilution flows with a primary flow calibrator (8.5.10).

d) Turn off all sensors and pumps.

e) Weigh the remaining fuel (7.8).

f) Remove the filter from the filter holder back into its sealed petri dish at the sampling site, or in a clean location after leaving the sampling site.

8.5.5 Gravimetric analysis of $PM_{2,5}$ mass

Follow the gravimetric filter analysis procedure in ISO 19867-1:2018, 5.3.8.4 with the exception of the changes listed here:

a) Determine the limit of detection (LOD) and limit of quantification (LOQ) for the gravimetric measurement system following guidance in Annex C.

b) Filters of any size may be used.

8.5.6 Thermal optical analysis of EC/OC mass

Thermal optical analysis of quartz filter samples should be performed by either the IMPROVE method[40] or NIOSH 5040[39]. Other protocols exist but are less common and are not recommended for use. All thermal optical measurements are method defined, and results cannot be directly compared, especially for EC quantification. The user should apply the same protocol consistently during a cookstove evaluation and testing.

8.5.7 Gas sensor calibration

Gas sensors should be calibrated according to the manufacturers' specifications. The calibration shall be checked by exposing the sensor to zero gas and span gas before and after a field sampling campaign. The zero and span check shall also be performed prior to sensor recalibration. The zero gas should contain 0 ppm CO, 0 ppm CO_2, with a balance of air or nitrogen. The span gas should contain a concentration of CO and CO_2 such that the plume measurements are within 20 % to 100 % of the span concentration. The sensor readings shall be recorded during the zero and span check and the difference in the reading and the reference concentration of the calibration gas shall be used to estimate the uncertainty of the gas sensors.

If an electrochemical sensor is used for CO measurement and the presence of O_2 is required for correct measurements, then the balance gas in the zero and span gas shall contain O_2.

If the sensor reaches its maximum range during a sampling event, then the sampling event is invalid.

8.5.8 Filter blanks

At least 3 laboratory blanks, 3 field blanks, and 3 dynamic field blank filters shall be collected for every field testing campaign for both $PM_{2,5}$ and EC/OC. Laboratory blanks are those that are prepared, stored, and analysed exactly like sample filters. Field blanks are prepared, stored, transported, and analysed exactly like sample filters. Dynamic field blanks are prepared, stored, transported, installed in the filter holder, and analysed exactly like sample filters. All gravimetric filter mass results shall be adjusted by subtracting the average artefact value measured from the filter blanks.

8.5.9 Leak testing

The sample train shall be tested for leaks before each sampling event. To test for leaks, a vacuum shall be applied to the sample train and the vacuum pressure shall be monitored with a vacuum gauge. The applied vacuum pressure should be equal to the maximum vacuum that occurs at any point in the sampling train during normal sampling. The leak rate shall be less than 0,1 % of the sampling flow rate at operating pressure. The leak-check procedure used and results obtained shall be recorded for each check performed. See ISO 19867-1:2018, A.7 for the recommended leak test method.

8.5.10 Flow rate quality control and tolerances

A primary volumetric flow calibrator, such as a bubble meter, shall be used to measure the in-line volumetric flow rate of the sample train before and after each sampling event. Flow measurements should be taken upstream of the cyclone when clean background air is sampled. The primary flow calibrator shall not be used for continuous flow measurement during the sampling event. The primary flow calibrator shall have a resolution of 1 % of reading and an accuracy of 3 % of reading or better. Additional continuous flow measurement devices, such as rotameters and real-time flow sensors, may be used in addition to, but not as a replacement for the primary calibrator flow measurement.

If a forced dilution train exists, the dilution flow should also be measured before and after each sampling event with the primary flow calibrator.

If the sample train has parallel quartz filters for EC/OC measurement, the primary quartz flow should also be measured before and after each sampling event with the primary flow calibrator.

The flow rates shall not differ by more than 5 % when measured before and after the sample event. The flow rate can be controlled with an adjustable metering valve, critical orifice/venturi, automated control valve (such as mass flow controllers), or pump speed controller.

NOTE A critical orifice can maintain a constant flow rate while pressure downstream of the orifice fluctuates, so long as pressure upstream of the orifice remains constant and the pressure drop across the orifice is sufficient to maintain sonic velocity (choked flow); however, if pressure upstream of the orifice changes (e.g. due to filter loading), then the flow rate will change.

8.5.11 Dilution

Dilution air shall be used to condition (i.e. cool and dry) the emission sample for representative partitioning of semi-volatile species, and thus to obtain representative measurement of PM mass concentration. Dilution air can be necessary to bring the sample concentrations within range of the sensors. Sufficient dilution also ensures no water condensation occurs inside the sample train.

The dilution ratio (dilution air: cookstove exhaust) should be high enough so the sample relative humidity remains below 60 %. In order to achieve repeatable size segregation, RH below 40 % is recommended. The dilution ratio should be high enough that the sample temperature is within 10 °C of the average ambient temperature during the sampling event. The dilution ratio should be low enough so the measured gas species concentrations are above the LOQ of the sensors. See Annex C for guidance determining LOQ. The dilution ratio should remain constant for the duration of the sampling time.

The cookstove plume dilutes naturally in free air as it rises above the cookstove. A multi-point sample probe can be positioned in the plume approximately 0,5 m to 1 m above the cooking vessel to achieve adequate mixing of natural dilution before the sample is drawn into the probe. Forced dilution need not be used if natural plume dilution is high enough to meet the dilution criteria in the above paragraph. Natural dilution can be insufficient when sampling from chimneys, near the cookstove exhaust outlet, or if ambient dilution air has high moisture content.

8.5.12 Background concentration measurement

8.5.12.1 Measurement location

8.5.12.1.1 General

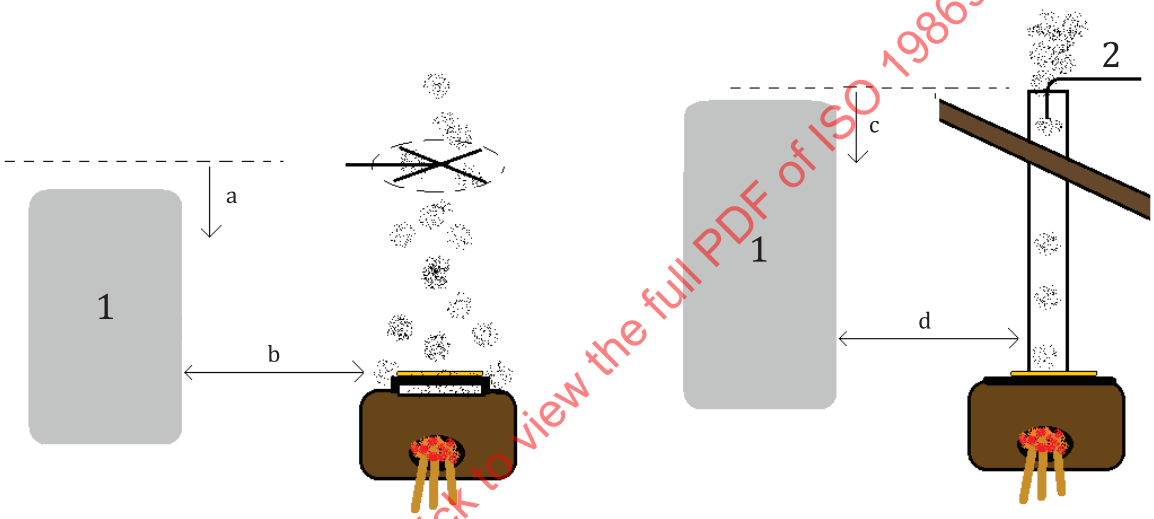
Background air concentrations shall be subtracted from measured plume concentrations. Background air concentrations can stratify and establish spatial gradients dependent on room geometry and ventilation.

8.5.12.1.2 Unvented cookstoves

For unvented cookstoves, the background air concentration should be measured at a location approximately 1 m from the plume horizontally, at a height equal to or below the probe height in order to measure the air that naturally mixes into the plume [see Figure 7, a)]. The background air measurement location should not be inside the breathing zone of a person to avoid artificially high CO_2 background concentration measurements.

8.5.12.1.3 Vented cookstoves

For vented cookstoves, the background measurement location should be at least 1 m away from the chimney horizontally. If the sample port is inside the home, then the background measurement location should also be inside the home. If the sample port is outside the home, then the background location should be outside the home, below the chimney outlet. See Figure 7, b).



a) Unvented cookstoves **b) Vented cookstoves**

Key

1 suitable background measurement zone
2 probe
a Below probe level.
b 1 m from plume.
c Below chimney outlet height.
d 1 m from chimney.

Figure 7 — Background measurement locations for unvented and vented stoves

8.5.12.2 Background gas sampling methods

8.5.12.2.1 General

Background gas concentrations (CO and CO_2) shall be measured by one or more of the following methods:

a) before and after a cooking event (pre- and post-test background periods) with the primary sample probe;

b) simultaneously during the cooking event with real-time background sensors; and/or

c) simultaneously during the cooking event with an integrated bag sample.

8.5.12.2.2 Pre/post cooking event background

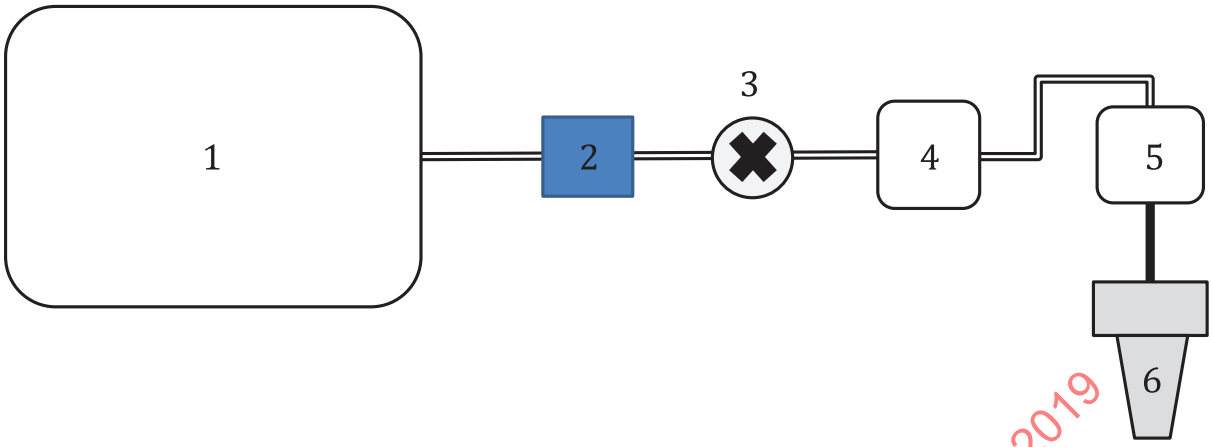
A pre-test background concentration measurement shall be performed after the sampling equipment is warmed up and before the start of the cooking event (i.e. cookstove lighting). The sample probe shall be moved to the background measurement location described in 8.5.12.1, and a background sample shall be taken for at least 10 min. After the cooking event, the same procedure shall be repeated to take a post-test background measurement.

