Setting national voluntary performance targets for cookstoves
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### Abbreviations and acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRI</td>
<td>acute lower respiratory infection</td>
</tr>
<tr>
<td>CHEST</td>
<td>Clean Household Energy Solutions Toolkit</td>
</tr>
<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>ERT</td>
<td>emission rate targets</td>
</tr>
<tr>
<td>GIAQ/HFC</td>
<td>(WHO) Guidelines for indoor air quality: household fuel combustion</td>
</tr>
<tr>
<td>IER</td>
<td>integrated exposure–response</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>IWA</td>
<td>international workshop agreement</td>
</tr>
<tr>
<td>MJₐ</td>
<td>megajoules delivered</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>particulate matter with an aerodynamic diameter ≤ 2.5 μm</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>PT</td>
<td>Performance Target</td>
</tr>
<tr>
<td>RR</td>
<td>relative risk</td>
</tr>
<tr>
<td>SD</td>
<td>standard deviation</td>
</tr>
<tr>
<td>VPT</td>
<td>voluntary performance target</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
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</table>
Overview

This document was prepared to support countries in setting voluntary performance targets (VPTs) for cookstoves and clean cooking solutions, such as those developed by the International Organization for Standardization (ISO) published in 2018.

Section 1 provides the background of the document, with the objective and target readership. Links to other documents are described, including module III of the “Clean Household Energy Solutions Toolkit” (CHEST) to support countries in designing and using a national strategy for cleaner household energy. The document is intended to assist policy-makers and technical staff in ministries responsible for standards and policies on cleaner household energy.

Section 2 describes the development of standards for cookstoves in lower- and middle-income countries. These include the new ISO laboratory test protocol and the VPTs. The latter comprise five tiered targets for each of five laboratory test parameters, tier 0 being the lowest performance (e.g. open fires and simple solid fuel stoves) and tiers 1–5 indicating increasingly good performance. The role of these targets in reducing the burden of disease and injuries associated with use of traditional solid fuels, cookstoves and kerosene is explained with reference to the WHO guidelines on indoor air quality: household fuel combustion (WHO GIAQ/HFC).

Section 3 provides background information on the new ISO standards for cookstoves and clean cooking solutions and the laboratory testing protocol (ISO 19867-1:2018), which provides information on device performance for assessing tiers of VPTs. The five parameters in the standard, namely efficiency, emissions of particulate matter (PM$_{2.5}$), emissions of carbon monoxide (CO), safety and durability, are defined and methods for their assessment outlined. ISO Technical Report 19867-3 describes how the tier values for each test parameter were determined, including for air pollutants, and the relations of levels of emissions to health risk.

Section 4 provides an overview of the ISO VPTs for thermal efficiency, emissions (CO and PM$_{2.5}$), safety and durability and derivation of the tiers for these five parameters.

Section 5 provides an example of laboratory test results for a particular stove and the relation of the results to the default VPT tiers.

Section 6 describes the basis for VPT tiers according to the health risks associated with exposure to emissions of PM$_{2.5}$ and CO as evaluated in the WHO GIAQ/HFC.

Section 7 provides examples of application of laboratory performance results to obtain tiers of exposure and how they should be reported and interpreted. As circumstances differ, the ISO VPTs also provide tier ratings for “high” and “low” ventilation scenarios, which are explained, with examples.

Section 8 considers circumstances in which user-defined tiers are determined with the WHO Performance Target (PT) model. Two scenarios are examined, one characterized by poor ventilation, small kitchens
and longer stove use (which would require lower emission rates to meet air quality targets) and one characterized by better ventilation, larger kitchens and shorter stove use (in which air quality targets could still be met with higher emission rates). This user-defined approach to setting tier values should be applied carefully, with fully justified input data for the model, and cautions and recommendations for reporting included.

These sections build on each other: section 2 provides the justification for the ISO standards for cookstoves, technical resources and WHO’s contribution to the ISO standards. Sections 3 and 4 show how the ISO harmonized laboratory test protocols and the VPTs have led to international consensus on assessing the performance of the stoves and fuels that may be developed, marketed and used as people move from traditional solid fuels and kerosene to cleaner alternatives. Section 5 provides an example of laboratory test results for a stove and the association with default VPT tiers. Sections 6–8 describe the basis for VPT tiers in default emission tiers for PM\textsubscript{2.5} and CO, alternative scenarios for PM\textsubscript{2.5} and CO in high- and low-ventilation scenarios and user-defined emission tiers for PM\textsubscript{2.5} and CO based on the WHO PT model.

Section 9 discusses key considerations in applying the ISO standards and VPTs in a policy for a transition to cleaner, safer household energy. While very clean, safe, efficient, modern energy carriers (including electricity) may be the ultimate target, it is recognized that this goal may not be achievable by all in the short term. Consideration of a policy for the promotion of devices and fuels that meet intermediate rather than the highest tiers of performance must be justified and reviewed regularly.

Section 10 provides six interrelated resources for planning more efficient, cleaner, safer household energy. The first three are ISO products, namely the laboratory testing protocol, VPTs and a field-testing protocol (ISO 19869:2019). The other three are WHO products: an online emissions model that can be used to generate customized performance target tiers when the conditions differ markedly from those on which the ISO VPT default tiers were based (the WHO PT model); a database of studies that provide model input variables (kitchen volume, air exchange rate and duration of stove use per day); and protocols for measuring these three model inputs when the published values are considered too few or otherwise inapplicable.

As for all standards and related resources, the document will evolve as practical experience in countries increases and new evidence on best practice becomes available. Feedback on this document is welcome and can be sent to householdenergy@who.int.
1 Introduction

1.1 Aims and objectives

The aim of this document is to support countries and their partners in setting national voluntary performance targets (vPTs) for clean cookstoves and clean cooking solutions, by using information from WHO guidelines and International Organization for Standardization (ISO) standards on cookstoves. The objectives are to:

• explain the contribution of laboratory testing to cleaner cooking in homes, including the strengths and limitations and association with field-testing;
• describe the rationale for and derivation of the vPT tiers described in Part 3 of ISO/TR 19867-3 (1) for the five parameters of stove performance: thermal efficiency, emissions of particulate matter with an aerodynamic diameter ≤ 2.5 µm (PM$_{2.5}$) and of carbon monoxide (CO), safety and durability;
• illustrate practical use of the default and alternative (high and low ventilation) scenarios for PM$_{2.5}$ and CO emissions provided in the ISO/TR 19867-3 standard;
• explain when user-defined tiers may be more appropriate than the default or alternative scenario; and
• explain how user-defined tiers can be generated from the online WHO PT model and the caution to be exercised.

This document and the ISO standards in ISO/TC285 (2) are cited in module III of the WHO Clean Household Energy Solutions Toolkit (CHEST) and are designed to support countries in developing and implementing a national strategy for cleaner household energy.

