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Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols —

Part 1: Standard test sequence for emissions and performance, safety and durability

Fourneaux et foyers de cuisson propres — Protocoles d'essai en laboratoire harmonisés —

Partie 1: Séquence générale d'essais en laboratoire

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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 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 www.iso.org/patents.

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For an explanation on 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 WTO principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

A list of all the parts in the ISO 19867 series can be found on the ISO website.

Introduction

This document is intended for use as laboratory measurement procedures to determine performance for cookstoves used primarily for cooking or water heating. Its purpose is to provide metrics that can be used to indicate a cookstove's performance under controlled conditions. This document provides a standard test sequence that can be used to compare the performance of various cookstove types, cookstove fuels, and cooking practices under controlled laboratory test conditions, as specified in this document.

This document was developed to achieve two goals:

a) greater alignment in methodology and metrics around the world, and

b) adaptation of methodology and metrics to the wide variety of cookstove types, cookstove fuels, and cooking practices.

For the purpose of this document, the intended user group refers to the approximately 2,8 billion people worldwide who are currently cooking with open fires or rudimentary stoves.

For evaluation of the performance and predicted outcomes of a cooking system in the field [comprising cookstove(s), fuel(s), cooking vessel(s), kitchen, ventilation, and user(s)], ISO 19869[1)] applies.

This document was developed from best practices from existing cookstove testing protocols, the experience of cookstove testing centres in many countries, and standards and testing methodology in related sectors.

Air pollutant emissions results are expressed in units of mass of pollutant per useful energy delivered and represent the mass of emissions per unit of cooking energy delivered. Emission results are also expressed in units of mass of pollutant per time and represent the mass rate of emission per unit time. Procedures for determining emissions require a complex set of individual measurements, rather than a single measured value. Thus, the results obtained depend as much on the procedure used to perform the measurements as they depend on the cookstove and the test method. The procedure used to perform the complex set of individual measurements is critical to obtaining the results.

Energy efficiency results are expressed as thermal efficiency. Cooking power results are expressed in units of watts.

Safety and durability results are expressed as a points-based rating system to enable individual countries and organizations to select levels based on their priorities. Durability methods are intended to evaluate the aspects of cookstove designs that can affect usable life and consumers' perceptions of quality. Durability testing methods include evaluation of extended runs, quenching, external and internal impacts, coating adhesion, corrosion, and material failure temperature.

1) In preparation.

Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols —

Part 1: Standard test sequence for emissions and performance, safety and durability

1 Scope

This document is applicable to cookstoves used primarily for cooking or water heating in domestic, small-scale enterprise, and institutional applications, typically with firepower less than 20 kW and cooking vessel volume less than 150 l, excluding cookstoves used primarily for space heating. For solar cookstoves, the provisions of this document are applicable only for evaluating cooking power, safety, and durability. Solar cookstoves have zero on-site emissions, and their cooking power can be determined according to ASAE S 580.1. This document does not cover electric stoves. Safety evaluation of electric stoves can be found in IEC 60335-2-6[62].

This document specifies laboratory measurement and evaluation methods for

a) particulate and gaseous air pollutant emissions,

b) energy efficiency,

c) safety, and

d) durability of cookstoves.

This document does not include evaluation of off-gassing from manufacturing oils, coatings, adhesives, and other materials (which can be found in ISO 10377 and ISO 14159). This document does not include evaluation of safety for cookstoves designed to burn a liquid and/or gaseous fuel, such as LPG (liquefied petroleum gas), alcohol, plant oil, kerosene, etc. Safety evaluation of gas-fuelled cookstoves can be found in ISO 23550 and ISO 23551 (all parts). This document does not include durability evaluation of rechargeable batteries in fan-assisted cookstoves. This document provides a standard test sequence to establish international comparability in measurement of cookstove emissions and efficiency. Guidelines for reporting results from the laboratory measurement and evaluation methods are described. For cookstoves used in applications covered by additional requirements (e.g., local air quality and safety regulations), additional test conditions and special evaluation methods may apply.

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.

ASAE S580.1. Testing and Reporting Solar Cooker Performance, *American Society of Agricultural and Biological Engineers*. Available from https://www.asabe.org/media/200979/s580.1.pdf

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 https://www.electropedia.org/

3.1
as fired
condition of a fuel as it is about to be tested in a *cookstove* (3.19)

3.2
as received
condition of a fuel as it is received for testing in a *cookstove* (3.19)

3.3
ash
non-combustible residue remaining after combustion of a fuel under specified conditions, typically expressed as a percentage of the mass of dry matter in fuel

Note 1 to entry: Ash content can be determined using a muffle furnace under a temperature of 580 °C to 600 °C.

3.4
batch-loaded cookstove
cookstove (3.19) into which fuel is infrequently loaded during operation

EXAMPLE Batch-loaded cookstoves can include, but are not limited to, TLUD (top-lit up-draft) stoves.

3.5
biofuels
materials of biological origin used as fuel

EXAMPLE Biofuels can include but are not limited to wood, agricultural residues, dung, biogas, and processed lignocelluloses (e.g. charcoal, briquettes, and pellets).

3.6
black carbon
class of highly light-absorbing carbonaceous aerosols, typically composed largely of *elemental carbon* (3.25)

3.7
built-in-place cookstove
cookstove (3.19) in which the majority of assembly and/or construction takes place where it will be used

3.8
burning rate
rate at which test fuel is consumed in a *cookstove* (3.19), in g [*dry basis* (3.22)] per minute

3.9
burn sequence
combustion of fuel in a *cookstove* (3.19) from *ignition* (3.39) to an end point defined in a specific protocol

3.10
char
carbonaceous residue resulting from pyrolysis or incomplete combustion of solid *biofuels* (3.5)

3.11
char energy efficiency
ratio of the energy of *char* (3.10) produced to the energy of *fuel fed* (3.33), *as fired* (3.1)

3.12
char mass productivity
ratio of the mass of *char* (3.10) produced to the mass of *fuel fed* (3.33)

3.13
continuously fed cookstove
cookstove (3.19) in which fuel is constantly or frequently fed during operation

EXAMPLE Continuously fed cookstoves can include, but are not limited to, rocket stoves.

3.14
cooking efficiency
thermal efficiency (3.57) for *cookstoves* (3.19) used only for cooking

Note 1 to entry: *Thermal efficiency* (3.57) for *space heating* (3.56) can differ from cooking efficiency for *cookstoves* (3.19).

3.15
cooking power
average rate of energy delivered to the contents of a *cooking vessel* (3.18) over any chosen period during the course of a *cooking sequence* (3.16) or other task

Note 1 to entry: The cooking power is expressed in kilowatts.

3.16
cooking sequence
operation of a *cookstove* (3.19) that uses the heat energy released during a *burn sequence* (3.9) for the preparation of food or the heating of water, with a recorded or prescribed series of power level settings, durations, and *cooking vessel* (3.18) utilisations

Note 1 to entry: The *cooking sequence* (3.16) commences with the placement of the first *cooking vessel* (3.18) on the stove and ends when the last cooking vessel is removed.

Note 2 to entry: The entire *cooking sequence* (3.16) is normally embedded within a *burn sequence* (3.9), though in special cases *retained heat cookers* (3.52) might continue cooking after the fire has been extinguished or while additional cooking tasks are undertaken.

3.17
cooking time
elapsed time from the time when the food is placed on the *cookstove* (3.19) to the time that the food is removed from the *cookstove*

3.18
cooking vessel
pot or container in which food or water is heated and prepared

3.19
cookstove
appliance primarily employed for the cooking of food, but which may also be employed for space or water heating, or other purposes

3.20
dilution system
apparatus that mixes a sample stream with air, nitrogen, or other gases of known composition in a controllable ratio

3.21
dilution tunnel
device in which ambient or cleaned air is mixed with an emission stream in a controlled and measured volumetric flow rate

3.22
dry basis
basis for describing the composition of a fuel sample as the ratio of the mass of a component to the mass of a fuel in its *dry fuel* (3.23) state, expressed in percent

3.23
dry fuel
fuel from which most moisture has been removed according to a drying procedure

3.24
durability
ability of a *cookstove* (3.19) to continue to be operated for an extended period in a *safe* (3.53) manner and with minimal loss of performance

3.25
elemental carbon
particulate carbonaceous material emitted during combustion that demonstrates a refractory nature according to a defined thermal-optical protocol

3.26
emission factor
ratio of the mass of a pollutant emitted to a defined measure that quantifies the activity emitting the pollutant

EXAMPLE Potential defined measures for emission factors include the *useful energy delivered* (3.59), mass of the *fuel consumed* (3.31), the dry mass of the *fuel consumed,* or the energy of the *fuel consumed.*

3.27
emission rate
mass of an air pollutant emitted per unit time, reported in units such as mg/h or g/s.

3.28
field
locations where cooking is normally performed in real-world situations, such as homes and target communities

3.29
field testing
observation or measurement of any part or parts of a *cookstove* (3.19) system conducted under various actual use conditions, instead of under controlled conditions in a *laboratory* (3.40)

3.30
firepower
over a specified period in the *burn sequence* (3.9), rate of energy release from the combustion of the fuel assuming complete combustion

Note 1 to entry: The firepower is expressed in kilowatts.

3.31
fuel consumed
mass (kg) of unburned *fuel fed* (3.33) minus mass of *residual fuel* (3.51), if applicable, during a defined *burn sequence* (3.9)

Note 1 to entry: For applicability of *residual fuel* (3.51), see details in testing protocol.

3.32
fuel energy used
product of the *heating value* (3.37) of the *raw fuel* (3.50) and its mass as fired, less the product of the heating value of the *residual fuel* (3.51), if applicable, and its mass

Note 1 to entry: For applicability of *residual fuel* (3.51), see details in testing protocol.

3.33
fuel fed
fuel supplied to a *cookstove* (3.19) during the course of the *burn sequence* (3.9)

3.34
fugitive emissions
emissions that escape from a *cookstove* (3.19) into the surrounding space of the cooking environment, as opposed to emissions that are removed directly from the stove via a chimney

3.35
gravimetric method
quantification of a sample of *particulate matter* (3.46) through the direct measurement of mass

3.36
griddle cookstove
plancha cookstove
cookstove (3.19) with which the majority of cooking occurs by placing the food directly on a heated surface, usually a metal or ceramic plate

Note 1 to entry: Regional terms for a griddle cookstove include *plancha*, comal and mittad.

3.37
heating value
energy per unit mass released in the complete combustion of a sample of fuel, as determined by combustion in a suitable calorimeter

Note 1 to entry: The state of the fuel is specified [*as received* (3.2), *as fired* (3.1), or *dry fuel* (3.23)].

Note 2 to entry: The heating value is specified as either *higher heating value* (3.38) or *lower heating value* (see 3.42).

Note 3 to entry: The heating value is expressed in MJ/kg.

3.38
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

Note 1 to entry: See Reference [36].

Note 2 to entry: The heating value is expressed in MJ/kg.

3.39
ignition
initiation of a period of a self-sustained combustion reaction

3.40
laboratory
facility that provides controlled conditions for conducting research and evaluating performance

3.41
laboratory testing
measurement of product performance quantified under controlled and documented conditions, where performance can be replicated by duplicating those conditions

3.42
lower heating value at constant pressure
absolute value of the specific heat (enthalpy) of combustion per unit mass (MJ/kg) of the fuel burned in oxygen at constant pressure under such conditions that all the water of the reaction products remains as water vapour (at 0,1 MPa), the other products being as for the *higher heating value* (3.38), all at the reference temperature

Note 1 to entry: See Reference [43].

3.43
maximum cooking power
highest *cooking power* (3.15) for which a *cookstove* (3.19) is designed

Note 1 to entry: The maximum cooking power is expressed in kW.

3.44
minimum cooking power
lowest *cooking power* (3.15) for which a *cookstove* (3.19) is designed

Note 1 to entry: The minimum cooking power is expressed in kW.

3.45
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

3.46
particulate matter
solid and liquid matter of a sufficiently small size to be suspended in gas

3.47
pot skirt
device that encircles a *cooking vessel* (3.18) for the purpose of increasing heat transfer to the *cooking vessel*

Note 1 to entry: A pot skirt can be a design feature or addition to the *cookstove* (3.19), or an integral part of a specialized *cooking vessel* (3.18).

3.48
$PM_{2,5}$
fine *particulate matter* (3.46) such that the aerodynamic diameter of the particles is less than or equal to 2,5 µm

3.49
procedures
systematic methods specified for accomplishing certain tasks related to the testing or assessment of *cookstoves* (3.19)

3.50
raw fuel
mass of unburned fuel supplied to a *cookstove* (3.19) during the course of a *burn sequence* (3.9)

3.51
residual fuel
material [typically *char* (3.10)] that has a usable energy content that remains after a *burn sequence* (3.9) is completed

3.52
retained heat cooker
insulated container that can accommodate one or more *cooking vessels* (3.18) that have been heated on a *cookstove* (3.19)

3.53
safe
capacity to be used at an acceptable level of risk of harm

3.54
safety
ability of a *cookstove* (3.19) to be operated at an acceptable level of risk of harm

3.55
solar cookstove
device that delivers useful cooking heat from energy received from the sun

3.56
space heating
delivery of useful heat from a heat source into a household or other indoor space

3.57
thermal efficiency
ratio of *useful energy delivered* (3.59) to *fuel energy used* (3.32)

3.58
traditional cookstove
type of *cookstove* (3.19) or three-stone open fire that has been in long existence in a region and has been established from generation to generation

3.59
useful energy delivered
energy transferred to the contents of a *cooking vessel* (3.18), including sensible heat energy that raises the temperature of the contents of the *cooking vessel* and the latent heat of evaporation of water from the *cooking vessel*

Note 1 to entry: For *cookstoves* (3.19) that are used for both cooking and *space heating* (3.56), useful energy delivered may also include heat delivered to a living space.

3.60
water heater
appliance designed to transfer heat into one or more water containers

3.61
wet basis
basis for describing the composition of a fuel sample as the ratio of the mass of a component to the mass of a fuel in its *as received* (3.2) state, expressed in percent

4 Symbols and abbreviated terms

ASTM	American Society for Testing and Materials
BC	black carbon
C	carbon
CI	confidence interval
CO	carbon monoxide
CO_2	carbon dioxide
D	diameter
dscm	dry standard cubic metre
EC	elemental carbon
EF	emission factor
EPA	U.S. Environmental Protection Agency
H	hydrogen

HAP	household air pollution
IER	integrated exposure-response function
LPG	liquefied petroleum gas
LPM	litres per minute
N	nitrogen
OC	organic carbon
P	pressure
$PM_{2,5}$	particulate matter with an aerodynamic diameter ≤ 2,5µm
PTFE	polytetrafluoroethylene
Re	Reynolds number
RTD	resistance temperature detector
SF_6	sulphur hexafluoride
STP	standard temperature and pressure
WHO	World Health Organization
~	approximately
Δ	change

5 Laboratory-based measurements of emissions and performance

5.1 General

In this clause, measurements and metrics for emissions and for performance are specified. Required and optional measurements are specified for the standard test sequence (see Clause 6).

Cookstoves that do not use combustion (e.g., solar cookstoves) shall be tested for cooking power using appropriate methods, such as ASAE S580.1, and zero on-site emissions shall be reported.

For the testing of built in place (fixed type) cook stoves, tests shall be carried out on representative models built on site in the testing laboratory.

Further information on laboratory-based measurement of emissions and performance is provided in Annex A.

5.2 Testing conditions

Environmental conditions (temperature, pressure, relative humidity, air current velocity, and background pollutant concentrations) shall be noted and recorded immediately before and immediately after each test, and results shall include correction for background concentrations, as needed.

Testing conditions for cookstoves that use fuel combustion shall be as follows:

a) environmental temperature comprised between 5 °C to 40 °C;

b) air current velocity <1,0 m/s;

c) cookstove shall be placed to avoid interference or cross-contamination between the cookstove and any other source of emissions or heat production.

Testing conditions for solar cookstoves shall be as specified in ASAE S580.1, except for a deviation for average wind velocity ≤1,5 m/s.

Real-time instruments shall be stored and used in an environment as required by the instrument manufacturers.

If emissions samples are collected in an environment with the potential for liquid condensation (exhaust temperature > saturation temperature), then samples shall be dried prior to reaching any dry-based analyser.

5.3 Measurements

5.3.1 Required measurements for standard test sequence

For Clause 6, measurements shall include for each test phase:

a) mass of fuel fed;

b) mass of char remaining at the end of the test phase, if present;

c) moisture content of fuel, as fired, on a wet basis, if applicable;

d) energy content of fuel, as fired (lower heating value);

e) energy content of char remaining at the end of the test phase (lower heating value), if present;

f) mass of water in cooking vessel(s) at the beginning and end of the test phase;

g) temperature of water in cooking vessel(s); for tests of thermal efficiency only (without emissions), temperature and time shall be recorded at least every 1 min; for tests of emissions, time during the test phase, as well as all temperatures and emissions measurements, shall be recorded by a data acquisition system at least every 10 s;

h) mass of emissions of $PM_{2,5}$ by the gravimetric (filter) method;

i) mass of emissions of CO (according to performance-based specifications in 5.3.7);

j) mass of emissions of CO_2 (according to performance-based specifications in 5.3.7);

k) useful energy delivered (5.4.2).

5.3.2 Required metrics for standard test sequence

For Clause 6, metrics reported separately for each test phase shall include:

a) thermal efficiency with no energy credit for remaining char, if present;

b) thermal efficiency with energy credit for remaining char, if present;

c) char energy productivity, if char is present;

d) char mass productivity, if char is present;

e) cooking power;

f) fuel-burning rate;

g) mass of $PM_{2,5}$ per useful energy delivered;

h) mass of $PM_{2,5}$ per time;

i) mass of CO per useful energy delivered;

j) mass of CO per time;

k) mass of CO_2 per useful energy delivered;

l) mass of CO_2 per time.

For solid-fuel stoves that produce char, thermal efficiency shall be reported both without energy credit (5.4.4) and with energy credit (5.4.5) for remaining char.

5.3.3 Continuous emission data

For Clause 6, continuous emission data for CO and CO_2 shall be recorded at least every 10 s and shall be reported along with results as specified in Clause 9, Reporting test results.

5.3.4 Optional measurements

For Clause 6, optional measurements may include for each test phase:

a) mass of emissions of BC by the real-time light absorption (aethalometer) method;

b) mass of emissions of BC by the transmissometer method;

c) mass of emissions of OC and EC by the thermal optical method;

d) count of aerosol particles by the condensation particle counter method;

e) mass or count of emissions of other pollutants, as needed.

5.3.5 Optional metrics

For Clause 6, optional metrics reported separately for each test phase may include:

a) mass of BC per useful energy delivered;

b) mass of BC per time;

c) mass of OC per useful energy delivered;

d) mass of OC per time;

e) mass of EC per useful energy delivered;

f) mass of EC per time;

g) count of aerosol particles per useful energy delivered;

h) count of aerosol particles per time;

i) mass of other pollutants per useful energy delivered;

j) mass of other pollutants per time;

k) other emission factors, such as mass of pollutant per mass of dry fuel consumed.

5.3.6 Measurement quality objectives

For Clause 6, standard test sequence, data shall be rejected if they do not meet the measurement acceptance criteria specified in Table 1. For measurement of $PM_{2,5}$ mass, the analytical balance shall have a resolution of 0,01 mg or better. The mass of filter loading shall be at least 10 times greater than the accuracy and precision of the balance (see 5.3.8.4.1.5).

Table 1 — Measurement acceptance criteria for standard test sequence

Measurement	Indicators	Acceptance criteria
Water and fuel mass, electronic balance	Accuracy	±1 g
	Precision	±1 g
Water temperature, thermocouple or RTD (resistance temperature detector)	Accuracy	±0,5 °C
	Precision	±0,5 °C
Fuel heat of combustion (lower heating value)	Accuracy	±0,5 %
	Precision	±0,5 %
Fuel moisture content mass, electronic balance	Accuracy	±1 g
	Precision	±0,5 g
$PM_{2,5}$ mass, analytical balance	Accuracy	±0,05 mg
	Precision	±0,05 mg
$PM_{2,5}$ mass, sampling air flow rate	Accuracy	±3 % nominal
	Precision	±3 % nominal
Dilution tunnel gas volumetric flow rate	Accuracy	±5 % nominal
	Precision	±5 % nominal
Dilution tunnel gas temperature, thermocouple	Accuracy	±1 °C
	Precision	±1 °C

5.3.7 Measurement of carbon monoxide and carbon dioxide

Carbon monoxide (CO) and carbon dioxide (CO_2) concentrations shall be measured with a method that can be verified with calibration gases to meet the performance-based specifications given in Table 2. This verification shall be documented. Examples of reference methods are indicated in Table 2.

Table 2 — Performance-based specifications for methods of measuring CO and CO_2

Measurement	Informative reference	Indicators	Acceptance criteria
CO concentration	EPA Method 10[92]	Calibration linearity	±2 % of scale
CO_2 concentration	EPA Method 3A[86]	Zero bias	±5 % of scale
		Span bias	±5 % of scale
		Zero drift	±3 % of scale
		Span drift	±3 % of scale

5.3.7.1 System operation

All sampling systems shall be tested for leaks on each day of testing. The leak rate shall be less than 0,1 % of the sampling flow rate at operating pressure. The leak-check method used and its validation (as evidence of its effectiveness) shall be documented. The leak-check procedure used and results obtained shall be recorded for each check performed. See A.7 for recommended leak test method.

5.3.7.2 Verification

Measurements of gaseous pollutant concentrations shall be verified per Table 2 with certified calibration gases at the beginning and end of a period of cookstove testing. Verifications shall be documented. A failed final verification shall invalidate all pollutant concentration data obtained subsequent to the last passed verification.

5.3.8 Total-capture dilution-tunnel gravimetric method for measurement of $PM_{2,5}$

5.3.8.1 General

This method is applicable for the determination of $PM_{2,5}$ emissions from cookstoves, see Annex B. As shown in Figures B.1 to B.4, the exhaust from a cookstove shall be collected with a total collection hood, and shall be combined with ambient dilution air. Particulate matter shall be sampled from a single point in a dilution tunnel and collected on a filter. The particulate mass shall be determined gravimetrically after the removal of unbound water with a desiccator or after equilibration at constant temperature and humidity.

NOTE This method is similar to EPA Method 5G[89].

5.3.8.2 Equipment and supplies

5.3.8.2.1 Sampling train

The sampling train configuration is shown in Figure B.5, and shall consist of the following components:

5.3.8.2.1.1 Probe

The sampling probe shall be constructed of stainless steel (e.g. 316 or grade more corrosion resistant) seamless tubing.

Isokinetic sampling should be performed. See Annex A for more information on isokinetic sampling.

5.3.8.2.1.2 Particle size-selective sampling device

A cyclone or impactor shall be used to sample $PM_{2,5}$. The cyclone or impactor for the measurement of $PM_{2,5}$ should be designed such that the separation curve of $PM_{2,5}$ has a similar shape separation efficiency of 50 % at 2,5 µm, as specified in ISO 25597:2013, Figure B.1.

5.3.8.2.1.3 Filter holder

The holder design shall provide a positive seal against leakage from the outside or around the filters.

5.3.8.2.1.4 Metering system

The sampling air flow rate shall be controlled with a critical orifice, mass flow controller, or other control device.

— If a critical orifice is used, then gauge pressure across the critical orifice shall be monitored to ensure critical pressure drop is achieved.

— If a valve is used as a manual control device, then the sampling air flow rate shall be measured with a dry gas meter or other volumetric air flow measurement device.

— If a dry gas meter is used, then a dryer is required. The dryer shall be any system capable of removing water from the sample gas to less than 1,5 % moisture (volume percent) prior to the metering system.

— If a volumetric air flow measurement device is used, then air pressure and temperatures shall be measured and the measurements shall be used to correct for any inconsistent conditions between the dilution tunnel sampling location air flow and sampling system air flow.

5.3.8.2.2 Air flow measurement device

Dilution-tunnel air flow may be measured with a Pitot static tube, Pitot array, orifice plate, constant volume pump, or hot-wire anemometer. If a Pitot tube or other anemometric probe is used, then traverse

measurements are required (see 5.3.8.3.4 to 5.3.8.3.6). If an orifice plate or constant volume pump is used, the orifice or pump shall be located downstream of the sampling location.

5.3.8.2.3 Dilution tunnel gas temperature measurement

A temperature sensor capable of measuring temperature to within ±1 °C shall be used.

