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

Part 3: Voluntary performance targets for cookstoves based on laboratory testing

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

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

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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 (see www.iso.org/directives).

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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 World Trade Organization (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 parts in the ISO 19867 series can be found on the ISO website.

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

Introduction

It is recognized that performance assessed through laboratory testing does not always accurately represent performance when the device/fuel combination is in actual use. Although field performance is often worse than laboratory-based performance, it is still valuable to assess the performance and progress of improved cookstoves through laboratory testing, because laboratory tests can provide guidance for best practices in design that can be translated into better cookstove performance in the field.

Differences between performance as measured in the laboratory and in the field arise for a number of reasons, including the test protocols and actual conditions, variations in the type and characteristics of the fuel (e.g., moisture of wood), deterioration of the cookstove over time, user behaviour, etc., which can impact multiple aspects of cookstove performance.

These benchmarks are based on laboratory test results, thus their validity for real performance estimation of cookstoves and cooking solutions in the field is limited. Guidance on how the targets may be implemented is provided in this document.

Countries and organizations can use these voluntary performance targets as examples and might prefer to develop performance targets based on their own priorities, needs, and markets. Readers are reminded that these voluntary performance targets are only provided as examples.

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

Part 3: Voluntary performance targets for cookstoves based on laboratory testing

1 Scope

This document provides voluntary performance targets for cookstoves and is intended to supplement ISO 19867-1. These voluntary performance targets are intended for use with the results of the laboratory testing specified in ISO 19867-1.

These voluntary performance targets are provided as informative guidance, and are not intended as normative requirements for the testing of cookstoves. Performance targets can be considered as an approach to benchmarking potential performance of cookstoves and clean cooking solutions, and provide guidance to help organizations and countries with international collaboration and trade in household energy technologies, fuels, and related products.

This document is therefore not intended to serve as the sole basis for decisions about which technologies/fuels to promote for a given setting, since the performance of a given technology will likely differ under real-use conditions. The best way to assess real-world impacts of a stove intervention or program is through field studies, see ISO 19869[1)], as well as other existing methods[2][3].

In addition to the limitations arising from differences from real-word performance, laboratory test metrics (efficiency, emissions, safety, and durability) do not inform other factors that are critical to the impacts a product, program, or intervention may achieve. These factors include, but are not limited to geographic/cultural suitability, price-affordability, acceptability to the target user group, and other socio-economic factors.

These voluntary performance targets for emissions are intended to evaluate cookstoves used for small-scale household applications, with maximum firepower of up to 10 kW. Cookstoves that have firepower above 10 kW could emit substantially more overall pollutants into the household environment than those under 10 kW, while still meeting targets based on grams emitted per megajoule of useful energy delivered.

2 Normative references

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19867-1 apply.

1) Under preparation. Stage at the time of publication ISO/DIS 19869:2018.

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

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

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

4 Symbols and abbreviated terms

ACH	air changes per hour
ALRI	acute lower respiratory infection
CI	confidence interval
CO	carbon monoxide
g	gramme
h	hour
HAP	household air pollution
IER	integrated exposure-response function
J	joule
m	metre
min	minute
mg	milligramme
MJ	megajoule
MJ_d	megajoules delivered
$PM_{2,5}$	particulate matter with an aerodynamic diameter ≤2,5 µm
ppm	parts per million
RR	relative risk
SD	standard deviation
WHO	World Health Organization
µg	microgramme

5 Default target values

5.1 General

Tiered performance targets provide a set of reference values against which to monitor and assess progress on five criteria: efficiency, emissions of fine particulate matter ($PM_{2,5}$), emissions of carbon monoxide, safety, and durability. The tiers range from the lowest level, Tier 0, representing the performance typical of open fires and the simplest types of solid-fuel cookstoves, to the highest level, Tier 5, which represents high levels of performance sought for each of these five characteristics. Distributed between these lower and upper levels are tiers representing intermediate goals that can be used to assess progress along a continuum of performance.

5.2 Default performance tiers

Voluntary performance targets and associated tiers are shown in Table 1. For unvented devices (no chimney or flue), emissions listed represent total emissions. For vented devices (with flue or chimney), emissions represent ‘fugitive’ emissions that are not captured by the device-venting system.

For emissions of $PM_{2,5}$ and CO, default tier levels are shown in Table 1; two alternative sets of tier levels for these same emissions are provided in 6.3 for conditions with ventilation rates assumed at higher and lower values.

NOTE Ventilation rate refers to air changes per hour (ACH) and can include natural and mechanical ventilation. The term “ventilation rate” is synonymous with the terms “air change rate” and “air exchange rate.”

These alternative scenarios demonstrate how the targets may change based on conditions that can vary between regions and settings.

Clause 6 provides more information on sources of tiered targets, the basis for selection of tiers, interpretation of tiers, further detail on default and alternative scenarios, and how users of these standards can customize performance targets.