8.5.12.2.3 Real-time background

If possible, background gas concentrations should be measured in real time with dedicated background gas sensors, because background concentrations can change throughout a sampling event. The background gas sensors shall meet the same specifications as the gas sensors in the sample train and may be located in the forced dilution sample train. If real-time background sensors are used, then the pre/post background sampling method shall also be performed (8.5.12.2.2). During the pre-test and post-test background periods, the sample probe shall be relocated so the dilution train and sample train measure the same parcel of air in order to verify agreement between the background and sample gas sensors.

8.5.12.2.4 Integrated bag sample background

An average background concentration can be measured by collecting a background sample in a bag. A dedicated sample train (as shown in Figure 8) is required, consisting of a PM filter, flow control valve, pump, and bag. The flow rate should be set so the bag does not fill completely by the end of the cooking event. The filter shall be a HEPA or gravimetric filter that removes PM from the gas stream. Alternate configurations of the pump and flow control device described in 8.5.12.3.4 may be used. The bag should be made of polyvinyl fluoride (PVF) or other appropriate material and should have a sufficiently large volume such that the bag does not fill completely over the course of the cooking event. The bag shall be completely evacuated before sampling. The start and end of the bag sample period shall coincide with the start and end of the cooking event. After a cooking event, the concentration inside the bag shall be measured by sampling the bag with the sample gas sensors (by connecting the bag to the cyclone inlet). The flow rate of the background sample train should be set to collect a volume of air large enough to completely purge the sample gas sensors at the nominal sample train flow rate. Alternatively, collected gases can be analysed using calibrated gas sensors in the laboratory.



Key

1 bag
2 pump
3 metering valve
4 HEPA filter
5 filter holder
6 cyclone

Figure 8 — Background concentration measurement train including optional polyvinyl fluoride (PVF) bag for integrated bag sample of gases and optional cyclone and filter holder for integrated PM mass concentration

8.5.12.3 Background PM sampling methods

8.5.12.3.1 General

Background PM concentration may be assumed to be negligible if supported by measurement. In all other cases, background PM concentration shall be measured by one or more of the following methods:

a) before and after a cooking event with a real-time PM sensor added to the sample train; and/or

b) continuously with an integrated pump and filter sample.

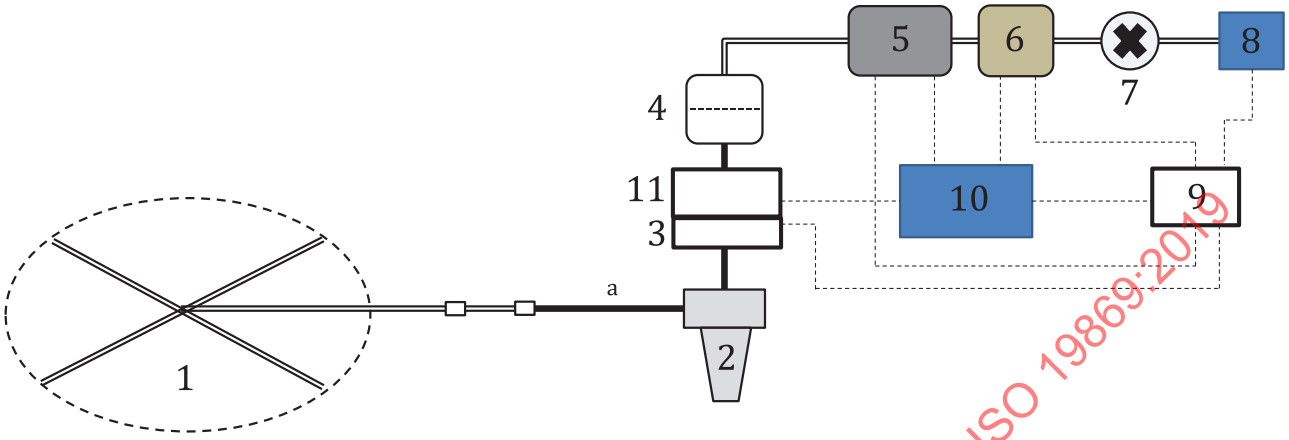
8.5.12.3.2 Assumed to be negligible background

The background PM concentration may be assumed to be negligible if the majority of dilution air is supplied by forced dilution of clean (PM removed) air, or if it is measured that there is negligible particulate matter in the background air.

8.5.12.3.3 Pre/post cooking event background with real-time sensor

A real-time PM sensor can be added to the sample train as shown in Figure 9. If the sensor is connected to the sample train in a series upstream of the filter holder (Figure 9), then particle loss in the sensor shall be less than 3 % or the sensor shall be connected in parallel with the filter holder (Figure 10). The PM sensor may be optical, tapered element oscillating microbalance, or rely on another measurement principle. The sensor output need not be calibrated to a mass concentration, but the sensor shall be zeroed, and the output signal shall be linear over the full range of PM concentrations to which it is exposed during a sampling event for a given batch of PM. The real-time PM sensor output shall be logged to a data file, as with real-time gas sensors. The background PM concentration is calculated based on the relative magnitude of the PM signal during the pre and post background periods compared to the test period.

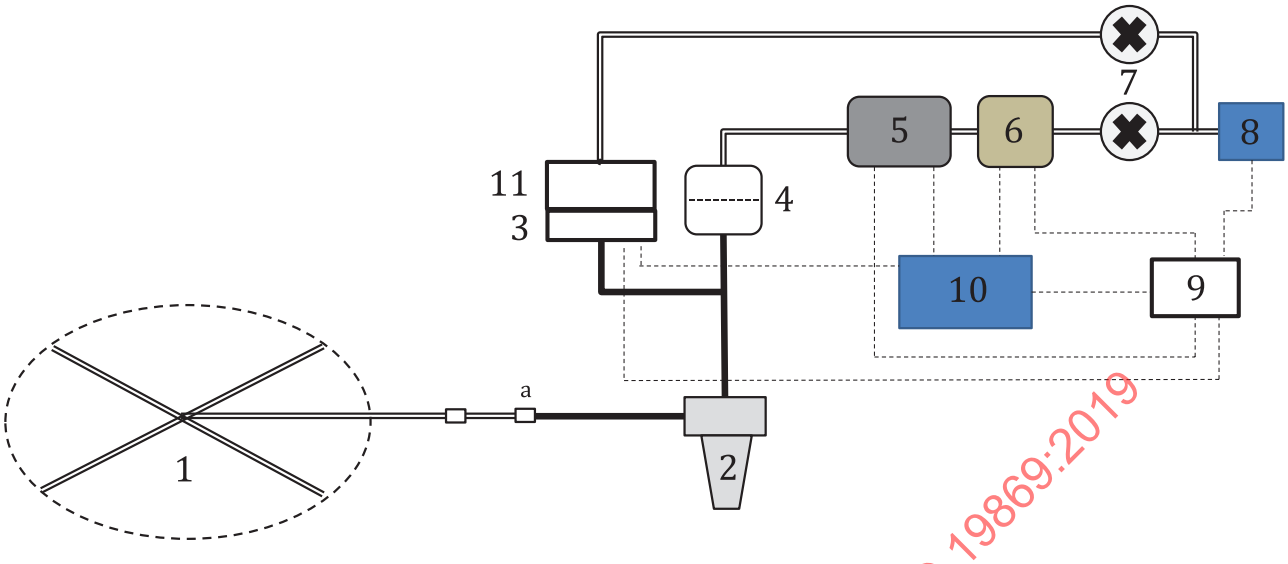
Optical (light-scattering) sensors provide a qualitative indication of PM emissions, but can provide a quantitative indication of PM mass only if calibrated with a mass-based method (e.g. gravimetric method) for each sampling period with unique combustion conditions. If a light-scattering sensor is used, then this method is based on the assumption that the light-scattering properties of the aerosol are similar during the background and test sampling periods, and this assumption is not always reliable.



Key

1	sampling probe	7	metering valve
2	cyclone	8	pump
3	temperature and relative humidity sensors	9	Power supply
4	filter holder	10	data acquisition system
5	carbon dioxide sensor	11	real-time PM
6	carbon monoxide sensor	a	Conductive tubing.

Figure 9 — Real-time PM sensor in series with gravimetric filter



Key

1	sampling probe	7	metering valves
2	cyclone	8	pump
3	temperature and relative humidity sensors	9	Power supply
4	filter holder	10	data acquisition system
5	carbon dioxide sensor	11	real-time PM sensor
6	carbon monoxide sensor	a	Conductive tubing.

Figure 10 — Real-time PM sensor in parallel with gravimetric filter

8.5.12.3.4 Pump and filter background

An average background PM concentration can be measured by collecting a pump and filter background sample for gravimetric analysis. A dedicated sample train (as shown in Figure 8) is required, consisting of a $PM_{2,5}$ particle separator, PM filter holder and filter, flow control valve, and pump. The background sample train components shall meet the same specifications of the primary sample train components. The same gravimetric procedures of collecting and weighing the PM sample shall be followed. The flow rate shall be set to produce the correct cut point of the particle separator. The start and end of the background filter sample period shall coincide with the start and end of the cooking event. This method should not be used if the majority of dilution air mixed into the sample is clean (PM removed) air.

8.5.12.4 Background EC/OC sampling methods

If EC/OC emissions are measured, background EC and OC concentrations may be assumed to be negligible, or shall be measured continuously with an integrated pump and filter sample.

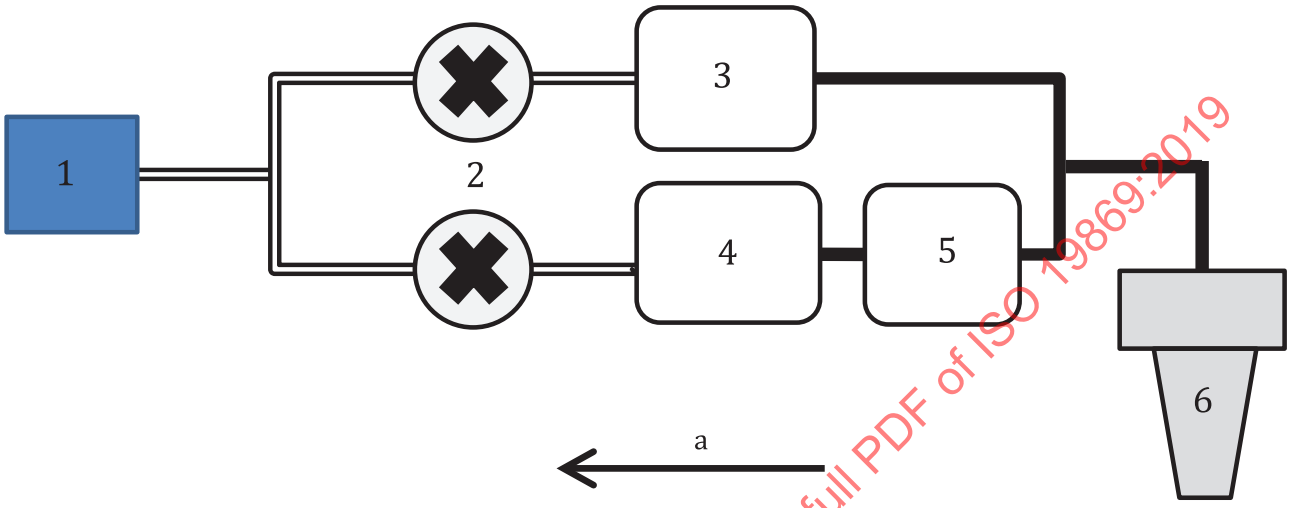
8.5.12.4.1 Assumed to be negligible background

The background EC and OC concentrations may be assumed to be negligible if the majority of dilution air is supplied by forced dilution of clean (PM removed) air, or if it is measured that there is negligible particulate matter in the background air.