1.2 Intended readership

This document is intended to guide the setting of vPTs for cookstoves and clean cooking solutions on the basis of ISO and WHO standards and guidelines and is designed specifically for use by groups involved in developing and implementing standards and policies on clean household energy:

• policy and technical staff in ministries, departments and agencies that contribute to a multi-sectoral strategy on cleaner household energy;
• laboratory staff who test stoves and fuels used for cooking and report the results; and
• personnel in national standards bodies responsible for setting standards for cookstoves and clean cooking solutions.
2 Background

2.1 ISO standards for clean cookstoves and clean cooking solutions

2.1.1 Requirement for standards

Standards are critical to ensure that stove technology and fuels used in houses, like other everyday products, are safe, perform well and do not adversely impact health. When standards (and the associated test methods and procedures) are applied correctly, governments and their agencies can set policies and foster product innovation to ensure that products that enter the market meet the needs and expectations of consumers and are safe.

While some standards and test protocols have been available in some countries for a number of years, the International Organization for Standardization (ISO) Technical Committee (TC) 285, WHO and other collaborators have only recently set common standards and associated testing procedures for cooking technologies. TC 285 includes ISO member bodies and liaison bodies such as the Clean Cooking Alliance (previously known as the Global Alliance for Clean Cookstoves).

2.1.2 International Workshop Agreement

A set of voluntary tiered standards for cookstove performance was agreed in 2012 in an “international workshop agreement” (IWA) (3), a relatively rapid ISO process for introducing an internationally agreed document, which may be a basis for an international standard. While an IWA reflects due process in ISO, it does not have the status of a full ISO international standard because it has not achieved the degree of consensus required (4).

IWA 11:2012 (now withdrawn) set five tiered targets for four parameters of stove performance: fuel efficiency (including both thermal efficiency at high power and specific consumption at low power), total emissions (PM$_{2.5}$ and CO combined), indoor emissions (PM$_{2.5}$ and CO combined) and safety. WHO contributed to the IWA by ensuring that the lowest targets for emissions were consistent with the WHO air quality guidelines, namely, the annual average intermediate target 1 for PM$_{2.5}$ (35 µg/m$^3$) (5) and the guideline 24-h average for CO (7 mg/m$^3$) (6).

Application of tiered performance targets for efficiency, total emissions, indoor emissions and safety in households with few resources presented challenges to those involved in cookstove design and promotion. Some considered that setting demanding, aspirational targets (especially for PM$_{2.5}$) would devalue other gains in efficiency and safety provided by low-cost improved stoves, which may also
somewhat reduce the health risk by slightly decreasing emissions. Others considered that the aspirational targets would improve quality and performance overall, drive innovation and increase value for money.

### 2.1.3 Formal international standards

Despite the challenges and debate raised by the IWA, there has been growing acceptance of and support for the principles that it introduced, which are considered to have helped in achieving better cookstove performance and quality. The experience led to a proposal, accepted in 2013, that ISO establish a technical committee for standardization in the field of cookstoves and clean cooking solutions. ISO TC 285 was created in 2013 and began preparing international standards in 2014.

ISO TC 285, like other ISO committees, reaches agreement by international consensus. Standards are drafted by working groups composed of experts nominated by the national standards bodies that make up the ISO membership and liaison organizations. ISO TC 285 has included representatives of 29 countries and observers from 16 other countries, as experts to the working groups or on the TC, who comment and vote on draft standards after national consultation. ISO operates by consensus, and every comment is considered carefully. One working group of the Committee was responsible for the laboratory testing protocol and for the vPTs. ISO standards also involve technical “liaison organizations”. WHO is a category A liaison organization in TC 285, providing a public health perspective and expertise; it has been involved in setting the laboratory testing protocol, the vPTs and the field-testing protocol.

### 2.1.4 Voluntary performance targets

The ISO laboratory testing protocol (8), which is described further in section 3, covers testing of the five parameters of stove performance, thermal efficiency, PM$_{2.5}$ and CO emissions, safety and durability, and reporting of the procedure and the results.

The VPTs, published by ISO in a technical report (1), are established for each the five parameters of stove performance by rating the results of laboratory testing in one of six tiers, from 0, which represents the typical performance of open fires or simple traditional stoves that burn solid fuels, to 5, which represents the best performance that can reasonably be expected and are consistent with WHO air quality guideline values for PM$_{2.5}$ and CO emissions. The basis for selecting tier values is explained in sections 4 and 6.

### 2.2 Contribution of WHO guidelines for indoor air quality to ISO cookstove standards

The WHO guidelines for indoor air quality: household fuel combustion (WHO GIAQ/HFC) (9) have guided development of the components of the VPTs that directly impact health.

---

1 At the time of establishment of the Committee.
2 Defined as: “General agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to reconcile any conflicting arguments. NOTE Consensus need not imply unanimity” (7).
2.2.1 Effects of cooking fuel combustion on air quality in developing countries

About 3 billion people rely primarily on solid fuels (e.g. wood, crop wastes, dung, charcoal) and kerosene for everyday cooking. Transitions to cleaner fuels have occurred in many countries over the past 30–40 years with socio-economic development; however, the concurrent increase in the global population has meant that the absolute number of people who rely on polluting fuels has not changed (10). If policies on access to energy in poor countries do not change radically, future population growth, particularly in Africa, will result in little, if any, further reduction in the number of people who rely on solid fuels and kerosene (10).

Reliance on unclean cooking fuels and technologies leads to serious, interrelated problems for health, development and the environment. Use of inefficient, frequently unvented cookstoves, almost all of which burn solid fuels or kerosene, results in very high exposure to household air pollution; furthermore, gathering fuel limits the time that women and children have to engage in more productive activities. Use of solid fuel also diminishes forest resources and accelerates climate change due to both unsustainable harvesting of wood for fuel and emission of products of incomplete combustion (including black carbon and methane).

WHO has estimated that the public health impact of household air pollution is almost 4 million premature deaths per year from pneumonia, chronic respiratory disease, lung cancer, stroke and cardiovascular disease (11). Household air pollution also increases the risks of vision loss due to cataracts and of low birth weight (12).

2.2.2 WHO guidelines for indoor air quality: household fuel combustion

The WHO GIAQ/HFC, published in 2014 (9), provide recommendations for national policy to reduce and ultimately eliminate the adverse health effects of household air pollution. The guidelines are based on extensive reviews of evidence on pollutant emissions and exposure levels, risks to health and safety (e.g. burns), the effectiveness of various interventions and their co-benefits with respect to finance and climate change (13). The WHO GIAQ/HFC build on previously published guidelines for the levels of air pollutants (indoors and outdoors) and annual average values for small particles ($PM_{2.5}$) (5) and 24-h values for CO (6) (Table 1). The recommendations are designed to help achieve those guideline pollutant levels in and around homes in all settings, both indoors and outdoors.