Table 1 — Voluntary performance targets – default values[a]

	Tier[b]	Thermal efficiency %	Emissions		Safety (score)[c]	Durability (score)[d]
			CO g/MJ[d]	$PM_{2,5}$ mg/MJ[d]		
Better performance	5	≥50	≤3,0	≤5	≥95	<10
	4	≥40	≤4,4	≤62	≥86	<15
	3	≥30	≤7,2	≤218	≥77	<20
	2	≥20	≤11,5	≤481	≥68	<25
	1	≥10	≤18,3	≤1030	≥60	<35
	0	<10	>18,3	>1030	<60	>35

[a] For non-default values, see Clause 6.

[b] The tier level for each performance metric should be reported separately. See example in Table 2.

[c] Safety protocols (see ISO 19867-1:2018, Clause 7) cover solid-fuel stoves and solar cookers only.

[d] Durability protocols (see ISO 19867-1:2018, Clause 8) evaluate common material failures in biomass cookstoves. The protocol is not comprehensive of all failures that might be found in the field, nor are the tests found in the durability protocol applicable for all cookstoves. Instead the durability protocol seeks to cover the most prevalent durability concerns found across a range of cookstove technologies and construction materials.

For $PM_{2,5}$ and CO, equivalent kitchen concentrations at each level of emissions performance (tier) under the assumptions of the model used to derive these values are provided in 6.3, along with further description of the model and references.

5.3 Reporting the tiers

Test conditions (e.g., fuel burning rate, fuel moisture, cookstove operating procedure) should be reported when reporting results against targets (tiers). A simple average of the values obtained from testing at different power levels should be used when reporting results against targets, unless there are demonstrable data from the field, in which case a weighted average can be used. See ISO 19867-1.

The tier ratings for thermal efficiency should be determined by the lower bounds of the 90 % confidence intervals for the combined results. See example in Table 2.

The tier ratings for $PM_{2,5}$ and CO emissions should be determined by the upper bounds of the 90 % confidence intervals for the combined results. See example in Table 2.

Cookstove performance should be reported separately for all tier categories including CO, $PM_{2,5}$, thermal efficiency, safety, and durability, further described in Clause 6. See example in Table 2.

EXAMPLE A cookstove with emissions of $PM_{2,5}$ of 336 mg/MJ_d on the upper bound of the 90 % confidence interval for the combined result would be Tier 2 for $PM_{2,5}$, and emissions of CO of 0,9 g/MJ_d on the upper bound of the 90 % confidence interval for the combined result would be Tier 5 for CO. See example in Table 2.

For CO, $PM_{2,5}$, and thermal efficiency, performance should be reported based on individual test-phase-wise reporting and averaging (see example results table, Table 2).

Table 2 — Example table of reported results

Metric		Test Sequence Phase				Performance against target (e.g. tier rating)
		High	Medium	Low	Combined[b]	
Thermal efficiency without char[a] (%)	Mean	31,4	34,7	35,1	33,7	**3**
	SD	1,9	1,7	2,1	1,9	
	90 % CI	29,6-33,2	33,1-36,3	33,1-37,1	**31,9**-35,5	
Thermal efficiency with char[a] (%)	Mean	33,6	37,0	39,8	36,8	**3**
	SD	2,2	1,6	2,0	1,9	
	90 % CI	31,5-35,7	35,5-38,5	37,9-41,7	**35,0**-38,6	
Char energy productivity (%)	Mean	4,1	3,3	2,7	3,4	n.a.
	SD	0,9	0,7	0,5	0,7	
Char mass productivity (%)	Mean	2,2	1,3	0,7	1,4	n.a.
	SD	0,6	0,3	0,1	0,3	
Cooking power (kW)	Mean	1,6	1,2	0,7	n.a.	
	SD	0,2	0,1	0,1		
Fuel burning rate (g/min)	Mean	16,5	12,8	8,9	n.a.	
	SD	1,9	1,1	0,7		
$PM_{2,5}$ per useful energy (mg/MJ_d)	Mean	497	203	216	305	**2**
	SD	55	19	22	32	
	90 % CI	445-549	185-221	195-237	274-**336**	
CO per useful energy (g/MJ_d)	Mean	0,6	0,8	1,1	0,8	**5**
	SD	0,1	0,2	0,1	0,1	
	90 % CI	0,5-0,7	0,6-1,0	1,0-1,2	0,7-**0,9**	
Safety	Score	88				**4**
Durability	Score	18				**3**

[a] For solid-fuel stoves that produce char, thermal efficiency should be reported both 1) without energy credit and 2) with energy credit for remaining char. Thermal efficiency without char is applicable when users do not use the char remaining after cooking as fuel. Thermal efficiency with char is applicable when users use the char remaining after cooking as fuel.

[b] Values in bold are the conservative bounds of the 90 % confidence intervals for determining the tier level, as described in 5.3.

Some of the fuels/technologies that fall within the general scope of ISO 19867-1, including gas/liquid-fuelled cookstoves, are not covered by the safety testing protocol (see ISO 19867-1:2018, Clause 7) that serves as the basis for the tiered targets in Table 1. Accordingly, test results obtained from other safety testing protocols should be reported separately.