5.3.8.2.4 Hood for collecting emissions from cookstoves without tall chimneys

The hood shall be constructed of steel (which may include stainless steel), as shown in Figure B.1, and shall be enclosed on three sides with a face opening of approximately 0,6 m × 1,2 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct. The surface that the cookstove is placed on shall be made of non-combustible heat-resistant material. The hood and duct system shall be electrically grounded to prevent static charging that can cause particle loss due to deposition to the inside walls.

When testing stoves with low emissions, in order to ensure sufficient capture of emissions in the form of mass collected on filters, additional dilution as shown in Figure B.1 should not be applied. When testing stoves with high emissions, additional dilution may be used to prevent overloading filters and to prevent instrument ranges from being exceeded. If increased air flow causes an excessive increase in hood face velocity, additional dilution air should be used to reduce hood face velocity. Hood face velocity should be less than 0,25 m/s. Hood face velocity may be measured with a hot-wire anemometer. Dilution air may be filtered.

5.3.8.2.5 Hood for collecting total emissions from cookstoves with tall chimneys

The hood shall be constructed of steel, as shown in Figure B.2, and shall be enclosed except for a face opening of approximately 1,2 m × 1,8 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.6 Hood for collecting fugitive (indoor) emissions from cookstoves with tall chimneys

The hood shall be constructed of steel, as shown in Figure B.3, and shall be enclosed except for a face opening of approximately 1,2 m × 1,8 m. The hood shall have a standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.7 Hood for collecting chimney emissions from cookstoves

The hood shall be constructed of steel, as shown in Figure B.4, with a large-end minimum diameter of 4 times the duct diameter, and a small-end standard 0,1 m to 0,3 m diameter coupling capable of connecting to a standard 0,1 m to 0,3 m diameter duct.

5.3.8.2.8 90° Elbows

Steel 90° elbows, 0,1 m to 0,3 m in diameter, shall connect the hood to the dilution tunnel (straight duct) and optional damper assembly. At least one 90° elbow shall be upstream of the sampling section (see Figures B.1 to B.4).

5.3.8.2.9 Straight duct

Volumetric flow rate through the ducting should be chosen so that flow is fully turbulent at a Reynolds number of at least $Re = 10^4$. See Annex A for example calculations.

Steel duct, 0,1 m to 0,3 m diameter, shall be used for the sampling section (dilution tunnel). If an anemometry probe (e.g., Pitot tube, hot-wire anemometer probe) is used for air velocity measurement, then in the sampling section, at least 8 duct diameters downstream of the mixing baffles or elbow, there shall be two holes (velocity traverse ports) at 90° to each other of sufficient size to allow entry of the probe for traverse measurements. Alternatively, this downstream point shall be the location of a Pitot

array. At least 12 duct diameters downstream of the mixing baffles or elbow shall be one or more holes (sampling ports) of sufficient size to allow entry of the sampling probe. The length of duct from the hood outlet to the sampling ports shall not exceed 10 m.

5.3.8.2.10 Mixing baffles

Adequate mixing shall be demonstrated. Mixing baffles are optional and not required if adequate mixing is demonstrated without mixing baffles. See A.8 for a method for validating well-mixed emissions in a duct.

To achieve adequate mixing through the use of mixing baffles, two steel semicircles may be attached at 90° to the duct axis on opposite sides of the duct, upstream of the sampling section. The space between the baffles should be approximately 0,3 m.

5.3.8.2.11 Blower

A squirrel cage or other type of fan capable of extracting gas from the dilution tunnel of sufficient flow to maintain the required volumetric flow rate and exhausting the gas to the atmosphere shall be used.

5.3.8.3 System preparation

5.3.8.3.1 Dilution tunnel assembly and cleaning

Schematics of dilution tunnels are shown in Figures B.1 to B.4. The dilution tunnel dimensions and other features are described in 5.3.8.2.4 to 5.3.8.2.11. The dilution tunnel, sealing joints, and seams shall be assembled to prevent air leakage. The dilution tunnel shall be cleaned with an appropriately sized wire chimney brush as needed before each testing period.

5.3.8.3.2 Draft determination for cookstoves with chimneys

The dilution tunnel hood shall be centrally located over the cookstove chimney exhaust. The dilution tunnel blower shall be operated at the flow rate to be used during the test sequence. The draft imposed on the cookstove by the dilution tunnel (i.e., the difference in draft measured with and without the dilution tunnel operating) shall be measured. The distance between the top of the cookstove stack exhaust and the dilution tunnel hood shall be adjusted so that the dilution-tunnel induced draft is less than 1,25 Pa. During this check and adjustment, no fire shall be in the cookstove, and any air supply controls, fuelling doors, or other movable parts on the cookstove shall be in the same position(s) as during testing.

5.3.8.3.3 Smoke capture

During a trial test sequence with the cookstove, the dilution tunnel shall be operated, and the exhaust shall be visually monitored. The cookstove shall be operated, and it shall be determined whether any visible exhaust is seen to escape. If any visible exhaust is seen to escape, then adjustments shall be made as necessary to the face opening in the fume hood, the air velocity, or the distance between the chimney and the hood, until no visible exhaust is escaping. The cookstove shall be operated, and it shall be confirmed that all visible exhaust is collected by the hood. The trial test sequence shall be stopped, and the draft determination procedure described in 5.3.8.3.2 shall be repeated, if a cookstove with a chimney is tested.

5.3.8.3.4 Air velocity measurements with an anemometric probe

If an anemometric probe (e.g., Pitot static tube) is used as an air velocity measurement device, then during a trial test sequence, a velocity traverse shall be conducted, and the probe shall be located in the dilution tunnel as described in 5.3.8.3.6.

Pitot ports can clog in particle-laden streams. If a Pitot static tube is used, then it shall be demonstrated that the Pitot ports have not clogged during the measurement period. Back purging may be required to prevent the Pitot ports from clogging (see Reference [83], EPA Method 2, 6.1.2).

5.3.8.3.5 Velocity traverse with an anemometric probe

If a Pitot static tube or other anemometric probe is used as an air velocity measurement device, then the following procedure shall be performed. The diameter of the duct at the velocity traverse port location through both ports shall be measured.

NOTE 5.3.8.2.2 specifies that various devices may be used to measure air flow. This subclause (5.3.8.3.5) provides instructions for using a Pitot static tube — the most common air flow measurement device.

The duct area shall be calculated using the average of the two diameters. A pretest leak-check of Pitot lines should be conducted. The calibrated Pitot static tube shall be placed at the centroid of the dilution tunnel in either of the velocity traverse ports. The damper or similar device on the blower inlet should be adjusted until the velocity indicated by the Pitot static tube is approximately 3,67 m/s, which is the recommended velocity for the recommended dilution tunnel diameter of 0,15 m to ensure fully turbulent flow. Alternatively, dilution tunnel diameters of 0,1 m to 0,3 m may be used. Air velocity may be adjusted to obtain total capture of emissions, and the Reynolds number shall be $>10^4$ to ensure fully turbulent flow.

The Δp and temperature shall continue to be read until the velocity has remained constant (less than 5 % change) for 1 min. Once a constant velocity is obtained at the centroid of the duct, a velocity traverse shall be performed (see informative Reference [83], EPA Method 2, Section 8.3) using four points per traverse. Guidance on collecting appropriate duct traverse measurements can be found in the following references ISO 3966, EPA Method 1[82], or VDI 2640[102].

If the traverse is conducted using a Pitot static tube, then a properly scaled differential pressure measurement device shall be used. Functionality shall be verified by performing a leak test of the Pitot tube assembly immediately before and after traverse measurements. A successful leak test will demonstrate the ability to maintain a stable (±2,5 cm H_2O) pressure of 7,6 cm H_2O and 7,6 cm H_2O vacuum on the impact and static pressure ports, respectively, for at least 15 s.

The Δp and tunnel temperature shall be measured at each traverse point and the readings shall be recorded. The total gas dry volumetric flow rate corrected to standard conditions shall be calculated using Formula (1) (see informative Reference [83], EPA Method 2, Section 12). The moisture may be assumed to be 4 % (100 % relative humidity at 29,4 °C). Direct moisture measurements (e.g., those described in informative Reference [87], EPA Method 4) may also be used.

$$Q_{\mathrm{d}} = (1-H)\times v \times A \times \frac{T_{\mathrm{std}} p_{\mathrm{s}}}{T_s p_{\mathrm{std}}} \tag{1}$$

where

Q_{d} is the total gas dry volumetric flow rate corrected to standard conditions, m^3/s;

H is the water vapor in the gas stream as a proportion of volume, unitless fraction;

v is the average gas velocity in the duct, m/s;

A is the cross-sectional area of the duct, m^2;

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

T_{s} is the absolute temperature of gas in the duct at the location of velocity measurement, K;

p_{std} is the standard absolute pressure, 760 mm Hg;

p_{s} is the absolute pressure of gas in the duct at the location of velocity measurement, mm Hg.

5.3.8.3.6 Testing velocity measurements with an anemometric probe

After obtaining velocity traverse results that meet the flow rate requirements, a point of average velocity shall be chosen, and the anemometric probe (e.g, Pitot static tube) and temperature sensor shall be placed at that location in the duct. Alternatively, the anemometric probe and the temperature sensor shall be located at the duct centroid and a velocity correction factor shall be calculated for the centroidal position. The anemometric probe shall be mounted to prevent movement during the test sequence, and the port holes shall be sealed to minimize air leakage. The anemometric probe opening shall be aligned to be parallel with the duct axis at the measurement point. This condition shall be checked to ensure it is maintained during the test sequence (at ~30 min intervals). The temperature and velocity shall be monitored during pretest trial test sequences to ensure that the proper flow rate is maintained. Adjustments shall be made to the dilution tunnel flow rate as necessary.

5.3.8.4 Filter sample analysis

The total-capture dilution-tunnel method specified in 5.3.8.1 to 5.3.8.3 and the filter sample analysis method specified in this subclause shall be used for Clause 6.

5.3.8.4.1 Filter sample analysis equipment and supplies

5.3.8.4.1.1 Desiccator or equilibration chamber

Filters shall be conditioned before and after sampling in either

a) an air-tight enclosure for removing unbound water from filters through the use of a dessicant, or

b) a chamber for achieving an equilibration environment through controlling relative humidity and temperature conditions for filters.

5.3.8.4.1.2 Desiccant

Anhydrous calcium sulphate, calcium chloride, or silica gel, indicating type (changes colour with moisture) shall be used in the desiccator.

5.3.8.4.1.3 Hygrometer

A hygrometer with an accuracy of ±5 % shall be used to measure moisture in the air inside the desiccator or equilibration chamber.

5.3.8.4.1.4 Temperature sensor

A temperature sensor with an accuracy of ±2 °C shall be used to measure the temperature of the air inside the desiccator or equilibration chamber.

5.3.8.4.1.5 Analytical balance

An electronic analytical balance shall be used for gravimetric analysis of filters. The analytical balance shall have a resolution of 0,01 mg or better, an accuracy of 0,05 mg or better, and a precision of 0,05 mg or better. The accuracy and precision of the balance shall be at least 10 times better than the mass of filter loading.

5.3.8.4.1.6 Filters

Glass fibre, quartz fibre, or PTFE (Teflon) membrane filters with a diameter of 37 mm to 100 mm, without organic binder, exhibiting at least 99,95 % efficiency (<0,05 % penetration) on 0,3 µm dioctyl phthalate smoke particles shall be used.

NOTE The filter media selected can affect the accuracy of gravimetric particulate matter measurements. Factors for consideration include media type, collection efficiency, and pressure drop. Advantages and disadvantages of three common filter media are presented in Table A.1.

5.3.8.4.2 Pretest preparation

5.3.8.4.2.1 Filter check

Using tweezers and/or clean disposable surgical gloves, one labeled (identified) and weighed filter shall be placed in the filter holder. The filter shall be properly centred and the gasket (if present) shall be properly placed so as to prevent the sample gas stream from circumventing the filter. Each filter shall be checked for tears after assembly is completed. If tears are found after a test is completed, then the gravimetric result shall be rejected.

5.3.8.4.2.2 Leak-check

A leak-check of the sampling train shall be conducted on each day of testing. The leak rate shall be less than 0,1 % of the sampling flow rate at operating pressure. See A.7 for recommended leak test method.

5.3.8.4.2.3 Preliminary determinations

The pressure, temperature and the average velocity of the tunnel gases shall be determined. Moisture content of diluted tunnel gases may be assumed to be 4 % for flow rate calculations. The moisture content may be measured directly as in informative Reference [87].

5.3.8.4.2.4 Sampling train operation

The probe inlet shall be positioned at the stack centroid, and the openings around the probe and porthole shall be blocked off to prevent unrepresentative dilution of the gas stream.

5.3.8.4.3 Test

Sampling shall begin at the start of the test sequence as defined in Clause 6. During the test sequence, a constant sample flow rate and dilution tunnel flow rate shall be maintained (within 10 % of the initial proportionality ratio).

The data for sample flow rate and dilution tunnel flow rate shall be recorded at least once every 10 min during each test sequence.

For the purposes of proportional sampling rate determinations, data from calibrated flow rate devices, such as glass rotameters, may be used to determine acceptability limits.

At the end of the test sequence (see Clause 6), the sampling pump shall be turned off.

5.3.8.4.4 Filter weighing

At the beginning of the weighing session, the balance calibration shall be checked with a certified weight that is of a similar weight to the filter. This check shall be repeated no less frequently than for every tenth filter weighed. The filters shall undergo a drying period of at least 24 h in a desiccator, or an equilibration period of at least 24 h in a chamber with control of temperature and humidity, before the tare and gross weighings. The filters shall be returned to the desiccator or equilibration chamber for at least an additional 6 h before the second weighing. If the weights taken after the 24 h and 6 h equilibrations agree to within 0,05 mg (taking into account the precision of the balance), the filter

weight shall be accepted. The 6 h equilibration/weighing cycle shall be repeated until two weights agree to 0,05 mg. Temperature and relative humidity for filter conditioning shall be reported with results.

5.3.9 Measurement of biomass fuel energy content

A sufficient number of biomass fuel samples shall be tested to provide a representative sample. The number of biomass fuel samples needed shall be determined from the number necessary to reduce the standard error on the mean of all samples to less than 0,5 MJ/kg, calculated using Formula (2):

$$\sigma_{\mathrm{M}} = \frac{\sigma}{\sqrt{N}} \tag{2}$$

where

σ_{M} is the standard error of the mean;

σ is the standard deviation of the individual samples;

N is the number of samples.

5.4 Calculations

5.4.1 Calculation of mass of $PM_{2,5}$

The mass of $PM_{2,5}$ shall be calculated using Formula (3).

$$m_{\mathrm{PM}_{2,5}} = \frac{Q_{\mathrm{tunnel}}}{Q_{\mathrm{sample}}} \times m_{\mathrm{sample}} \tag{3}$$

where

$m_{\mathrm{PM2,5}}$ is the mass of fine particulate matter emitted during the sampling period, mg;

Q_{tunnel} is the volumetric flow rate of gas in the dilution tunnel, m^3/min;

Q_{sample} is the volumetric flow rate of gas in the sample stream, m^3/min;

m_{sample} mass of fine particulate matter collected on the filter, mg.

5.4.2 Useful energy delivered calculation

Useful energy delivered shall be calculated using Formula (4).

$$Q_1 = C_{\mathrm{P}} \times G_1 (T_2 - T_1) + (G_1 - G_2)\gamma \tag{4}$$

where

Q_1 is the useful energy delivered, kJ;

C_p is the isobaric mass-specific approximate heat capacity of water between 20 °C and 100 °C: 4,18 $kJ \cdot kg^{-1} \cdot K^{-1}$;

G_1 is the initial mass of water in the cooking vessel, kg;

G_2 is the final mass of water in the cooking vessel, kg;

T_1 is the initial temperature of water in the cooking vessel, °C;

T_2 is the temperature of the local boiling point or the highest temperature attained of the water in the cooking vessel, °C;

γ is the latent heat of water vaporization at the local boiling point, kJ/kg.

For cookstoves with multiple cooking vessels, Formula (4) shall be used to calculate useful energy delivered for each cooking vessel, and the total useful energy delivered shall be the sum of useful energies calculated for all cooking vessels.

5.4.3 Cooking power calculation

Cooking power shall be calculated using Formula (5):

$$P_c = \frac{Q_1}{(t_3 - t_1)} \tag{5}$$

where

P_c is the cooking power, kW;

Q_1 is the useful energy delivered, kJ;

t_3 is the final time at end of a test phase, s;

t_1 is the initial time at beginning of a test phase, s.

5.4.4 Cooking thermal efficiency calculation with no energy credit for remaining char

Cooking thermal efficiency with no energy credit for any remaining char shall be calculated using Formula (6):

$$\eta_c = \frac{Q_1}{BQ_{net.af}} \times 100\ \% \tag{6}$$

where

η_c is the cooking thermal efficiency with no energy credit for remaining char, %;

Q_1 is the useful energy delivered, kJ;

B is the mass of the fuel fed, kg;

$Q_{net.af}$ is the lower heating value of fuel, as fired, kJ/kg.

5.4.5 Cooking thermal efficiency calculation with energy credit for remaining char

Cooking thermal efficiency with energy credit for remaining char shall be calculated using Formula (7):

$$\psi_c = \frac{Q_1}{BQ_{net.af} - CQ_{net.char}} \times 100\ \% \tag{7}$$

where

Ψ_c is the cooking thermal efficiency with energy credit for remaining char, %;

Q_1 is the useful energy delivered, kJ;

B is the mass of the fuel fed, kg;

$Q_{net.af}$ is the lower heating value of fuel, as fired, kJ/kg;

C is the mass of the remaining char, kg;

$Q_{net.char}$ is the lower heating value of remaining char, kJ/kg.

NOTE The metric defined by Formula (7) is equivalent to the term 'exergy efficiency', as used in the biomass energy field and described in ISO/TR 21276.

5.4.6 Char energy productivity

For cookstoves with remaining char, char energy productivity shall be calculated using Formula (8):

$$E_{char} = \frac{CQ_{net.char}}{BQ_{net.af}} \times 100\% \quad (8)$$

where

E_{char} is the char energy productivity, %;

C is the mass of the remaining char, kg;

$Q_{net.af}$ is the lower heating value of fuel, as fired, kJ/kg;

B is the mass of the fuel fed, kg;

$Q_{net.char}$ is the lower heating value of remaining char, kJ/kg.

5.4.7 Char mass productivity

For cookstoves with remaining char, char mass productivity shall be calculated using Formula (9):

$$m_{char} = \frac{C}{B} \times 100\ \% \quad (9)$$

where

m_{char} is the char mass productivity, %;

C is the mass of the remaining char, kg;

B is the mass of the fuel fed, kg.

5.4.8 Emission factor calculation

The emission factor shall be calculated using Formula (10).

$$EF = \frac{M_i}{Q_1} \quad (10)$$

where

EF is the pollutant emission factor, mg/kJ;

M_i is the total mass of pollutant emissions during the test, mg;

Q_1 is the useful energy delivered, kJ.

5.4.9 Emission rate calculation

The emission rate shall be calculated using Formula (11).

$$ER = \frac{M_i}{(t_3 - t_1)} \tag{11}$$

where

ER is the pollutant emission rate, mg/s;

M_i is the total mass of pollutant emissions during the test, mg;

t_3 is the final time at end of test, s;

t_1 is the initial time at beginning of test, s.

5.5 Determination of heating value

The heating value shall be determined using a representative sample of the fuel in a bomb calorimeter (see ISO 18125). Representative samples should first be weighed, then the free water content of the samples should be determined by drying at 3 °C above the local boiling point of water. The dry samples shall then be tested in a bomb calorimeter (see ISO 18125) to determine the higher heating value (HHV). Representative samples may also be analysed for C, H, and N (see ISO 16948).

The lower heating value at constant pressure at the as-fired moisture level shall be calculated by the following formulae per ISO 18125 as follows.

Lower heating value at constant pressure for a dry sample (dry basis, in dry matter):

$$\begin{aligned} q_{p,\mathrm{net,d}} &= q_{V,\mathrm{gr,d}} + 6{,}15 \times w(\mathrm{H})_\mathrm{d} - 0{,}8 \times \left[w(\mathrm{O})_\mathrm{d} + w(\mathrm{N})_\mathrm{d} \right] - 218{,}3 \times w(\mathrm{H})_\mathrm{d} \\ &= q_{V,\mathrm{gr,d}} - 212{,}2 \times w(\mathrm{H})_\mathrm{d} - 0{,}8 \times \left[w(\mathrm{O})_\mathrm{d} + w(\mathrm{N})_\mathrm{d} \right] \end{aligned} \tag{12}$$

Lower heating value at constant pressure at a required moisture content M (e.g., as received, M_{ar}, whereupon the symbol of heating value is $q_{p,\mathrm{net,ar}}$) is calculated:

$$\begin{aligned} q_{p,\mathrm{net,m}} &= \left\{ q_{V,\mathrm{gr,d}} - 212{,}2 \times w(\mathrm{H})_\mathrm{d} - 0{,}8 \times \left[w(\mathrm{O})_\mathrm{d} + w(\mathrm{N})_\mathrm{d} \right] \right\} \times (1 - 0{,}01M) - 24{,}43 \times M \\ &= q_{p,\mathrm{net,d}} \times (1 - 0{,}01M) - 24{,}43 \times M \end{aligned} \tag{13}$$

where

$q_{p,\mathrm{net,m}}$ is the lower heating value at constant pressure, in J/g, of the biofuel with moisture content; M (usually as received M_{ar});

$q_{V,\mathrm{gr,d}}$ is the higher heating value at constant volume, in J/g, of the moisture-free fuel;

$w(\mathrm{H})_\mathrm{d}$ is the hydrogen content, in percentage by mass, of the moisture-free (dry) biofuel (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance);

$w(O)_d$ is the oxygen content, in percentage by mass, of the moisture-free biofuel;

$w(N)_d$ is the nitrogen content, in percentage by mass, of the moisture-free biofuel;

M is the moisture content, in percentage by mass, for which the calculation is required. On the dry basis, $M = 0$; on the air-dried basis, $M = M_{ad}$; on the as-sampled or as-fired (as received, ar) basis, $M = M_{ar}$ (total moisture content as received).

The enthalpy of vaporization (constant pressure) for water at 25 °C is 44,01 kJ/mol. This value corresponds to 218,3 J/g for 1 % (mass/mass) of hydrogen in the biofuel sample or 24,43 J/g for 1 % (mass/mass) of moisture, respectively.

NOTE $w(O)_d + w(N)_d$ may be derived by subtracting from 100 the percentages of ash, carbon, hydrogen and sulphur.

5.6 Secondary dilution system methods

An air pollutant sample stream may be diluted with air, nitrogen, or other gases for purposes including

a) drying the sample,

b) cooling the sample, and

c) decreasing the sample concentration to the range of the measurement instruments used.

5.6.1 Secondary dilution systems used in the standard test sequence

In Clause 6, direct sampling from the dilution tunnel, without the use of an additional dilution system, shall be used for determining emissions of $PM_{2,5}$, CO, and CO_2. For determination of emissions of other pollutants, the measurement of which is optional, secondary dilution system methods may be used.

5.6.2 Secondary dilution system calibration

The secondary dilution system shall be calibrated by the direct measurement of the volumetric flow rate through the system using a primary flow instrument, such as a bubble flow meter or equivalent, with an accuracy and precision of ±3 % (or better) of the nominal flow rate, or by using a tracer gas with a corresponding gas analyser.

5.7 Carbon mass balance method

The carbon mass balance method may be used as an optional quality assurance check with the total-capture method specified in Clause 6. See Annex A for more information.

6 Standard test sequence for emissions and performance

6.1 General

This clause is applicable only to fuel-burning cookstoves (e.g. not applicable to solar cookstoves).

The standard test sequence characterizes performance of cookstove systems (including appropriate fuel, cooking vessel, and operating procedure) with international comparability for cookstoves tested at three power levels — low, medium, and high — and results at each power level shall be reported separately. The standard test sequence allows for both

a) comparing cookstove systems of different types, and

b) comparing the same cookstove system at different facilities.