<table>
<thead>
<tr>
<th>Pollutant (unit of guideline)</th>
<th>Mean concentration over averaging time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 min</td>
</tr>
<tr>
<td>$PM_{2.5}$ ($\mu g/m^3$)</td>
<td>–</td>
</tr>
<tr>
<td>CO ($mg/m^3$)</td>
<td>100</td>
</tr>
</tbody>
</table>
The main WHO recommendations for target emission rates from household fuel combustion (9) are listed below.

**Recommendation 1 (strong):**

**Recommendation 1: Emission rate targets**

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Emission rate targets</th>
<th>Strength of recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission rates from household fuel combustion should not exceed the following emission rate targets (ERTs) for PM$_{2.5}$ and CO.</td>
<td>PM$_{2.5}$ (unvented) 0.23 (mg/min)</td>
<td>Strong</td>
</tr>
<tr>
<td></td>
<td>PM$_{2.5}$ (vented) 0.80 (mg/min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO (unvented) 0.16 (g/min)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO (vented) 0.59 (g/min)</td>
<td></td>
</tr>
</tbody>
</table>

The target emission rates are 0.23 mg/min and 0.80 mg/min for PM$_{2.5}$ and 0.16 g/min and 0.59 g/min for CO from unvented and vented sources, respectively. The implications for the improved stoves and fuels that will be required are discussed briefly. Additional information is provided in reference 8, including on making recommendations and evaluating the strength of the evidence on which they are based. Separate guidance is provided for unvented and vented stoves, as those with a chimney or other venting mechanism can improve indoor air quality by moving a significant fraction of the pollutants outdoors.

Recommendation 1 sets the target emission rates from stoves necessary to meet the WHO air quality guidelines in kitchens for two important pollutants, PM$_{2.5}$ and CO. The reference air quality levels are the annual average guideline of 10 µg/m$^3$ and intermediate target-1 level of 35 µg/m$^3$ for PM$_{2.5}$, and the 24-h average guideline level of 7 mg/m$^3$ for CO. The method used to derive these emission rates is essentially the same as that used for estimating the ISO VPTs and is described further in section 3.2.

**Recommendation 2 (strong):**

**Recommendation 2: Policy during transition to low emission technologies**

Governments and their implementation partners should develop strategies to accelerate efforts to meet these air quality guidelines ERTs (see Recommendation 1). Where intermediate steps are necessary, transition fuels and technologies that offer substantial health benefits should be prioritized.

Recommendation 2 reflects two conclusions from the evidence reviewed and evaluated (12,14):

1. The relation between exposure to PM$_{2.5}$ and the risks for most of the health outcomes studied is non-linear. Thus, exposure must be reduced to values close to the actual guideline (10 µg/m$^3$) to avert most of the adverse effect on health. This exposure–response relation is illustrated by the case of pneumonia in children in section 2.3.4, which shows how the emissions model is used to generate VPT tiers for PM$_{2.5}$ emissions.
2. While everyday use of improved solid-fuel cookstoves, especially those with chimneys, resulted in average reductions of 40–50% in PM$_{2.5}$ and CO in kitchens, the levels of PM$_{2.5}$ were still well above the WHO guideline (and intermediate target 1), and those of CO in kitchens were at or below the 24 h guideline value. The finding for PM$_{2.5}$ implies that no substantial health benefit would be achieved with currently available improved biomass stoves and that near-exclusive use of clean energy carriers, such as liquefied petroleum gas, biogas, ethanol and electricity, is required.

Recommendation 2 thus highlights the importance of giving priority to cleaner fuels and stoves, recognizing that widespread adoption of means for clean cooking will not be achievable for all in the short to medium term. Consequently, improved biomass stoves that are promoted as transitional technologies must perform well enough to guarantee some health benefit. Testing of emission rates (and actual measurement of household air pollution and exposure in homes when possible) was recommended as the most effective way of assessing whether the improved stoves that are being considered for wider use are likely to benefit health.

**Recommendation 3 (strong)** addresses household use of coal, which is widespread in China and several other countries, and discourages use of unprocessed coal in homes because of the well-established risk for lung cancer (for which there is no safe level of exposure) and common contamination of this fuel by arsenic, fluorine and other toxins that are not destroyed during combustion (15).

**Recommendation 3**

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Strength of recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unprocessed coal should not be used as a household fuel.</td>
<td>Strong</td>
</tr>
</tbody>
</table>

**Recommendation 4 (conditional):**

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Strength of recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The household use of kerosene is discouraged while further research into its health impacts is conducted.</td>
<td>Conditional²</td>
</tr>
</tbody>
</table>

Household use of kerosene is discouraged, pending further research on its effects on health. The recommendation addresses continuing widespread use of kerosene in homes. While the evidence for health effect is not as strong as that of solid fuels and coal, use of kerosene is discouraged, as emissions of pollutants known to be toxic (especially from unpressurized stoves) exceed guideline levels, and there is growing evidence of adverse health outcomes among people exposed to kerosene pollution (16).

**Safety**

The guidelines also include safety, with the following general considerations. Household fuel combustion, particularly in developing countries, is associated with a substantial risk of injury from burns, scalds and...
house fires. Technologies and fuels introduced with the purpose of reducing emissions may reduce such risks, but risk reduction should not be assumed. Accordingly, steps should be taken to minimize exposure to emissions and to reduce the risk of injury as far as possible in the design of technologies and in testing and evaluating them in the field.

### 2.2.3 Implications of WHO guidelines for cookstove standards

The ISO VPTs for clean cookstoves and clean cooking solutions were based on the following points from the WHO GIAQ/HFC:

- the importance of progress towards “clean” fuels and stoves that result in air quality in and around homes that is at, or close to, the WHO guideline levels for PM$_{2.5}$ and CO;
- measurements of emission factors should be done using a standardized laboratory protocol, to assess the level of pollution produced by stoves and fuels under consideration;
- recognition that adoption and use of cleaner fuels will be delayed for many households, especially in poorer, rural areas. The emissions from transitional technologies and fuels must therefore be tested to ensure that they have at least some health benefit, to understand their baseline performance and to encourage continuous improvement in stove performance;
- recognition that, while laboratory-testing of emissions provides a standardized benchmark of performance, emissions in everyday use will vary, and measurement of air quality and exposure in the home is an important complementary aspect of evaluation of stoves and fuels; and
- the priority of reducing the risk of burns and scalds; as these risks cannot be assumed to be reduced with use of stoves and cooking systems that are more efficient and cleaner, separate assessments of safety are required.

ISO documents 19867-1, parts 1 and 3, and 19869 (1, 8, 17) together provide a consensus-based international framework for assessing the performance of stoves and fuels that may be developed, marketed and used as people move from traditional solid fuel and kerosene to cleaner alternatives. These ISO documents, which directly address the health risks of emissions and safety with other aspects of performance (as informed by the WHO GIAQ/HFC), are therefore important in implementation of the WHO guidelines.