6 Technical basis and guidance for implementation

6.1 General

This clause provides information on the technical basis for the tiered performance targets, and guidance on how these targets may be implemented, covering the following:

a) definitions of the tier levels for thermal efficiency and emissions ($PM_{2,5}$ and CO);

b) the empirical basis for selection of the tiers, including:

— the emissions model used for $PM_{2,5}$ and CO,

— description of the integrated exposure-response function (IER) providing the basis for $PM_{2,5}$ tiers,

— application of evidence of both chronic and acute toxic effects for CO, and

— laboratory test data used as the basis for safety and durability tiers;

c) default and alternative sets of targets for $PM_{2,5}$ and CO, with equivalent kitchen pollutant concentrations as predicted by the emissions model, and percentages of homes meeting key criteria at each tier level; and

d) guidance on selecting relevant tiers for different settings.

6.2 Thermal efficiency

6.2.1 Definition of tier categories for thermal efficiency

Based on the ratio of useful energy delivered to fuel energy used during controlled laboratory testing, tier categories are defined as follows in Table 3 for each tier:

Table 3 — Definitions of thermal efficiency tier categories

Tier category	Tier	Definition
Highest	5	The thermal efficiency that is at a level representative of the best existing technology for fuel-combustion cookstoves
Intermediate	1-4	Mathematical division of range based on even spacing with five levels, with Tier 1 set to reflect performance observed with simple cookstove technology improvements
Lowest	0	The thermal efficiency observed with open fires and other simple solid fuel cookstove technologies

6.2.2 Empirical basis for tiers

Tiers for thermal efficiency are multiples of 10 % from 10 % to 50 %. These tiers were chosen because published test results show that the most advanced cookstoves approach or exceed a thermal efficiency of 50 %, while open fires and rudimentary cookstoves achieve an efficiency around 10 % or less[4].

6.2.3 Fuel efficiency based on thermal efficiency

Region-specific fuel efficiency targets for cookstoves that do not produce char used as fuel can be ascertained by determining the thermal efficiency of the relevant baseline technologies and then calculating the fuel savings using Formula (1).

$$\text{Percent fuel savings} = [1 - (\eta_T/\eta_x)] \times 100\ \% \tag{1}$$

where

η_T is the traditional cookstove thermal efficiency, %;

η_x is the intervention cookstove thermal efficiency, %.

The implied fuel savings per baseline cookstove event displaced with an intervention cookstove, assuming a traditional cookstove thermal efficiency of 10 %[5], are as follows in Table 4, provided only as an example.

Table 4 — Example of anticipated fuel savings based on thermal efficiency for cookstoves that do not produce char

	Tier	Thermal Efficiency	Fuel Savings
Better performance ↑	5	>50 %	>80 %
	4	>40 %	>75 %
	3	>30 %	>67 %
	2	>20 %	>50 %
	1	>10 %	>0 %
	0	<10 %	—
NOTE This example table is for a baseline cookstove with a thermal efficiency of 10 %.			

EXAMPLE If thermal efficiency >50 %, then compared with a baseline thermal efficiency of 10 %, anticipated fuel savings >80 %.

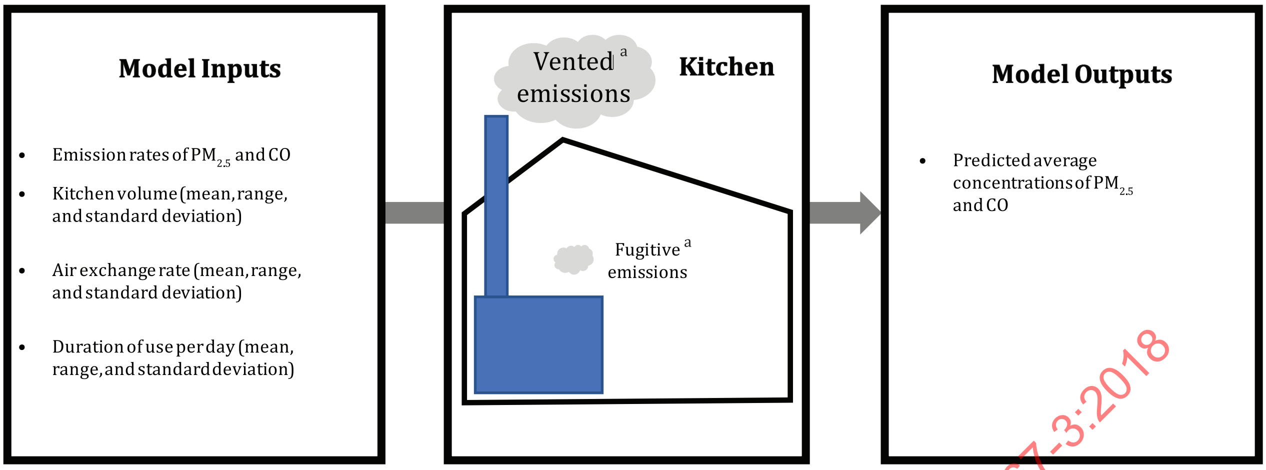
Similar tables with tiers corresponding to fuel savings targets could be developed for specific regions where the baseline technologies have well-characterized thermal efficiencies.