8.5.12.4.2 Pump and filter background

Average background EC and OC concentrations can be measured by collecting a pump and filter background sample for thermal optical EC/OC analysis. A dedicated sample train (as shown in Figure 11) is required, which is similar to the background $PM_{2,5}$ sample train of Figure 8 with quartz filters added in parallel flow configuration. The primary quartz filter shall be added in parallel with the

gravimetric $PM_{2,5}$ filter, and the backup quartz filter shall be added in series downstream of the $PM_{2,5}$ filter. Flow control is added to the primary quartz flow train. The background sample train components should meet the same specifications of the primary sample train components. The same thermal optical procedures of collecting and analysing EC/OC samples should be followed. The flow rate should be set to produce the correct cut point of the particle separator. The flow rate across the primary and backup quartz filter should be equal. The start and end of the background filter sample period should coincide with the start and end of the cooking event. This method should not be used if the majority of dilution air mixed into the sample is clean (PM removed) air.



Key

1 pump
2 metering valves (flow control)
3 primary quartz holder
4 backup quartz holder
5 gravimetric filter holder
6 cyclone
a Flow direction.

Figure 11 — Sample train for measuring integrated pump and filter background concentrations of EC, OC, and $PM_{2,5}$

8.5.13 Fuel measurements

The types of fuel used shall be identified. For biomass fuels, each species should be identified, if possible. For wood, if specific species cannot be determined, hardwoods, softwoods, and sizes greater and smaller than 25 mm in diameter should be categorized separately. Fuel parameters that shall be determined (see 7.8) are the moisture content, total energy consumed, effective carbon fraction, and the effective heating value.

Fuels are often heterogeneous; care should be taken to select representative fuel pieces for laboratory analysis.

8.5.14 Metric calculations

8.5.14.1 General

Emission ratios shall be calculated from measured concentrations, after which emission factors and emission rates shall be calculated using the carbon mass balance method.

Carbon emission ratios shall be calculated as the ratio of pollutant concentrations to total carbon concentration. The effective fuel carbon fraction shall be used to perform a carbon mass balance to equate the carbon emitted with fuel mass consumed. Mass based emission factors shall then be calculated from carbon emission ratios as grams of pollutant per kilogram fuel. Fuel energy-based emission factors (grams pollutant per megajoule) shall be calculated from mass-based emission factors and fuel heating value. Emission rates shall be calculated from fuel energy-based emission factors, energy consumption, and measured sampling time.

8.5.14.2 CO and CO_2 concentrations

Calculation of the average CO concentration, in g/m^3, is given in Formula (20). The average CO_2 concentration follows the same calculation steps.

The real-time data of the CO sensor, including warm-up, pre-test background, test, and post-test background periods, is represented as a time series of concentration measurements logged from a real-time sensor:

$$C_{\mathrm{CO,ppm,realtime}} = C_{\mathrm{CO,ppm,realtime},1}, \ldots C_{\mathrm{CO,ppm,realtime},n}, \ldots, C_{\mathrm{CO,ppm,realtime},N} \quad (20)$$

where

$C_{\mathrm{CO,ppm,realtime}}$ is the CO concentration measured by the real-time CO sensor, in ppm;

n is the data point index with $n = 1,2,3,\ldots, N$.

The average concentration of CO during the pre-test background period is given by:

$$C_{\mathrm{CO,ppm,prebkg}} = \frac{\sum_{n(t_{\mathrm{prebkg,start}})}^{n(t_{\mathrm{prebkg,end}})} C_{\mathrm{CO,ppm,realtime}}}{n(t_{\mathrm{prebkg,end}}) - n(t_{\mathrm{prebkg,start}}) + 1} \quad (21)$$

where

$C_{\mathrm{CO,ppm,prebkg}}$ is the average CO concentration during the pre-test background period, in ppm;

$n(t_{\mathrm{prebkg,end}})$ is the pre-test background period end data point index;

$n(t_{\mathrm{prebkg,start}})$ is the pre-test background period start data point index;

$C_{\mathrm{CO,ppm,realtime}}$ is the real-time CO data series, in ppm.

The average concentration of CO during the test period is given by:

$$C_{\mathrm{CO,ppm,test}} = \frac{\sum_{n(t_{\mathrm{test,start}})}^{n(t_{\mathrm{test,end}})} C_{\mathrm{CO,ppm,realtime}}}{n(t_{\mathrm{test,end}}) - n(t_{\mathrm{test,start}}) + 1} \quad (22)$$

where

$C_{\mathrm{CO,ppm,test}}$ is the average CO concentration during the test period, in ppm;

$n(t_{\mathrm{test,end}})$ is the test period end point index;

$n(t_{\mathrm{test,start}})$ is the test period start point index;

$C_{\mathrm{CO,ppm,realtime}}$ is the real-time CO data series, in ppm.

The average concentration of CO during the post-test background period is given by:

$$C_{\mathrm{CO,ppm,postbkg}} = \frac{\sum_{n(t_{\mathrm{postbkg,start}})}^{n(t_{\mathrm{postbkg,end}})} C_{\mathrm{CO,ppm,realtime}}}{n(t_{\mathrm{postbkg,end}}) - n(t_{\mathrm{postbkg,start}}) + 1} \quad (23)$$

where

$C_{\mathrm{CO,ppm,postbkg}}$ is the average CO concentration during the post-test background period, in ppm;

$n(t_{\mathrm{postbkg,end}})$ is the post-test background period end data point index;

$n(t_{\mathrm{postbkg,start}})$ is the post-test background period start data point index;

$C_{\mathrm{CO,ppm,realtime}}$ is the real-time CO data series, in ppm.

The average CO background concentration can be calculated as the average of pre-test and post-test background concentrations:

$$C_{\mathrm{CO,ppm,bkg}} = \frac{C_{\mathrm{CO,ppm,prebkg}} + C_{\mathrm{CO,ppm,postbkg}}}{2} \quad (24)$$

where

$C_{\mathrm{CO,ppm,bkg}}$ is the average CO background concentration, in ppm;

$C_{\mathrm{CO,ppm,prebkg}}$ is the pre-test background CO concentration, in ppm;

$C_{\mathrm{CO,ppm,postbkg}}$ is the post-test background CO concentration, in ppm.

Alternatively, the real-time CO background concentration can be measured and represented as a time series of concentration measurements logged from a real-time sensor:

$$C_{\mathrm{CO,ppm,bkg,realtime}} = C_{\mathrm{CO,ppm,bkg,realtime},1}, \ldots C_{\mathrm{CO,ppm,realtime,bkg},n}, \ldots, C_{\mathrm{CO,ppm,bkg,realtime},N} \quad (25)$$

where

$C_{\mathrm{CO,ppm,bkg,realtime}}$ is the real-time background CO concentration data series, in ppm;

n is the data point index: n = 1,2,3,..., N.

In this case, the average background CO concentration is:

$$C_{\mathrm{CO,ppm,bkg}} = \frac{\sum_{n(t_{\mathrm{test,start}})}^{n(t_{\mathrm{test,end}})} C_{\mathrm{CO,ppm,bkg,realtime}}}{n(t_{\mathrm{test,end}}) - n(t_{\mathrm{test,start}}) + 1} \quad (26)$$

where

$C_{\mathrm{CO,ppm,bkg}}$ is the average background CO concentration, in ppm;

$n(t_{\mathrm{test,end}})$ is the test period end point index;

$n(t_{\mathrm{test,start}})$ is the test period start point index;

$C_{\mathrm{CO,ppm,bkg,realtime}}$ is the real-time background CO data series, in ppm.

Alternatively, the average CO background concentration $C_{CO,ppm,bkg}$ can be measured directly from an integrated bag sample without recording and averaging real-time data.

The average concentration of CO (background subtracted) is:

$$C_{CO,ppm} = C_{CO,ppm,test} - C_{CO,ppm,bkg} \quad (27)$$

where

$C_{CO,ppm,}$ is the average CO concentration, in ppm;

$C_{CO,ppm,test}$ is the average CO plume concentration during the test period, in ppm;

$C_{CO,ppm,bkg}$ is the average background CO concentration during the test period, in ppm.

The ideal gas law is used to convert CO concentration units of ppm to g/m^3 at standard conditions.

$$C_{CO} = \frac{C_{CO,ppm} \times P_{std} \times MW_{CO}}{10^6 \times R \times T_{std}} \quad (28)$$

where

C_{CO} is the average CO concentration, in g/m^3;

$C_{CO,ppm}$ is the average CO concentration, in ppm;

P_{std} is the standard pressure, 101 325 Pa;

MW_{CO} is CO molecular weight, 28,01 g/mol;

10^6 is the conversion factor, 1 000 000 ppm;

R is the ideal gas constant, 8,314 m^{3}Pa/K/mol;

T_{std} is the standard temperature, 293,15 K.

8.5.14.3 PM Concentration

The PM mass concentration is determined gravimetrically. The initial $M_{PM,filter,i}$ and final $M_{PM,filter,f}$ filter mass shall be measured following 8.5.5. The PM mass collected on the filter is:

$$M_{PM,filter} = M_{PM,filter,f} - M_{PM,filter,i} \quad (29)$$

where

$M_{PM,filter}$ is the mass of PM collected on filter, in mg;

$M_{PM,filter,f}$ is the final PM filter mass, in mg;

$M_{PM,filter,i}$ is the initial PM filter mass, in mg.

Subtract the artefact value ($M_{PM,filter,blank}$) determined from analysis of the blank filters (see 8.5.8):

$$M_{PM} = M_{PM,filter} - M_{PM,filter,blank} \quad (30)$$

where

M_{PM} is the artefact corrected PM mass, in mg;

$M_{PM,filter}$ is the mass of PM collected on filter, in mg;

$M_{PM,filter,blank}$ is the mass of PM collected on blank filter, in mg.

The volumetric flow rate through the PM filter measured before the test $Q_{filter,pre}$ and after the test $Q_{filter,post}$ are converted to standard conditions:

$$Q_{filter,pre,std} = Q_{filter,pre} \times \frac{P_{pre}}{P_{std}} \times \frac{T_{std}}{T_{pre}} \quad (31)$$

where

$Q_{filter,pre,std}$ is the pre-test standard volumetric flow rate through PM filter, in l/min;

$Q_{filter,pre}$ is the pre-test volumetric flow rate through PM filter measured at actual conditions, in l/min;

P_{pre} is the pre-test ambient pressure, in Pa;

P_{std} is the standard pressure, 101 325 Pa;

T_{std} is the standard temperature, 293,15 K;

T_{pre} is the pre-test ambient temperature, in K.

$$Q_{filter,post,std} = Q_{filter,post} \times \frac{P_{post}}{P_{std}} \times \frac{T_{std}}{T_{post}} \quad (32)$$

where

$Q_{filter,post,std}$ is the post-test standard volumetric flow rate through PM filter, in l/min;

$Q_{filter,post}$ is the post-test volumetric flow rate through PM filter measured at actual conditions, in l/min;

P_{post} is the post-test ambient pressure, in Pa;

P_{std} is the standard pressure, 101 325 Pa;

T_{std} is the standard temperature, 293,15 K;

T_{post} is the post-test ambient temperature, in K.