### 2.3 WHO definition of clean household energy for health

WHO defines clean transitional and polluting fuels and technologies as described below, although the definitions will be revised as necessary. WHO does not advocate certain fuel and technology options over others but supports use of the cleanest possible fuels and technologies in each setting.

WHO defines clean fuels and technologies as those that do not emit PM$_{2.5}$ at levels higher than those recommended in the air quality guidelines (5). Combinations of fuel and technology that have been found not to exceed either the annual average guideline level of 10 µg/m$^3$ or the interim target 1 level of 35 µg/m$^3$ will be classified as “clean” for reporting on achievement of the Sustainable Development Goals. As explained in the guidelines (5):
The interim targets are intended as incremental steps in a progressive reduction of air pollution in more polluted areas; they are intended to promote a shift from concentrations involving acute, serious health consequences to concentrations that, if achieved, would result in significant reductions in the risk of acute and chronic effects. Such progress towards guideline values should be the objective of air quality management and health risk reduction in all areas.

Fuels and technologies known to be clean for health at the point of use are categorized as clean for household emissions of PM$_{2.5}$ and CO. These are: solar, electric, biogas, liquefied petroleum gas and alcohol fuels, including ethanol. For other fuel–technology combinations, including biomass, the cooking system is classified as clean if it meets the emission rate targets in the WHO guidelines, as confirmed by laboratory testing by a third party according to an international protocol.

The VPT tiers align with WHO guideline levels that confer a minimal health risk. According to the tier system of the ISO 19867-3 Voluntary performance targets for cookstoves based on laboratory testing (1), a stove that achieves tier 4 or tier 5 for PM$_{2.5}$ emissions is classified as clean for PM$_{2.5}$ emissions. A stove that achieves tier 5 for CO emissions is classified as clean for CO emissions (Table 2).

### Table 2. WHO categorization of ISO VPT emission tiers as clean, transitional and polluting

<table>
<thead>
<tr>
<th>ISO VPT tier</th>
<th>WHO category for CO</th>
<th>WHO category for PM$_{2.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Clean</td>
<td>Clean</td>
</tr>
<tr>
<td>4</td>
<td>Transitional</td>
<td>Clean</td>
</tr>
<tr>
<td>3</td>
<td>Transitional</td>
<td>Transitional</td>
</tr>
<tr>
<td>2</td>
<td>Polluting</td>
<td>Polluting</td>
</tr>
<tr>
<td>1</td>
<td>Polluting</td>
<td>Polluting</td>
</tr>
<tr>
<td>0</td>
<td>Polluting</td>
<td>Polluting</td>
</tr>
</tbody>
</table>

WHO defines transitional fuels and technologies as those that provide some health benefit. The emissions of transitional stove–fuel combinations exceed the GIAQ/HFC recommended emission rate targets and consequently exceed the WHO guideline levels for PM$_{2.5}$ and CO; however, they still reduce health risks compared to other options. If these categories are linked to the ISO VPT tiers, a stove that achieves tier 3 for PM$_{2.5}$ emissions is classified as transitional for PM$_{2.5}$, indicating that it is associated with a substantial reduction in health risk but cannot be considered clean for health. Stoves and devices that achieve below the tier 3 level for PM$_{2.5}$ are consider polluting for PM$_{2.5}$ emissions. A stove that achieves tier 3 or 4 for CO emissions is classified as transitional for CO emissions.

WHO defines polluting fuels and technologies as cooking solutions that are a risk to health at the point of use. The WHO guidelines discourage the use of kerosene and recommend against the use of unprocessed coal in the home. Thus, these fuels are considered polluting. Other fuels and technologies, including biomass, are classified according to the ISO VPT tiers. A stove that rates tier 0, 1 or 2 for PM$_{2.5}$ emissions is...
2.4 Scope of WHO guidelines for indoor air quality: household fuel combustion and voluntary performance targets

The WHO GIAQ/HFC address air pollution from all sources, both in the home, including cooking, heating and lighting, and outside; the recommendations therefore apply to emissions from all these sources. The ISO laboratory testing protocol, the VPTs and the field-testing protocol are restricted to cooking. ISO TC285 addresses standards for “cookstoves and clean cooking solutions”; however, as the PM$_{2.5}$ emission levels used to derive the PM$_{2.5}$ VPT tiers are based on the WHO guidelines, these tiers can also be used to classify space-heating devices as clean, transitional or polluting.

It is therefore recommended that the ISO VPTs be used within a comprehensive strategy on household energy, supported by the WHO CHEST toolkit, described in section 10.

Household air pollution generated from household fuel use also contributes to outdoor ambient air pollution, which can re-enter houses, thus affecting indoor air quality. Extremely high concentrations of ambient PM$_{2.5}$ could therefore render indoor concentrations unsafe despite use of a tier 5 (for PM$_{2.5}$) stove.
3 Laboratory protocols for evaluating cookstove performance

3.1 Introduction

The ISO harmonized laboratory test protocols ensure standardized, repeatable testing of stoves, which is a key component of the ISO standards for cookstoves and clean cooking solutions (8). The protocol requires a standard test sequence for comparison of the performance of different cookstove types, cookstove fuels and cooking practices under controlled laboratory conditions. This common approach is designed to assess the performance of technologies before they are widely promoted and also to understand their baseline performance. The standard sequence is summarized in Box 1, and definitions of measurement parameters and reporting are given in sections 3.2 and 3.3. See ISO documentation for full details (1).

The VPTs, described further in section 4, are based on the results of laboratory testing with the standard procedure. Five parameters of stove performance are covered in VPTs: thermal efficiency, emissions of PM$_{2.5}$ and of CO, safety and durability.

ISO/TC 285 also recognized that a standard laboratory test procedure, while valuable for meaningful comparisons, may not reflect performance in homes with local mixes of cooking tasks. The ISO committee therefore developed an international standard field-testing protocol for use in homes (17). The standard is used to evaluate use, usability, fuel consumption, energy consumption, power, safety and durability, with a recommendation to measure ambient concentrations of PM$_{2.5}$ and CO and personal exposure in order to evaluate cooking system performance under actual conditions.

3.2 Test parameters: definitions and methods

The ISO laboratory-testing protocol is designed for evaluating stove performance. The VPTs, published by ISO in a separate document (1), are established for each of the five parameters of stove performance by rating the results of laboratory testing in one of six tiers. Definitions of each parameter and testing method used in the VPTs are provided in Table 3; for full details, see ISO documentation (1).