6.3 Pollutant emissions

6.3.1 Linking emissions rates of $PM_{2,5}$ and CO to health risks: the emissions model

The voluntary performance targets for emissions of $PM_{2,5}$ and CO are based on evidence of health risks of exposure to these pollutants, compiled and evaluated by the World Health Organization in its air quality guidelines[6][7][8]. A single box model has been used to link emission rates to indoor air quality concentrations, and hence to health risks. The methodology is briefly summarized below and described in detail in the WHO *Guidelines for indoor air quality: household fuel combustion*[8]. Relationships between emissions and health risks are based on a set of assumptions that are defined in the document.

The simple box model used to model relationships between emissions of $PM_{2,5}$ and CO and predicted indoor air concentration for the two pollutants is shown in Figure 1. As is the case with all models, there are uncertainties and limitations associated with their assumptions and estimates, as noted above, and thus the modelled linkages between emissions, indoor air quality, and health are not meant as a substitute for field studies. Field studies are recommended as the best way to assess real-world impacts of a stove intervention or program.



a A vented (chimney) cookstove is illustrated; for this type of cookstove, some (usually most) of the emissions are vented to the exterior, and some are 'fugitive' (emitted directly into the kitchen); these fugitive emissions are used for the emission rate values. For unvented stoves, total emissions are used for the emission rate values.

Figure 1 — Box model used to predict indoor pollutant concentrations based on emission rates and the other data inputs shown

This model incorporates three characteristics of the kitchen and the devices to relate emission rates to pollutant concentrations, namely kitchen volume and air exchange rate, and the duration of the use of the device each day. Values for these input variables for the default targets have been derived from a wide range of studies, listed in Table 5 (full reference information in the Bibliography).

Table 5 — Studies providing model input data for the default set of targets for duration of cooking, air exchange rate, and kitchen volume

Region	Source data (References in Bibliography)
South Asia	[9][10][11][12][13][14][15][16][17]
East Asia	[18]
Latin America	[19][20][21][22][23][24]

Note that, for vented devices, emissions that are directed to the exterior of the kitchen by the chimney or flue are not counted. Only the fugitive emissions (which are measured using the laboratory test protocol of ISO 19867-1) are assumed to contribute to indoor air pollution. It is recognized that this is a simplifying assumption as some of the vented emission may re-enter the home. Indoor deposition rate is not included in the model. At typical indoor concentrations, indoor deposition amounts are negligible.

To reflect the distribution of values of these input variables seen in practice (and shown by the range and standard deviations in Table 8), the model uses Monte Carlo simulation. As a consequence, the output of the model is also a distribution, and is expressed in terms of the percentage of homes that achieve a given concentration of pollutant.

Based on the set of assumptions defined in this document, the box model allows calculation of an estimated indoor average concentration of the pollutant of interest, namely $PM_{2,5}$ or CO, based on a specified emission rate, and using the specified distributions of air exchange rate, kitchen volume, and duration of device use per day. This same model can be used—in effect by running it backwards—to determine what emission rate would be needed to achieve a specified indoor concentration of the pollutant. This is how the emission factors (and rates) provided for the targets have been derived: pollutant concentrations have been selected (based on health risk evidence), and the emission rates required to meet these concentration levels then determined. As noted, with the model, the emission rates depend on values chosen for air exchange, kitchen volume, and duration of device use per day, and these values are provided alongside the targets in 6.3.2 (for $PM_{2,5}$) and 6.3.3 (for CO).

6.3.2 Fine particulate matter ($PM_{2,5}$)

6.3.2.1 Definition of tier categories for $PM_{2,5}$

The tier categories for $PM_{2,5}$ emissions are defined as follows in Table 6:

Table 6 — Definition of $PM_{2,5}$ tier categories

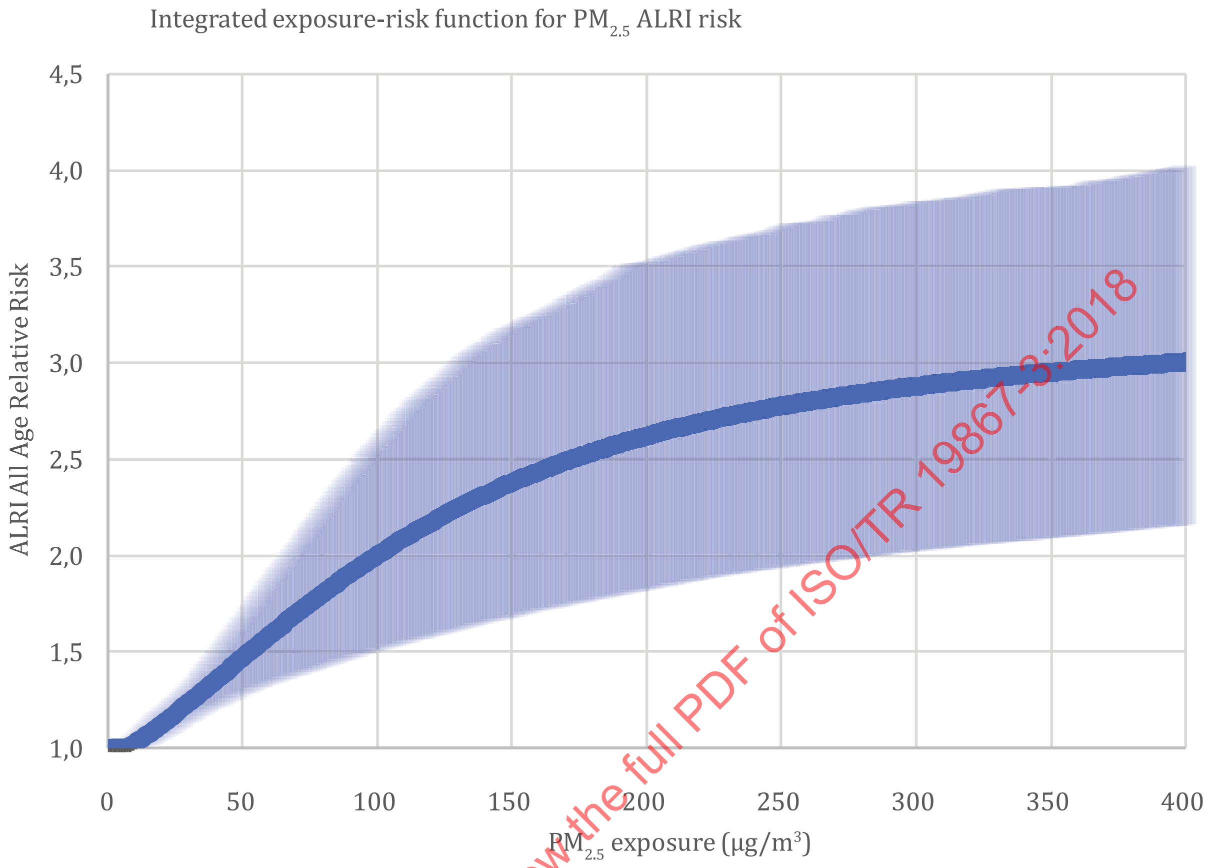
Tier category	Tier	Definition
Highest	5	The highest tier for $PM_{2,5}$ is the emission rate that, under the stated emission model assumptions, would result in kitchen indoor air quality that meets the WHO annual mean air quality guideline value of 10 µg/m^3[6] for 90 % of homes. This is the level of $PM_{2,5}$ associated with minimal adverse health risk, and has a relative risk[a] for child acute lower respiratory infections (ALRI) of 1,0 in the integrated exposure response function (IER)[25].
Intermediate	1-4	Intermediate emission rate tiers have been set to achieve levels of indoor air quality that are equivalent to relative risks of 3,15 (Tier 1), 3,0 (Tier 2), 2,5 (Tier 3), and 1,5 (Tier 4), based on the IER for child ALRI. The value for Tier 1 was selected to be consistent with performance observed with simple cookstove technology improvements.
Lowest	0	An emission rate higher than Tier 1, consistent with that observed with open fires and other simple solid fuel cookstove technologies.

[a] Relative risk (RR) is the risk of a disease experienced by individual exposed to one level of a risk factor (i.e. a higher level) compared to the risk experienced by individuals exposed to a lower level of the risk factor. An RR of 1,0 implies no additional risk, while a RR of 2,0 (for example) means twice the risk.

6.3.2.2 Empirical basis for tiers

To set levels of emission performance that relate to specified levels of health risk, the following approach has been used. Evidence is available to relate levels of exposure to $PM_{2,5}$ to levels of risk through 'integrated exposure-response functions' (IERs). These functions are termed 'integrated' since evidence is combined on disease risk from combustion risk factors (i.e., exposure to $PM_{2,5}$) including outdoor air pollution, second-hand smoking, household air pollution, and active smoking (for this last source, adult diseases only) to develop a single integrated risk model for all $PM_{2,5}$ sources. To date, IERs have been defined for five conditions, namely acute lower respiratory infections (ALRI) in children, and ischemic heart disease, stroke, chronic obstructive pulmonary (lung) disease, and lung cancer in adults[25].

Since the values and shapes of these functions vary across the five diseases, the IER for child ALRI has been selected as the primary IER function for the current purposes following the approach taken by WHO in the *Guidelines for indoor air quality: household fuel combustion*[8], which used the child ALRI IER because it had the strongest empirical exposure-response evidence for HAP. This IER is shown in Figure 2. The IER is used to estimate health risk due to household air pollution exposure; health effects from household air pollution depend on actual air pollution levels in the home from cookstoves and other pollutions sources, time spent in the home, and other factors. The IER represents the best current evidence, and as new evidence becomes available, the IER function and confidence interval may change.



NOTE The solid blue line defines the relationship between level of exposure to $PM_{2,5}$ (X-axis) and relative risk (Y-axis), while the shaded region shows the 95 % uncertainty bounds (Source Reference[25]).