The average PM filter flow rate is:

$$Q_{filter} = \frac{Q_{filter,pre,std} + Q_{filter,post,std}}{2} \quad (33)$$

where

Q_{filter} is the average PM filter flow rate, in l/min;

$Q_{filter,pre,std}$ is the pre-test PM filter flow rate at standard conditions, in l/min;

$Q_{filter,post,std}$ is the post-test PM filter flow rate at standard conditions, in l/min.

Alternatively, if a real-time flow sensor is used, the average real-time flow reading may be used instead of the pre and post flow measurement.

The test time t_{test} is the length of time that emissions were sampled:

$$t_{test} = t_{test,start} - t_{test,end} \quad (34)$$

where

t_{test} is the test time, in min;

$t_{test,start}$ is the test start time, hh:mm:ss;

$t_{test,end}$ is the test end time, hh:mm:ss.

The total volume of air sampled through the filter is:

$$V_{filter} = \frac{Q_{filter} \times t_{test}}{1000} \quad (35)$$

where

V_{filter} is the volume of air sampled through PM the filter, in m^3;

Q_{filter} is the average PM filter flow rate, in l/min;

t_{test} is the test time, in min.

The PM mass concentration (uncorrected for background) is:

$$C_{PM,sample} = \frac{M_{PM}}{V_{filter}} \quad (36)$$

where

$C_{PM,sample}$ is the PM mass concentration sampled, in mg/m^3;

M_{PM} is the artefact corrected PM mass, in mg;

V_{filter} is the volume of air sampled through PM filter, in m^3.

For cases where the background PM concentration is negligible, assume:

$$C_{PM,bkg} = 0 \quad (37)$$

where $C_{PM,bkg}$ is background PM concentration, in mg/m^3.

For cases where the background PM concentration is not negligible, $C_{PM,bkg}$ can be measured gravimetrically with a background pump and filter system and calculated following Formulae (29) to (36).

Alternatively, the real-time PM concentration can be measured with a real-time PM sensor in the primary sample train. The real-time data of the PM sensor, including warm-up, pre-test background,

test, and post-test background periods, is represented as a time series of the PM signal logged from a real-time sensor:

$$PM_{realtime} = PM_{realtime,1}, \ldots PM_{realtime,n}, \ldots, PM_{realtime,N} \quad (38)$$

where

$PM_{realtime}$ is the real-time PM data series, in arbitrary units;

n is the data point index: n = 1,2,3,..., N.

The average PM signal during the pre-test background period is given by:

$$PM_{prebkg} = \frac{\sum_{n(t_{prebkg,start})}^{n(t_{prebkg,end})} PM_{realtime}}{n(t_{prebkg,end}) - n(t_{prebkg,start}) + 1} \quad (39)$$

where

PM_{prebkg} is the average pre-test background period PM signal, in arbitrary units;

$n(t_{prebkg,end})$ is the pre-test background period end data point index;

$n(t_{prebkg,start})$ is the pre-test background period end data point index;

$PM_{realtime}$ is the real-time PM data series, in arbitrary units.

The average PM signal during the test period is given by:

$$PM_{test} = \frac{\sum_{n(t_{test,start})}^{n(t_{test,end})} PM_{realtime}}{n(t_{test,end}) - n(t_{test,start}) + 1} \quad (40)$$

where

PM_{test} is the average test period PM signal, in arbitrary units;

$n(t_{test,end})$ is the test period end data point index;

$n(t_{test,start})$ is the test period end data point index;

$PM_{realtime}$ is the real-time PM data series, in arbitrary units.

The average PM signal during the post-test background period is given by:

$$PM_{postbkg} = \frac{\sum_{n(t_{postbkg,start})}^{n(t_{postbkg,end})} PM_{realtime}}{n(t_{postbkg,end}) - n(t_{postbkg,start}) + 1} \quad (41)$$

where

$PM_{postbkg}$ is the average post-test background period PM signal, in arbitrary units;

$n(t_{postbkg,end})$ is the post-test background period end data point index;

$n(t_{postbkg,start})$ is the post-test background period end data point index;

$PM_{realtime}$ is the real-time PM data series, in arbitrary units.

The average PM background signal is the average of the pre-test and post-test background signals:

$$PM_{bkg} = \frac{PM_{prebkg} + PM_{postbkg}}{2} \quad (42)$$

where

PM_{bkg} is the average background PM signal, in arbitrary units;

PM_{prebkg} is the pre-test background period PM signal, in arbitrary units;

$PM_{postbkg}$ is the post-test background period PM signal, in arbitrary units.

The average PM background concentration is calculated based on the relative magnitude of the background period PM signal compared to the test period PM signal:

$$C_{PM,bkg} = C_{PM,sample} \times \frac{PM_{bkg}}{PM_{test}} \quad (43)$$

where

$C_{PM,bkg}$ is the average PM background concentration, in mg/m^3;

$C_{PM,sample}$ is the PM mass concentration sampled, in g/m^3;

PM_{bkg} is the average background PM signal, in arbitrary units;

PM_{test} is the average test period PM signal, in arbitrary units.

Once the background PM concentration is determined, the PM mass concentration (background corrected) is:

$$C_{PM} = C_{PM,sample} - C_{PM,bkg} \quad (44)$$

where

C_{PM} is the average PM concentration (background subtracted), in mg/m^3;

$C_{PM,sample}$ is the average PM mass concentration sampled, in mg/m^3;

$C_{PM,bkg}$ is the average PM background concentration, in mg/m^3.

8.5.14.4 EC/OC concentration

The EC and OC mass concentration shall be determined by thermal optical analysis. Data quality should be reviewed to ensure objectives are met. The EC and OC mass loading on the primary and back-up quartz filters ($m_{EC,prim}$, $m_{OC,prim}$, $m_{EC,back}$, $m_{OC,back}$) should be determined by either the NIOSH 5040[39] or IMPROVE[40] methods. The mass of EC and OC on the primary and backup filters shall be calculated as follows:

$$M_{EC(or\ OC),prim} = m_{EC(or\ OC),prim} \times \frac{\pi D_{prim}{}^2}{4} \quad (45)$$

where

$M_{EC(or\ OC),prim}$ is the mass of EC or OC on primary filter, in mg;

$m_{EC(or\ OC),prim}$ is the mass density of EC or OC on primary filter, in mg/cm^2;

D_{prim} is the primary quartz filter spot diameter, in cm.

$$M_{EC(or\ OC),back} = m_{EC(or\ OC),back} \times \frac{\pi D_{back}^{\ 2}}{4} \quad (46)$$

where

$M_{EC(or\ OC),back}$ is the mass of EC or OC on backup filter, in mg;

$m_{EC(or\ OC),back}$ is the mass density of EC or OC on backup filter, in mg/cm^2;

D_{back} is the backup quartz filter spot diameter, in cm.

The volumetric flow rate through the primary quartz filter measured before the test $Q_{prim,pre}$ and after the test $Q_{prim,post}$ are converted to standard conditions:

$$Q_{prim,pre,std} = Q_{prim,pre} \times \frac{P_{pre}}{P_{std}} \times \frac{T_{std}}{T_{pre}} \quad (47)$$

where

$Q_{prim,pre,std}$ is the pre-test volumetric flow rate through primary quartz filter at standard conditions, in l/min;

$Q_{prim,pre}$ is the pre-test volumetric flow rate through primary quartz filter at actual conditions, in l/min;

P_{pre} is the pre-test actual pressure, in Pa;

P_{std} is the standard pressure, 101 325 Pa;

T_{std} is the standard temperature, 293,15 K;

T_{pre} is the pre-test actual temperature, in K.

$$Q_{prim,post,std} = Q_{prim,post} \times \frac{P_{post}}{P_{std}} \times \frac{T_{std}}{T_{post}} \quad (48)$$

where

$Q_{prim,post,std}$ is the post-test volumetric flow rate through primary quartz filter at standard conditions, in l/min;

$Q_{prim,post}$ is the post-test volumetric flow rate through primary quartz filter at actual conditions, in l/min;

P_{post} is the post-test actual pressure, in Pa;

P_{std} is the standard pressure, 101 325 Pa;

T_{std} is the standard temperature, 293,15 K;

T_{post} is the post-test actual temperature, in K.

The average primary quartz filter flow rate is:

$$Q_{\text{prim}} = \frac{Q_{\text{prim,pre,std}} + Q_{\text{prim,post,std}}}{2} \quad (49)$$

where

Q_{prim} is average primary quartz filter volumetric flow rate, in l/min;

$Q_{\text{prim,post,std}}$ is post-test volumetric flow rate through primary quartz filter at standard conditions, in l/min;

$Q_{\text{prim,pre,std}}$ is pre-test volumetric flow rate through primary quartz filter at actual conditions, in l/min.

The total volume of air sampled through the primary quartz filter is:

$$V_{\text{prim}} = \frac{Q_{\text{prim}} \times t_{\text{test}}}{1000} \quad (50)$$

where

V_{prim} is the volume of air sampled through primary quartz filter, in m^3;

Q_{prim} is the average primary quartz filter volumetric flow rate, in l/min;

t_{test} is the test time, in min.

The total volume of air sampled through the back-up quartz filter is the volume of air sampled through the gravimetric PM filter [see Formula (35)]:

$$V_{\text{back}} = V_{\text{filter}} \quad (51)$$

where

V_{back} is the volume of air sampled through backup quartz filter, in m^3;

V_{filter} is the volume of air sampled through PM filter, in m^3.

The EC and OC mass concentrations measured by the primary quartz filter are:

$$C_{\text{EC,prim}} = \frac{M_{\text{EC,prim}}}{V_{\text{prim}}} \quad (52)$$

where

$C_{\text{EC,prim}}$ is the EC concentration measured by primary quartz filter, in mg/m^3;

$M_{\text{EC,prim}}$ is the EC mass on primary quartz filter, in mg;

V_{prim} is the volume of air sampled through primary quartz filter, in m^3.

$$C_{\text{OC,prim}} = \frac{M_{\text{OC,prim}}}{V_{\text{prim}}} \quad (53)$$

where

$C_{OC,prim}$ is the OC concentration measured by primary quartz filter, in mg/m^3;

$M_{OC,prim}$ is the OC mass on primary quartz filter, in mg;

V_{prim} is the volume of air sampled through primary quartz filter, in m^3.

The EC and OC mass concentrations measured by the back-up quartz filter are:

$$C_{EC,back} = \frac{M_{EC,back}}{V_{back}} \quad (54)$$

where

$C_{EC,back}$ is the EC concentration measured by backup quartz filter, in mg/m^3

$M_{EC,back}$ is the EC mass on backup quartz filter, in mg;

V_{back} is the volume of air sampled through backup quartz filter, in m^3.

$$C_{OC,back} = \frac{M_{OC,back}}{V_{back}} \quad (55)$$

where

$C_{OC,back}$ is the OC concentration measured by backup quartz filter, in mg/m^3

$M_{OC,back}$ is the OC mass on backup quartz filter, in mg;

V_{back} is the volume of air sampled through backup quartz filter, in m^3.

The EC mass concentration measured by the back-up quartz filter ($C_{EC,back}$) is not used further in the calculations. A quality control check should be made to verify that $C_{EC,back} = 0$. If $C_{EC,back} \neq 0$, then there is a problem with the sampling or filter analysis method.