**Box 1. ISO standard laboratory test sequence**

- Heat water on a cookstove system.
- Test at high, medium and low power of the cookstove system.
- Repeat the sequence at least five times to increase statistical power.
- Conduct standard safety test (10 components).
- Conduct standard durability test (7 components).
Table 3. Definitions and summary of the test method for five parameters of stove performance in the ISO harmonized laboratory-testing protocol

<table>
<thead>
<tr>
<th>Test parameter</th>
<th>Definition</th>
<th>Testing and reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal efficiency</td>
<td>Ratio (%) of useful energy delivered (to the cooking vessel) to fuel energy used during testing</td>
<td>Thermal efficiency and emission of PM$_{2.5}$ and CO are measured during a test sequence to determine increases in the temperature and steam production of a known mass of water. The sequence is conducted at high, medium and low power levels for the stove (unless the stove is designed to operate at only one or two of these levels). Thermal efficiency is reported with and without allowance for the energy content of residual char. Emissions are reported as total emissions and those that escape into the room (“fugitive emissions”) for stoves with chimneys. Results are reported for each of the three power levels and also as arithmetic means of values.</td>
</tr>
<tr>
<td>PM$_{2.5}$ emissions</td>
<td>Mass (in mg) per unit of useful energy delivered (MJ$_d$); also expressed as emission rate (mg/min)</td>
<td></td>
</tr>
<tr>
<td>CO emissions</td>
<td>Mass (in g) per unit of useful energy delivered (MJ$_d$); also expressed as emission rate (g/min)</td>
<td></td>
</tr>
<tr>
<td>Safety*</td>
<td>Weighted total safety score, between 25 (worst safety) and 100 (best safety)</td>
<td>Safety is measured in a standard set of tests of 10 characteristics that include tipping angle, surface temperature, containment of fuel, containment of flames and sharp angles. Each characteristic is scored from “poor” (1) to “best” (4), and an overall weighted score is derived, with greater weight given to characteristics such as containment of flames because of potential harm.</td>
</tr>
<tr>
<td>Durability*</td>
<td>Total durability score, between 0 (best durability) and 37 (worst durability)</td>
<td>Durability is measured in a standard set of tests of seven characteristics that include impact resistance, damage after extended use, corrosion and coating adhesion. Each of these characteristics is given a risk factor, +0 being best and (up to) +6 being worst; an overall score is derived by summing all risk factor scores. Weighting is built into the risk factor scales, some of which cover the range 0–5 and others 0–6.</td>
</tr>
</tbody>
</table>

---

* Safety protocols apply to solid-fuel stoves and solar cookers only; reference is made to safety standards for other types of stove and fuel, e.g. electric (IEC 60335-2-6) and gas-fuelled cookstoves (ISO 23550 and ISO 23551).

* Durability protocols are used to evaluate common material failures in biomass cookstoves. The protocol does not cover all failures that might occur in the field, nor are the tests in the protocol applicable to all cookstoves. The protocol covers the most prevalent concerns for durability in a range of cookstove technologies and construction materials.

The ISO standard recommends that test procedures for efficiency and emissions be repeated to obtain a mean and a standard deviation (SD) for estimation of statistical precision (90% confidence intervals). The standard test sequence should be repeated a minimum of five times, and the number of repetitions should be reported.
3.3 Selection of parameters and relevance to health

Emissions of PM$_{2.5}$ and CO, thermal efficiency, safety and durability are the five parameters of stove performance judged to be the most directly or indirectly relevant to health and safety.

Emissions of PM$_{2.5}$ and CO and the safety of the stove–fuel combination directly impact health. The relations between emissions and air quality are covered in section 6.1.1. The safety score provides an indication of the risks for burns, scalds and cuts of users, children and other adults in the home.

Thermal efficiency indicates the amount of fuel consumed for cooking and related tasks, which in turn influences the amount of fuel that must be collected and/or purchased and the time required to procure fuel and to cook. The time spent collecting fuel and the cost of fuel may impact the health of family members, while burning more fuel is likely to be associated with higher emissions and personal exposure.

The durability score indicates aspects of cookstove design that affect their usable life and consumers’ perceptions of quality, which may influence the duration of use of the stove in the household. If a new stove is used less or abandoned and not replaced, any benefits in terms of more efficient, cleaner combustion and safety will be lost.

3.4 Cookstove performance in the laboratory and in homes

Readers should be aware that stove testing in the laboratory under controlled conditions, however carefully conducted, frequently does not represent the level of performance in the home when the stove is used for cooking and other tasks, which is what matters in terms of impacts on health, safety, fuel use, costs and other aspects. A review of substantial differences between laboratory and field performance (14) indicated several reasons for these discrepancies. First, the actual tasks may differ; e.g. in the laboratory, water is heated, whereas in the home the stove is used for other cooking activities and other uses (e.g., heating bath water, preparing animal feed). Secondly, whereas the fuel used in laboratory testing is selected and prepared in a standard way, the fuel used in the home may vary, with use of different types of wood or several fuels, such as wood, dung and crop wastes. The fuel moisture content may also vary, especially during wet seasons. Thirdly, while laboratory technicians adhere to a specified protocol that is designed to be repeatable, use of a stove in the homes varies widely, both among homes and within homes on different occasions (Fig. 1).
Differences between laboratory and field performance are more frequent for biomass and solid fuel stoves than for liquid or gaseous fuels, as there are fewer differences in technical and user factors for these prepared fuels. Greater agreement between laboratory and field test results was found for solid fuels that are more homogeneous, such as biomass pellets, and technologies that require less user attention, such as batch-fuelled gasifiers (18).

Despite differences in the performance of stoves between the laboratory and the field, the ISO standards (and the WHO CHEST toolkit) emphasize laboratory testing as a benchmark of performance because the procedure is standardized and allows comparisons. In addition, as laboratory testing is usually conducted under optimum conditions, poor performance in the laboratory indicates that the stove would probably perform worse in the home, and its use may be discouraged. When possible, laboratory testing should be complemented by field testing.
4.1 Introduction

The ISO laboratory test protocol described above is used for measuring stove performance according to five parameters in a laboratory setting. The vPTs, published by ISO (1), are set by rating the results of laboratory testing of each of the five parameters of stove performance in one of six tiers, graded from 0 (poorest performance) to 5 (best performance) (Table 4).

The tiers for the five parameters should be reported separately; for example, a stove could be reported as in tier 4 for thermal efficiency, tier 4 for CO, tier 3 for PM$_{2.5}$, tier 0 for safety and tier 5 for durability. The association between test results and tier values is described further, with an example, in section 5.

The VPT Technical Report is available for purchase through the ISO website (www.iso.org) and the websites of national standards bodies (8).