Cookstoves that are designed for operation at only one power level shall be tested at only that power level. Cookstoves that are designed for operation at only two power levels shall be tested at only those power levels. Separate results for the two or three power levels may be weighted based on the percentage of time that typical users operate cookstoves at each power level, if such field data are available. If field data are used to support weighted results, then a detailed description of the methodology and statistical indicators of the representativeness of the field data shall be provided along with the laboratory test results. Weighted results may be reported, but results shall also be reported separately for low, medium, and high power.

EXAMPLE 1 Fieldwork in a certain region could estimate that typical combined cooking sequences are 50 % low-power, 10 % medium-power, and 40 % high-power. If $PM_{2,5}$ emissions are 38 mg/MJ_d at low-power, 24 mg/MJ_d at medium-power, and 46 mg/MJ_d at high-power, then the weighted average would be: (0,50 × 38) + (0,10 × 24) + (0,40 × 46) = 39,8 mg/MJ_d.

If field data are not available, then results cannot be weighted, but averaged results may be used for voluntary performance targets (ISO/TR 19867-3).

If the manufacturer's instructions and field information are in conflict, then the conflict shall be reported along with the information used to test the cookstove. The test report shall include a statement indicating whether the tests were performed according to manufacturer's instructions or based on field information. Supplementary information on the standard test sequence is provided in Annex C.

6.2 Phases of the standard test sequence

As depicted in Figures 1 and 2, the duration of each phase shall include a fuel burning period plus the variable time needed for shut-down. Cookstoves designed for variable power should be tested with fuel burning periods of approximately 30 min for each test phase. Cookstoves designed for only one power level should be tested with fuel-burning periods of either approximately 30 min or approximately 60 min. The optional 30 min or 60 min period shall be determined by the manufacturer's specifications for the cookstove.

Phase 1. At the beginning of the phase, the cookstove and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at high power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed before commencing Phase 2. For cookstoves designed for one power only, Phase 1 shall be the only test phase, as shown in Figure 1.

Phase 2. At the beginning of the phase, the cookstove shall be at operating temperature after completion of Phase 1 (see illustration of phases in Figure 2), and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at medium power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed before commencing Phase 3.

Phase 3. At the beginning of the phase, the cookstove shall be at operating temperature after completion of Phase 2 (see illustration of phases in Figure 2), and the water in the cooking vessel shall be at ambient temperature. Emissions shall be captured during startup, operation at low power, and during shutdown. Any char remaining shall be removed from the cookstove and weighed.

NOTE Cookstove operating temperature is not specified, because it varies for cookstoves.

6.3 Standard test sequence diagrams

The standard test sequence for cookstoves with only one power level is illustrated in Figure 1.

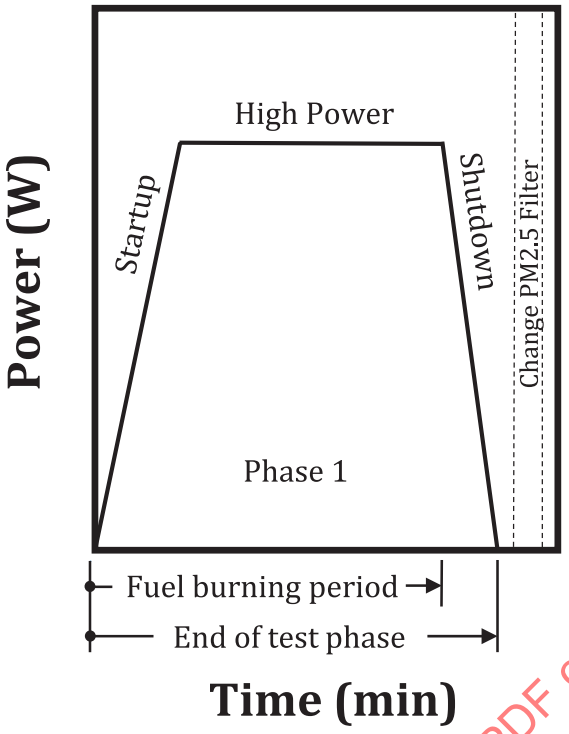


Figure 1 — Diagram of the standard test sequence for cookstoves with a single power level

The standard test sequence for cookstoves with a range of cooking power is illustrated in Figure 2.

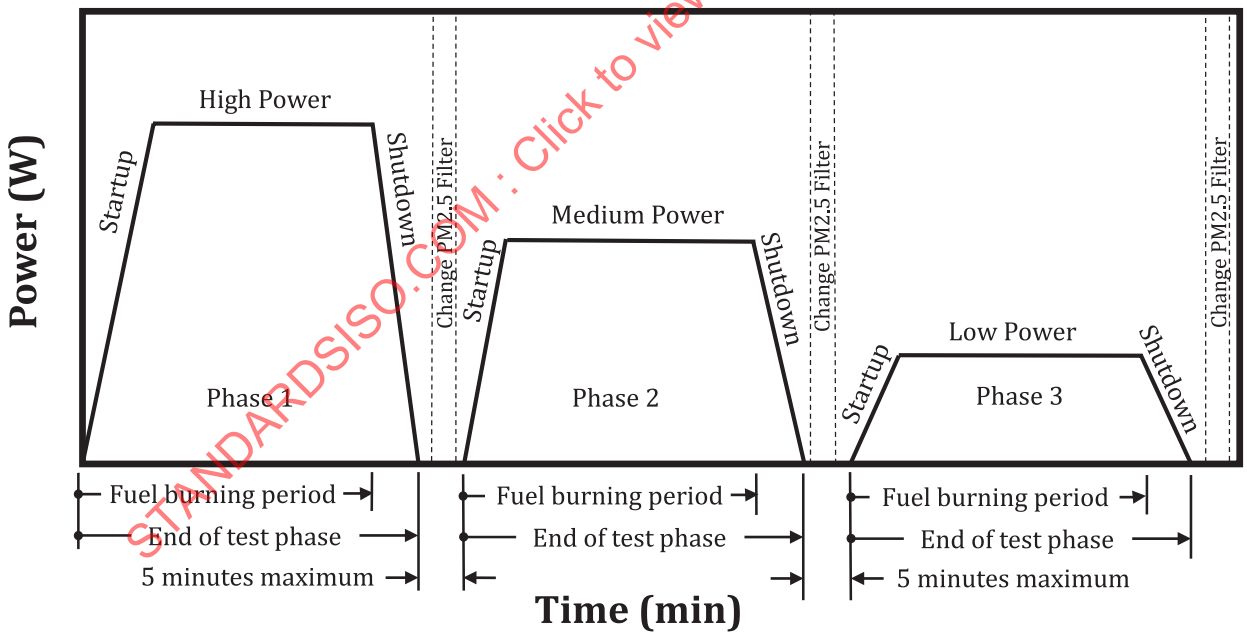


Figure 2 — Diagram of the standard test sequence for cookstoves with a range of cooking power

6.4 Limitations

The standard test sequence is designed to simulate operation of a cookstove system over a range of conditions typical of field use, but laboratory-based tests can have limited ability to predict performance in the field due to variation in fuels, cooking vessels, foods prepared, user behaviour, and environmental conditions. The standard test sequence is designed to produce repeatable and comparable results under

controlled conditions, but a limitation of this type of test is that certain conditions can be difficult to control — for example, operator behaviour, including the distribution and addition of fuel, for some continuously fed cookstoves.

NOTE The standard test sequence is based on best practices from established testing protocols and the experience of many testing centres, but the standard test sequence is a new method that is likely to require refinement as data from laboratory and field testing become available.

6.5 Cookstove system requirements

Following are requirements for testing a cookstove system defined as including the cookstove, cooking vessel, fuel, and operating procedure. A detailed cookstove system description shall be included in the test results, as specified in Clause 9.

6.5.1 Cookstove

A representative sample of produced cookstoves shall be used. For manufactured cookstoves produced with a high level of quality control over materials and tolerances, one cookstove can be representative. For artisan-produced cookstoves developed in settings with a lower level of quality control over materials and tolerances, three or more cookstoves might be needed to constitute a representative sample.

NOTE 1 Indicators of a high level of quality control include

a) cookstoves produced with interchangeable parts,

b) parts and assemblies are produced according to engineering drawings with tolerances,

c) parts and assemblies produced using tooling such as jigs, fixtures, dies, and moulds,

d) parts and assembled cookstoves are inspected for compliance with tolerances,

e) parts and assembled cookstoves are rejected if out of compliance with tolerances, and

f) final assembled cookstoves are inspected for compliance with performance criteria.

NOTE 2 Artisan-produced cookstoves are generally made by hand by skilled workers, rather than mass-produced in factories.

6.5.2 Cooking vessel

A cooking vessel (typically a pot) with appropriate size and shape shall be used. The cookstove shall be tested with a cooking vessel similar to those used in the field, if field data are available. If the cookstove is designed for a certain cooking vessel, then the cookstove shall be tested with that cooking vessel.

EXAMPLE Cookstoves designed for round-bottomed pots, pots with built-in pot skirts, or pots of a specific size shall be tested with the corresponding pot.

The cookstove shall be tested with a cooking vessel with appropriate size and water mass that enables water to be heated to within 1 °C of the local boiling point (with no time limit) without a lid on the cooking vessel at the highest power level.

6.5.3 Fuel

A fuel with appropriate size, shape, composition, energy content, and moisture content shall be used. The cookstove shall be tested with fuel similar to that used in the field, if field data are available. If a cookstove is designed for a certain type of fuel, then the cookstove shall be tested with that fuel.

EXAMPLE A cookstove designed for a certain type of pellet fuel shall be tested with that fuel.

A fire start-up fuel with appropriate size, shape, composition, and moisture content shall be used. The cookstove shall be tested with a start-up fuel similar to that used in the field, if field data are available. If a cookstove is designed for a certain type of start-up fuel, then the cookstove shall be tested with that

start-up fuel. An accelerant, such as kerosene or alcohol, may be used as a start-up fuel if specified by the manufacturer in written instructions.

6.5.4 Operating procedure

The cookstove shall be operated during testing as specified by the manufacturer's instructions (see Clause 10 for marking and packaging requirements). If field data are available that indicate a cookstove is typically not operated as intended, then the cookstove shall be operated following procedures similar to field use. If field data are used to support operation that does not match the manufacturer's instructions, then a detailed description of the methodology and statistical indicators of the representativeness of the field data shall be provided along with the laboratory test results.

WARNING — Do not exceed design load limits and other possible safety limitations.

6.6 Determination of cooking power levels

6.6.1 Low power

If a cookstove has controls, such as fan speed or air adjustment, then the controls shall be adjusted to their lowest setting that enables operation during the low-power test phase.

If a minimum cooking power level is specified by the manufacturer, then the cookstove shall be operated at that cooking power during the test. If field data are available, then the cookstove shall be operated at the lowest power level typically observed in the field. If field data are not available, then the cookstove shall be operated at a practical low-power level to be determined by the interested parties (e.g., certification bodies, manufacturers, suppliers, customers, inspectors, research organizations, sponsors, testing laboratories). The average low-power level shall be reported in the test results.

If the manufacturer's instructions and field information are in conflict, then the conflict shall be reported along with the information used to test the cookstove. The test report shall include a statement indicating whether the tests were performed according to manufacturer's instructions or based on field information.

6.6.2 Medium power

The medium-power level shall be determined by calculating the mid-point between low power and high power. The average medium-power level shall be reported in the test results.

6.6.3 High power

If a cookstove has controls, such as fan speed or air adjustment, then the controls shall be adjusted to their highest setting that enables operation during the high-power test phase.

If a maximum cooking power level is specified by the manufacturer, then the cookstove shall be operated at that cooking power during the test. If field data are available, then the cookstove shall be operated at the highest power level typically observed in the field. If field data are not available, then the cookstove shall be operated at a practical high-power level to be determined by the interested parties (e.g., certification bodies, manufacturers, suppliers, customers, inspectors, research organizations, sponsors, testing laboratories). The average high-power level shall be reported in the test results.

6.7 Procedure for standard test sequence

Specific procedures shall vary depending on the type of cookstove identified in Annex D, as specified in 6.8. The general procedure for testing at each power level is as follows.

6.7.1 Test preparation

The following test preparation steps shall be taken:

a) Personnel conducting the test shall be familiar with the operation method of the cookstove, and personnel shall possess appropriate qualifications and experience in cookstove testing.

b) Photographs of test equipment, test setup, and cookstove serial numbers, where available, shall be taken and included with the test report.

c) Each instrument shall be calibrated to meet requirements specified in Clause 5, Laboratory-based measurement of emissions and performance.

d) Suitable types of fuel shall be selected (see 6.5.3).

e) Trial test sequences shall be conducted to determine the amount of fuel required for the fuel-burning period, approximately 30 min of operation at each power level from ignition until the CO_2 concentration measured in the exhaust drops to approximately half of its steady-state background-subtracted value, except for cookstoves designed for only one power level. For these cookstoves, optional fuel-burning periods are either approximately 30 min or approximately 60 min of operation from ignition until the CO_2 concentration measured in the exhaust drops to approximately half of its steady-state background-subtracted value.

f) The lower heating value of biomass fuel shall be determined (see 5.5).

g) The water in the cooking vessel shall be weighed and the mass of water, G_1, and the initial water temperature, T_1, shall be recorded.

h) The temperature sensor shall be placed in the cooking vessel using a holder, and the tip of the sensor shall be located in the centre of the volume of water in the cooking vessel. The lid shall not be placed on the cooking vessel.

i) The ambient temperature, humidity, wind speed, and altitude shall be recorded.

j) The local boiling point of water shall be determined by heating water (using any cookstove or heating device) to a vigorous rolling boil and measuring the temperature with the temperature sensor.

NOTE The local boiling point can vary with altitude and/or atmospheric pressure.

6.7.2 Test steps

The following test steps shall be taken:

a) The fire shall be lit and the time shall be recorded, t_1, when ignition occurs (e.g., when a match is struck).

b) The temperature of the water shall be recorded at least every 1 min during the test phase. For tests including emissions, measurements of water temperature and time shall be recorded by a data acquisition system at least every 10 s, see 5.3.1 (g).

c) If the local boiling point temperature is reached before 30 min (or optional 60 min for cookstoves with only one power level), record the time, t_2. See Figure 3.

d) If at the end of 30 min (or optional 60 min for cookstoves with only one power level) the local boiling point temperature has been reached, then record the water temperature, T_2. The test shall be ended when

1) the water temperature drops to 5 °C below the boiling temperature attained, or

2) 5 min elapse after the end of the 30 min period (or optional 60 min period for cookstoves with only one power level), whichever occurs first.

See Figures 3 and 4.

e) If at the end of 30 min (or optional 60 min for cookstoves with only one power level) the local boiling point temperature has not been reached, then record the water temperature, T_2, and the test shall be ended when

   1) the water temperature drops to 5 °C below the maximum recorded temperature obtained within the 30 min test (or optional 60 min test for cookstoves with only one power level), or

   2) 5 min elapse after the end of the 30 min period (or optional 60 min period for cookstoves with only one power level), whichever occurs first.

   See Figure 5.

f) Shut-down procedure for continuously fed cookstoves is as follows: fuel feeding shall be stopped at the end of the fuel burning period, any char shall remain in the cookstove, and unburned solid fuel (e.g., wood) shall be removed from the cookstove. Any char shall be allowed to continue to burn until the end of the test phase, as defined in Steps d) and e).

g) The mass of char remaining at the end of the test phase shall be recorded, if present.

h) Upon conclusion of the test, the water shall be weighed and recorded as G_2.

i) The electrical power shall be recorded, if the cookstove has a fan. The manufacturer's electrical power rating (in W) of the fan may be reported, or the electrical power (in W) may be measured with a wattmeter.

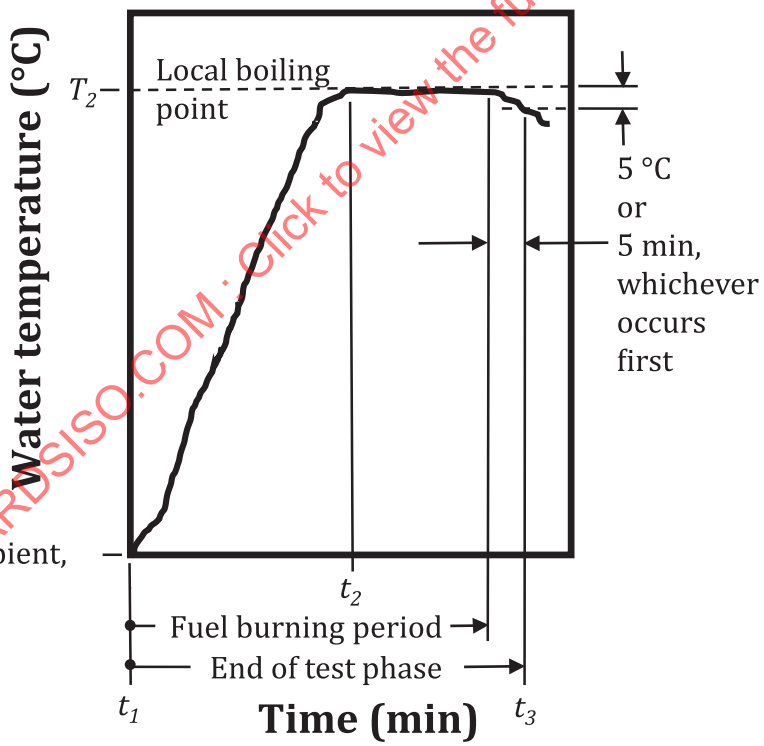


Figure 3 — Illustrative graph of water temperature versus time for any test phase when water temperature reaches the local boiling point before the end of the fuel burning period

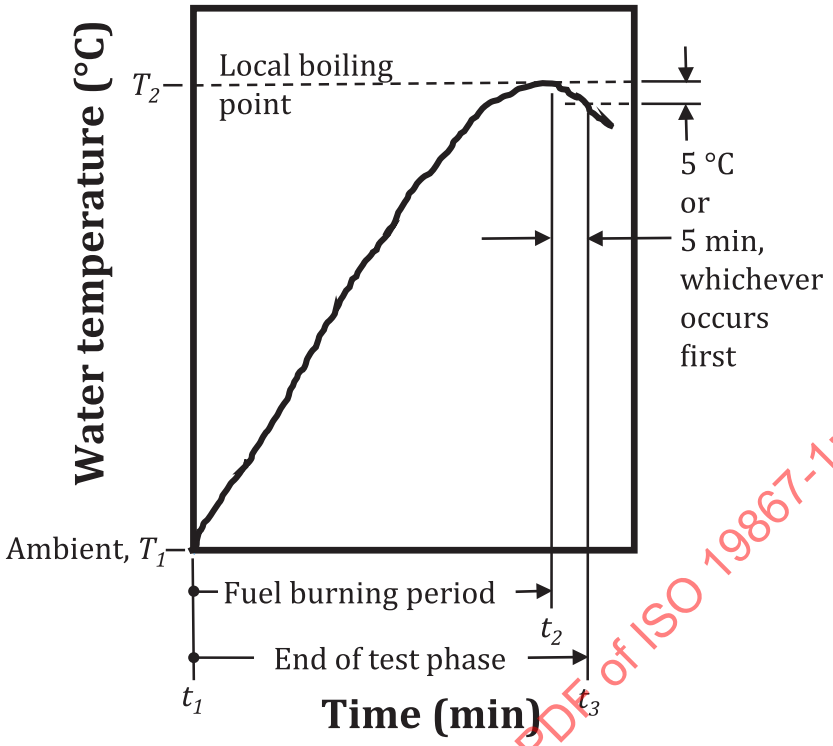


Figure 4 — Illustrative graph of water temperature versus time for any test phase when water temperature reaches the local boiling point at the end of the fuel burning period

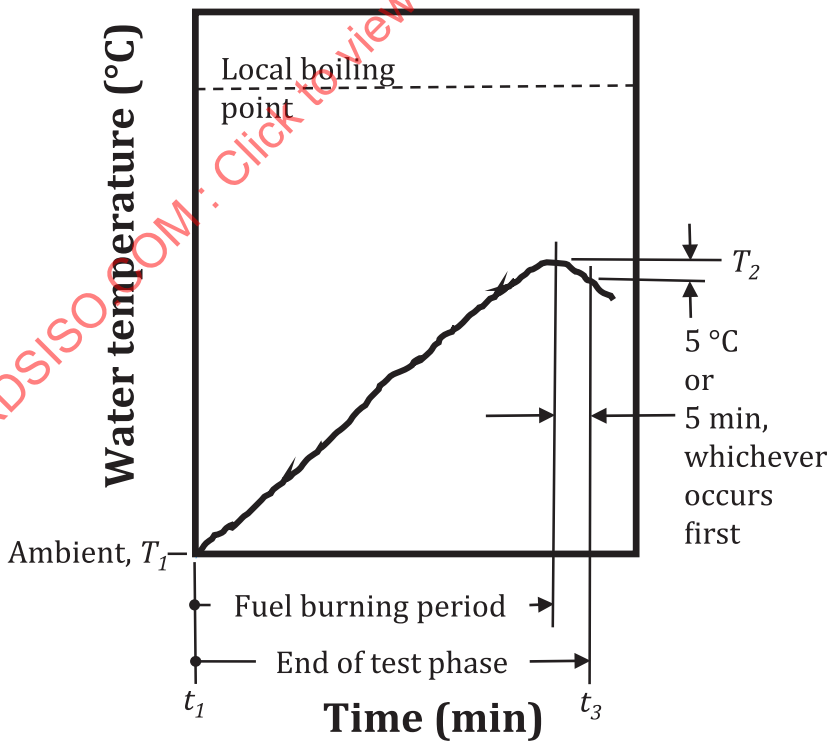


Figure 5 — Illustrative graph of water temperature versus time for any test phase when water temperature does not reach the local boiling point

6.7.3 Emission testing

Emission testing shall be conducted simultaneously with efficiency testing (see 6.7.2). The following emission testing steps shall be taken:

a) The emission sampling shall be started immediately before lighting the fire.

b) Emission sampling shall be taken from a dilution tunnel.

c) The sampling and measurement of PM, CO, and optional pollutants (e.g., BC, EC, OC) shall refer to Clause 5.

d) The emission sampling shall continue until the end of the test phase.

One $PM_{2,5}$ filter sample is required per test phase, but optional additional filter samples may also be taken to fully characterize the performance of cookstoves. For example, separate filter samples may be taken during startup, refuelling, steady-state, and/or shutdown phases of the burn sequence. Considerations for taking optional filter samples include the additional sampling equipment and the resolution of the balance used to weigh the filters. A balance with higher resolution can be necessary to weigh lightly loaded filters.

6.7.4 Test replicates

A minimum of five replicate tests shall be performed for each cookstove/fuel combination, and the number of replicates shall be reported. If greater statistical confidence is desired to meet user needs (e.g. for rating against performance targets), then more than five replicate tests should be conducted. The number of test replicates performed to achieve statistical confidence is described in basic statistics — for example, see free-of-cost informative references *Technologies and Fuels Testing: Protocols*[109] and *Electronic Statistics Textbook*[122]. For all required metrics listed in 5.3.2, mean values, standard deviations, and 90 % confidence intervals shall be reported. A greater level of confidence may be obtained to meet programmatic goals, but increasing confidence comes at a cost in terms of time and/or money. Users should seek to balance the level of confidence with practicality and costs.

6.8 Specific procedures for cookstove types

Specific procedures shall vary depending on the type of cookstove identified in Annex D.

6.8.1 Plancha cookstoves

Plancha (griddle) cookstoves shall be tested in two modes with different vessels to represent the range of cooking performed with these cookstoves:

a) with typical cooking vessels (pots), and

b) with water in contact with 60 % of the hottest surface area of the plancha. For testing with water in contact with the plancha, the cookstove shall be tested with either the 'plancha-olla' (plancha-pot) method or the 'Mylar pot' method.

If the 'plancha-olla' (plancha-pot) method is used, then metal sides shall be welded to the griddle to form a vessel with water in contact with 60 % of the hottest surface area.

Further information on assembling Mylar pots is provided in C.4.

6.8.2 Chimney cookstoves

For cookstoves with chimneys, total emissions shall be measured including both the chimney exhaust and the fugitive emissions (indoor emissions) from the cookstove body, although some chimney cookstoves can have no fugitive emissions. Additionally, fugitive emission rates shall be measured separately. See 5.3.8.2.5 to 5.3.8.2.7 and Figures B.1 to B.4.

In case of any modification of chimney height, the modification shall be reported, along with a disclaimer that performance can be affected by the modification.