Figure 2 — Integrated exposure-response function for child ALRI

This IER function allows estimation of the level of exposure to $PM_{2,5}$ that is associated with a specified relative risk.

EXAMPLE The value for average $PM_{2,5}$ exposure corresponding to a relative risk of 2,0 is (approximately) 100 μg/m³, which means a doubling of risk at this level of exposure.

For the purposes of these performance targets, increments of RR for child ALRI have been selected as described above in the definition of tier categories. Having estimated the target levels of $PM_{2,5}$ exposure that are associated with these values of RR, the box model has been used to determine the emission rates required to achieve each of the specified $PM_{2,5}$ targets.

Although the IERs indicate risk of disease at specified levels of personal exposure, the box model provides values for the ambient concentration in the kitchen. Many studies show that average personal exposure levels for women, men, and children tend to be lower than the average concentration in the kitchen. This difference is seen because most people do not spend all their time in the kitchen micro-environment, although very young children and older and sick individuals are more likely to do so. A protective approach has been used with these targets, which seeks to create indoor environments that are safe for health, however much time individuals choose or need to spend in these settings. Thus, the emission targets here provide conservative guidance on varying levels of protection to the indoor environment where the cookstoves are used.

6.3.2.3 Default values for $PM_{2,5}$

The default emission factors for $PM_{2,5}$ (as shown in Table 1 in 5.2) are presented in Table 7 with additional details on the corresponding relative risks, emission concentration, emission rate, and the percentage of homes meeting each tier level. The model input assumptions for air exchange rate, kitchen volume, and number of hours spent cooking per day that were used to derive these default emission factor targets are shown in Table 8.

As described in 6.3.1, the box model is used to calculate emission rates to meet indoor air quality targets. To convert these emission rates to emission factors in measurement units of mass per megajoule of useful energy delivered, emission rates were multiplied by the assumed average cooking time and divided by the assumed required useful energy delivered for daily cooking needs (11 MJ)[26].

Table 7 — Default emission factors, rates, equivalent concentrations and % homes meeting specified criteria, for $PM_{2,5}$

	Tier	RR	mg/MJ_d	Normalized Emission Rate mg/min	$\mu g/m^3$	Percentage of homes meeting the tier level
Better performance	5	1,0	≤5	≤0,2	≤10	≥90 %
	4	≤1,5	≤62	≤2,7	≤50	≥50 %
	3	≤2,5	≤218	≤9,5	≤170	≥50 %
	2	≤3,0	≤481	≤21	≤400	≥50 %
	1	≤3,15	≤1 031	≤45	≤800	≥50 %
	0	>3,15	>1 031	>45	>800	<50 %

NOTE Tier reporting is based on emission factor, and normalized emission rate is a derived property. Measured emission rates from laboratory testing are not used to determine tiers for reporting.

Table 8 — Model input assumptions for default emission factor targets for $PM_{2,5}$ and CO

Model input variable	Values utilized				Source data (references in Bibliography)
	Mean	Range		Standard deviation	
		Minimum	Maximum		
Air exchange rate (ACH)	21[a]	4	100	11	[11][13][14] [18][23][24] [27]
Kitchen volume (m^3)	28[a]	5	100	16,8	[9][10][12][16][17][19][20][21] [22]
Duration of cooking (h/day)	4,2[b]	1	8	1,5	[9][10][13] [15][16][17][28]

a Geometric mean.

b Arithmetic mean.

6.3.2.4 High and low ventilation scenarios for $PM_{2,5}$

Two additional scenarios are provided for a high air exchange rate and a low exchange rate. These scenarios demonstrate how the emission rates necessary to achieve a given tier level vary in different ventilation scenarios. These examples are provided to demonstrate how different conditions can affect the targets. These examples are intended to be illustrative, not applied.

The air exchange rates used in the default-, high-, and low-ventilation scenarios are listed below:

— Default: geometric mean of 21, range of 4 (minimum) to 100 (maximum), standard deviation of 11, as shown in Table 8.

— High-ventilation scenario: geometric mean of 30, range of 4 to 100, standard deviation of 15.

— Low-ventilation scenario: geometric mean of 10, range of 4 to 100, standard deviation of 5.

The same kitchen volume and duration of cooking were used for the high- and low-ventilation scenarios as for the default scenarios.

As shown in Table 9, in regions and settings with high ventilation, the $PM_{2,5}$ emission rate necessary for a cookstove to reach Tier 5 emissions is higher than in the default scenario table. If the air exchange rate measured in a particular setting is found to be similar to the high- or low-ventilation scenario, that scenario can be used to determine appropriate tiers for $PM_{2,5}$.

Air exchange rate can be estimated using the tracer gas method[29].

EXAMPLE At the upper end of the published data, studies have reported averages of ~35 air changes per hour with maxima up to 100 ACH, whereas at the lower end means have been reported at ~15 with minima of 4 ACH[14][23][27].