**Table 4.** Tier values for ISO voluntary performance targets; values for PM$_{2.5}$ and CO emissions are default values

<table>
<thead>
<tr>
<th>Performance</th>
<th>Tier</th>
<th>Thermal efficiency (%)</th>
<th>Emissions (default)</th>
<th>Safety (score)</th>
<th>Durability (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>≥ 50</td>
<td>≤ 3.0</td>
<td>≥ 95</td>
<td>≤ 10</td>
</tr>
<tr>
<td>Better performance</td>
<td>4</td>
<td>≥ 40</td>
<td>≤ 4.4</td>
<td>≥ 86</td>
<td>≤ 15</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>≥ 30</td>
<td>≤ 7.2</td>
<td>≥ 77</td>
<td>≤ 20</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>≥ 20</td>
<td>≤ 11.5</td>
<td>≥ 68</td>
<td>≤ 25</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>≥ 10</td>
<td>≤ 18.3</td>
<td>≥ 60</td>
<td>≤ 35</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>&lt; 10</td>
<td>&gt; 18.3</td>
<td>&lt; 60</td>
<td>&gt; 35</td>
</tr>
</tbody>
</table>

*Source: reference 1, Table 1*

MJ$_{d}$, megajoules delivered

The tier values for PM$_{2.5}$ and CO shown in Table 4 are described as “default” values; that is, they were derived in the emissions model from the average of values from all the available studies on air exchange rate, kitchen volume and duration of stove use. Calculation of VPT tiers for emissions of PM$_{2.5}$ and CO from
evidence of health risk associated with exposure is described further in section 6. Additional information on selecting suitable emission tiers for PM$_{2.5}$ and CO according to national and local conditions is discussed in section 7.

4.2 Derivation of tier values for each of the five parameters of cookstove performance

The tier values for PM$_{2.5}$ and CO emissions are derived as shown in Tables 5 and 6. While tier values are specific to each test parameter, the common principle for all five is that tier 0 is generally the performance typical of an open fire or simple solid fuel stove with no chimney, while tier 5 represents the best that can be expected according to the performance observed in the laboratory.

In summary, the tiers for each parameter are set as follows:

- For thermal efficiency, tier 1 is set at a level observed with simple improvements to cookstove technology, and the remaining tiers are derived by mathematical division of the range to tier 5.
- For safety and durability, tiers 1–4 are mathematical divisions of the range between tier 0 and tier 5.
- For emissions of PM$_{2.5}$ and CO, the tiers are based on evidence of health risks at different levels of exposure, as shown in Tables 5 and 6.

Emissions of PM$_{2.5}$

The basis for VPT tiers for emissions of PM$_{2.5}$ is evidence of a health risk of exposure, as described further in section 6. Information on selecting suitable emission tiers for PM$_{2.5}$ according to national and local conditions is discussed in section 7.

Table 5. Definition of PM$_{2.5}$ tier categories

<table>
<thead>
<tr>
<th>Tier category</th>
<th>Tier number(s)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>5</td>
<td>The highest tier for PM$<em>{2.5}$ is the emission rate that, under the stated emission model assumptions, would result in 90% of homes achieving kitchen indoor air quality that meets the WHO annual mean air quality guideline value of 10 µg/m$^3$. This level of PM$</em>{2.5}$ is associated with minimal adverse health risk and has a relative risk for child acute lower respiratory infections (ALRI) of 1.0 in the integrated exposure response function (IER).</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1–4</td>
<td>Intermediate emission rate tiers have been set so that 50% of homes 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. Tier 1 was set at this value to be consistent with performance observed with simple cookstove technology improvements.</td>
</tr>
<tr>
<td>Lowest</td>
<td>0</td>
<td>An emission rate higher than tier 1, consistent with that observed with open fires and other simple solid fuel cookstove technologies.</td>
</tr>
</tbody>
</table>

Source: reference 1, Table 6
Emissions of CO

The basis for VPT tiers for emissions of CO is evidence of a health risk of exposure, as described further in section 6. Additional information on selecting suitable emission tiers for CO according to national and local conditions is discussed in section 7.

Table 6. Definition of CO tier categories

<table>
<thead>
<tr>
<th>Tier category</th>
<th>Tier number(s)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>5</td>
<td>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 concentration that meets the WHO 24-h mean air quality guideline value of 7 mg/m³.</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1-4</td>
<td>The Tier 1 emission rate has been set so that 90% of homes would have kitchen CO concentration at or below 230 mg/m³ during cooking events, a level associated with mild adverse acute symptoms from CO exposure (see empirical basis for tier section, 6.2). The remaining intermediate emission rate tiers (2–4) represent equal mathematical divisions between Tiers 1 and 5 for the percentage of homes covered at 7 mg/m³ daily average CO concentration.</td>
</tr>
<tr>
<td>Lowest</td>
<td>0</td>
<td>An emission rate higher than Tier 1, and consistent with that observed with open fires and other simple solid fuel cookstove technologies.</td>
</tr>
</tbody>
</table>

Source: reference 1, Table 10 (content in italics added)

Application of standard laboratory test results to default tiers is explained further in section 5, with examples. Further examples of emission VPT tiers and confirmation of the selection of representative emission VPT tiers are given in section 6.
SETTING NATIONAL VOLUNTARY PERFORMANCE TARGETS FOR COOKSTOVES
## Application of standard laboratory test results to default voluntary performance target tiers

Examples of laboratory tests results for a particular stove and their relation to default VPT tiers are shown in Table 7. The appropriateness of default VPT tiers is discussed in section 7. To identify the correct tier for each of the five test parameters, laboratory test results (Table 7) are compared with the values provided in ISO/TR 19867-3 (Table 8); the values that fit the test results are shown in bold. As noted above, the tier for each parameter should be reported separately.

**Table 7. Laboratory results for an example stove**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Test sequence phase</th>
<th>Combined(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Thermal efficiency without char (%)</td>
<td>Mean</td>
<td>31.4</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>90 % CI</td>
<td>29.6–33.2</td>
</tr>
<tr>
<td>Thermal efficiency with char (%)</td>
<td>Mean</td>
<td>33.6</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>90 % CI</td>
<td>31.5–35.7</td>
</tr>
<tr>
<td>Fuel burning rate (g/min)</td>
<td>Mean</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.9</td>
</tr>
<tr>
<td>PM(_{2.5}) per useful energy (mg/MJ(_d))</td>
<td>Mean</td>
<td>497</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>90 % CI</td>
<td>445–549</td>
</tr>
<tr>
<td>CO per useful energy (g/MJ(_d))</td>
<td>Mean</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>90 % CI</td>
<td>0.5–0.7</td>
</tr>
<tr>
<td>Safety</td>
<td>Score</td>
<td>88</td>
</tr>
<tr>
<td>Durability</td>
<td>Score</td>
<td>18</td>
</tr>
</tbody>
</table>

*Source: Adapted from reference 1, Table 2, with the rows Char energy productivity (%) and Char mass productivity (%) omitted. MJ\(_d\), megajoules delivered.*

\(^{a}\) The combined value is the arithmetic mean of the three values (or two, if only two power values were used in the test sequence); in some circumstances, a weighted mean may be used. See reference 1 for further information.
### Table 8. Default ISO VPT tier values