6.8.3 Charcoal-fuelled cookstoves

Unless otherwise specified by the manufacturer or determined by actual use in the field, the charcoal fuel shall be ignited using kerosene as the starter fuel. The amount of kerosene shall be 5 % by weight of the weight of the charcoal fuel load.

The cooking vessel shall be placed on the cookstove after the kerosene flames out (typically 4 min to 6 min).

If the cookstove has an air-control device (e.g. door or damper), the air-control device shall be operated per manufacturer's instructions or per actual use in the field. If information on the operation of the air-control is not available, then the air-control device shall be fully open during the high-power test phase, and fully closed during the low-power test phase. The low-power phase shall be performed with hot charcoal remaining from the high-power phase.

Charcoal-fuelled cookstoves designed for two power levels shall be tested at two power levels (high and low). Charcoal-fuelled cookstoves may be tested at a medium-power level by adjusting the fuel loading and/or the air control device, if present.

NOTE Charcoal stoves are typically capable of operating at relatively low power compared to other types of stoves. Some testing protocols for charcoal stoves specify that a lid be placed on the cooking vessel, but this document specifies that a cooking vessel (pot) with ambient temperature water is to be placed on the cookstove at the beginning of the high-, medium-, and low-power test phases. Useful energy delivered is determined by measuring the increase in the temperature of the water and the mass of any steam produced. With the method described in this document, useful energy delivered and thermal efficiency are determined for all stove types without a lid on the pot.

6.8.4 Solar cookstoves

Solar cookstoves shall be tested for cooking power per ASAE S580.1.

7 Safety measurements

Methods for evaluating safety include assessment of sharp edges and points (including snagging of garments in solar cookstove panels), tipping, containment of fuel, obstructions, temperature, shielding of chimney, flame location, and size. These methods are applicable to solid-fuel cookstoves and solar cookstoves only, and these methods are not applicable to electric cookstoves and gas/liquid-fuelled cookstoves. Safety evaluation of electric stoves can be found in IEC 60335-2-6[62]. Safety evaluation of gas-fuelled cookstoves can be found in ISO 23550 and ISO 23551 (all parts).

A points-based rating system is used to allow individual countries and organizations to select levels based on their priorities.

Supplementary information on laboratory-based safety measurements is provided in Annex E.

7.1 Measurement equipment

Equipment for safety testing, in addition to the cookstove, fuel, and cooking vessel:

a) tape measure or ruler;

b) Data Collection Form[106] to assist with data entry and calculations (optional);

c) cloth, rag, or some form of loose clothing;

d) chalk;

e) thermometer;

f) hand-held infrared (IR) thermometer with emissivity adjustment.

7.2 Taking measurements

7.2.1 General

The range of scores for the safety method is 25 to 100, with 25 having the most safety concerns, and 100 having the fewest safety concerns.

Cookstoves for testing should be selected randomly to prevent bias. Cookstoves shall be new and unused. One cookstove should be tested for safety. However, for situations with potentially high variability in production quality, multiple sets of cookstoves should be tested (see 6.5.1).

7.2.2 Test 1: Sharp edges and points

7.2.2.1 Equipment

Equipment required for this test is a cloth, rag, or loose clothing.

7.2.2.2 Procedure

The cookstove need not be lit for this procedure.

a) Rub cloth gently over the entire exterior surface of the cookstove (including reflector panels on solar cookstoves) to find areas that catch or tear the cloth.

b) Record number of areas on the surface of the cookstove that snag or tear the cloth. Masonry (e.g., stone, clay, brick) cookstoves can provide resistance to the material being run over the surface, but this resistance should not be deemed unsatisfactory unless the cookstove moves or the rag becomes completely snagged.

7.2.2.3 Scoring

The scoring system for the sharp edges and points test is provided in Table F.1.

7.2.3 Test 2: Cookstove tipping

7.2.3.1 General

Portable cookstoves should come back to rest upright after being tipped [see 7.2.3.3, Step d)] from their usual resting position. Testing for this hazard should be performed only if the cookstove weighs less than 25 kg and is not secured to the ground or wall. The number of runs conducted should be equal to the number of legs or corners on the base of the cookstove (because it is not always clear where a cookstove's centre of gravity is located). If tipping toward the direction of a fuel entry point is not possible, instead use multiple other tipping directions for the procedure. Measurements should be taken with care because the change in height can be small.

Built-in-place cookstoves should be tested for tipping by determining the load required to reach tip-over conditions.

7.2.3.2 Equipment

Equipment required for this test is as follows:

a) cookstove;

b) fuel;

c) ruler/tape measure.

7.2.3.3 Procedure for portable cookstoves

a) Set cookstove on flat surface and load with fuel but do not ignite.

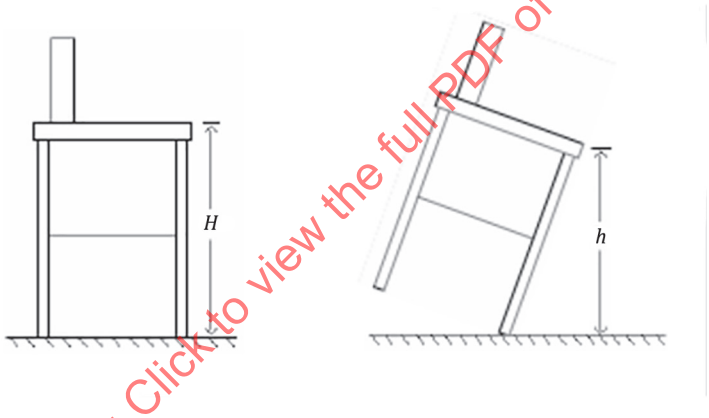
b) All cookstove covers and/or utensils remain in their normal positions. Cooking vessels are not included; remove any cooking vessel prior to conducting the test.

c) With the cookstove stable and upright, measure the height of the tallest point (standing height, cm) on the side you will tip towards.

d) Slowly tip cookstove to the chosen side until the cookstove is able to tip over on its own (when the centre of gravity is directly above the point of contact with the ground).

e) Hold cookstove tilted where it can overturn and measure the new height of the same point chosen in step c) (tipped height).

f) Repeat process for as many runs as there are legs on the cookstove (or four times for a circular base).



Key

H standing height, measured prior to tilt

h tipped height, measured after tilt

Figure 6 — Diagram of height measurements for cookstove tipping test

7.2.3.4 Scoring

The scoring system for the cookstove tipping test is provided in Table F.2.

7.2.4 Test 3: Containment of fuel

7.2.4.1 General

Flaming fuel should rarely fall from the cookstove when it is overturned and embers/burning fuel should have little chance of being expelled from the combustion chamber.

7.2.4.2 Equipment

Equipment required for this test is as follows:

a) fuel;

b) cooking vessel;

c) ruler/tape measure;

d) calculator (optional).

7.2.4.3 Procedure

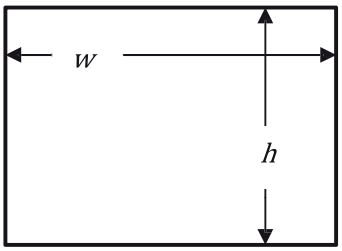
a) Stock the cookstove with fuel but do not ignite.

b) All cookstove covers and/or utensils remain in their normal positions.

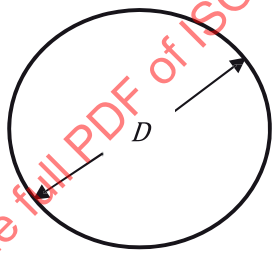
c) Place the cooking vessel onto the burner surface.

d) Visually inspect to find exposed areas through which fuel can be seen (often around the sides of the cooking vessel or through the fuel loading chamber).

e) Measure the area of each exposed area. Examples of area calculation are provided in Figure 7. Choose the appropriate formula based on the shape of the gap.



Area = $w \times h$



Area = $\pi \times D^2/4$
where $\pi \approx 3{,}141\ 6$

Key

w width

h height

D diameter

Figure 7 — Diagram of exposed area of fuel for rectangular and circular cookstoves

f) Calculate the sum of all the individual exposed areas, which will be the total area of fuel exposed, A.

g) Box-type and panel-type solar cookstoves receive the best rating. Concentrating-type solar cookstoves are scored based on the distance outside the curved mirror volume that an intense bright spot (the focal point) is projected. The rating is 'Poor' if the focal point is more than 30 cm outside the mirror volume or 'Best' if the focal point is ≤30 cm outside the mirror volume.

WARNING — Reflection of sunlight into the eyes can be a safety issue for certain types of solar cookstoves. Use protective goggles.

The use of protective goggles should be included in manufacturer's instructions (see Clause 10 for marking and packaging instructions). Note or record any reflection issues in the report.

7.2.4.4 Scoring

The scoring system for the containment of fuel test is provided in Table F.3.

7.2.5 Test 4: Obstructions near cooking surface

7.2.5.1 General

A ruler or tape measure is used to find the difference in height of the cooking surface to the height of any protrusions closely surrounding it.

7.2.5.2 Equipment

Equipment required for this test is a ruler or tape measure.

7.2.5.3 Procedure

a) Inspect cookstove for skirt (a skirt is present if cooking vessel sits partially into a near-cylindrical extension to the cookstove). Do not perform this procedure if skirt is present. Cookstoves with skirts receive a 'Good' rating if the skirt holds the cooking vessel in position on top of the stove.

b) Do not perform this procedure for solar cookstoves. Solar cookstoves receive the 'Best' rating.

c) Measure the height of the cooking surface.

d) For each obstruction or protrusion closely surrounding the cooking surface, measure the height of the obstruction in cm. Obstructions can include small but solid obstructions such as handles perpendicular to the griddle.

e) For each obstruction or protrusion, calculate the height difference between the cooking surface and obstruction. The maximum height difference (Δh_{max}) is used to find the rating and score.

7.2.5.4 Scoring

The scoring system for the obstructions near cooking surface test is provided in Table F.4.

7.2.6 Tests 5, 6, and 7

7.2.6.1 General

For Tests 5, 6, and 7, the ambient air temperature (°C) is used as a reference point to allow comparison between the cookstove and surrounding area temperatures. Solar cookstoves are excluded from Tests 5, 6, and 7.

Test 5: Surface temperature, is employed with the intention that burns should not occur if the cookstove surface is touched for a short duration.

Test 6: Heat transfer to the environment, is employed with the knowledge that large amounts of heat transmission to surroundings can ignite combustibles or the household structure in the area of the cookstove. The following procedures are used if the cookstove is placed within 10 cm of a combustible or has a combustion chamber less than 5 cm in height from the ground. If the cookstove is located outside these bounds it receives a rating of 'Best.' Alternate procedures are provided for cookstoves that are designed to be attached to the floor or wall.

Test 7: Handle temperature, is intended to measure parts of the cookstove that are touched during regular operation. Temperatures should not reach a level where use can cause harm either directly or indirectly.

7.2.6.2 Equipment

Equipment required for these tests is as follows:

a) fuel;

b) igniter;

c) chalk;

d) ruler/tape measure;

e) hand-held thermocouple.

Additional recommended equipment is as follows:

f) variable-emissivity infrared thermometer;

g) forward-looking infrared radiometer (FLIR) camera.

7.2.6.3 Procedure

a) Ensure the cookstove is shaded during the evaluation.

b) Record air temperature.

c) Chalk extra-thick lines on the cookstove at heights of 0,9 m and 1,5 m, if the cookstove reaches these heights measured from the ground.

d) Chalk an 8 cm × 8 cm grid onto the cookstove surface below the 0,9 m line, and between the 0,9 m and 1,5 m lines, if applicable. The grid should cover the entire targeted surface of the cookstove with lines spaced 8 cm apart vertically and horizontally.

e) If the cookstove's undercarriage is within 5 cm of the floor, then chalk a grid within an outline of the cookstove's dimensions on the floor. If the cookstove is located within 10 cm of a wall, then chalk a grid within an outline of the cookstove's dimensions on the wall, and also chalk a grid on the wall 16 cm higher than the top of the cookstove.

f) Horizontal cooking surfaces, such as burners or griddles, are excluded for Tests 5 and 6.

g) Ignite fuel and wait until cookstove has reached its maximum temperature (approximately 20 min to 40 min) before proceeding, adding fuel when necessary.

h) Record temperature data using the thermocouple at each grid intersection.

i) Begin the wall and floor measurements by moving the cookstove away (if it is safe to do so) to take measurements for up to 1 min, then return the cookstove to its original position for at least 5 min, taking surface temperature and handle temperatures during this duration. Repeat step h) until all data points have been checked. No more than 1 min should elapse when taking data with the cookstove moved away from its original position. After the data-taking period, place the cookstove back in its original position for a period of no less than 3 min to give the surfaces time to warm back up.

j) If the cookstove is mounted to the floor or wall, record cookstove surface temperatures near where the cookstove attaches to the floor and/or wall.

k) Find the maximum temperature for each surface below/above 0,9 m height (the child line — see E.1.7 for information), for metallic or non-metallic surfaces, for floor and wall, and for metallic or non-metallic handle temperature.

l) Cookstoves that do not have any components that need to be touched during cookstove use receive a rating of 'Best' for Test 7.

NOTE This test applies only to handles and other parts that are touched during regular operation, but Test 5 applies to surfaces that could be inadvertently touched.

7.2.6.4 Scoring

The scoring system for the surface temperature test is provided in Table F.5.

The scoring system for the heat transfer to the environment test is provided in Table F.6.

The scoring system for the handle temperature test is provided in Table F.7.

7.2.7 Test 8: Chimney shielding

7.2.7.1 General

Test 8 evaluates the chimney shield for the risk of contact.

7.2.7.2 Equipment

Equipment required for this test is a ruler or tape measure.

7.2.7.3 Procedure

a) If the cookstove has no chimney, the rating is 'Best'.

b) If the chimney has no protective shielding or the shielding does not have holes, use the surface temperature from Test 5.

c) If the chimney has a protective covering, inspect it for any open holes.

d) Measure the area of the largest open hole or gap in the chimney shielding, which will be the area, *A*. Calculate the area using the formulae in Test 3 (see 7.2.4.3).

7.2.7.4 Scoring

The scoring system for the chimney shielding test is provided in Table F.8.

7.2.8 Test 9: Flames surrounding cooking vessel

7.2.8.1 Equipment

Equipment required for this test is a cooking vessel.

7.2.8.2 Procedure

a) If a griddle-type cookstove has concentric rings that can be removed, then they shall be removed for the test.

b) Keep fire in cookstove fully lit.

c) Place cooking vessel into cooking position.

d) Observe the uncovered flames surrounding the cooking vessel for 5 min. Measure the maximum height of the flame, and whether it is less than 4 cm, greater than 4 cm, or if the flames reach the top of the cooking vessel and handles.

e) 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).

f) Solar cookstoves receive the 'Best' rating.

7.2.8.3 Scoring

The scoring system for the flames surrounding cooking vessel test is provided in Table F.9.

7.2.9 Test 10: Flames exiting fuel chamber

7.2.9.1 Equipment

No equipment is required for this test.

7.2.9.2 Procedure

a) Remove cooking vessel from cookstove.

b) Keep fire in cookstove burning at high-power operational level.

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) Solar cookstoves receive the 'Best' rating.

7.2.9.3 Scoring

The scoring system for the flames exiting fuel chamber test is provided in Table F.10.

7.2.10 Overall safety score

To calculate the overall safety score, the score from each of the 10 procedures is multiplied by a weighting factor based on the system provided in Table F.11, and then summed for a total score.

For procedures with multiple values, the minimum value is used to calculate the overall score. The total point score will be between 25 and 100.

7.2.11 Optional Test 11 for plancha (griddle) stoves

7.2.11.1 Equipment

Equipment required for this test is a scale.

7.2.11.2 Procedure

Remove the griddle from the stove and measure the mass (kg).

7.2.11.3 Scoring

Griddle weight is not combined into the overall safety score and shall be reported separately. The scoring system for determining whether the griddle is 'low', 'medium', or 'high' weight is provided in Annex F, Table F.12. Note that the performance of the stove can be influenced by the griddle weight and material, and considerations of safety for moving the griddle should be integrated with the impact on performance.

7.3 Materials

This standard includes evaluation of materials for durability (see Clause 8), and durability of materials can affect the safety of a cookstove. This standard does not include the direct evaluation of materials for safety, but the following are requirements for materials used for cookstove construction.

Non-combustible materials shall be used, except for the following applications:

a) components or accessories fitted outside the appliance,

b) internal components of controls and safety equipment,

c) operating handles, and

d) electrical equipment. All such materials shall remain undistorted at operating temperatures.

No part of the appliance shall contain any material known to be harmful. No part of the appliance shall contain asbestos. Hard solder, containing cadmium in its formulation, shall not be used.

Where thermal insulation is used, it shall be made of non-combustible material and shall not be a known hazard to health in its applied position. The thermal insulation shall withstand normal thermal and mechanical stresses.

8 Durability measurements

The durability methods are intended to evaluate the aspects of cookstove designs that can affect usable life and consumers' perceptions of quality.

A points-based rating system is used to allow individual countries and organizations to select levels based on their priorities.

Supplementary information on laboratory-based durability measurements is provided in Annex E.

8.1 Equipment for durability stress testing

Equipment for durability stress testing, in addition to the cookstove, fuel, and cooking vessel:

a) high-temperature safety gloves and protective sleeves;

b) safety glasses;

c) representative fuel — enough for 17 h of operation;

d) infrared thermometer with adjustment for emissivity of the measured surface;

e) ruler;

f) tube with inner diameter of 2,5 cm, measuring 1 m in length;

g) steel sphere with diameter between 1,8 cm and 2,2 cm;

h) 2 cm diameter steel rod segments with the following masses:

   — 25 g ± 1 g (approximately 1 cm in length);

   — 50 g ± 1 g (approximately 2 cm in length);

   — 100 g ± 1 g (approximately 4 cm in length);

   — 150 g ± 1 g (approximately 6 cm in length);

   — 200 g ± 1 g (approximately 8 cm in length);

   — 250 g ± 1 g (approximately 10 cm in length);

i) electric kiln or muffle furnace (e.g. GS-Bead Cube or Paragon QuikFire 6[2]);

2) These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

j) sodium chloride solution, 35 g/l, or simulated seawater solution, which may include other compounds in addition to NaCl;

k) spray water bottle;

l) metal tongs;

m) air-tight chamber containing a small humidifier;

n) reference materials (40 mm × 40 mm × ≥0,5 mm):

— mild steel;

— hot-dipped galvanized steel;

— ASTM Stainless steel 304, or equivalent;

— ASTM Stainless steel 409 or 410, or equivalent;

o) cutting tool, such as a razor blade, scalpel, or box cutter;

p) flexible ruler;

q) Scotch brand #845 tape (a specific tape is used for consistency);

r) Cooking vessel with a diameter between 22 cm and 30 cm;

s) water container or pitcher appropriate for pouring;

t) digital camera.

8.2 Taking measurements

The range of scores for the durability stress test ranges from 0 to 37, with 0 having no identified durability concerns. See 8.2.8.4.

Cookstoves for testing should be selected randomly to prevent bias. Two new and unused cookstoves should be tested. However, for situations with potentially high variability in production quality, multiple sets of cookstoves should be tested (see 6.5.1).

8.2.1 General

Applicable durability stress tests may be determined using Table 3.

Table 3 — Guidelines for determining which durability stress tests are applicable

Test	Test applicability
Visual inspection of cookstove	All cookstoves
Extended run test	All cookstoves
External impact test	All cookstoves
Internal impact test	All cookstoves
Corrosion test	Cookstoves with any metal components or metallic coatings
Coating adhesion test	Cookstoves with coating on any components. If unsure whether coating is present, conduct test.
Quenching test	All cookstoves
Material failure temperature test	All cookstoves

The series of durability tests should be completed in the order outlined in Figure 8. A minimum of two copies of each cookstove should be used for testing. After completing internal impact testing, one of

the two cookstoves should be broken down into its primary components, if possible. This process may require the use of basic hand tools.

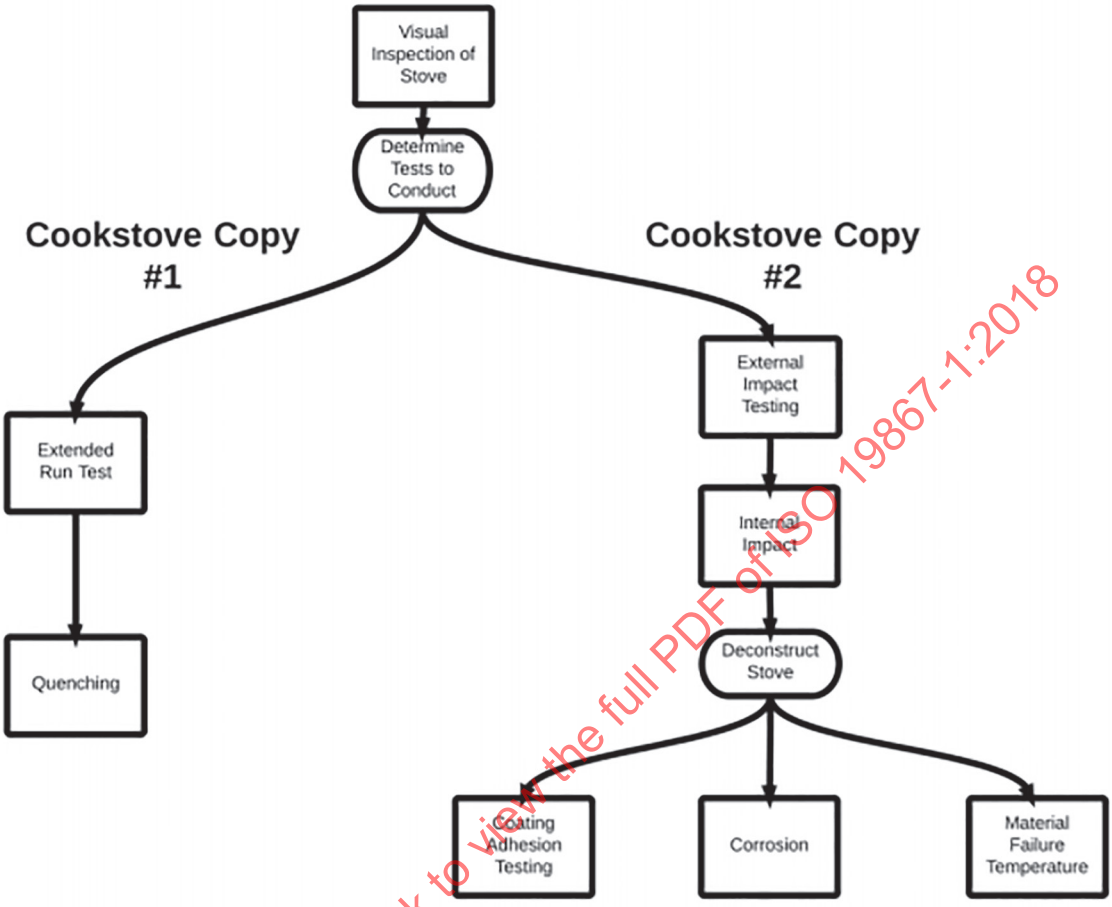


Figure 8 — Sequential order of cookstove durability stress tests

8.2.2 Test 1: Extended run

8.2.2.1 General

This test determines the temperature that cookstove components reach during use. This test focuses exclusively on steady state temperatures. Temperatures recorded during the extended run test are used to evaluate risk of component failure, realistic ranges for thermal shock testing, and bounds for thermal cycling.

8.2.2.2 Equipment

Equipment required for this test is as follows:

a) high-temperature safety gloves and protective sleeves;

b) safety glasses;

c) representative fuel sufficient for 12 h of operation;

d) infrared thermometer with adjustable emissivity;

e) ruler.

8.2.2.3 Procedure

a) Place the cookstove in a location where it can be operated for at least 3 d.

WARNING — The location should have adequate ventilation to prevent exposing the tester to pollutants.