Table 9 — High and low ventilation scenario $PM_{2,5}$ emission factors and rates[a]

	Tier	RR	µg/m³	High ventilation		Low ventilation	
				Emission factor mg/MJ_d	Normalized Emission Rate mg/min	Emission factor mg/MJ_d	Normalized Emission Rate mg/min
Better performance	5	1,0	≤10	≤7	≤0,3	≤2	≤0,1
	4	≤1,5	≤50	≤92	≤4	≤32	≤1,4
	3	≤2,5	≤170	≤321	≤14	≤115	≤5
	2	≤3,0	≤400	≤733	≤32	≤252	≤11
	1	≤3,15	≤800	≤1 489	≤65	≤550	≤24
	0	>3,15	>800	>1 489	>65	>550	>24

NOTE Tier reporting is based on emission factor, and normalized emission rate is a derived property. Measured emission rates from laboratory testing are not used to determine tiers for reporting.

[a] The percentage of homes meeting the specified criteria are unchanged from Table 7.

6.3.3 Carbon monoxide (CO)

6.3.3.1 Definition of tier categories for CO

The tier categories for CO emissions are defined as follows in Table 10:

Table 10 — Tier categories for CO emissions

Tier category	Tier	Definition
Highest	5	The highest tier for CO is the emission rate that, under the stated emission model assumptions, would result in 90 % of homes having kitchen CO concentrations that meets the WHO 24 h mean air quality guideline value of 7 mg/m^3.
Intermediate	1-4	The Tier 1 emission rate has been set so that 90 % of homes would have kitchen CO concentration at or below 230 mg/m^3 during cooking events, a level associated with mild adverse acute symptoms from CO exposure (see empirical basis for tiers section, 6.3.3.2). The remaining intermediate emission rate tiers (2 to 4) represent equal mathematical divisions between Tiers 1 and 5 for the percentage of homes covered at 7 mg/m^3 daily average CO concentration.
Lowest	0	An emission rate higher than Tier 1, and consistent with that observed with open fires and other simple solid fuel cookstove technologies.

6.3.3.2 Empirical basis for tiers

For CO, consideration has been given to two recognized mechanisms by which this gas adversely affects health, namely (a) long-term chronic exposure to low and medium levels of CO and (b) acute (short-term, over minutes or hours) toxicity from higher levels of CO.

For protection against chronic CO exposure, the Tier 5 emission rate has been set such that 90 % of homes will have average levels of kitchen CO concentrations that meet the WHO 24-hr CO air quality guideline of 7 mg/m^3, developed to protect against adverse health effects from chronic low-dose exposure[7].

For protection against the effects of acute exposure, Tier 1 has been set such that—during cooking events — 90 % of homes will have kitchen indoor air quality at or below 230 mg/m^3, a concentration at which subjects may experience mild symptoms from CO exposure, namely headache and impaired judgement at 2 h to 3 h of exposure[30] – see Table 11. At the Tier 1 level, over 99,98 % of homes are covered at or below 930 mg/m^3 during cooking events. This is the concentration at which subjects may experience dizziness, nausea, and convulsions within 45 min, and would be insensible within 2 h to 3 h from start of exposure[30].

While the approach described draws on the best available evidence for setting performance target tiers in a way that combines protection from both chronic health effects and acute toxicity, it should be noted that the relationship between short-term exposure to CO, Carboxyhemoglobin levels, and symptoms (e.g. as reported in[30]) can be quite variable between individuals, and according to factors such as exercise (see Reference [7] CO chapter). The guidance provided on the percentage of homes that would be expected to avoid the mild and severe symptoms described should therefore be used with caution.

While it is generally recommended that all stoves be used in well-ventilated areas, stoves at Tiers 0 and 1 for CO should not be used indoors due to risks from acute toxicity from this pollutant; particular care should be taken with charcoal stoves. For enclosed spaces with minimal ventilation, there is no safe level of CO emissions.

6.3.3.3 Default values for CO

The default emission factors for CO (as are shown in Table 1 in 5.2) are included in Table 11 with additional details including corresponding emission concentration and emission rate. For each tier, Table 11 also includes the 24 h average concentrations expected (i.e., the concentration in 50 % of homes that use a cookstove with the given emissions rate), which is shown in the fifth column. Similarly, the average cooking event concentration expected (i.e., the concentration in 50 % of homes that use a cookstove with the given emissions rate) is shown in the sixth column for a daily cooking duration of 4,2 h (Table 11). In addition, for each tier level, Table 11 shows the percentage of homes covered at 230 mg/m^3.

For CO, the same methods for calculating emission rates and converting emission rates to emission factors are used as the methods for $PM_{2,5}$ (see 6.3.2.3).