<table>
<thead>
<tr>
<th>Performance</th>
<th>Tier</th>
<th>Thermal efficiency (%)</th>
<th>CO (g/MJ delivered)</th>
<th>PM$_{2.5}$ (mg/MJ delivered)</th>
<th>Safety (score)</th>
<th>Durability (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better performance</td>
<td>5</td>
<td>≥ 50</td>
<td>≤ 3.0</td>
<td>≤ 5</td>
<td>≥ 95</td>
<td>&lt; 10</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>≥ 40</td>
<td>≤ 4.4</td>
<td>≤ 62</td>
<td>≥ 86</td>
<td>&lt; 15</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>≥ 30</td>
<td>≤ 7.2</td>
<td>≤ 218</td>
<td>≥ 77</td>
<td>&lt; 20</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>≥ 20</td>
<td>≤ 11.5</td>
<td>≤ 481</td>
<td>≥ 68</td>
<td>&lt; 25</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>≥ 10</td>
<td>≤ 18.3</td>
<td>≤ 1030</td>
<td>≥ 60</td>
<td>&lt; 35</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>&lt; 10</td>
<td>&gt; 18.3</td>
<td>&gt; 1030</td>
<td>&lt; 60</td>
<td>&gt; 35</td>
</tr>
</tbody>
</table>

Source: Adapted from reference 1, Table 1 (bolding added to reflect example test results discussed in the text).

Note: Default emission tiers correspond to generic settings. The appropriate type of VPT tier (default, alternative or user-defined) should be selected according to national and local conditions.

In this example, the combined thermal efficiency (without char)\(^1\) is reported in Table 7 as 33.7%. The tier rating for thermal efficiency is determined by the lower bound of the 90% confidence interval for the combined results, which is 31.9%. In Table 4, this value lies in the range ≥ 30% to < 40%, which is defined as tier 3. This is better than tier 2 (from 20% to ≤ 30%), but not good enough for tier 4 (40% to < 50%). In this case, the lower bound of the 90% confidence interval for thermal efficiency with char (35.5%) also falls in tier 3.

For combined PM$_{2.5}$ emissions, the value of 305 mg/MJ$_{\text{d}}$ places the stove in the range of > 218 mg/MJ$_{\text{d}}$ to 481 mg/MJ$_{\text{d}}$, which is tier 2. The laboratory testing protocol provides results as both emission factors and emission rates. It is important to use emission factors when comparing laboratory test results against VPT tiers. Section 6.3 describes the relation between normalized emission rates and measured emission factors.

The combined CO emissions from the stove in this example are 0.8 g/MJ$_{\text{d}}$, which places the threshold far below tier 5 emissions (3.0 g/MJ$_{\text{d}}$); thus, the stove qualifies as tier 5 for CO emissions.

A similar approach is taken to assigning tier values for safety and durability. The laboratory tests gave a safety score of 88, which is higher than the tier 4 value and lower than the tier 5 value; thus, the stove qualifies as tier 4 for safety. The stove received a durability score of 18, which is greater than the tier 4 value of 15 but lower than the tier 3 value of 20; thus, the stove is classified as tier 3 for durability.

\(^1\) For solid-fuel stoves that produce char (residual unburnt fuel that has some energy content, or “credit”), thermal efficiency is reported both with and without allowance for that energy “credit.” Thermal efficiency without allowance for 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 or for another purpose.
VPT tiers for emissions of PM$_{2.5}$ and CO are based on evidence that exposure to these pollutants is a risk to health according to the WHO GIAQ/HFC. This section provides a step-by-step description of the method for setting VPT tiers for emissions of PM$_{2.5}$ and CO.

6.1 Emissions of PM$_{2.5}$

6.1.1 Relation between pollutant concentration and emission rate: the emissions model

The emissions of pollutants from cookstoves are used to estimate health risk, as emission per unit time is used to estimate air quality in kitchens. Although ventilation, usage and other factors affect the levels of pollution in the home, the underlying determinant is the level of pollutants emitted from the stove (9). If the levels of pollutant emissions can be kept low, the quality of indoor air will usually be good.

Pollutant concentrations in the kitchen can be estimated from emission rates in a simple box model, the most common approach, illustrated in Fig. 2 (19). This modelling technique was used for the WHO GIAQ/HFC, the IWA 11: 2012 (now withdrawn) and the VPTs.

Fig. 2. Model of kitchen emissions
The model inputs include the rate of emission of the pollutant (e.g. PM$_{2.5}$) and three characteristics of a kitchen that may affect pollutant concentrations:

- air exchange rate in the kitchen, which is a measure of ventilation;
- the volume of the kitchen; and
- the duration of use of the stove each day, i.e. how long it is lit and emitting pollutants at a known rate.

The middle of the diagram represents the kitchen and the stove, which may or may not have a chimney (a pipe attached directly to the stove that vents outside). If there is no chimney, all the emissions enter the kitchen. If there is a chimney, depending on the design and condition of the stove, some emissions will escape into the room (known as “fugitive” emissions), and some will be vented outside (Fig. 3).

The outputs of the model, shown on the right of the diagram in Fig. 2, are the estimated average kitchen concentrations of the pollutants of interest generated according to the input and moderated by the presence of a chimney.

**Fig. 3.** Left, a stove with a chimney, from which some “fugitive” emissions escape into the kitchen and the rest are vented outside (photo credit: Nigel Bruce); right, an open fire with no chimney, from which all emissions are emitted into the kitchen (photo credit: Nigel Bruce).

Several iterations of this emissions model have been used since its initial application in the IWA 11:2012; these are summarized in Annex 1, with explanations of the nomenclature and the purposes for which they have been, and will be, used. The values of the three input variables for the emissions model are related to kitchen characteristics (air exchange rate, kitchen volume and duration of stove use per day) and were obtained from surveys carried out in homes in many countries. This information is the basis for creating the default tiers. The WHO database of studies from which input data on kitchen characteristics were derived is described in section 10, and references are provided in the ISO VPT Technical Report (1). Rather
than entering values for kitchen characteristics as averages for default tiers, the distribution of each variable has been used, as illustrated in Table 9.

Before setting VPT tiers, countries should ensure that the appropriate tiers (default, alternative or user defined) are selected, as further described in section 7.

**Table 9.** Means, standard deviations, minimum and maximum values of the distribution of model input variables used to set default VPTs

<table>
<thead>
<tr>
<th>Model input variable</th>
<th>Values utilized</th>
<th>Range</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Air exchange (ACH)</td>
<td>21.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Kitchen volume (m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>28.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Duration of cooking (h/day)</td>
<td>4.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

*Source: Adapted from reference 1, Table 8, with minor modifications to stylistic notation and organization.*

<sup>a</sup> Geometric mean (exponential of the mean of the log-transformed values)

<sup>b</sup> Arithmetic mean

The geometric mean has been used as a measure of air exchange rate and kitchen volume, as the distribution of these variables tends to be very positively (right) skewed; with such distributions, the geometric mean is a better indication of average values than the arithmetic mean.