When testing a cookstove that depends on sunlight (i.e. solar cookstoves), the cookstove should be placed in a location that receives full sunlight for at least 4 h. Testing of solar cookstoves should only be conducted on days with minimum cloud cover.

b) Prior to testing, each cookstove should be inspected in detail, and photographs should be taken illustrating each detail. Observations should be noted on a data sheet. Whenever possible, a ruler should be included in photographs, as a point of reference.

c) An infrared thermometer is sensitive to material emissivity. Emissivity of different cookstove construction materials can be determined using the guidelines in Annex G. Although emissivity can vary with temperature, unless a primary temperature standard is available it is necessary to assume constant emissivity with respect to temperature.

d) A simple two-dimensional schematic of the cookstove should be drawn and included on the data sheet. On this schematic, cracks, wear marks, chipped/damaged/discoloured coatings, and other signs of wear should be noted. Also on this form, the tester should document the locations of temperature measurements. Important measurement locations to include, when applicable, are as follows:

1) combustion chamber (multiple locations);
2) fuel entrance/cookstove mouth;
3) cookstove exit/cooking vessel support;
4) chimney;
5) exterior body (bottom, back, and sides of entrance);
6) reflectors (in the case of solar cookstoves);
7) burner (in the case of liquid and gasifier cookstoves).

e) Run the cookstove for 4 h. If cookstove power can be controlled, the cookstove should be run at the highest-possible firepower. Tests should be conducted with a water-filled cooking vessel.

NOTE 1 It is understood that some cookstove manufacturers specify the firepower to be used for optimum cookstove performance. However, for this test, the cookstove is operated at its maximum firepower, to create a worst-case scenario.

f) Temperature should be measured after the cookstove has been running for 4 h. While the cookstove is still running, begin by taking measurements of the cookstove exterior. After completing exterior measurements, the fire should be extinguished, where applicable, and any remaining fuel and char shall be removed from the stove, if applicable. The internal temperatures should be measured immediately, using the infrared thermometer. Care should be taken to ensure that the infrared thermometer is not exposed to infrared radiation from flames, as this will interfere with the accuracy of measurements.

NOTE 2 Details on calibration and use of an infrared thermometer can be found in Annex G.

Temperature should be measured as quickly as possible. All temperature measurements shall be completed within 5 min of completion of the 4 h run (if applicable).

The test should be run in such a manner as to maximize firepower.

NOTE 3 No strict meaning of 'maximum' firepower can be defined.

NOTE 4 Surface temperature data is only used to inform subsequent tests.

WARNING — Safety gloves, shirt with long sleeves, and safety glasses should be worn when measuring temperatures.

g) Temperatures should be recorded on a data sheet.

h) The cookstove should be allowed to cool for a minimum of 6 h.

i) Steps d) through h) should be repeated two additional times, for a total of three tests, with averaging of temperature measurements for each location.

j) Post-testing observations and photographs should be recorded and documented on the data sheet.

8.2.2.4 Scoring

The scoring system for the extended run test is provided in Table F.13.

8.2.3 Test 2: External impact

8.2.3.1 General

This test is used to determine the ability of the cookstove to withstand short duration impacts.

8.2.3.2 Equipment

Equipment required for this test is as follows:

a) tube with inner diameter of 2,5 cm, and 1 m in length;

b) steel sphere with diameter between 1,8 cm and 2,2 cm;

c) tubular spirit level;

d) 2 cm diameter steel rod segments with the following masses:

— 25 g ± 1 g (approximately 1 cm in length);

— 50 g ± 1 g (approximately 2 cm in length);

— 100 g ± 1 g (approximately 4 cm in length);

— 150 g ± 1 g (approximately 6 cm in length);

— 200 g ± 1 g (approximately 8 cm in length);

— 250 g ± 1 g (approximately 10 cm in length).

8.2.3.3 Procedure

a) Place the cookstove on a granite slab or other level working surface.

b) Secure the tube in a vertical orientation, such that the bottom of the tube is just touching the outside surface of the cookstove.

c) Place a steel sphere inside the tube. The steel sphere helps to ensure a repeatable impact.

d) Starting with the heaviest weight, drop the weight down the inside of the tube.

e) Move the tube away from the cookstove and observe for any substantial damage.

NOTE In the context of this test, substantial damage constitutes any of the following:

— chipped paint/coatings;

— cracks >2 cm in length;

— dents >5 mm in depth.

f) If substantial damage is observed, move the tube over a new region of the cookstove and repeat the test with a lighter weight.

g) Repeat steps a) through f) until substantial damage is not observed.

h) Repeat steps a) through f) for all external components of the cookstove.

8.2.3.4 Scoring

The scoring system for the external impact test is provided in Table F.14.

8.2.4 Test 3: Internal impact

8.2.4.1 General

This test is used to determine a cookstove's ability to withstand repeated, short-duration impacts.

8.2.4.2 Equipment

Equipment required for this test is as follows:

a) tube with inner diameter of 2,5 cm, and 1 m in length;

b) steel sphere with diameter between 1,8 cm to 2,2 cm;

c) tubular spirit level;

d) 2 cm diameter steel rod segments with the following masses:

— 25 g ± 1 g (approximately 1 cm in length);

— 50 g ± 1 g (approximately 2 cm in length);

— 100 g ± 1 g (approximately 4 cm in length);

— 150 g ± 1 g (approximately 6 cm in length);

— 200 g ± 1 g (approximately 8 cm in length);

— 250 g ± 1 g (approximately 10 cm in length).

8.2.4.3 Procedure

a) Place the cookstove on a granite slab or other level working surface.

b) Secure the tube in a vertical orientation, such that the bottom of the tube is just touching the internal surface of the cookstove.

c) Place a steel sphere inside tube. The steel sphere helps ensure a repeatable impact.

d) Starting with the heaviest weight, drop the weight down the inside of the tube ten times.

e) Move the tube away from the cookstove and observe for any substantial damage.

NOTE In the context of this test, substantial damage constitutes any of the following:

— chipped paint/coatings;

— cracks >2cm in length;

— dents >5mm in depth.

f) If substantial damage is seen, move the tube over a new region of the cookstove and repeat the test with a lighter weight.

g) Repeat steps a) through f) until substantial damage is not observed.

h) Repeat steps a) through g) for all internal components of the cookstove. Some components may need to be removed from the cookstove for testing.

8.2.4.4 Scoring

The scoring system for the internal impact test is provided in Table F.15.

8.2.5 Test 4: Corrosion

8.2.5.1 General

In this comparative test, the unknown and standard reference materials are tested in parallel, in order to more accurately evaluate the risk of corrosion. When samples are only coated on one side, all evaluations should be conducted on both the coated and uncoated sides of the material.

8.2.5.2 Equipment

Equipment required for this test is as follows:

a) electric kiln or muffle furnace (e.g., GS-Bead Tube or Paragon QuikFire 6[3)]);

b) sodium chloride solution, 35 g/l, or simulated seawater solution, which may include other compounds in addition to NaCl;

c) spray water bottle;

d) high-temperature safety gloves and protective sleeves;

e) safety glasses;

f) metal tongs;

g) air-tight chamber containing a small humidifier;

h) reference materials (40 mm × 40 mm × ≥0,5 mm):

— mild steel;

— hot-dipped galvanized steel;

— ASTM Stainless steel 304;

— ASTM Stainless steel 409 or 410.

8.2.5.3 Procedure

a) Collect samples of metal components from a disassembled cookstove.

b) Take photographs and record observations of samples on a data sheet prior to testing.

3) These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

c) Use temperatures from the extended run test (8.2.2) to determine the cycling temperature for each component, based on the origin of each component from the cookstove. If multiple temperatures were recorded, the maximum temperature should be used.

d) Prepare a 35 g/l salt solution in a spray bottle.

e) Set the humidifier to achieve a relative humidity of at least 95 %.

f) Place one of the test samples into the kiln with a sample of each of the reference materials.

g) Kiln temperature should be increased by approximately 10 °C/min, until the target cycling temperature determined in step c) is achieved.

h) Kiln temperature should be maintained for 30 min.

i) After 30 min, the kiln temperature should be lowered as fast as appropriate for the kiln.

j) Once the kiln temperature is below 150 °C, remove the samples from the kiln.

k) Samples should be sprayed liberally with the salt solution and then placed into the humidified chamber.

NOTE The goal of this step is to keep the droplets of salt solution on the metal samples while they are transported into the humidity chamber.

l) Store samples in the humidity chamber for at least 12 h.

m) Repeat steps f) through l) nine more times, for a total of 10 cycles.

n) Repeat steps f) through m) for the remaining samples. A different set of reference materials should be used for each sample material being tested. Multiple sets of samples can be placed in the humidity chamber at the same time if care is taken to keep track of the different materials.

8.2.5.4 Scoring

The scoring system for the corrosion test is provided in Table F.16.

8.2.6 Test 5: Coating adhesion

8.2.6.1 General

The adhesion testing presented in this test, Test 5, investigates how well a coating adheres to the cookstove and whether the strength of the coating improves. Maximum coating temperatures are investigated in Test 1 (see 8.2.2).

8.2.6.2 Equipment

Equipment required for this test is as follows:

a) electric kiln or muffle furnace(e.g., GS-Bead Cube or Paragon QuikFire 6[4]);

b) high temperature safety gloves and protective sleeves;

c) safety glasses;

d) cutting tool, such as a razor blade, scalpel, or box cutter;

e) flexible ruler;

4) These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

f) Scotch Brand #845 tape (A specific tape is used for consistency).

8.2.6.3 Procedure

a) Looking at the cookstove, identify all components that appear to be covered by some sort of coating. Record these items on the data sheet.

b) Collect samples of coated components (at least 5 cm × 5 cm) from a disassembled cookstove. Smaller samples can be used. However, sample size should be recorded on the data sheet.

c) Use the temperatures identified from Test 1 (see 8.2.2) to determine the target temperature for each component, based on the origin of each component from the cookstove. If multiple temperatures were recorded, the maximum temperature should be used.

e) Place one of the two samples from each component into the kiln.

f) Kiln temperature should be increased by approximately 10 °C/min, until the target temperature identified in step c) is achieved.

g) Kiln temperature should be maintained for 30 min.

h) After 30 min, the kiln temperature should be lowered as fast as appropriate for the kiln.

i) Repeat steps f) through h) four more times, for a total of five cycles.

j) Aged samples shall be removed from the kiln or muffle furnace and shall be allowed to cool to room temperature.

k) Using both aged and un-aged samples, attempt to cut cross-hatches through the samples, down to the substrate. Downward force on the cutting tool shall be (20 ± 10) Newton [the force of a weight of approximately (2 ± 1) kg]. The cross hatches should be spaced approximately 1 mm apart and be approximately 20 mm in length. Each cut should be made using a ruler and with one steady motion. If the cut does not penetrate the coating, it can be scored again using the straight edge to ensure that repeated cuts are being placed in the same location. Repeat the process until there are six vertical and six horizontal cuts (see Table 4).

l) After cutting has been completed, gently brush the samples to remove any loose material.

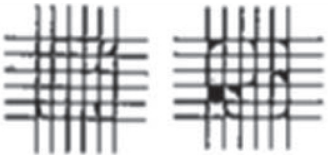
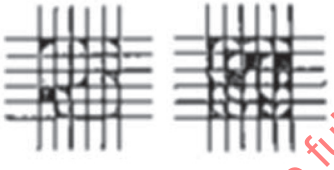
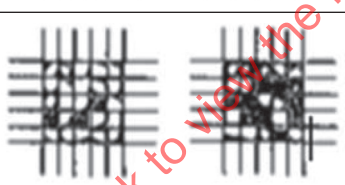
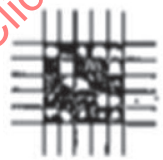
m) Pieces of tape should be pressed firmly onto the cut samples.

n) After leaving the tape in place for 2 min, remove the tape in one quick motion from each sample.

Using Table 4, estimate the amount of material removed by the tape. Each square on the grid represents 4 % of the sample.

o) Repeat steps c) through n) for the remaining cookstove components.

Table 4 — Material loss from adhesion testing (Adapted from ASTM 3359[72])

Description	Example	Estimated material loss
No apparent loss of coating material		0 %
Minimal loss of coating material		<5 %
Some coating material loss		5 % to 15 %
Significant coating material loss		15 % to 35 %
Severe coating material loss		35 % to 65 %
Substantial majority of material lost due to adhesion		>65 %

8.2.6.4 Scoring

The scoring system for the coating adhesion test is provided in Table F.17.

8.2.7 Test 6: Quenching

8.2.7.1 Equipment

Equipment required for this test is as follows:

a) representative fuel — enough for 5 h of operation;

b) high temperature safety gloves and protective sleeves;

c) safety glasses;

d) cooking vessel with a diameter between 22 cm and 30 cm, or to manufacturer's specification;

e) ruler;

f) water container or pitcher appropriate for pouring.

8.2.7.2 Procedure

a) Prior to testing, a detailed visual inspection of the cookstove should be conducted, including documentation with photographs. Observations should be recorded on a data sheet. Whenever possible, a ruler should be included in photographs, as a point of reference.

b) Fill a cooking vessel with water to within 10 mm of the brim.

c) The cookstove should be run for 1 h. If cookstove power can be controlled, then the cookstove should be run at the maximum possible firepower.

NOTE It is understood that some cookstove manufacturers specify the firepower for optimum performance. However, for this test the cookstove is operated at its maximum firepower, to model a worst-case scenario.

WARNING — The tester should wear safety glasses, high temperature safety gloves, and protective sleeves.

d) Quickly pour an additional 1 l of water into the cooking vessel, causing overflow of water into the cookstove.

WARNING — There is a risk of water overflowing the container and/or hot cookstove components. Extreme caution should be taken while conducting these tests.

e) Allow at least 16 h for the cookstove to dry completely.

f) Repeat steps b) through e) four times, for a total of five tests.

g) Post-testing observations, such as components that are cracked, warped, or otherwise deformed, shall be noted on the data sheet, and corresponding photographs should be taken.

8.2.7.3 Scoring

The scoring system for the quenching test is provided in Table F.18.

8.2.8 Test 7: Material failure temperature

8.2.8.1 General

In this test, the materials in the major components are heated to determine the temperature at which materials begin to break down and fail.

8.2.8.2 Equipment

Equipment required for this test is as follows:

a) electric kiln or muffle furnace (e.g., GS-Bead Cube or Paragon QuikFire 6[5]);

b) high-temperature safety gloves and protective sleeves;

c) digital camera.

8.2.8.3 Procedure

a) Collect samples of each of the major components used in the cookstove.

b) Use the temperatures derived from Test 1 (8.2.2) to determine the operating temperature for each component, based on the origin of each component from the cookstove. If multiple temperatures were recorded, the maximum temperature should be used.

5) These are examples of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

c) Testing should begin at 100 °C below the operating temperature determined in Test 1 (see 8.2.2).

EXAMPLE 1 A cookstove component that reached 350 °C during Test 1 (see 8.2.2) would begin testing at 250 °C.

For convenience, starting temperatures may be set at the closest 50 °C increment below the ideal temperature.

EXAMPLE 2 A component that would start testing at 265 °C could begin testing at 250 °C.

d) Place the sample in the kiln. Multiple samples can be heated in the kiln at once, assuming they have the same temperature target.

e) Kiln temperature should be increased by approximately 10 °C/min, until the target temperature identified in step b) is reached.

f) Kiln temperature should be maintained for 30 min at the target temperature.

WARNING — Some materials can off-gas or smoke. Care should be taken to maintain adequate airflow around the kiln.

g) After 30 min, kiln temperature should be lowered as fast as appropriate for the kiln.

h) Samples should be removed and photographed against a white background.

i) Repeat steps d) through h) using the same sample, increasing the kiln maximum temperature by 50 °C each time until component fails (see Note). The final kiln setting prior to the component failing is considered the maximum operating temperature.

NOTE In the context of this test, failure constitutes any of the following:

— significant corrosion;

— exposure of the majority of base material through coating;

— melted components;

— significant twisting or warping of components;

— in the context of organic materials, such as wood, failure is indicated by burned, scorched, or charred components.

j) Repeat steps c) through i) for the remaining components, as required.

8.2.8.4 Scoring

The scoring system for the material failure temperature test is provided in Table F.19. To calculate the overall durability score, the score from each of the 7 procedures shall be summed for a total score. For procedures with multiple values, the maximum value shall be used to calculate the overall score. The total point score shall be between 0 and 37, with 0 having no identified durability concerns.

8.2.9 Limitations for durability stress tests

8.2.9.1 Cookstove age

The tests outlined here do not inherently account for the age or current condition of any cookstove.

8.2.9.2 Fuel variability

The protocol does not specify fuels to be used during testing.

8.2.9.3 Evaluation ambiguity

Assignment of numeric scores is challenging for some tests because of the degree of ambiguity that is inherent to the tests.

8.2.9.4 Cookstove type

It is not possible to include tests for every possible cookstove design or type.

9 Reporting test results

9.1 General

This clause provides guidance on what to include when reporting test results and how to report them. Standardizing how results are reported helps to ensure that the necessary information is provided by the report, and helps to increase comparability between test results from different laboratories. Included here are minimum and recommended guidelines for content. A sample reporting template is provided in Annex H and can be downloaded as a Word document from Reference [109]. Testing organizations may also use their own reporting templates, but should adhere to the guidance presented here.

9.2 Report contents

9.2.1 Administrative information

Reports should include the following administrative information:

a) name and address, and telephone number of laboratory;

b) producer name or trademark;

c) distributor or distributing organization;

d) date cookstoves/fuels were received;

e) date cookstoves/fuels were tested;

f) description of cookstove(s) tested:

- make, model, version number of the cookstove/fuel and/or other information that can uniquely identify the tested cookstove;
- specifications (weight, height, materials, class/technology/key characteristics);
- accessories included in cookstove system such as pot skirts and fit-for-purpose pots;
- modifications and imperfections;
- photographs of cookstoves, including modifications, imperfections, and accessories;

g) date of report submission.

9.2.2 Tests and metrics

The tests types and test sequences used (see Clauses 6, 7, and 8) and corresponding output metrics should be outlined, including the following components.

9.2.2.1 Description of the test and output metrics

Brief descriptions of the test and the output metrics should be included (see the reporting template in Annex H for an example, which can be downloaded from Reference [109]).

9.2.2.2 Emissions and fuel performance testing

For emissions and fuel performance testing, results shall be presented per test sequence phase and aggregated per test.

The aggregate results may be averages or may be weighted averages of the three phases in accordance with specified local cooking or firepower regimes.

Report appendices should include all individual results from test replicates.

9.2.2.3 Testing and operational conditions

Testing and operational conditions shall be provided for emissions and fuel performance testing.

Required elements are the following:

a) ambient temperature, humidity, altitude, and local boiling point;

b) description of biomass fuels, including the fuel type and species, energy content, moisture content, dimensions, and extent of processing;

c) description of liquid fuels and gas fuels, including the composition and energy content;

d) description of cooking vessels including the gauge, weight, thickness, diameter, shape, and material.

Recommended elements are as follows:

a) photographs of biomass fuels;

b) photographs of cooking vessels;

c) compositional (proximate and ultimate) analysis of the fuel.

9.2.2.4 Tables and figures

9.2.2.4.1 Size

Tables and figures should be clearly readable without enlargement on a printed page (see template in Annex H for examples).

9.2.2.4.2 Tabular results

Tabular results should include the following for each test metric:

a) emissions and fuel performance: mean, median, minimum, maximum, standard deviation, and sample size;

b) safety and durability performance: total and subcategory index scores.

9.2.2.4.3 Graphical results

Graphical results shall be clearly decipherable when printed in greyscale.

Graphical results should include the following characteristics:

a) emissions and fuel performance: mean, standard deviation;

b) safety and durability performance: total and subcategory scores.

9.2.3 Reporting against performance targets

If results are reported against thresholds, then the report shall include the source of the thresholds. An example of voluntary performance targets for cookstoves can be found in ISO/TR 19867-3.

9.2.4 Quality assurance and quality control

A statement shall be included with the report affirming that quality assurance and quality control procedures were followed in accordance with this document (see template in Annex H for an example). Details of procedures may be included, such as leak checks (see 5.3.7.1) and verification (see 5.3.7.2). Laboratory accreditations may be included, such as accreditation by ISO/IEC 17025.

9.2.4.1 Deviations

Any deviations from normal operating procedures shall be listed and potential implications for outcomes shall be described.

9.2.4.2 Unique or additional procedures

Descriptions of unique or additional procedures and analysis should be described in detail.

9.2.4.3 Conflicts of interest

A statement declaring conflicts of interest shall be included in the report. If no conflict of interest exists, a statement shall be made in the report declaring that no conflict of interest exists.

9.2.4.4 Limitations

A statement of limitations on the interpretation and application of the results shall be included in the report.

9.2.4.5 Authorization

The report shall be signed by an authorized manager with a statement authorizing the results. Additionally, the report may be signed by a report writer.

9.3 Templates

A sample reporting template is provided in Annex H and can be downloaded as a Word document from Reference [109].

10 Marking and packaging

Marking and packaging, where applicable, shall be applied as follows. Packaging requirements need not be met by artisan cookstoves nor cookstoves built in situ; however, the artisan should supply basic information, such as: name of manufacturer, address/village/region, date of manufacture, and type of stove.

a) The marking shall be placed in a clear location on the cookstove.

b) The basic components of the mark shall consist of

- name of the manufacturer,
- name of product,
- trademark,
- specification and model number,

- maximum cooking power,
- cooking thermal efficiency at maximum power, reported both with and without energy credit for remaining char,
- production date,
- serial number, and
- any applicable standards numbers.

c) Documentation included with the product shall cover the following items:

- product instructions including complete operating instructions;
- parts list.

d) If applicable, documentation should also include

- product certification, and
- product warranty.

Annex A
(informative)

Laboratory-based measurements of emissions and performance — Additional considerations

A.1 General

Clause 5 is designed for cookstoves, but shares many principles with particulate and gaseous emission measurements that have been in use for many years for stationary combustion sources. One test procedure that shares many of these principles is the dilution tunnel method as currently specified for certification of space-heating stoves in many countries.

Another lab-based test procedure, the mass balance method, shares many principles with field-based procedures that have been widely used, especially where the use of a dilution tunnel is not practical. Total capture of the emissions is not required with the use of the mass balance method. The carbon mass balance method has been in use for many years for various applications.

The 'gold standard' for quantification of emissions and fuel efficiency is the use of the total-capture dilution tunnel method cross-checked with the carbon mass balance method. Obtaining consistently similar results for both methods does not prove accuracy but greatly improves confidence in the results.

Evaluating emissions and fuel efficiency from cookstoves is more complicated than the same task for other stationary sources due to the diversity of cookstove designs, fuels, and applications. For example, many stationary source applications primarily consist of operation at steady-state conditions. Cookstove applications include a wider range of power levels and functions. Additionally, some built-in-place cookstoves are large enough to preclude the application of typical laboratory test equipment and methods. In cases where the application of a dilution tunnel is not possible, the tests should be made on site or under appropriate conditions.

Evaluating emissions and fuel efficiency is also more complicated for solid-fuel cookstoves than for liquid/gas-fuelled cookstoves. Combustion of solid fuels is inherently more variable than liquid or gaseous fuels because the combustion process of solid fuels includes moisture vaporization (drying), hydrocarbon volatilization (pyrolysis and carbonization), char (carbon) gasification, and gas combustion. Furthermore, controlling combustion of solid fuels is more complicated than controlling combustion for typical liquid and gas counterparts.

A.2 Duct Reynolds number calculations

To achieve a minimum Reynolds number of 10^4, select a circular duct cross section and volumetric flow rate as given in Formula (A.1).

$$Re = \frac{Vd}{\nu} = \frac{4Q}{\nu\pi d} \geq 10^4 \tag{A.1}$$

where

Re is the value of the Reynolds number, unitless;

V is the velocity of air in the duct, m/s;

d is the diameter of the duct, m;

ν is the kinematic viscosity of air at sampling temperature and pressure, m^2/s;

Q is volumetric flow rate, m^3/s.

A.3 Calculation of minimum flow rate

For air at 20 °C and 100 kPa pressure (ν = 1,5 × 10^{-5} m^2/s), solve for the minimum flow rate for 0,15 m and 0,3 m ducting as given in Formula (A.2).

$$Q \geq \frac{10^4 \nu \pi d}{4} \tag{A.2}$$

$Q_{\min,D\,=\,0,15\ m} \geq 64\ m^3/hr\ (V \geq 1\ m/s)$

$Q_{\min,D\,=\,0,30\ m} \geq 130\ m^3/hr\ (V \geq 0,5\ m/s)$

where

Q is volumetric flow rate, m^3/s;

ν is the kinematic viscosity of air at sampling temperature and pressure, m^2/s;

d is the diameter of the duct, m;

V is the velocity of air in the duct, m/s;

$Q_{\min,D}$ is minimum volumetric flow rate, m^3/s.