The EC mass concentration (uncorrected for background) is the EC concentration measured by the primary quartz filter:

$$C_{EC,sample} = C_{EC,prim} \quad (56)$$

where

$C_{EC,sample}$ is the EC sample concentration, in mg/m^3;

$C_{EC,prim}$ is the EC concentration measured by primary quartz filter.

The OC concentration is corrected for VOC artefact by subtracting the OC concentration measured on the back-up quartz filter from the OC concentration determined for the primary quartz filter:

$$C_{OC,sample} = C_{OC,prim} - C_{OC,back} \quad (57)$$

where

$C_{OC,sample}$ is the sample OC concentration, in mg/m^3;

$C_{OC,prim}$ is the OC concentration measured on primary quartz filter, in mg/m^3;

$C_{OC,back}$ is the OC concentration measured on backup quartz filter, in mg/m^3.

For cases where the background EC and OC concentrations are negligible, assume:

$$C_{\mathrm{EC(or\,OC),bkg}} = 0 \tag{58}$$

where $C_{\mathrm{EC(or\,OC),bkg}}$ is the EC or OC background concentration, in mg/m^3.

For cases where the background EC or OC concentration are not negligible, $C_{\mathrm{EC,bkg}}$ and $C_{\mathrm{OC,bkg}}$ can be measured by thermal optical analysis with a background pump and filter system and calculated following Formulae (45) to (57).

Once the background EC and OC concentrations are determined, the EC and OC mass concentrations (background corrected) are:

$$C_{\mathrm{EC(or\,OC)}} = C_{\mathrm{EC(or\,OC),sample}} - C_{\mathrm{EC(or\,OC),bkg}} \tag{59}$$

where

$C_{\mathrm{EC(or\,OC)}}$ is the background-subtracted EC or OC concentration, in mg/m^3;

$C_{\mathrm{EC(or\,OC),sample}}$ is the sample EC or OC concentration, in mg/m^3;

$C_{\mathrm{EC(or\,OC),bkg}}$ is the background EC or OC concentration, in mg/m^3.

8.5.14.5 Total carbon concentration

The total carbon concentration in the emission sample C_{C} is the sum of the carbon concentrations from each species. The carbon concentration of each gas species is the species concentration multiplied by the mass fraction of carbon in the species. PM carbon (C_{EC} and C_{OC}) should be neglected if they are not measured.

$$C_{\mathrm{C}} = C_{\mathrm{CO_2}} \times \frac{\mathrm{MW_C}}{\mathrm{MW_{CO_2}}} + C_{\mathrm{CO}} \times \frac{\mathrm{MW_C}}{\mathrm{MW_{CO}}} + \frac{C_{\mathrm{EC}} + C_{\mathrm{OC}}}{1\,000} \tag{60}$$

where

C_{c} is the total carbon concentration, in g/m^3;

C_{CO2} is the CO_2 concentration, in g/m^3;

C_{CO} is the CO concentration, in g/m^3;

$\mathrm{MW_C}$ is carbon molecular weight, 12,01 g/mol;

$\mathrm{MW_{CO2}}$ is CO_2 molecular weight, 44,01 g/mol;

$\mathrm{MW_{CO}}$ is CO molecular weight, 28,01 g/mol;

C_{EC} is the EC concentration, in mg/m^3;

C_{OC} is the OC concentration, in mg/m^3.

8.5.14.6 Modified combustion efficiency

$$\mathrm{MCE} = \frac{C_{\mathrm{CO_2,ppm}}}{C_{\mathrm{CO_2,ppm}} + C_{\mathrm{CO,ppm}}} \tag{61}$$

where

MCE is the modified combustion efficiency, in mol/mol;

$C_{CO2,ppm}$ is the CO_2 concentration, in ppm;

$C_{CO,ppm}$ is the CO concentration, in ppm.

8.5.14.7 Carbon emission ratio

$$ERC_{CO} = \frac{C_{CO}}{C_C} \quad (62)$$

where

ERC_{CO} is the CO carbon emission ratio, in g/g;

C_{CO} is the CO concentration, in g/m^3;

C_C is the carbon concentration, in g/m^3.

$$ERC_{CO2} = \frac{C_{CO2}}{C_C} \quad (63)$$

where

ERC_{CO2} is the CO_2 carbon emission ratio, in g/g

C_{CO2} is the CO_2 concentration, in g/m^3;

C_C is the carbon concentration, in g/m^3.

$$ERC_{PM} = \frac{C_{PM}}{C_C} \quad (64)$$

where

ERC_{PM} is the PM carbon emission ratio, in mg/g

C_{PM} is the PM concentration, in mg/m^3;

C_C is the carbon concentration, in g/m^3.

$$ERC_{EC(or\ OC)} = \frac{C_{EC(or\ OC)}}{C_C} \quad (65)$$

where

$ERC_{EC(or\ OC)}$ is the EC or OC carbon emission ratio, in mg/g;

$C_{EC(or\ OC)}$ is the EC or OC concentration, in mg/m^3;

C_C is the carbon concentration, in g/m^3.

8.5.14.8 Emission factor, fuel mass based

Emission factors are calculated from carbon emission ratios using the effective fuel carbon fraction $CFrac_{eff}$ (g/g), which is determined in 7.8.

Once the effective fuel carbon fraction is determined, the fuel mass-based emission factors are calculated by:

$$EF_{\mathrm{CO,mass}} = ERC_{\mathrm{CO}} \times CFrac_{\mathrm{eff}} \times 1\,000 \quad (66)$$

where

$EF_{\mathrm{CO,mass}}$ is the fuel mass based CO emission factor, in g/kg;

ERC_{CO} is the CO carbon emission ratio, in g/g;

$CFrac_{\mathrm{eff}}$ is the effective fuel carbon fraction, in g/g.

$$\mathrm{EF_{CO2,mass}} = \mathrm{ERC_{CO2}} \times \mathrm{CFrac_{eff}} \times 1\,000 \quad (67)$$

where

$EF_{\mathrm{CO2,mass}}$ is the fuel mass based CO_2 emission factor, in g/kg;

ERC_{CO2} is the CO_2 carbon emission ratio, in g/g;

$CFrac_{\mathrm{eff}}$ is the effective fuel carbon fraction, in g/g.

$$EF_{\mathrm{PM,mass}} = ERC_{\mathrm{PM}} \times CFrac_{\mathrm{eff}} \times 1\,000 \quad (68)$$

where

$EF_{\mathrm{PM,mass}}$ is the fuel mass-based PM emission factor, in mg/kg;

ERC_{PM} is the PM carbon emission ratio, in mg/g;

$CFrac_{\mathrm{eff}}$ is the effective fuel carbon fraction, in g/g.

$$EF_{\mathrm{EC(or\ OC),mass}} = ERC_{\mathrm{EC(or\ OC)}} \times CFrac_{\mathrm{eff}} \times 1\,000 \quad (69)$$

where

$EF_{\mathrm{EC(or\ OC),mass}}$ is the fuel mass-based EC or OC emission factor, in mg/kg;

$ERC_{\mathrm{EC(or\ OC)}}$ is the EC or OC carbon emission ratio, in mg/g;

$CFrac_{\mathrm{eff}}$ is the effective fuel carbon fraction, in g/g.

8.5.14.9 Emission factor, fuel energy based

Fuel energy-based emission factors are calculated from fuel mass-based emission factors by applying a conversion factor between fuel mass consumed and fuel energy consumed. This conversion factor is the effective heating value (EHV), which is determined in 7.8.

Once the effective heating value is determined, the fuel energy-based emission factors are calculated by:

$$EF_{\mathrm{CO,energy}} = \frac{ERC_{\mathrm{CO}} \times CFrac_{\mathrm{eff}} \times 1\,000}{EHV} \quad (70)$$

where

$EF_{CO,energy}$ is the energy-based CO emission factor, in g/MJ

ERC_{CO} is the CO carbon emission ratio, in g/g;

$CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;

EHV is the effective heating value, in MJ/kg.

$$EF_{CO2,energy} = \frac{ERC_{CO2} \times CFrac_{eff} \times 1\,000}{EHV} \quad (71)$$

where

$EF_{CO2,energy}$ is the energy-based CO_2 emission factor, in g/MJ

ERC_{CO2} is the CO_2 carbon emission ratio, in g/g;

$CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;

EHV is the effective heating value, in MJ/kg.

$$EF_{PM,energy} = \frac{ERC_{PM} \times CFrac_{eff} \times 1\,000}{EHV} \quad (72)$$

where

$EF_{PM,energy}$ is the energy-based PM emission factor, in mg/MJ

ERC_{PM} is the PM carbon emission ratio, in mg/g;

$CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;

EHV is the effective heating value, in MJ/kg.

$$EF_{EC(or\ OC),energy} = \frac{ERC_{EC(or\ OC)} \times CFrac_{eff} \times 1\,000}{EHV} \quad (73)$$

where

$EF_{EC(or\ OC),energy}$ is the energy-based EC or OC emission factor, in mg/MJ

$ERC_{EC(or\ OC)}$ is the EC or OC carbon emission ratio, in mg/g;

$CFrac_{eff}$ is the effective fuel carbon fraction, in g/g;

EHV is the effective heating value, in MJ/kg.

8.5.14.10 Average emission rate

See 7.8 for determination of energy consumed E_{fuel} (MJ). This fuel consumption should be measured over the same time period as that the emissions are sampled.

$$ER_{CO} = \frac{EF_{CO,energy} \times E_{fuel}}{t_{test}} \quad (74)$$

where

ER_{CO} is the CO emission rate, in g/min;

$EF_{CO,energy}$ is the energy-based CO emission factor, in g/MJ;

E_{fuel} is the energy consumed, in MJ;

t_{test} is the test time, in min.

$$ER_{CO2} = \frac{EF_{CO2,energy} \times E_{fuel}}{t_{test}} \quad (75)$$

where

ER_{CO2} is the CO_2 emission rate, in g/min;

$EF_{CO2,energy}$ is the energy-based CO_2 emission factor, in g/MJ;

E_{fuel} is the energy consumed, in MJ;

t_{test} is the test time, in min.

$$ER_{PM} = \frac{EF_{PM,energy} \times E_{fuel}}{t_{test}} \quad (76)$$

where

ER_{PM} is the PM emission rate, in mg/min;

$EF_{PM,energy}$ is the energy-based PM emission factor, in mg/MJ;

E_{fuel} is the energy consumed, in MJ;

t_{test} is the test time, in min.

$$ER_{EC(or\ OC)} = \frac{EF_{EC(or\ OC),energy} \times E_{fuel}}{t_{test}} \quad (77)$$

where

$ER_{EC(or\ OC)}$ is the EC or OC emission rate,in mg/min;

$EF_{EC(or\ OC)}$ is the energy-based EC or OC emission factor, in mg/MJ;

E_{fuel} is the energy consumed, in MJ;

t_{test} is the test time, in min.

8.5.14.11 Relative humidity criteria

The RH sensor time series shall be inspected in the logged data file. The sample RH shall not exceed 60 %.

8.5.14.12 Uncertainty

Uncertainties in calibrations and calculations shall be propagated and reflected in the uncertainty of the resulting emissions metrics.