Table 11 — Default emission factors, rates, equivalent concentrations, and % homes meeting specified criteria, for CO

	Tier	Emission factor g/MJ_d delivered	Emission Rate mg/min	24 hour concentration at 50 % coverage mg/m^3 (ppm)	Cooking event concentration at 50 % coverage mg/m^3 (ppm)	Percent of homes covered at 7 mg/m^3 daily average[a]	Percent of homes covered at 230 mg/m^3 during cooking[b]
Better performance	5	**≤3,0**	≤133	2,3 (2,0)	13,6 (11,9)	≥90 %	≥99,9
	4	**≤4,4**	≤190	3,2 (2,8)	19,3 (16,8)	≥80 %	≥99,9
	3	**≤7,2**	≤315	5,4 (4,7)	32,6 (28,5)	≥60 %	≥99,3
	2	**≤11,5**	≤500	8,8 (7,7)	52,5 (45,8)	≥40 %	≥97,1
	1	**≤18,3**	≤800	14,0 (12,2)	84,1 (73,4)	≥20 %	≥90
	0	**>18,3**	>800	14,0 (12,2)	84,1 (73,4)	<20 %	<90

NOTE Tier reporting is based on emission factor, and emission rate is a derived property. Measured emission rates from laboratory testing are not used to determine tiers for reporting.

a WHO 24-hour air quality guideline[7].

b Concentration during cooking at which subjects experience slight headache and impaired judgement within 2 h to 3 h from start of exposure[30].

The model input assumptions for default emission factor targets for carbon monoxide (CO) are identical to those for $PM_{2,5}$ (Table 8).

6.3.3.4 High and low ventilation scenarios for CO

Two additional scenarios are provided for a high air exchange rate and a low air exchange rate using the same assumptions as in 6.3.2.4.

As shown in Table 12, in regions and settings with high ventilation, the CO emission rate necessary for a cookstove to reach Tier 5 emissions is higher than in the default scenario table.

Table 12 — High ventilation scenario emission factors and rates for CO[a]

	Tier	24 hour concentration at 50 % coverage mg/m3 (ppm)	Cooking event concentration at 50 % coverage mg/m3 (ppm)	High ventilation		Low ventilation	
				Emission factor g/MJ_d	Emission Rate mg/min	Emission factor g/MJ_d	Emission Rate mg/min
Better performance	5	2,3 (2,0)	13,6 (11,9)	≤4,4	≤190	≤1,4	≤60
	4	3,2 (2,8)	19,3 (16,8)	≤6,2	≤270	≤2,2	≤95
	3	5,4 (4,7)	32,6 (28,5)	≤10,3	≤450	≤3,7	≤160
	2	8,8 (7,7)	52,5 (45,8)	≤16,0	≤700	≤5,5	≤240
	1	14,0 (12,2)	84,1 (73,4)	≤26,9	≤1 175	≤9,9	≤430
	0	14,0 (12,2)	84.1 (73.4)	>26,9	>1 175	>9,9	>430

NOTE Tier reporting is based on emission factor, and emission rate is a derived property. Measured emission rates from laboratory testing are not used to determine tiers for reporting.

a The percentage of homes meeting the specified criteria are unchanged from Table 11.

6.4 Safety

6.4.1 Application of targets

The targets for safety provided in Table 1 in 5.2 are derived from the safety test protocol of ISO 19867-1:2018, Clause 7, which is designed for solid-fuel cookstoves and solar cookers. The tiers and their empirical basis, described here, therefore only apply to testing of solid fuel and solar cookers.

6.4.2 Definition of tier categories for safety

The tier categories for safety are defined as follows in Table 13:

Table 13 — Definitions of tier categories for safety

Tier category	Tier	Definition
Highest	5	Based on the laboratory safety assessment score for cookstoves (according to ISO 19867-1:2018, Clause 7), the highest tier is associated with a very low (but not zero) risk of injuries, namely burns, scalds, and lacerations.
Intermediate	1-4	Intermediate safety tiers are evenly spaced mathematically and represent the range of scores observed for existing cookstove technologies.
Lowest	0	The lowest tier is based on safety scores observed with open fires and other simple solid fuel cookstove technologies.

6.4.3 Empirical basis for tiers

Tiers for safety are based on divisions of the distributions of published test score results[2] and unpublished results.

6.5 Durability

Durability targets are set to reflect decreased risk of cookstove component failure and reflect the durability test protocol in ISO 19867-1:2018, Clause 8. The possible range of scores is 0 to 37, with 0 indicating the lowest possible risk and 37 the greatest. A score of 10 or lower for Tier 5 represents relatively low risk of component failure given normal cookstove operation, with each lower tier indicating subsequently increasing risk of component failure.

6.5.1 Definition of tiers for durability

The tier categories for durability are defined as follows in Table 14:

Table 14 — Definitions of tier categories for durability

Tier	Tier	Definition
Highest	5	Based on the durability assessment score for cookstoves (according to ISO 19867-1:2018, Clause 8), the highest tier is associated with durability of cookstove components and functioning which is at or close to the best achievable for this application.
Intermediate	1-4	Intermediate tiers have been set based on simple mathematical divisions to represent the range of durability scores observed for existing cookstove technologies.
Lowest	0	The lowest tier level is based on durability scores observed with solid fuel cookstove technologies with a relatively high risk of component failure.

6.5.2 Empirical basis for tiers

Tiers for durability are based on scores found through the development of the protocol as well as self-reported results.