A.4 Air pollutant emissions sampling and calculations

A.4.1 Isokinetic sampling of particulate matter

Isokinetic sampling is considered good practice and is recommended for sampling of particulate matter from a dilution tunnel (see Liu et al. 2008[118], Maricq et al. 2003[119], and Petrovic et al. 2015[120]). However, isokinetic sampling is not required, because for cookstove emissions, the count and mass median diameter of particles is typically less than 500 nm. For this reason, inertial deposition that dominates from particles >1 µm in diameter is not as large of a concern, and careful consideration of isokinetic sampling is not critical.

A.4.1.1 Sample tube diameter determination, dilution tunnel method

Using the dilution tunnel method, the internal diameter of the sampling tube can be determined as given in Formula (A.3).

$$d_{sample} = \sqrt[2]{d_{duct}{}^2 \times \frac{Q_{sample}}{Q_{duct}}} \tag{A.3}$$

where

d_{sample} is the internal diameter of the sampling tube, m;

d_{duct} is the internal diameter of the exhaust duct, m;

Q_{duct} is the volumetric flow rate through the exhaust system, m^3/s;

Q_{sample} is the sampling rate, m^3/s.

A.4.1.2 Sample tube diameter determination, carbon balance method

When employing the carbon mass balance method, determine the sampling tube's diameter as given in Formula (A.4).

$$d_{sample} = 2\sqrt{\frac{6Q_{sample}}{\pi v_{plume}}} \quad \text{(A.4)}$$

where

d_{sample} is the internal diameter of the sampling tube, m;

v_{plume} is the plume's velocity, m/s;

Q_{sample} is the sampling rate, m^3/s.

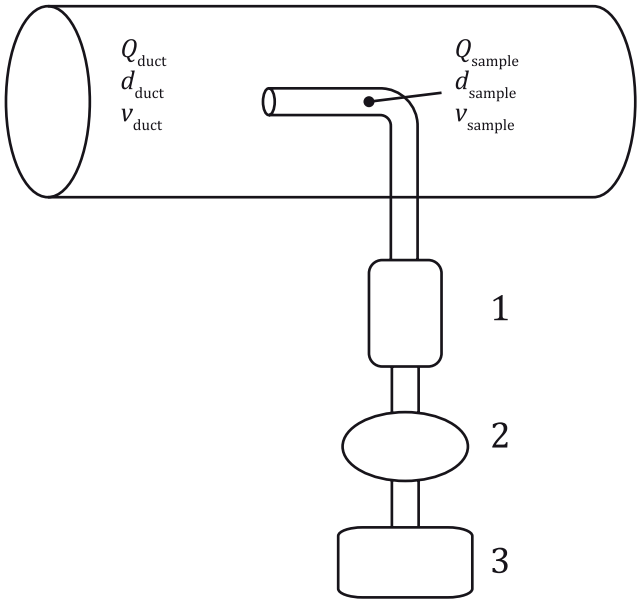
An anemometer or similar device may be used to approximate plume velocity. The temperature limits of the anemometer should be checked to ensure appropriate range for measuring the plume.

The sampling tube's axis should be parallel to the plume's velocity.

A.4.2 Aerosol mass concentration measurement

Aerosol mass concentration, such as $PM_{2,5}$, should be measured by sampling of aerosol onto quartz, glass fibre, or PTFE gravimetric filters as described in ISO 9096. See A.9 and Figure A.1.

Optical-based methods are not an acceptable reference for quantifying cookstove-generated aerosol mass concentrations because optical methods are calibrated to the optical properties of a given source and are less accurate than gravimetric methods, especially when significant mass is below ~50 nm to 100 nm (see Amaral et al. 2015[114]).



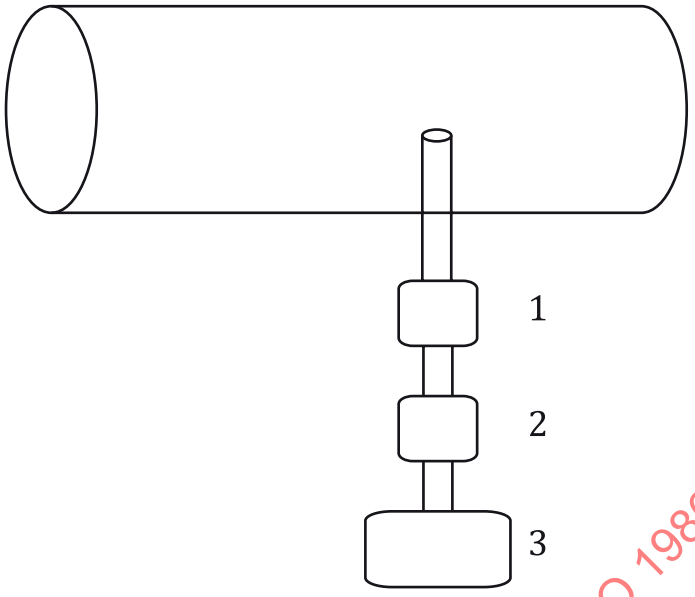
Key

1	cyclone or impactor
2	filter holder
3	pump and flow control
d_{sample}	internal diameter of the sampling tube, m
d_{duct}	internal diameter of the exhaust duct, m
Q_{duct}	volumetric flow rate through the exhaust system, m^3/s
Q_{sample}	sampling rate, m^3/s
v_{duct}	velocity of gas in duct, m/s
v_{sample}	velocity of gas in sample probe, m/s

Figure A.1 — Representative diagram of an aerosol mass concentration sampling system

A.4.3 Sampling of gaseous pollutants

Sampling of gaseous species need not be isokinetic, see Figure A.2. However, care should be taken to ensure gas analysis equipment is protected from high aerosol concentration and relative humidity that can be present in the duct. If reactive species are being sampled, care should be taken to choose appropriate sampling tube materials to reduce losses due to wall reactions. Typically, cookstove testing can be conducted using gas measurement instruments with a full scale of 10 000 ppm for CO_2 and 1 000 ppm for CO, although other full scales may be used depending on testing conditions.



Key

1 aerosol filtration
2 dryer
3 gas analyzer

Figure A.2 — Representative diagram of a suggested carbonaceous gas sampling system

A.4.3.1 Integrated measures

For integrated measures such as filter-based aerosol mass concentration, average mass emission rate from the source over the integration period, t, ($E_{s,i}$) can be calculated as given in Formula (A.5).

$$\dot{E}_{s,i} = R\left(\frac{m}{tQ_{\text{sample}}} - C_{i,0}\right)Q_{\text{duct}} \tag{A.5}$$

where

$\dot{E}_{s,i}$ is the average mass emission rate from the source over the integration period, g/s;

R is the dilution ratio of the solution, unitless;

m is the integrated mass of the pollutant sampled, g;

t is time, s;

Q_{sample} is the sampling volumetric flow rate, m^3/s;

$C_{i,0}$ is the mass concentration of the pollutant of interest in ambient air, g/m^3;

Q_{duct} is the volumetric flow rate through the exhaust system, m^3/s.

NOTE 1 Formula (A.5) is applicable for total-capture (hood and duct) based sampling schemes, but it is not relevant for sampling from a room or other indoor environment.

NOTE 2 It is assumed that the dilution stream, if any, contains negligible concentrations of the pollutant of interest. This assumption is not always true, especially if the primary dilution stream is ambient air from a polluted environment.

NOTE 3 Q_{duct} always refers to the pre-sample volumetric flow rate through the duct at the duct's temperature and pressure. However, it is rare in practice that measuring Q_{duct} post-sample could affect results because, typically, $Q_{duct} >> Q_{sample}$.

EXAMPLE A typical total capture system can have Q_{duct} = 7 000 LPM while Q_{sample} = 16,7 LPM, leading to an error of ~0,2 % if the Q_{duct} is defined incorrectly.

A.4.3.2 Real-time measurements

For real-time systems measuring concentration, such as a gas analyser, source emissions rate is defined as given in Formula (A.6).

$$\dot{E}_{s,rt} = RC_{sample,DTP}Q_{duct} \quad \text{(A.6)}$$

where

$\dot{E}_{s,rt}$ is the real-time source emission rate, g/s;

R is the dilution ratio of the solution, unitless;

$C_{sample, DTP}$ is the fire-generated mass concentration of the pollutant of interest at the same temperature and pressure as that of the duct, g/m^3;

Q_{duct} is the volumetric flow rate through the exhaust system, m^3/s.

Temperature and pressure correction can be applied as given in Formula (A.7).

$$C_{sample,DTP} = \left(C_{sample} - C_0\right)\left(\frac{T_{sample}}{T_{duct}}\right)\left(\frac{P_{duct}}{P_{sample}}\right) \quad \text{(A.7)}$$

where

$C_{sample, DTP}$ is the fire-generated mass concentration of the pollutant of interest at the same temperature and pressure as that of the duct, g/m^3;

C_{sample} is the measured concentration of the sample, g/m^3;

C_0 is the mass concentration of the pollutant of interest in ambient air, g/m^3;

T_{sample} is the temperature of the sample gas, K;

T_{duct} is the temperature of gas in the duct, K;

P_{duct} is the pressure in the duct, Pa;

P_{sample} is the pressure in the sample line, Pa.

NOTE 1 T and P are measured in absolute units, i.e. Kelvin and absolute Pascals.

NOTE 2 Sampling with instruments from a duct and dilution tunnel has inherent time lag. The sample will rise from the fire and travel through the duct, dilution tunnel, and sampling lines before finally arriving at the instrument. Additionally, the instrument may have its own time delay (e.g. electrochemical methods for measuring CO). For this reason, 'real-time' data may lag the behaviour of the cookstove, typically by 5 s to 30 s. It is important to consider time delays and instrument response times when analysing data, considering the effects of response time on aliasing, and when aligning data streams in the time domain.

A.5 Carbon balance method

For integrated measures such as filter-based aerosol mass concentration, average emissions rate from the source over the integration period, t, ($E_{s,i}$) can be calculated as given in Formula (A.8).

$$\dot{E}_{s,i} = R\frac{m}{z_C t} \tag{A.8}$$

where

$\dot{E}_{s,i}$ is the average emissions rate from the source over the integration period, g/s;

R is the dilution ratio, unitless;

m is the mass of pollutant collected on the filter, g;

z_C is the fraction of all elemental carbon, having originated from the fire, that passed through the sampling device, unitless;

t is time, s.

For fuel containing a dry mass fraction of elemental carbon, $f_{c,w}$, burned in a fire lasting time t, z_c can be written as given in Formula (A.9).

$$z_C = \frac{Q_{\text{sample}} \sum_{i=1}^{n} f_{c,i} \int_o^t (C_i - C_{i,0})\mathrm{d}t}{f_{c,w} m_w} \tag{A.9}$$

where

z_C is the fraction of all elemental carbon, having originated from the fire, that passed through the sampling device, unitless;

Q_{sample} is the volumetric sampling rate, m^3/s;

n is the number of carbon-containing molecules, unitless;

$f_{c,i}$ is the mass fraction of carbon in carbon-containing molecules, unitless;

C_i is the total mass concentration of any carbon-containing species, g/m^3;

$C_{i,0}$ is the ambient (background) mass concentration of any carbon-containing species, g/m^3;

t is the time duration of the fire, s;

$f_{c,w}$ is the dry mass fraction of elemental carbon contained in the fuel, unitless;

m_w is the mass of fuel, g.

NOTE To determine $f_{c,w}$, an elemental composition analysis of the fuel's dry carbon and ash content is required with the most important outcome being the elemental carbon mass fraction by dry fuel mass.

EXAMPLE A wood containing 45 % elemental carbon by dry mass is burned in a test. A given phase of the test lasts 30 min. Over this time, 500 g of dry wood mass is consumed. The ambient concentrations of CO_2 and CO are 400 ppm and 0 ppm, respectively. A researcher places a tube into the fire's emissions plume to measure $PM_{2,5}$. The time-varying concentrations of CO_2 and CO in the tube are shown in Figure A.3. Given that 5 mg of $PM_{2,5}$ deposited on the researcher's filter during the test and that the filter had a volumetric flow rate of 16,7 LPM, determine the total mass emission rate of $PM_{2,5}$ from the fire. The sampler has no dilution. Assume elemental carbon mass in wood is emitted primarily as CO_2 and CO.

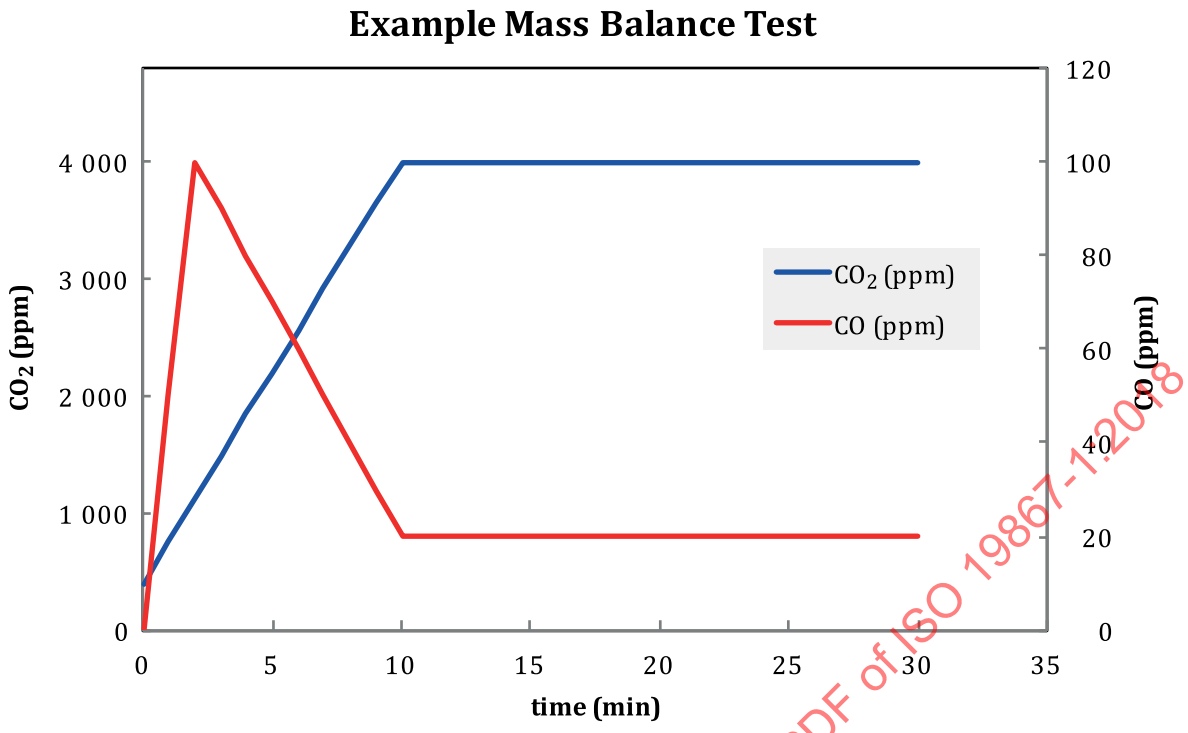


Figure A.3 — Time-varying concentration of CO_2 and CO in the sample tube

First, integrate the time series of CO_2 and CO.

$$\int_{t=0}^{t=30\ \text{min}} \left[C_{CO}(t) - C_{CO}(0)\right] dt = 980\ \text{ppm}\cdot\text{minute}$$

$$= 980\ \text{ppm}\cdot\text{minute}\left(\frac{\text{mol}}{24{,}79\ \text{l}}\right)\left(\frac{28\ \text{g}}{\text{mol}}\right) = 1{,}11\times10^{-3}\ \frac{\text{g}\cdot\text{min}}{\text{l}}$$

where

t is the time duration of the fire, s;

$C_{CO}(t)$ is the concentration of CO as a function of time (i.e. at the sampling rate provided by the instrument), g/m^3;

$C_{CO}(0)$ is the ambient concentration of CO (at $t = 0$, before the fire is lit), g/m^3.

NOTE 1 Conversion of ppm·min to units of g·min/l uses the molar volume of air at STP (24,79 l/mol) and molar mass of CO (28 g/mol).

Similarly, for CO_2:

$$\int_{t=0}^{t=30\ \text{min}} \left[C_{CO_2}(t) - C_{CO_2}(0)\right] dt = 0{,}160\ \frac{\text{g}\cdot\text{min}}{\text{l}}$$

where

t is the time duration of the fire, s;

$C_{CO_2}(t)$ is the concentration of CO_2 as a function of time (i.e. at the sampling rate provided by the instrument), g/m^3;

$C_{CO_2}(0)$ is the ambient concentration of CO_2 (at t = 0, before the fire is lit), g/m^3.

NOTE 2 Units of ppm·min are converted to g·min/l using the molar volume of air at STP (24,79 l/mol) and molar mass of CO_2 (44 g/mol).

Then, assuming f_c = 12/(12 + 16) for CO and f_c = 12/(12 + 2 × 16) for CO_2, z_C is calculated as:

$$z_C = \frac{Q_{sample}\sum_{i=1}^{n} f_{c,i}\int_o^t \left(C_i - C_{i,0}\right)dt}{f_{c,w}m_w} = \frac{16{,}7\,\frac{l}{min}\left(\frac{12\ g/mol}{28\ g/mol}1{,}11\times10^{-3}\,\frac{g\cdot min}{l} + \frac{12}{44}0{,}160\,\frac{g\cdot min}{l}\right)}{(0{,}45\times500\ g)} = 0{,}327\ \%$$

Finally, we arrive at the emission rate:

$$\dot{E}_{s,i} = R\frac{m}{z_C t} = 1\frac{5\ mg}{0{,}003\ 27\times30 min} = 51\frac{mg}{min}$$

NOTE 3 For more information on the carbon balance method, see Zhang et al. 2000[125].

A.6 Combustion efficiency

Combustion efficiency can be useful to determine for cookstove development and research purposes.

Due to the complexity of determining combustion efficiency, a proxy is often used as an indicator of combustion efficiency. Nominal combustion efficiency (CO_2/[CO_2 + CO + PM + HC_X], where HC_X is total hydrocarbons) or modified combustion efficiency (CO_2/[CO_2 + CO]) are useful proxies for combustion efficiency.

The determination of combustion efficiency may be based on DIN 1942[98], ASME PTC 4.1[96], or BS 845-1[97].

A.7 Leak test method

A.7.1 Application

This leak test method should be applied to

a) the entire part of a sampling system that operates under a vacuum (negative gauge pressure), in order to ensure the sample is not diluted, and

b) the entire part of a sampling system that operates under pressure (positive gauge pressure) in which volumetric flow measurement is required, in order to ensure that volumetric flow is accurately measured.

This leak test method may also be applied to a part of a sampling system that operates under positive pressure in which volumetric flow measurement is not required (e.g., between outlet of sampling pump and inlet of gas analyzers), but this is not a requirement, because if sufficient volumetric flow is maintained, then the sample is not diluted.

A.7.2 Procedure

The internal volume should be determined for the part of the sampling system to be leak tested. Internal volume should be determined either

a) by calculating volume from measured internal dimensions, or

b) by filling the system with water and measuring the volume directly.

Residual water may be removed from the sampling system with a vacuum pump.

The typical operating pressure of the sampling system should be measured.

The part of the sampling system under test should be pumped to the operating pressure (or lower for a system under vacuum, higher for a system under pressure), and the system should be closed off with valves.

The pressure change (if any) should be measured over time.

The leak rate should be calculated using the measured rate of change in pressure and the internal volume of the sampling system as given in Formula (A.10).

$$LR = V \times \Delta P_{\text{leak}} t \times P_{\text{atm}} \tag{A.10}$$

where

LR is the leak rate, l/min;

V is the internal volume of the sampling system, l;

ΔP_{leak} is the change in pressure during time t, due to the leak, Pa;

t is the elapsed time of the leak test, min;

P_{atm} is the atmospheric pressure, Pa.

A.7.3 System test

In addition to required leak tests, a periodic system test is recommended, as follows.

CO_2 gas should be delivered at a known flow rate into the emissions hood by either

a) measuring the change in mass of solid CO_2 (dry ice) over time, or

b) measuring the flow rate of compressed CO_2 gas (or other tracer gas).

The CO_2 concentration in the dilution tunnel should be calculated as given in Formula (A.11).

$$C = C_b + \frac{Q_{CO_2} \times 10^6}{Q_{\text{tunnel}}} \tag{A.11}$$

where

C is the concentration of CO_2 in the dilution tunnel, ppm;

C_b is the background concentration of CO_2 in ambient air, ppm;

Q_{CO2} is the volumetric flow rate of CO_2 delivered to the hood, l/min;

Q_{tunnel} is the volumetric flow rate of air in the dilution tunnel, l/min;

10^6 is the conversion factor to ppm.

The CO_2 concentration should be measured at the sampling location. The CO_2 gas analyser should be checked for calibration as specified in 5.3.7. If the calculated and measured CO_2 concentrations are not in close agreement (depending on system), then the emissions measurement system should be evaluated to identify and correct the problem.

A.8 Method for validating well-mixed emissions in a duct

A.8.1 General

This method is provided as an example for determining if diluted exhaust from a cookstove is well mixed in a duct prior to sampling with emission measurement instruments. In this method, a tracer gas is injected upstream of the sample port, roughly at the mouth or inlet of the duct, and a sample probe connected to the corresponding gas analyser takes measurements at several locations across (radially) the full diameter of the duct.

A.8.2 Equipment

This method requires

a) a sample probe,

b) a tracer gas (e.g., CO_2, CO, SF_6),

c) a precision mass or volumetric flow control device, and

d) a corresponding gas analyser for the tracer gas.

The sample probe should be long enough to traverse the full diameter of the duct.

It is recommended that the gas analyser have a measurement interval no greater than 1 s. When selecting a tracer gas, it is important to ensure the difference between the expected concentration of the diluted tracer gas in the duct and the background ambient concentration of the tracer exceeds the bias error of the analyser.

A.8.3 Preparation

Prior to the experiment:

a) Analysers should be zeroed and spanned.

b) Calculations should be performed to estimate the expected tracer gas concentration in duct after dilution. This calculated concentration shall be greater than the bias of the gas analyser to ensure accurate measurements.

A.8.4 Introduction of tracer to duct

The tracer gas should be introduced into the duct's inlet axial with airflow and at a similar velocity as the airflow (isokinetic injection). For additional certainty, more experiments may be performed with

tracer introduced tangentially to the duct; using both configurations can increase certainty that the sample is fully mixed in the duct.

A.8.5 Procedure

The procedure is as follows:

a) To begin the experiment, position the sample probe at the axis of the duct.

b) Next, inject tracer gas at a steady volumetric rate into the hood and wait until steady-state measurements are achieved on the gas analyser instrument (at least 1 min).

c) After reaching steady-state, leave the probe in the same position and turn off the sample gas. Continue sampling until the analyser reads background concentrations (at least 1 min).

d) Repeat this process as needed to achieve desired level of confidence.

e) When desired level of confidence is achieved for the first probe position, move the probe to a new axial location in the duct, closer to the wall, and repeat the process of pulsing on and off the tracer gas. Collect data for five axial positions in the duct (e.g. 0D, 1/4D, 1/2D, 3/4D, and D).

f) Compare results to predicted (calculated) gas concentrations and calculate the error.

In addition to analysing at mean concentration of diluted tracer, it is recommended that the variance of tracer concentration with respect to time be compared with the instrument's native variance (noise) when measuring ambient air. This step ensures that the tracer is not just well mixed on average, but also well mixed at the time scale of the instrument's sampling rate.

A well-mixed duct should have a tracer whose mean concentration is within 5 % of the expected value and no more than 10 % variation between the maximum and minimum measurement.

A.9 Guidance on filter media selection

Table A.1 provides guidance on filter selection.

Table A.1 — Advantages and disadvantages of filter types

Media Type	Polytetrafluoroethylene (PTFE/Teflon)	Glass Fibre	Quartz
Advantages	— Strong and robust — Chemically inert — Well suited for gravimetric measurements	— Low cost — Well suited for gravimetric measurements — Appropriate for thermal-optical EC/OC measurements	— Low cost — Appropriate for thermal-optical EC/OC measurements
Disadvantages	— Typically more expensive — Not appropriate for thermal-optical EC/OC measurements	— Can exhibit artifacts due to gas-to-particle conversions — More fragile than PTFE	— Fragile — often not well suited for gravimetric measurements, especially when the mass captured on the filter is small (<0,5 mg) — Prone to absorbing moisture, which can impact gravimetric measurements — Can exhibit artifacts due to gas-to-particle conversions if the filter has been strengthened through an alkali treatment
References: *Investigation of Filter Media*[95] and Hinds 2012[116].			