8.6 Reporting

A report for each cooking event shall contain the following information:

a) administrator information:
   1) organization/company;
   2) contact information; and
   3) technician names;

b) location:
   1) home (country, district, village, address, house ID, GPS coordinates); and
   2) cookstove (indoor/outdoor, location in home, ambient temp, humidity, and barometric pressure, photograph);

c) date;

d) temperature and weather conditions;

e) description of cooking system (note if any factors are controlled):
   1) cookstove (make, model, serial number, description, materials, dimensions, photograph);
   2) food cooked/cooking task (description, quantity, flavour, photograph);
   3) cooking vessels (shape, size, mass, materials, description, photograph);
   4) fuels (species, shape, dimensions, quantity, moisture content, any fuel analysis results, photograph); and
   5) cookstove operator (who);

f) description of equipment:
   1) sampling method (partial capture, total capture, other, etc.);
   2) components [schematic, component list (manufacturer and model), photograph]; and
   3) probe and/or hood (description, shape, dimensions, position within the cooking system, photograph);

g) cooking test data sheet:
   1) ambient conditions;
   2) start and stop times of pre-background period, cooking period, and post-background period;
   3) initial and final flow check readings;
   4) pre and post fuel measurements and fuel moisture content;
   5) pre and post dilution desiccant saturation percentage (by visual inspection); and
   6) additional notes;

h) gravimetric analysis data:
   1) filter ID, media, and size;
   2) pre mass (record individual weighings);

3) post mass (record individual weighings); and

4) filter PM mass;

i) EC/OC analysis data:

1) filter ID, media, and size;

2) filter deposition area;

3) primary quartz filter EC and OC loading per cm^2;

4) backup quartz filter EC and OC loading per cm^2;

5) analytical uncertainty; and

6) analytical method;

j) reporting metrics:

1) name of computer and directory where raw data log files and calculations are archived;

2) background air measurement and subtraction method;

3) fuel carbon released determination method for carbon balance;

4) fuel energy content determination method;

5) table of reporting metrics with uncertainty estimates expressed as 68 % confidence intervals; and

6) verification that all criteria were met for valid results (flow checks, RH check, gas calibration checks).

9 Power measurement

9.1 General

In this clause, the cooking power and average firepower are determined. Solar cookstoves shall be tested for cooking power and efficiency as described in 9.4.

The units and subclause corresponding to the different types of measurements discussed in this clause are given in Table 10. All the measurements in Table 10 are associated with performance assessment (see 5.2.3). All the measurements in Table 10 are optional.

Table 10 — Power measurements, units, and subclauses

Measurement	Units	Subclause
Cooking power	W	9.2
Average firepower	W	9.3
Cooking power for solar stoves	W	9.4.1
Cooking efficiency for solar stoves	Dimensionless ratio	9.4.2

9.2 Cooking power

Cooking power of a cookstove is the rate (per time) of useful energy delivered to the cooking vessel(s) and its contents. This measurement can be determined as a peak cooking power, average cooking power over some cooking sequence, or some other condition such as minimum cooking power.

The cooking power at any selected time can be determined by placing a cooking vessel of known mass and material containing water of a known mass onto the cookstove operating in the condition to be assessed.

For high power, the cookstove is operated during some field testing session, for example cooking a meal.

The cooking power is the change in enthalpy of the cooking vessel and its contents per unit time.

$$P_{\text{cook}} = \frac{\left[c_{\text{p,p}} \times \left(M_{\text{pot}} + M_{\text{lid}}\right) + c_{\text{p,w}} \times \left(M_{\text{w}}\right)\right] \times \left(T_2 - T_1\right)}{t} \tag{78}$$

where

P_{cook} is the cooking power;

$c_{\text{p,p}}$ is the specific heat of the cooking vessel material, in J/gK;

$c_{\text{p,w}}$ is the specific heat of water, 4,186 J/gK;

M_{pot} is the cooking vessel mass, in g;

M_{lid} is the lid mass, in g;

M_{W} is the mass of water, in g;

T_1 is the initial water temperature, in °C;

T_2 is the final water temperature, in °C;

t is the time between initial and final water temperatures, in s.

EXAMPLE An aluminium pot ($c_{\text{p,p}}$ = 0,89 J/g/K) with lid and total mass of 1 000 g, containing 4 000 g of water, is fitted with a thermocouple immersed in the water. The pot is placed on the cookstove while it is operating in the condition of high power. The water temperature is monitored. After it has risen 5 °C from its initial temperature, the time and temperature are noted to a precision of 1 s and 0,1 °C, respectively. After 120 s, these readings are recorded again, noting a change of 7,5 °C.

P_{cook} = [0,89 × (1 000) + 4,816 × 4 000] × 7,5/120 = 1 102 W

All measured and reported quantities shall include uncertainty estimates (see Annex C for uncertainty guidelines).

9.3 Average firepower

The average firepower is the average energy consumption rate of a cooking system during a burn sequence. The instantaneous cookstove power during a burn sequence depends on the fuel characteristics, cookstove design, type of meal cooked, and the cook behaviour. The average firepower (kW) is a constant power that would consume the same amount of fuel during the burn sequence. The average firepower metric characterizes the burn sequence to compare how cooking technologies are operated, to inform simulated laboratory testing of an appropriate test sequence, and to help evaluate potential applications for cooking technologies.

9.3.1 Test conditions

This measurement procedure is applicable for controlled and uncontrolled cooking tests. The type of cooking test, the test protocol, and any controlled factors shall be reported with the results.

9.3.2 Required measurements

Required measurements are as follows:

a) energy consumed (from either 7.6 or 7.8);

b) time of burn sequence.

9.3.3 Required equipment

The energy consumed shall be determined using the equipment specified in 7.6 or 7.8. In addition, a timing device is required to measure the burn sequence time.

9.3.4 Measurement protocol

Follow the procedures described in 7.6 or 7.8 to determine the fuel energy consumed. Record the start time of the burn sequence when the cookstove is first lit. Record the stop time of the burn sequence when cooking is finished and the cookstove user has either extinguished the fire or let the fire naturally burnout.

9.3.5 Data analysis and calculations

9.3.5.1 Burn sequence time

$$\Delta t_{burn} = t_{stop} - t_{start} \tag{79}$$

where

Δt_{burn} is the burn sequence time, in s;

t_{start} is the start time, hh:mm:ss;

t_{stop} is the stop time, hh:mm:ss.

9.3.5.2 Average firepower

$$P_{ave} = \frac{E_{fuel} \times 10^6}{\Delta t_{burn}} \tag{80}$$

where

P_{ave} is the average firepower, in W;

E_{fuel} is the energy consumed, in MJ;

Δt_{burn} is the burn sequence time, in s.

9.3.6 Reporting

All measured and reported quantities shall include uncertainty estimates (see Annex C for uncertainty guidelines). Results shall be reported according to the provisions of 7.6 or 7.8 with the following additions:

a) burn sequence time;

b) average firepower metric with uncertainty estimates; and

c) description of cooking task.

9.3.7 Limitations

The timing of the end of the burn sequence is potentially subjective, and this determination can have a significant effect on the average firepower metric.

Cooking power provides a much more useful description of the cooking cycle than the average firepower. The average firepower is a relatively simple measurement that can be used to make approximate comparisons between burn sequences.

9.4 Power calculations for solar thermal cookstoves

9.4.1 Cooking power

Cooking power, in W, shall be determined using appropriate methods as given in ASAE S580.1.

9.4.2 Cooking efficiency

Cooking efficiency is the ratio of cooking power (as determined by the method in 9.4.1) divided by the average solar power intercepted by the device during the test. The intercept area is the sum of the areas of the solar cookstove aperture and reflector(s) normal to the sun direction when set at the angles for maximum power (these angles shall be specified by the manufacturer).

10 Safety assessment

10.1 Context

This clause describes safety assessments that are part of the preliminary assessment (5.2.2) and performance assessment (5.2.3). These assessments result in one deliverable, a safety assessment report (10.8). The context of this safety assessment is the evaluation of (a) baseline conditions with the existing cooking system and practices or (b) one model of a manufactured cookstove that is intended for sale or distribution to households and/or small businesses in a local community. Laboratory testing can identify some safety risks that are inherent to the cookstove itself. However, even if the cookstove passes the laboratory tests, there may be other risks when it is used in a household setting. Therefore, field testing is also necessary to uncover these risks.

10.2 Purpose

The purpose of the safety assessment is to report to decision makers estimates of the likelihood of occurrence of serious hazards in a sample of one model of cookstove in a representative field setting. A setting is a particular household arrangement of a cookstove, cooking fuels, and cooking vessels in a kitchen or cooking area, and all the conditions in the cooking area that impact safety. These conditions include the number and ages of people in the household, kitchen size and presence of other items, possible presence of animals, and house architecture. For statistical purposes, the setting should be typical of those found in the region of study.

The safety assessment is not intended to be a compliance inspection.

The safety testing methods included in this document include some details of existing safety testing protocols from ISO 19867-1 and References [21], [22], and [23].

10.3 Assumptions

Cookstove safety field test assessments require some constraining assumptions about ‘typical’ usage settings and activities. These assumptions include the following.

a) If the cookstove has been recently introduced in the location, it is appropriate for the user's cooking requirements (e.g. in terms of capacity, food types, temperatures).

b) The user has received training or instruction materials on proper use of the cookstove, and, if relevant, on fuel storage and fuel preparation.

c) Assessing hazards may require multiple samples of each particular cookstove to be evaluated. In some cases there may be a need to disassemble or damage some test samples.

d) The primary exposed target of these risk assessments is people; secondary targets are property (such as buildings), animals, and the natural environment. Monetary risks, although they may be considerable, are beyond the scope of this document.

10.4 Serious hazards

Only serious acute hazards are included in the safety assessment. Chronic hazards such as those due to long exposure to combustion emissions, or disabilities due to long-term carrying of wood or water are not included. Clause 8 specifically addresses measurement of emissions, from which health outcomes due to chronic exposure may be inferred. Other serious hazards not specifically related to cookstoves (e.g. poor home construction in an earthquake zone, industrial fuel production) are beyond the scope of this document.

High likelihood of serious hazards may lead to a 'fail' decision, which indicates that there are serious safety risks with use of the stove system. This document provides methods of obtaining evidence that can be used (possibly in conjunction with other information) in making this decision. See 10.8 for further discussion.

Following is a list of the most likely serious hazards that may be relevant in the setting under study:

a) serious hazards that may be encountered while gathering fuels (e.g. wood, straw, dung) (see References [24] and [25]):

   1) land mines encountered while foraging in conflict areas;

   2) criminal attacks while in remote areas;

   3) animal attacks;

   4) injuries while carrying or chopping fuel;

b) serious hazards that may be encountered in handling of liquid-fuelled or gas-fuelled cookstoves or fuels:

   1) gas or vapor explosions;

   2) fires from ignition of spilled fuel;

   3) poisoning from ingestion of liquid fuels;

   4) skin or eye injuries due to contact with fuel;

c) serious hazards that may be encountered in cooking activities:

   1) cooking vessel spills onto a person, causing burn injury;

   2) person touches or falls onto hot cookstove or cooking vessel;

   3) cookstove tips over, causing burn injury;

   4) cookstove ignites items surrounding the cookstove;

   5) chimney fire, leading to house fire;

   6) cookstove breaks while heated, exposing fire; or

   7) acute carbon monoxide exposure.

10.5 Training of safety inspectors

The methodology of the safety assessment is based on direct inspection of a sample of representative households by safety inspectors. Safety inspectors shall receive training in skills required to observe hazards and to conduct cookstove tests as described below. At a minimum, the training should include guidance on how to conduct the physical tests in 10.6, and in how to identify the serious hazards listed in 10.4. The training may include sample photographs, videos, guidance, and advice on how inspectors can spot non-obvious hazards. Such training may also include training on identification of hazardous odours. This training may be performed using kitchen facilities at regional testing and knowledge centres, where various hazards can be simulated for training purposes. Training may also be conducted at the site of the manufacturer. Safety inspections will inevitably require personal judgements, but training can improve the reliability of these judgements.

Prior to household visits, inspectors shall become familiar with the types of cookstoves commonly used in the project location, as well as any new cookstoves introduced. Inspectors shall review the manufacturer's instructions on proper placement and operation of the cookstove model(s) installed in the community to be inspected. The document to be reviewed shall be the same guide, in the same languages, that was provided to each household when the cookstoves were distributed (if applicable).

10.6 Field safety assessment procedure

10.6.1 General

This procedure can be used for any type of cookstove within the scope of this document, whether it is in current use or a newly introduced model. If the assessment is being conducted for a new cookstove, it shall have been in frequent use in a household setting for a period exceeding 3 months. This 3-month period allows time for the cook to practice using the new cookstove. It is further assumed that the cookstove model under test has previously passed the laboratory safety testing protocol as defined in ISO 19867-1. Informed consent from each homeowner is required for the assessment to take place.

For the preliminary assessment level (see 5.2.2), a minimum of 20 households shall be inspected for serious hazards by trained inspectors. Inspectors may prefer to conduct the assessment with an assistant or co-inspector, as is common practice[22]. If resources permit, it is recommended that at least two different inspectors conduct independent inspections of some of the same households. Replication of the assessment will permit inter-subjective reporting to enhance reliability.

For the performance assessment level (see 5.2.3), the sample size for household safety inspections cannot be based on the sample sizes prescribed in the study design in 5.5, which are intended for determining means or median values. Safety assessments seek to identify relatively rare risks, i.e. the 'tails' of a distribution rather than the central values. Moreover, there are several kinds of serious hazards in cookstove use, and they each can have different likelihoods of occurrence. Therefore, rather than defining a precise number of samples, the safety assessment requires collection of background information to yield rough estimates of risks of various kinds across the entire population in the test location.

The activities described in 10.6.2, 10.6.3, and 10.6.4 shall be conducted and reported.

10.6.2 Background information gathering

Prior to conducting household visits, a literature search of reported results of hazards from cookstoves (e.g. injuries, fires) shall be conducted. In some cases, insurance data can be available for evidence on various types of risks. Emergency services and hospital emergency room statistics can be useful to identify some cookstove-related risks. The possible presence of land mines, dangerous animals, or criminal attacks in forested areas and hazardous topography in areas where fuel is collected shall also be investigated. This background information shall be compiled and documented in Part 1 of the safety assessment report (see 10.8). This documentation will be helpful to alert safety inspectors to likely hazards in this location.

10.6.3 Household setting risk factors survey

Inspectors shall survey a representative sample of at least 30 households that frequently use the cookstove. Inspectors shall observe not only the cookstove but also the setting and activities that occur around the cookstove. These inspections should be conducted when the cookstove is in use, because some aspects of the inspection will require temperature measurements of the heated cookstove. The likelihood of serious hazards is increased in settings in which certain risk factors are present. The safety assessment questionnaire (see Annex B) provides a list of questions that can be performed at each household. Any risk factors identified in the inspection survey shall be highlighted. The number of highlighted risk factors in each household shall be totalled. All raw data shall be compiled in a report, which constitutes Part 2 of the safety assessment report (see 10.8). During the inspection, the inspector shall take photographs of the cookstove in areas where cooking normally occurs, and take photographs of particular safety risks observed.

While on site, the inspector shall report immediately to the home owner or cook concerning any serious risks that can mitigated relatively easily, such as moving the cookstove to a safer location or removing nearby flammable materials.

10.6.4 Physical checks of cookstove and kitchen safety

10.6.4.1 General

Inspectors should be aware that the physical tests take more time than the household inspection (10.6.3). Inspectors shall conduct the following series of physical tests in no less than 20 representative households in the region of interest. Data from the household surveys in 10.6.3 shall be used to guide the selection of representative households.

NOTE These tests are not intended to duplicate the safety tests of the cookstove performed in a laboratory. These tests are intended to identify serious hazards that can add safety risk factors when the cookstove is placed and operated in typical settings in the household.

The physical tests shall be conducted in the sequence provided herein, beginning with the procedures of 10.6.4.3 and proceeding through 10.6.4.8.

The kitchen and cooking vessels shall be cleaned and left in a neat and safe condition after the conclusion of all physical tests.

10.6.4.2 Equipment

The following equipment is required for conducting safety checks of the cooking system:

a) camera with flash capability and date-time storage capability;

b) flashlight/torch;

c) portable carbon monoxide detector with quantitative output in ppm;

d) hand-held surface thermocouple, or field pyrometer for remote temperature readings, range 0 °C to 600 °C or thermal imaging camera, if available;

e) 50 cm long, 1 cm diameter metal bar or pipe to use for probing or moving hot objects;

f) insulated gloves compliant with ISO 15383:2001[26] Type 1;

g) ruler, tape measure, and protractor;

h) micrometer or other tool for measuring sheet metal thickness;

i) a vessel commonly used with the cookstove, with water for filling; and

j) fuel commonly used in the stove, sufficient to operate the stove for approximately 45 min.

10.6.4.3 Test 1: Cookstove and cooking vessel stability test

The cookstove and vessel should not be prone to easily tipping, which could result in burns or fires.

This test should be performed when the cookstove is cold.

a) Ask the cook to provide the largest cooking vessel that is used with the cookstove. Fill with water to within 3 cm of the rim.

b) Gently move the cookstove a few centimetres in various directions and examine the movement of water within the vessel.

c) For cookstoves with multiple component parts such as a three-stone fire, the test should be performed by gently and carefully applying pressure to the cookstove components holding the vessel (e.g. rocks or other support) and monitoring the movement of water within the vessel.

d) Score in Table 11 the likelihood that gentle movement is sufficient to cause the vessel to spill liquids or for the cookstove to tip over under normal conditions.

Table 11 — Scoring system for the stability test

Test observations	Rating	Score
Cooking vessel readily spills water when slightly moved, and/or cookstove support appears top-heavy and unstable.	Poor	1
Cooking vessel spills some water when moved 2 cm, but cookstove support appears stable.	Fair	2
Cooking vessel is well supported and cookstove is stable.	Best	4

10.6.4.4 Test 2: Containment of liquid fuels test

Liquid fuels can be a serious hazard if they can easily spill from a cooking system when it is overturned.

This test applies to cookstoves powered by liquid fuels such as kerosene or ethanol, and gelled liquid fuels. The cookstove shall not be lit for this test. Solid-fuelled, gas, and solar cookstoves may skip this test and receive no rating on this test.

a) Ask the cook to provide fuel normally used with the cookstove, and to fill the cookstove with fuel as he or she would do normally (if applicable), but not ignite.

b) Slowly tip the cookstove until it is lying on its side. Record whether any fuel spills onto the ground or floor.

WARNING — If any fuel has spilled out, it should be cleaned up immediately.

Score the result of the test as shown in Table 12.

Table 12 — Scoring system for the containment of liquid fuels test

Fuel spills out from horizontal stove	Rating	Score
Fuel spillage occurs	Poor	1
Fuel spillage does not occur	Best	4

10.6.4.5 Test 3: Flames surrounding cooking vessel test

This test begins with igniting the fire, because flames can reach their peak height early during the burning process in a cookstove. Solar cookers, having no flames, may skip this test and receive no rating for this test.

a) Ask the cook to light the fire in the normal manner. Observe and note any unsafe practices.

b) Place the cooking vessel into cooking position, with water in the vessel.

c) Observe whether there are any uncovered flames surrounding the cooking vessel that are visible from any angle. If so, measure the maximum height of the flame, and record whether it is less than 4 cm, greater than 4 cm, or if the flames reach the top of the cooking vessel and handles.

d) Continue the test until the water in the vessel boils.

e) Record maximum height reached by flames during this period.

f) Cookstoves that fully enclose all flames (such as cookstoves that use a griddle) receive a rating of 'Best' (because there is no danger from a stray flame).

The scoring system for the flames surrounding cooking vessel test is provided in Table 13.

Table 13 — Scoring for flames surrounding cooking vessel test

Amount of uncovered flames touching cooking vessel	Rating	Score
Entire cooking vessel and/or handles	Poor	1
Most of cooking vessel, not handles	Fair	2
Less than 4 cm up the sides of the cooking vessel, not handles	Good	3
None	Best	4

10.6.4.6 Test 4: Surface temperatures test

The importance of this test is apparent since children have a tendency to touch cookstoves and the cook is likely to come into contact with cookstove surfaces during normal use. People are assumed to be susceptible to accidental contact at heights below 1,5 m. Therefore, heights above this level are considered out of reach from accidental contact and are not tested. The most deficient rating based on temperature and location is used to determine the likelihood of burns when touching a cookstove.

Surface temperatures for burn thresholds follow guidance in ISO 13732-1[27], pertaining to unintentional contact of very young children, thus a contact period of 15 s is specified.

NOTE ISO 13732-1[27] does not provide guidance for the protection against discomfort or pain, only burn thresholds.

Cookstoves receive a score of 'Best' if their surface temperatures do not exceed a pain threshold of 44 °C (see Reference [28]). Cookstoves receive a score of 'Good' if their surface temperature does not exceed the burn thresholds in ISO13732-1[27], which differs by cookstove material, but does exceed the pain threshold of 44 °C. Cookstoves receive a score of 'Poor' if their surface temperature exceeds the burn threshold, which differs by cookstove material. The lowest safe surface temperature is for metal surfaces; this temperature is used for defining safe temperatures for the wall and floor.

No cooking vessels shall be placed on the cookstove for this test, unless the cookstove is designed to function only with a cooking vessel in place (e.g. certain sunken pot stoves with chimneys). Some cookstoves are designed to be operated at high power only with a cooking vessel in place; in these cases, a cooking vessel should be placed on the stove. The combustion chamber of the cookstove shall be cleared of any residual ash and char from previous use prior to this test.

a) Ask the cook to ignite the fuel and wait until cookstove has reached its maximum temperature (at least 30 min at full power) before proceeding, adding fuel when necessary.

b) Record temperature data using the thermocouple or other instrument (e.g. imaging pyranometer), and record maximum temperature found.

c) Record maximum temperature data on touchable surfaces of the cookstove including handles (if applicable) and external body of the cookstove. Do not test the cooking surface and the adjacent top surface. Note the location of the cookstove where temperature was measured.

d) If it is possible to take temperature measurements of the wall or floor near the stove while the stove is lit, these should be taken and recorded. If the cookstove is mounted to the floor or wall,

record cookstove surface temperatures near places where the cookstove attaches to the floor and/or wall. Wall temperature measurements should be taken below 1,5 m.

e) Extinguish the fire.

f) If it was not possible to take measurements of the wall or floor while stove was lit, these measurements should be recorded immediately after the fire is extinguished. If the cookstove is mounted to the floor or wall, record cookstove surface temperatures near places where the cookstove attaches to the floor and/or wall.

The scoring system for the surface temperatures test is provided in Table 14, Table 15, and Table 16.