Annex B
(normative)

Total-capture dilution-tunnel gravimetric method for measurement of $PM_{2,5}$

See 5.3.8. Emissions collection apparatus shall conform to the required minimum dimensions specified in Figures B.1, B.2, B.3, and B.4. Duct diameter shall be between 0,1 m and 0,3 m. A duct diameter of 0,15 m should be used where feasible.

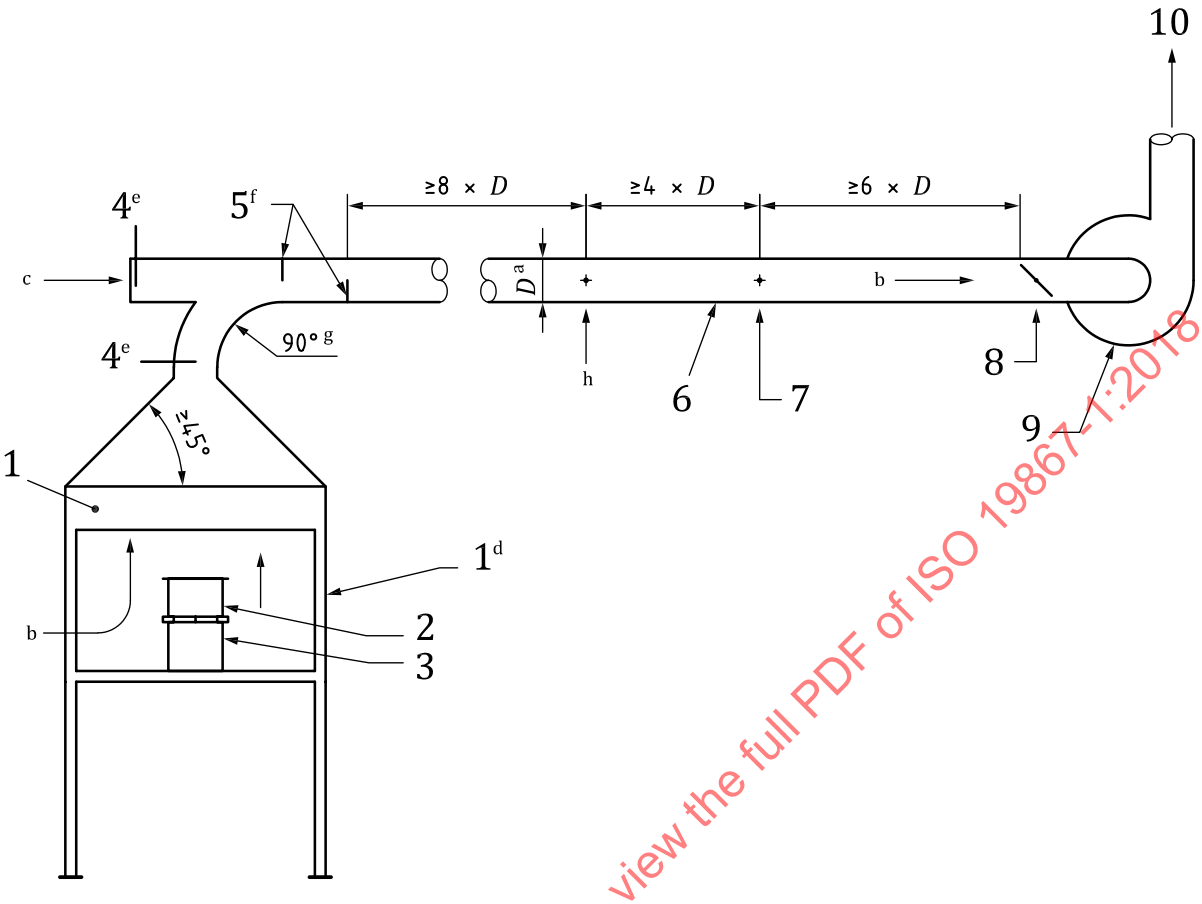
The opening of the hood shall face toward the user or tester. The hood shall be designed so as to fully enclose the stove being tested. The shape of the hood and the layout of the components need not conform to those depicted in the figures; these features are shown schematically for illustration purposes only.

Another approach to controlling the flow rate may be used in place of the damper.

The provision of additional dilution air with the use of the two gate valves shown in Figure B.1 is optional. See 5.3.8.2.4.

If only fugitive emissions are to be sampled as shown in Figure B.3, then a separate duct shall be provided to exhaust chimney emissions.

NOTE 'Tall chimneys' refers to chimneys whose height prevents enclosure within a typical hood as depicted in Figure B.1.

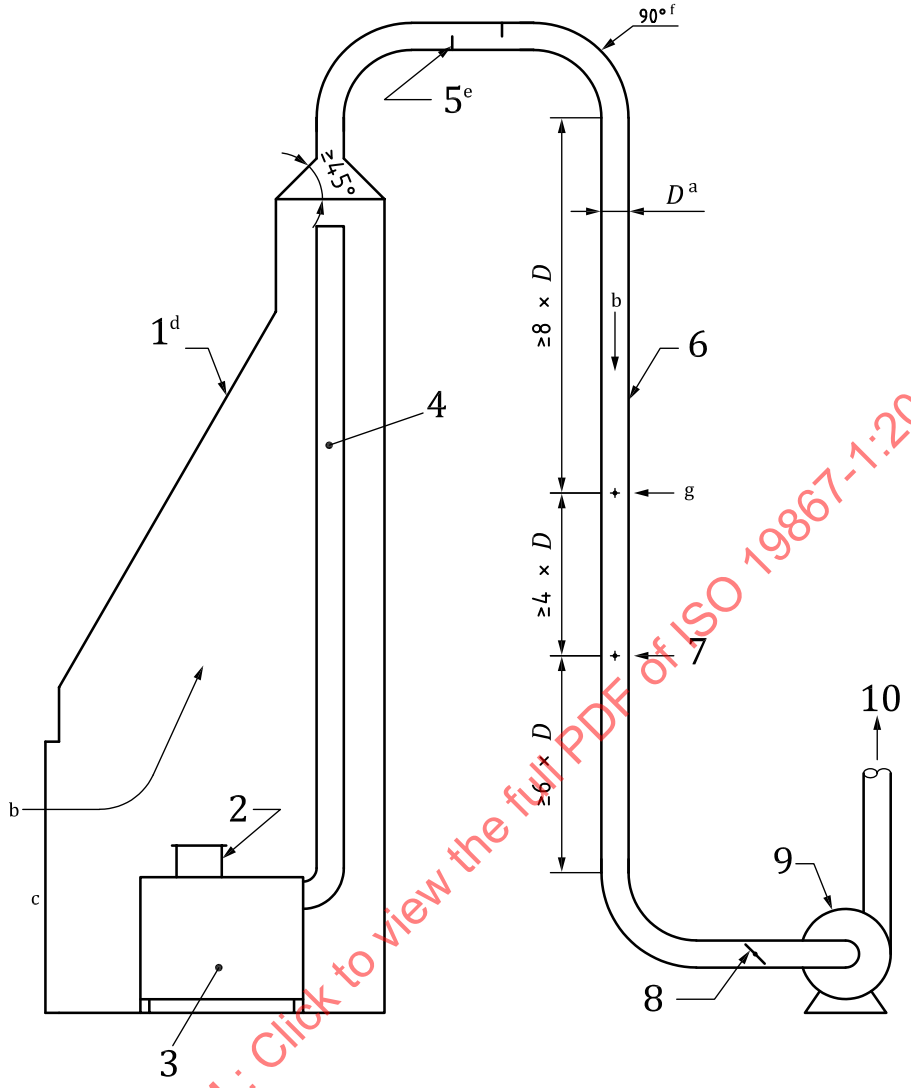


Key

1	hood	a	D = 15 cm recommended or 10 cm to 30 cm acceptable.
2	cooking vessel	b	Air flow.
3	cookstove	c	Additional dilution air (optional).
4	gate valve	d	Hood enclosed on three sides.
5	baffles	e	Optional.
6	dilution tunnel	f	See Note.
7	sample ports	g	Elbow.
8	damper or other flow control	h	Velocity measurement location.
9	blower		
10	exhaust		

NOTE Baffles not required if adequate mixing is demonstrated (see text).

Figure B.1 — Hood and dilution tunnel apparatus for collecting emissions from cookstoves without tall chimneys

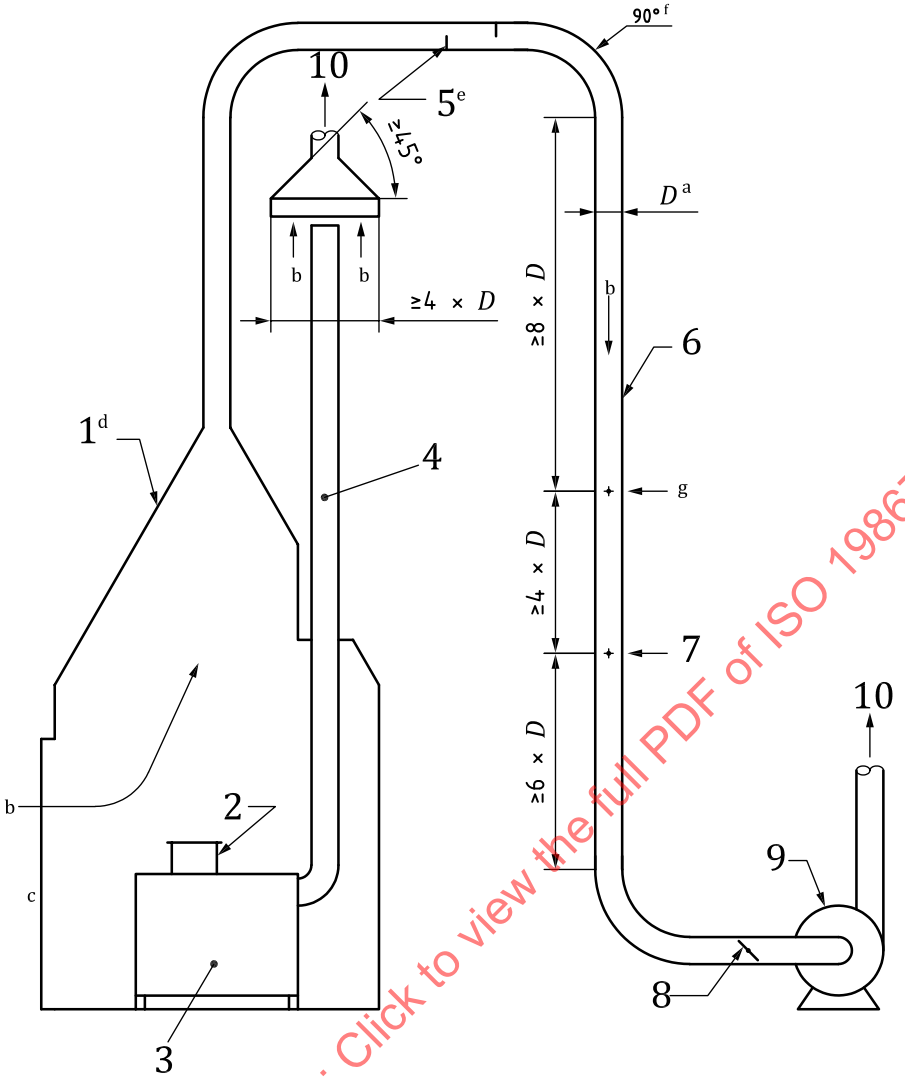


Key

1	hood	a	D = 15 cm recommended or 10 cm to 30 cm acceptable.
2	cooking vessel	b	Air flow.
3	cookstove	c	Open face area.
4	chimney	d	Hood enclosing cookstove and chimney.
5	mixing baffles	e	See Note.
6	dilution tunnel	f	Elbow.
7	sample ports	g	Velocity measurement location.
8	damper or other flow control		
9	blower		
10	exhaust		

NOTE Baffles not required if adequate mixing is demonstrated (see text).

Figure B.2 — Hood and dilution tunnel apparatus for collecting total emissions from cookstoves with tall chimneys

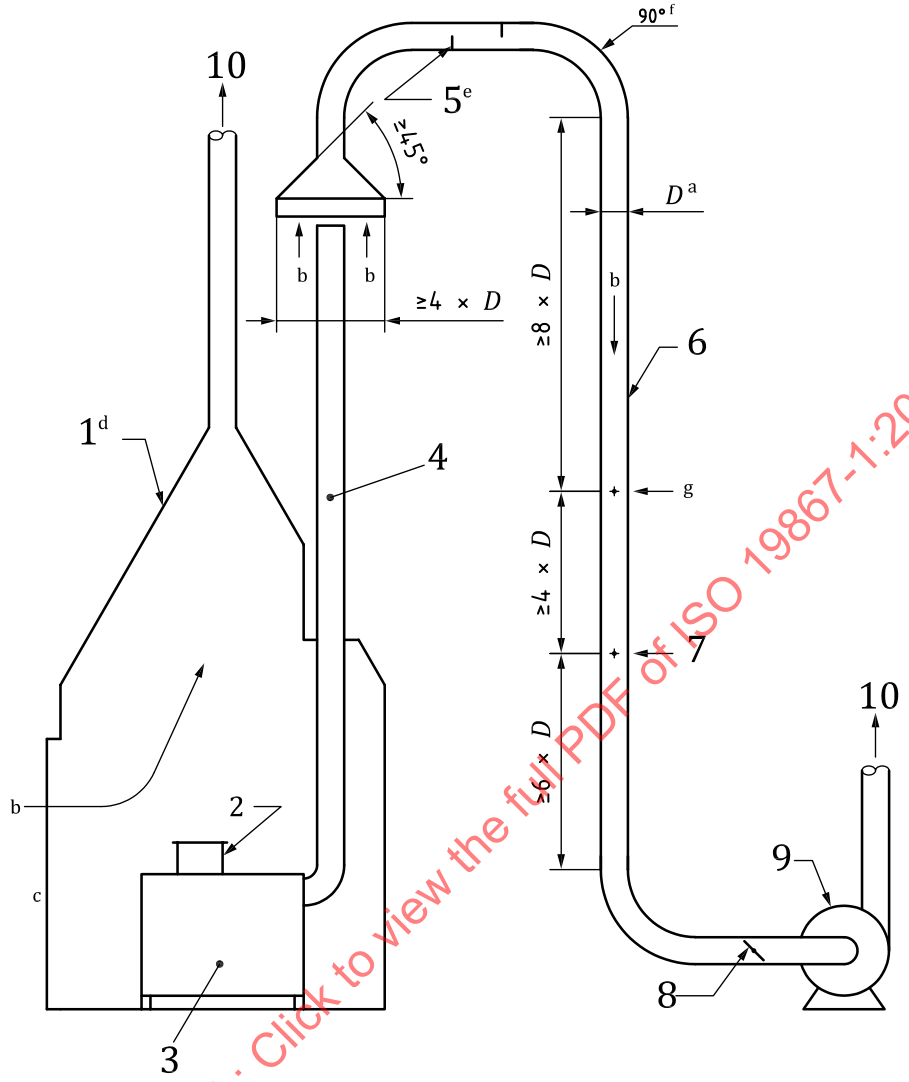


Key

1	hood	a	D = 15 cm recommended or 10 cm to 30 cm acceptable.
2	cooking vessel	b	Air flow.
3	cookstove	c	Open face area.
4	chimney	d	Hood enclosing cookstove.
5	mixing baffles	e	See Note.
6	dilution tunnel	f	Elbow.
7	sample ports	g	Velocity measurement location.
8	damper or other flow control		
9	blower		
10	exhaust		

NOTE Baffles not required if adequate mixing is demonstrated (see text).

Figure B.3 — Hood and dilution tunnel apparatus for collecting fugitive (indoor) emissions from cookstoves with tall chimneys

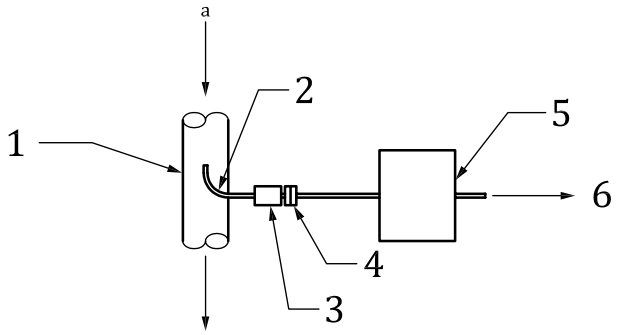


Key

1	hood	a	D = 15 cm recommended or 10 cm to 30 cm acceptable.
2	cooking vessel	b	Air flow.
3	cookstove	c	Open face area.
4	chimney	d	Hood enclosing cookstove.
5	mixing baffles	e	See Note.
6	dilution tunnel	f	Elbow.
7	sample ports	g	Velocity measurement location.
8	damper or other flow control		
9	blower		
10	exhaust		

NOTE Baffles not required if adequate mixing is demonstrated (see text).

Figure B.4 — Hood and dilution tunnel apparatus for collecting chimney emissions excluding fugitive emissions from cookstoves



Key

1 dilution tunnel
2 sampling probe
3 $PM_{2,5}$ size selective device
4 filter holder
5 metering system (including pump)
6 exhaust
a Air flow.

Figure B.5 — $PM_{2,5}$ sampling train

Annex C
(informative)

Standard test sequence — Additional considerations

C.1 Cooking vessel

It is important to test with an appropriate size of cooking vessel or as specified by the manufacturer. In general, a larger cooking vessel has greater surface area with potential for improved heat transfer and enhanced performance in testing, but a cooking vessel that is too large would not typically be used in the field. For example, a cooking vessel that is too large might not be used in the field because the contents of the vessel cannot be brought to the desired cooking temperature (typically the local boiling point of water).

C.2 Low power

For continuously fed cookstoves, such as rocket-type cookstoves, extremely low cooking power can be achieved if very small size (matchstick size) fuel is used, but this fuel size is not typical of actual use in the field. If field data are available, then the cookstove shall be operated at the lowest practical power level observed in the field with the fuel size typically used in the field.

C.3 High power

For continuously fed cookstoves, such as rocket-type cookstoves, one way to generally define high power during testing (and during use in the field) is to feed fuel at a rate that allows flames to touch the bottom of the cooking vessel but not to extend up the sides of the vessel. For this type of cookstove, cooking power exceeding manufacturers' specifications has frequently been observed in the field when users overfill the fuel/air opening with fuel. A way to approximately simulate this overfeeding of fuel is to feed fuel at a rate that allows flames to extend up the sides of the cooking vessel but not to extend past the top of the vessel.

C.4 Assembly of Mylar pot for testing plancha cookstoves

Flexible Mylar pots conform to the griddle surface of plancha cookstoves. See Figure C.8.

NOTE Mylar is a trademark, and other similar polyester film products are available.

WARNING — Use extreme caution when handling Mylar pots containing hot water. Use personal protective equipment specified in C.4.1, and see Figure C.8.

Griddle cookstoves may be tested with either the 'plancha-olla' (plancha-pot) method or the 'Mylar pot' method — see 6.8.1.

C.4.1 Materials

Materials needed for the Mylar pot test are as follows:

Mylar pot materials:

a) Mylar (polyester) film (material dimensions should be approximately 0,127 mm thick and 122 cm wide);

b) metal sheet, (material dimensions should be approximately 0,38 mm thick and 5 cm wide).

Personal protective equipment required for safely handling Mylar pots containing hot water:

a) thick rubber gloves with long gauntlets;

b) thick rubber high-top boots;

c) thick rubber apron;

d) splash shield that fully covers face.

See Figure C.8.

C.4.2 Mylar pot assembly process

The Mylar pot should be assembled as follows. See Figure C.1 for an illustration.

a) Measure the total surface area of the griddle.

b) Calculate 60 % of the surface area of the griddle. The result will be the surface area of the bottom of the Mylar pot. It is also possible to construct two or more pots whose bottom surface area collectively totals 60 % of the surface area of the griddle (see Example 2).

c) Calculate the height of the pot needed to contain 5 L of water (see Table C.1 for equivalences). Add 5 cm to the calculated height for the metal frame that will link the walls.

d) Draw the bottom of the pot on Mylar (dimensions sufficient to cover 60 % of the griddle). Draw the walls at the height calculated in step c).

e) Cut the Mylar around the edge.

f) Carefully fold inside all the walls of Mylar. Do not cut the excess Mylar.

g) Cut and place a strip of metal around the walls.

h) Rivet the strip metal.

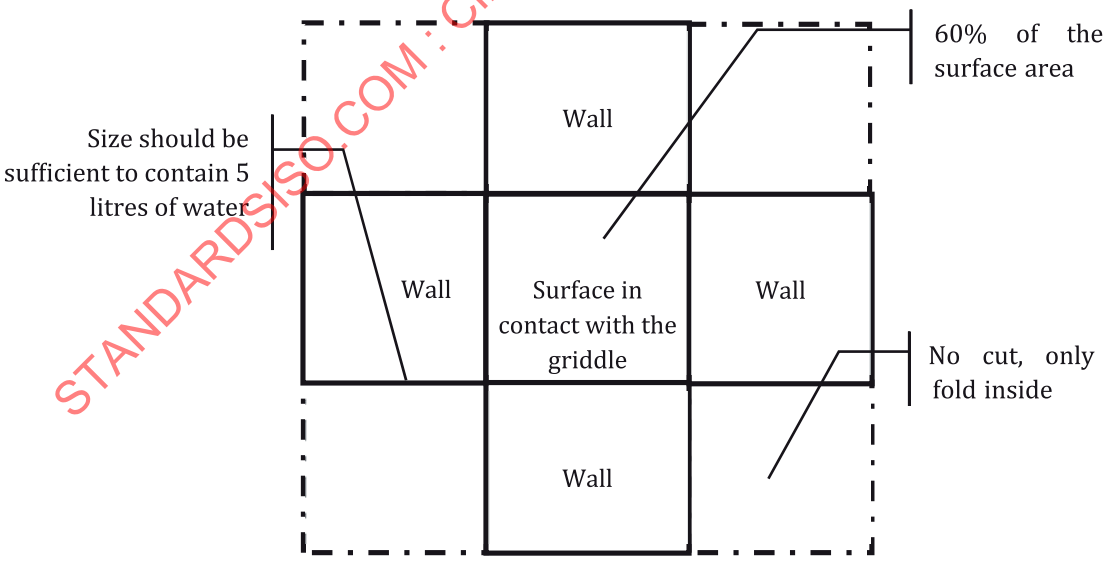


Figure C.1 — Assembly of Mylar pot

NOTE Equivalences are provided in Table C.1.

Table C.1 — Equivalences

5 litres water	5 000 cubic centimetre of water	305,1 cubic inches of water

EXAMPLE 1 An example Mylar pot assembly process is provided for a griddle with the dimensions 40 cm by 60 cm in Figures C.2 to C.4.