Table 14 — Scoring system for cookstove surface temperature, metal surfaces

Temperature (T) of touchable areas on cookstove, metal surfaces, °C	Rating	Score
$T > 54$	Poor	1
$44 < T \leq 54$	Good	3
$T \leq 44$	Best	4

Table 15 — Scoring system for cookstove surface temperature, non-metal surfaces

Temperature (T) of touchable areas on cookstove – non-metal surfaces, °C	Rating	Score
$T > 65$	Poor	1
$44 < T \leq 65$	Good	3
$T \leq 44$	Best	4

Table 16 — Scoring system for wall and floor temperature

Temperature (T) of touchable areas on wall or floor, °C	Rating	Score
$T > 54$	Poor	1
$44 < T \leq 54$	Good	3
$T \leq 44$	Best	4

10.6.4.7 Test 5: Flames exiting fuel chamber test

Solar cookers, having no flames, may skip this test and receive no rating for this test.

a) Remove cooking vessel from cookstove.

b) Keep fire in cookstove fully lit, adding fuel when necessary.

c) Visually inspect the amount, if any, of flames coming out of the fuel chamber.

d) The rating is 'Poor' if flames are protruding and 'Best' if flames are contained.

e) The scoring system for the flames exiting fuel chamber text is shown in Table 17.

Table 17 — Scoring system for flames exiting fuel chamber test

Occurrence of fire	Rating	Score
Flames protrude	Poor	1
Flames are contained	Best	4

10.6.4.8 Test 6: Carbon monoxide test

Carbon monoxide (CO) exposure can result in serious adverse health impacts, through (a) long-term, chronic exposure, as well as (b) acute, short-term exposure (which can take place over minutes or hours). Additional discussion about the importance of measuring the concentration of CO in household settings is included in Clause 12. Standards for levels of CO concentration that are protective for health have been issued by the World Health Organization; the 24 h mean air quality guideline value for CO is 7 mg/m^3, which would ensure that the household area is safe for health regardless of time spent in the kitchen[37]. The 15 min guideline for exposure is 100 mg/m^3 to protect against health impacts from acute exposure episodes. Mild adverse effects of CO exposure have been seen at levels of 230 mg/m^3 of exposure for 2 h to 3 h, including headache and impaired judgement.

Solar cookers, involving no combustion, may skip this test and receive no rating for this test.

a) This test should be conducted following tests 1 to 5, thus ensuring the cookstove has been in operation for more than 30 min in the kitchen, using the same fuel normally used by the household. As with all tests in the safety assessment, the inspector should not direct the cook to make any adjustments to ventilation other than the normal conditions for cooking (e.g. windows should not be opened by the inspector).

b) Measure the level of carbon monoxide in the centre of the kitchen or cooking area using a portable instrument. In addition, record 5 or more readings in mg/mm^3 at different times and locations in the home. Record readings during an entire meal preparation event conducted under typical local conditions (e.g. typical fuel(s), cooking vessels, and cookstove operation). Report the highest reading and the median of 5 or more readings in mg/m^3.

c) At the time of measurement, the inspector should note what sources of ventilation were used in the house. Were windows open? Was there a door open from the cooking area to the rest of the house, or to the outdoors? Was a fan used? The inspector should also record wind speed and direction, as well as indoor and outdoor temperature.

10.6.4.9 Test 7: Cookstove shutdown test

Even after a stove is extinguished, surrounding surfaces can still be hazardous to touch, and there can be lingering emissions for an extended period of time. These observations shall be recorded.

a) The inspector shall ask the cook to shut down the cookstove in the normal manner.

b) Observe the cook as she/he extinguishes the fire. Are safe practices used? For example, if the cookstove has a chamber where char is collected, observe where chamber is placed and whether it presents any burn risk.

c) Note the presence of any residual emissions.

If it was not possible to take measurements of walls or floor while stove was lit, these measurements should at this time be promptly recorded with the scoring system for test 4 (see 10.6.4.6).

10.6.4.10 Overall summary of physical test scores

Table 18 indicates the relationship of the physical tests to several of the serious hazards. Table 18 shall be used, along with information from the inspection survey, to estimate the likelihood of each of the hazards for each cookstove in the sample.

Not all hazards are associated with a test protocol; those hazards that are not associated with a test protocol do not appear in Table 18 and shall be scored based on the inspection data.

When more than one test listed in Table 18 is conducted, the test with the lowest score shall be listed in the third column along with that score.

Table 18 — Summary of physical test scores for each household

Serious hazard	Physical test	Lowest score on a test
Gas or vapor explosions	2	
Fires from ignition of spilled fuel	2	
Hot cooking vessel spills onto person, causing burn injury	1	
Person touches or falls onto hot cookstove or walls	4, 7	
Cookstove tips over, causing burn injury	1, 2, 4	
Cookstove ignites items surrounding the cookstove, leading to a house fire	3, 4, 5	
Cookstove breaks while heated, exposing fire / fuels	3, 5	
Acute carbon monoxide exposure	6	

The lowest score on any of the tests is an indication of a more likely hazard. This information shall be used, along with the inspection survey for the household, to inform the inspector's decisions about the likelihood of each hazard.

The physical test results for each household shall be documented as Part 3 of the safety assessment report (see 10.8).

10.7 Hazard likelihood matrix

For assessment purposes, it is assumed that the life of a cookstove is 5 years, unless otherwise specified by the manufacturer. For each of the serious hazards listed in 10.4, the inspector shall assign a risk exposure score as presented in Table 19.

Table 19 — Risk exposure scores

Risk exposure score	Description
0	**Improbable**: So unlikely, it can be assumed occurrence will not be experienced in the life of the cookstove
1	**Remote**: Unlikely, but possible to occur in the life of the cookstove.
2	**Occasional**: Likely to occur sometime in the life of the cookstove.
3	**Probable**: Will occur several times in the life of the cookstove.
4	**Frequent**: Likely to occur often in the life of the cookstove.

A matrix of serious hazards (rows) and their estimated likelihood (columns) shall be completed for each household visited. The matrix shall be filled in for the household being inspected only. This matrix shall be filled in by the inspector within 24 h of visiting the respective household. The structure of the matrix is as shown in Table 20, which uses the serious hazards list from 10.4.

Table 20 — Hazard likelihood matrix

Serious hazard	0 Improbable	1 Remote	2 Occasional	3 Probable	4 Frequent
1 – land mines encountered while foraging for cooking fuel					
2 – criminal attacks while foraging for cooking fuel					
3 – animal attacks while foraging for cooking fuel					
4 – accidents while carrying or chopping cooking fuel					
5 – gas or vapour explosions					

Table 20 *(continued)*

Serious hazard	0 Improbable	1 Remote	2 Occasional	3 Probable	4 Frequent
6 – fires from ignitions of spilled fuel					
7 – poisoning from ingestion of liquid fuel					
8 – Skin or eye injuries due to contact with fuel					
9 – cooking vessel spills onto person, causing severe burns					
10 – person touches or falls onto hot cookstove					
11 – cookstove tips over					
12 – cookstove ignites items surrounding the cookstove, leading to a house fire					
13 – chimney fire, leading to a house fire					
14 – cookstove breaks while heated, exposing fire					
15 – acute carbon monoxide exposure					

Any risk factors identified in the household setting (based on the inspector's survey data) can increase the likelihood of one or more of the serious hazards. Of primary importance is to report on the presence of any of the serious hazards with a likelihood of 'occasional' or greater within the life of the cookstove. Such a risk is considered high and should be reported as a serious hazard risk.

If any imminent hazards are observed during the inspection, the inspector shall alert the homeowner and make an initial effort to remove the hazards. This may include something as simple as moving the cookstove to a safer location, removing flammable material next to the stove, or closing leaks in a chimney.

10.8 Safety assessment report

The safety assessment report shall include all of the data from the following three parts:

— Part 1 - Background information (10.6.2)

— Part 2 - Household risk factors surveys (10.6.3)

— Part 3 - Household physical tests (10.6.4)

Using all the data and assessments collected from all households visited, the inspector shall compile a complete report with an executive summary that includes a general discussion of the observations, along with answers to the following questions and prompts.

a) What serious hazards are most likely to be present in the test location?

b) Are any of these hazards an inherent fault of the cookstove, or are they hazards due to the settings in which they were installed?

c) Other comments may be added, such as suggestions for mitigating safety risks in cookstove placement or support structures, simple ways to reduce emissions into the kitchen, and other remedies.

d) Based on all the facts gathered, what conclusions are warranted regarding the usage of this cookstove?

The safety assessment report shall compile the background information (10.6.2), risk factors surveys (10.6.3), results of the physical checks (10.6.4), the hazard likelihood matrix (10.7), and the inspector's observations, as described above in items (a) through (d). This report constitutes the final deliverable

from the safety assessment. The report provides evidence that shall be used (in conjunction with other information beyond the scope of this document) in making the pass/fail decision on a cookstove.

11 Durability assessment

11.1 General

This clause provides a method to evaluate durability. Claims of cooking device durability associated with this document shall be based on a qualitative survey/field inspection described in 11.4.

The durability assessment applies to all types of cooking devices. The durability assessment can be performed at the preliminary and performance assessment levels. The survey is the same at each assessment level, and the sample size is what determines the assessment level.

The survey results are aggregated into quantitative output metrics in 11.5. For cookstoves of a defined age, the output metrics are:

a) fraction of stoves that are non-functional, and

b) fraction of stoves with a particular failure.

For stoves of various ages, the fraction of total stove failures or fraction of specific component failures can be plotted as a function of stove age to produce a failure curve.

Laboratory testing can evaluate aspects of cooking device designs that may affect usable life and consumers' perceptions of quality (see ISO 19867-1), but in-field durability assessments can also evaluate how the cooking device condition and functionality change over time. Levels of emissions and levels of performance in cooking systems should apply over time and are not only relevant during the first few weeks or months of use. If cooking devices deteriorate quickly, they are unlikely to be adopted and will not lead to the desired implementation goals.

When assessing durability, however, it is important to evaluate the state that the cooking device is in when it is first received by the community and after it has been used over a duration established by the user of the method (number of weeks, months, or years). It is advisable that this duration be within the time limit of the manufacturer's warranty, if applicable. The durability assessment for a cooking device can compare baseline performance (assessed at the time of installation and initial use) with the performance level after a duration within field conditions that can impact the state of the cooking device.

Durability assessments characterize the physical state of the parts of the cooking devices through the time and mode of use (e.g. combustion chamber, burners, chimney, and any other parts relevant to the operation of the type of cooking device). Durability should be tested for individual parts based on type of material. Combustion chambers of various materials will have a different durability under high temperature, depending on duration of daily use, the daily temperature range it is subjected to, and the cycle of hot and cold periods of the cooking device. Similarly, variation in materials used for the cookstove grate may impact the capacity of the grate to withstand high temperatures.

While the manufacturer's stated lifetime for a cooking device may be considered during the procurement stage, the outcomes of this testing may inform manufacturers or program implementers about the claims they make regarding the lifetime and durability of their stove.

11.2 Test schedule

Regional field conditions can impact a particular cooking device (e.g. wet or dry climate; dust). Metal components, for instance, may be vulnerable to oxidation in humid climates; likewise, motorized fans may have limited lifetime in dusty regions. Durability assessments shall include basic information obtained from the user for notation of geographic coordinate location(s) where the appliance was used, frequency of use, and local climatic conditions.