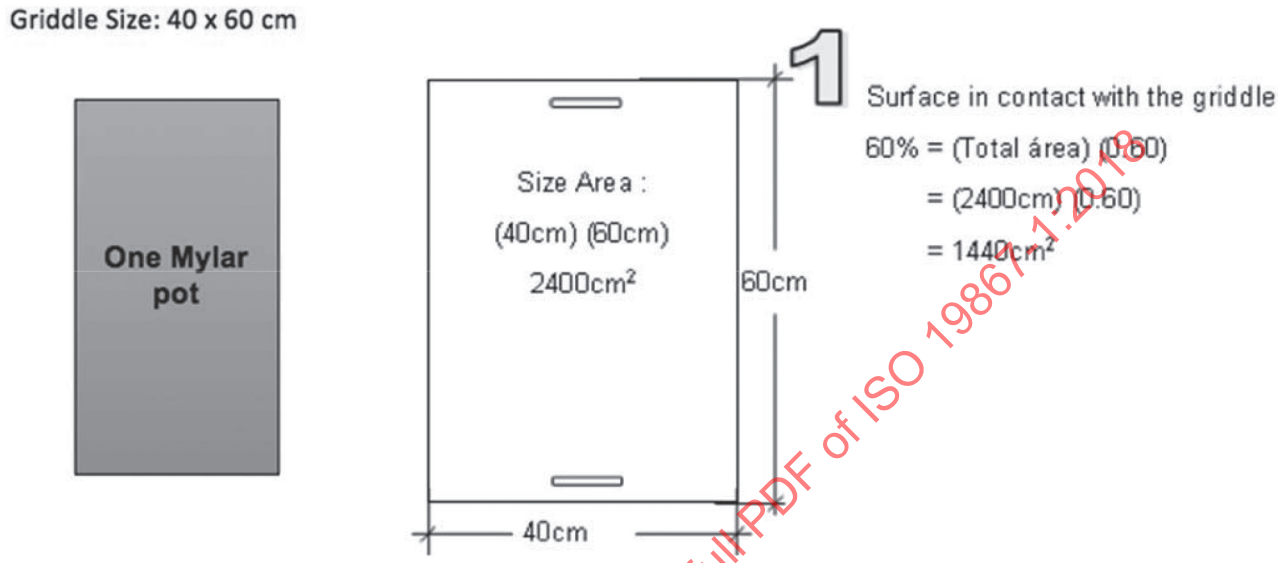


Figure C.2 — Example calculation of Mylar pot size for 40 cm by 60 cm griddle

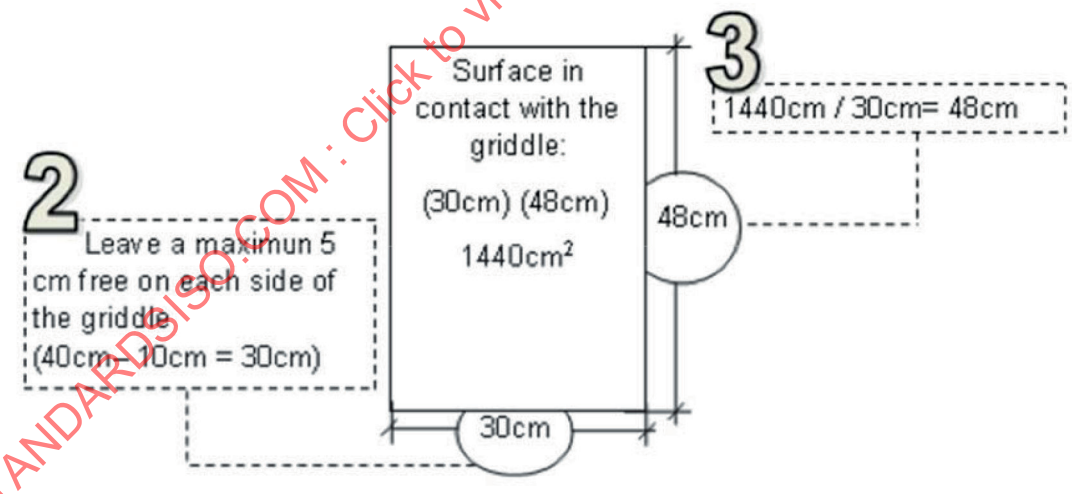


Figure C.3 — Example dimensions of Mylar pot surface in contact with 40 cm by 60 cm griddle surface

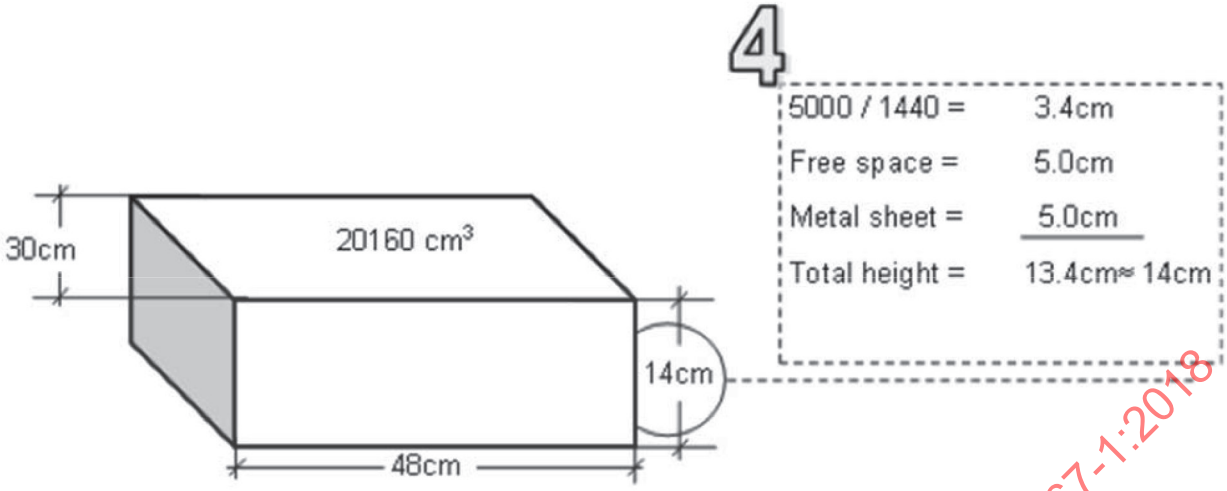


Figure C.4 — Example Mylar pot dimensions for 40 cm by 60 cm griddle

EXAMPLE 2 An example assembly process using two Mylar pots is provided in Figures C.5 to C.7.

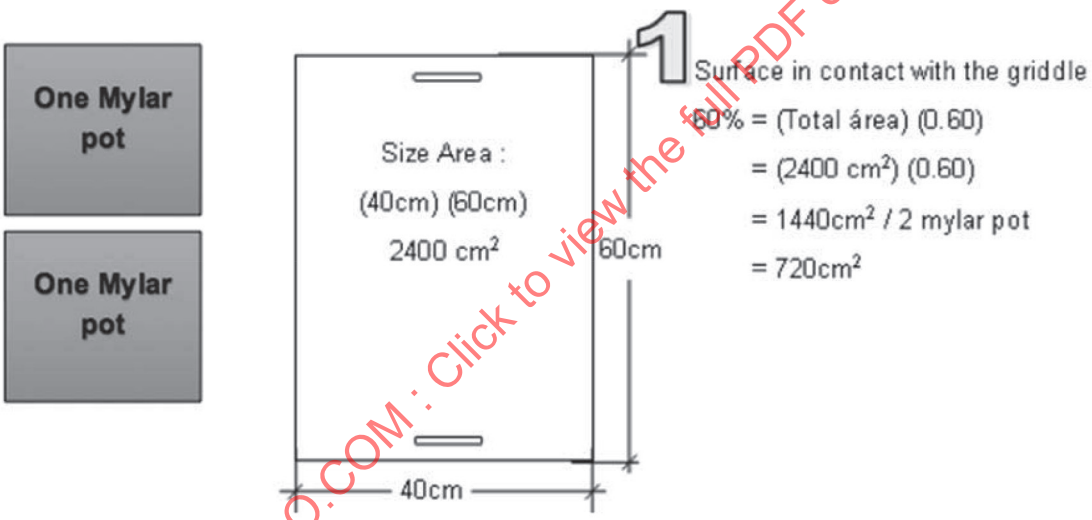


Figure C.5 — Example calculation of pot size using two Mylar pots for 40 cm by 60 cm griddle

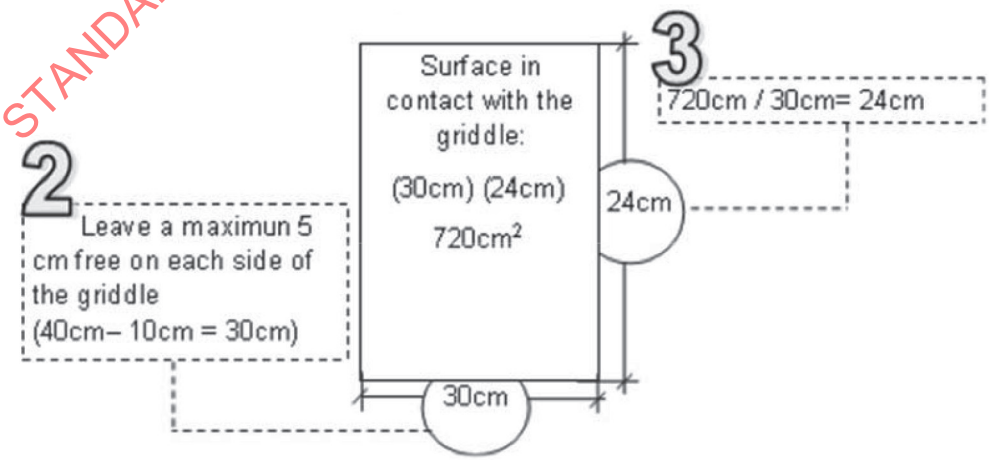


Figure C.6 — Example dimensions of Mylar pot surface for each of two mylar pots in contact with 40 cm by 60 cm griddle

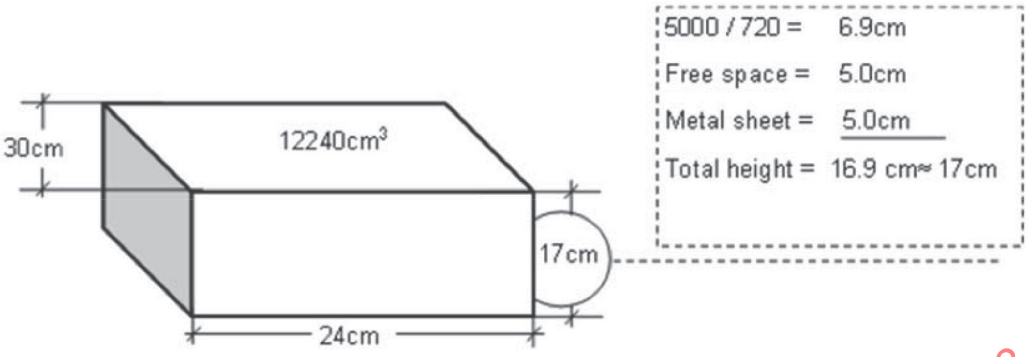


Figure C.7 — Example dimensions of each of two Mylar pots for 40 cm by 60 cm griddle

Figure C.8 — Photograph of a tester wearing required personal protective equipment and holding a typical Mylar pot

Annex D
(informative)

Cookstove family determination

D.1 General

Test sequences and testing protocols can vary based on certain characteristics of the cookstove. These characteristics are fuelling process, heating surface, exhaust type, and fuel type. The cookstove family should be determined for each cookstove prior to testing to understand if there are any relevant variations of the test sequence and testing protocols.

D.2 Fuelling process

Excluding solar cookstoves, a fuelled cookstove is defined as either a batch-loaded cookstove or a continuously fed cookstove. Information applicable to continuously fed cookstoves is in 6.7.2 and C.2 and C.3.

D.3 Heating surface(s)

A cookstove can either have a plancha surface (also known as a griddle surface), a single burner, or multiple burners. 6.8.1 and C.4 describe how to conduct a standard test sequence for a plancha cookstove. 5.4.2 describes how to calculate useful energy delivered for cookstoves with multiple cooking vessels on multiple burners.

D.4 Exhaust type

A cookstove can either have a chimney (also known as a flue) or not have a chimney (open cookstove). 6.8.2 describes how to conduct a standard test sequence for a chimney cookstove.

D.5 Fuel type

D.5.1 Solid-fuel

A solid-fuel cookstove is designed to burn a solid fuel, such as wood, charcoal, coal, dung, pellets, or other biomass.

D.5.2 Liquid/gas-fuel

A liquid/gas-fuel cookstove is designed to burn a liquid and/or gaseous fuel, such as LPG (liquefied petroleum gas), biogas, alcohol, plant oil, or kerosene. For safety evaluation of liquid/gas-fuel cookstoves, see ISO 23550 and ISO 23551 (all parts).

D.5.3 Solar

A solar powered cookstove is one in which radiation from the sun is used to heat and cook. 5.1 describes how cooking power is determined for solar cookstoves. 7.2 outlines how safety test procedure varies for solar cookstoves.

D.5.4 Electric

Electric stoves are outside the scope of this document. For safety evaluation, see IEC 60335-2-6[62].

Annex E
(informative)

Laboratory-based safety and durability measurements — Additional considerations

E.1 Safety considerations

E.1.1 General

There are a few characteristics of cookstoves and fires that could be potential safety hazards, causing fires, burns, and cuts. Design and evaluation of cookstoves may include evaluation of safety considerations, which can be done with simple equipment.

E.1.2 Stability

It is important that a cookstove be stable enough to maintain an upright orientation when in operation. Burning fuel can be expelled from a combustion chamber or spilled when a cookstove becomes overturned. This expulsion can cause burns to the eyes and can also set fire to surrounding materials or household structure. Burning or boiling contents can spill onto surrounding persons or materials. See 7.2.3 for the cookstove tipping test.

E.1.3 Sharp edges and points

Sharp edges and points can entangle clothes and overturn the cookstove or can cut flesh. Consequently, exterior surfaces of a cookstove should not catch or tear any article of clothing or cut hands during normal use. See 7.2.2 for the sharp edges and points test.

E.1.4 Obstructions near cooking surface

Areas surrounding the cooking surface should be flat so that cooking vessels being moved from the cookstove do not collide with protruding components and overturn boiling contents onto hands or nearby children. See 7.2.5 for the obstructions near cooking surface test.

E.1.5 Chimney heat

Chimneys can become extremely hot during use and easily cause burns. The high temperatures present on a chimney are from hot flue gases leaving the cookstove, often creating higher temperatures on the chimney than anywhere else on the cookstove. See 7.2.7 for the chimney shielding test.

E.1.6 Flames

Flames touching the cooking vessel should be concealed and not able to come into contact with hands or clothing. Large amounts of flames around the cooking vessel can easily ignite clothes or produce severe burns to the hands and other parts of the body. Flames or fuel should not protrude from any fuel loading area or storage container during use. Uncontrolled flames that exit these areas very easily ignite clothes and burn nearby children and adults. See 7.2.8 for the flames surrounding cooking vessel test and 7.2.9 for the flames exiting fuel chamber test.

E.1.7 Surface temperature test

The importance of this test is apparent since children have a tendency to touch cookstoves and women are likely to come into contact with cookstove surfaces during normal use. Since children are more

sensitive to heat than adults, lower surfaces temperatures are suggested for heights within accidental touch of a child (0,9 m or less). Conversely, adults are assumed to be susceptible to accidental contact at heights below that of 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 material, temperature, and location is used to determine the likelihood for a person to avoid burns when touching a cookstove. See 7.2.6 for the surface temperature test.

E.1.8 Handle temperature test

Components where excessive temperatures can occur that need to be handled during regular use include doors for combustion chambers and handles to regulate the flow of gas/liquid. See 7.2.6 for the handle temperature test.

E.1.9 Review of safety scoring

Scoring and content of the safety test protocol will be reviewed when additional empirical evidence relating safety test scores with actual risks in practice has been reviewed and/or accrued.

E.2 Durability considerations

E.2.1 General

Durability affects numerous aspects of the cookstove sector, including usability, performance, safety, and user perception. The tests are relevant for multiple technology types, but not all of the tests are needed for every type of cookstove. The rate of temperature change (both heating and cooling) can have a major impact on material durability. Due to the existence of hot combustion temperatures and relatively cool cooking temperatures of many cooking practices, there is a risk for sudden temperature changes, or thermal shock, which can crack or break many components of the cookstove. Cookstoves also can reach extremely high temperatures at which materials can begin to breakdown and fail.

Cookstoves can also be exposed to rough handling and treatment, including but not limited to transportation, dropping of the cookstove, dropping of other items on the cookstove, and tipping over of the cookstove. Similar to external components, internal cookstove components are often exposed to rough handling and treatment, including but not limited to fuel being added to the combustion chamber and removal of ash or charcoal. One major difference between external and internal components of a cookstove is that internal components are often subjected to repeated impacts. Materials also have the potential to corrode or rust, including from temperature, humidity, a high rate of thermal cycling, and salts. Cookstove materials often have coatings (i.e. paint, powder coating, enamel, etc.) for corrosion prevention and aesthetics. However, these coatings can be damaged by impacts and temperature, which affects both user perception and product durability. Although adhesion of a coating is often reduced after a thermal cycling, in some cases the coatings 'cure', which improves their strength.

E.2.2 Durability testing order

The order in which durability tests are conducted was established because certain tests require the cookstove to be fully assembled while others target specific components. Tests are conducted in two parallel paths.

E.2.3 Extended run test

Information about the rate of temperature change of components can be useful for evaluating both component failure and risk, but evaluation of component failure and risk is considered outside the scope of this protocol.

Steady state temperature information collected in this step is used repeatedly in subsequent tests.

E.2.4 Quenching test

Many international thermal shock testing procedures evaluate performance based upon material strength of small sample pieces. This approach is not appropriate for cookstoves, since cookstove components are typically difficult or impossible to disassemble. Because of this constraint, tests are conducted on the complete cookstove.

E.2.5 Limitations to cookstove durability tests

E.2.5.1 Cookstove age

The tests can only evaluate potential durability risks based on the state of the cookstove being tested. Because the results of many of the tests outlined in this protocol will be affected by the current condition of a cookstove, it is critical to document the appearance and condition of test cookstoves prior to beginning testing. Understanding this limitation is important when using the protocol to compare different cookstove designs or samples. Unbiased comparisons require that the cookstoves being tested are of an approximately equal age. This test protocol can be conducted on new as well as aged cookstoves to evaluate how durability changes with age.

E.2.5.2 Fuel variability

Fuels can be highly variable in composition and energy content. These variations can have a direct impact on some of the tests outlined in this protocol. Two examples include the resulting surface temperatures and corrosion of cookstoves. Surface temperature will be influenced by the energy content of the fuel being used. Fuel variability will also impact the amount of corrosion or discolouration seen in cookstoves, due to variations in fuel composition. Whenever possible, the fuels used for testing should be the ones specified by the manufacturer and/or similar to the fuels used in practice, to ensure that testing represents actual conditions.

E.2.5.3 Evaluation ambiguity

This protocol seeks to assign numeric risk factor scores for each test.

Wherever possible, concrete evaluation criteria have been included, but tests conducted by different individuals can result in slightly different predicted risk scores. However, these differences are anticipated to be fairly minor for any given test.

E.2.5.4 Cookstove type

This protocol has sought to include tests appropriate for a wide range of cookstove designs and configurations.

When interpreting the results, it is important to remember that the scoring system is meant to identify known risks. The results do not imply that all possible durability risks have been tested. Some cookstove designs will require additional, targeted durability tests for specific potential failure modes.

E.3 Safety and durability testing

Both the safety and durability stress methods include quantitative scores. In order to compare different types and designs of cookstoves, a method of scoring was required. The use of numeric scores allows multiple different tests to be combined, which is not possible using letter scores. These methods should be accessible to and feasible in a broad range of organizations, with fairly minor financial investment in equipment and only basic training.

Annex F
(informative)

Scoring tables for safety and durability tests

The scoring tables provided in this annex correspond to the safety tests detailed in Clause 7 and the durability tests detailed in Clause 8.

F.1 Safety tests

F.1.1 Sharp edges and points test

Table F.1 — Scoring system for sharp edges and points test

Number of catches	Rating	Score
Four or more	Poor	1
Three	Fair	2
One or two	Good	3
None	Best	4

F.1.2 Cookstove tipping test

For each run, divide the tipped height (h) by the standing height (H) to find the ratio. The largest ratio from all the runs is the maximum ratio (R), which is used to identify the rating and score from Table F.2.

Table F.2 — Scoring system for cookstove tipping test

Maximum ratio R	Rating	Score
>0,978	Poor	1
0,961 < R ≤ 0,978	Fair	2
0,940 < R ≤ 0,961	Good	3
≤0,940	Best	4

F.1.3 Containment of fuel test

The rating and score are determined from the total area of fuel exposed, A, using Table F.3.

Table F.3 — Scoring system for containment of fuel test

Area exposed A cm^2	Rating	Score
A > 250	Poor	1
150 < A ≤ 250	Fair	2
50 < A ≤ 150	Good	3
A ≤ 50 or solar	Best	4

F.1.4 Obstructions near cooking surface test

Table F.4 — Scoring system for obstructions near cooking surface test

Maximum height difference Δh_{max}	Rating	Score
$\Delta h_{max} > 4$	Poor	1
$2{,}5 > \Delta h_{max} \geq 4$	Fair	2
$1 > \Delta h_{max} \geq 2{,}5$ or cookstove with skirt	Good	3
$\Delta h_{max} \leq 1$ or solar	Best	4

F.1.5 Surface temperature test

For each surface, calculate the difference between maximum temperature and the air temperature, ΔT.

Table F.5 — Scoring system for surface temperature test

Surface	Difference between maximum temperature and air temperature ΔT	Rating	Score
Below child line (<0,9 m) Metallic	$\Delta T > 50$	Poor	1
	$44 < \Delta T \leq 50$	Fair	2
	$38 < \Delta T \leq 44$	Good	3
	$\Delta T \leq 38$	Best	4
Below child line (<0,9 m) Non-metallic	$\Delta T > 58$	Poor	1
	$52 < \Delta T \leq 58$	Fair	2
	$46 < \Delta T \leq 52$	Good	3
	$\Delta T \leq 46$	Best	4
Above child line (≥0,9 m) Metallic	$\Delta T > 66$	Poor	1
	$60 < \Delta T \leq 66$	Fair	2
	$54 < \Delta T \leq 60$	Good	3
	$\Delta T \leq 54$	Best	4
Above child line (≥0,9 m) Non-metallic	$\Delta T > 74$	Poor	1
	$68 < \Delta T \leq 74$	Fair	2
	$62 < \Delta T \leq 68$	Good	3
	$\Delta T \leq 62$	Best	4

F.1.6 Heat transfer to the environment test

For each surface, calculate the difference between maximum temperature and the air temperature, ΔT.

Table F.6 — Scoring system for heat transfer to the environment test

Surface	Difference between maximum temperature and air temperature ΔT	Rating	Score
Floor	$\Delta T > 65$	Poor	1
	$55 < \Delta T \leq 65$	Fair	2
	$45 < \Delta T \leq 55$	Good	3
	$\Delta T \leq 45$	Best	4

Table F.6 *(continued)*

Surface	Difference between maximum temperature and air temperature ΔT	Rating	Score
Wall	$\Delta T > 80$	Poor	1
	$70 < \Delta T \leq 80$	Fair	2
	$60 < \Delta T \leq 70$	Good	3
	$\Delta T \leq 60$	Best	4

F.1.7 Handle temperature test

For each surface, calculate the difference between maximum temperature and the air temperature, ΔT.

Table F.7 — Scoring system for handle temperature test

Surface	Difference between maximum temperature and air temperature ΔT	Rating	Score
Metallic	$\Delta T > 32$	Poor	1
	$26 < \Delta T \leq 32$	Fair	2
	$20 < \Delta T \leq 26$	Good	3
	$\Delta T \leq 20$	Best	4
Nonmetallic	$\Delta T > 44$	Poor	1
	$38 < \Delta T \leq 44$	Fair	2
	$32 < \Delta T \leq 38$	Good	3
	$\Delta T \leq 32$	Best	4

F.1.8 Chimney shielding test

Table F.8 — Scoring system for chimney shielding test

Hole area A cm^2	Rating	Score
$A > 150$	Poor	1
$50 < A \leq 150$	Fair	2
$10 < A \leq 50$	Good	3
$A \leq 10$	Best	4

F.1.9 Flames surrounding cooking vessel test

Table F.9 — Scoring system 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 cooking vessel, not handles	Good	3
None or solar cookstove	Best	4

F.1.10 Flames exiting fuel chamber test

Table F.10 — Scoring system for flames exiting fuel chamber test

Occurrence of fire	Rating	Score
Flames protrude	Poor	1
Flames are contained	Best	4

F.1.11 Overall safety score

To calculate the overall safety score, the score from each of the 10 procedures is multiplied by a weighting factor based on Table F.11, and then summed for a total score:

Table F.11 — Overall safety scoring system

Procedure	Weight
1	1,5
2	3
3	2,5
4	2
5: Metal, <0,9 m	2
5: Metal, >0,9 m	
5: Non-metal, <0,9 m	
5: Non-metal, >0,9 m	
6: Floor	2,5
6: Wall	
7: Metallic	2
7: Non-metallic	
8	2,5
9	3
10	4

For procedures with multiple values, the minimum value is used to calculate the overall score. The total point score will be between 25 and 100.

F.1.12 Plancha (griddle) stove weight test

Table F.12 — Plancha (griddle) stove weight test

Low weight	<8 kg
Medium weight	$8 \leq m < 10$ kg
High weight	≥10 kg