Use of distributions of values in the emissions model rather than means gives a more representative spread of values. A Monte Carlo simulation is used for a distribution of values (see Box 2), which generates a distribution of kitchen air quality concentrations. The model output can most helpfully be interpreted as the percentage of homes in which the air quality contains a specified concentration of a pollutant or less. See Box 3.

**Box 2. Monte Carlo simulation**

This technique is a useful means of dealing with uncertainty – in this case in the values of model input variables such as air exchange rates or kitchen volumes. Random selections of values of these variables are used in repeated runs (≥ 1000) of the model. The output values of each variable (e.g. PM concentration) are then compiled in a distribution, and the median of the distribution gives the value that would be achieved in 50% of homes.

**Box 3. Example of emissions model input and output**

With a PM<sub>2.5</sub> emission rate of 2.7 mg/min and assumed mean (SD) values for air exchange of 21.0 (11.0) per hour, a kitchen volume of 28.0 (16.8) m<sup>3</sup> and stove use per day of 4.2 (1.5) h (as per Table 9), 50% of homes would have a PM<sub>2.5</sub> concentration of ≤ 50 µg/m<sup>3</sup>. 
The emissions model can thus be used to estimate indoor pollution concentrations from emission rates and survey-derived values for kitchen characteristics.

### 6.1.2 Setting emission rates to achieve specified indoor concentrations of pollutants for the voluntary performance target tiers

For setting VPT tiers, the emissions model described above was used backwards to determine the emission rate that corresponds to a specified indoor pollutant concentration. Starting with the concentration that we wish to achieve, such as 50% of homes at or below a concentration of 50 µg/m³ of PM$_{2.5}$, and assuming the same values for air exchange, kitchen volume and duration of use, the emission rate can be calculated – in this case, 2.7 mg/min, as shown in Box 3.

Thus, emission rates and factors can be derived for VPTs. A specified pollutant concentration is selected for a stated health risk, and the emission rates required to meet the specified concentration have been determined. To derive tiers of PM$_{2.5}$, increments of RR for ALRI in children were selected, as described in the definition of tier categories. Tables 5 and 6 define PM$_{2.5}$ and CO tier categories based on emission rates, and section 6.1.3 describes the derivation of specified PM$_{2.5}$ concentrations for each of the associated RRs defined.

The different types of emission tiers for different scenarios (default, alternative, user-defined) and selection of the most representative scenario are described in section 7. Section 8 describes use of the WHO PT model, including data input, running the model, the outputs and their interpretation and application to VPT tiers.

### 6.1.3 Association between relative risk for pneumonia in children and indoor air pollution concentration for voluntary performance target tiers

Epidemiological studies have elucidated the relationship between exposure to PM$_{2.5}$ and the risks for a number of specific diseases, which are described as “integrated exposure–response” (IER) curves (20). The health risk is defined as a “relative risk”; and IERs are currently available for five disease conditions: for children, ALRI; for adults, chronic obstructive pulmonary disease, stroke, cardiovascular disease and lung cancer. As the shapes of the IER curves differ somewhat for the five disease conditions, that for child pneumonia was selected according to the approach used in the WHO GIAQ/HFC (Fig. 4).

---

1 Relative risk (RR) is the risk of a disease experienced by an individual exposed to a higher level of a risk factor as compared with the risk experienced by an individual exposed to a lower level of the risk factor. An RR of 1.0 implies no additional risk, while an RR of 2.0 (for example) indicates twice the risk.
Fig. 4. Integrated exposure–response function for acute lower respiratory tract infection in children. The red lines and arrows illustrate the specified PM$_{2.5}$ concentration for RRs of 1.5 (VPT tier 4) and 2.5 (VPT tier 3)

Integrated exposure–response function for PM$_{2.5}$ ALRI risk

Source: Adapted from reference 20

For emissions of PM$_{2.5}$, it has been assumed that 90% of homes should meet tier 5 and 50% tiers 1–4. To derive the tiers of PM$_{2.5}$, increments of the RR for ALRI in children were selected, as indicated in Table 5, and RRs of 3.15, 3.0, 2.5, 1.5 and 1.0 were set for PM$_{2.5}$ tiers 1–5, respectively. Tier 5, with an RR of 1.0, implies no additional risk. Next, the specified PM$_{2.5}$ concentration for each of the associated RR values is defined with the IER function. For example (and as illustrated in Fig. 4), an RR of 1.5 (tier 4) for ALRI in children is associated with a mean PM$_{2.5}$ concentration of 50 µg/m$^3$, while an RR of 2.5 (tier 3) is associated with a mean concentration of 170 µg/m$^3$.

The emissions model is then used to determine the emission rates required to achieve the concentration of PM$_{2.5}$ defined for each tier. Fig. 5 summarizes the steps in derivation of emission VPT tiers for PM$_{2.5}$.

Fig. 5. Calculation of VPT tiers for emissions of PM$_{2.5}$

6 RRs for child ALRI
VPT tiers 0–5 (6 tiers) are set at increments of RR for child ALRI.

Integrated exposure–response (IER) curves
6 specified PM$_{2.5}$ concentrations
6 specified PM$_{2.5}$ concentrations are defined from IER curves for RR values.

Emissions model
6 corresponding emission rates
The emissions model is used to determine the emission rates required to achieve the PM$_{2.5}$ concentration defined for each tier.

Calculation and assumptions
6 VPT tiers set for emission of PM$_{2.5}$
Set to reflect a certain percentage of homes meeting each tier level.

6 corresponding emission factors (mass of pollutant per unit energy delivered)
Emission rates converted to emission factors by multiplying by the assumed average cooking time and dividing by the assumed required useful energy delivered.
6.2 Emissions of carbon monoxide

The tiers for CO emissions are also based on evidence of health risk. They are determined with a modified approach, however, as IER functions are not yet available for this pollutant. Furthermore, exposure to CO affects health in two distinct ways.

- In the short term, within a few hours, exposure to high levels of CO is acutely toxic, causing drowsiness, convulsions, loss of consciousness and death when the level is sufficiently high.

- In the long term, over many years, exposure to at least moderate levels of CO increases the risks for chronic diseases, such as cardiovascular disease, and, when pregnant women are exposed, increases the risk of an infant with reduced birth weight.

The tiers shown in Table 6 include both mechanisms, with acute toxicity at higher concentrations and chronic effects at lower concentrations.

Tier 0 represents the concentration of CO observed from open fires and simple, unvented solid fuel stoves. Tier 1 is set to represent a concentration of CO in 90% of homes (under the default model assumptions) that is < 230 mg/m$^3$, which, over 2–3 h (i.e. typical duration of stove use), leads to mild symptoms of acute toxicity, such as headache and impaired judgement (21). Tier 5 is set to represent the situation in which 90% of homes meet the WHO 24-h air quality guideline for CO of 7 mg/m$^3$, which would avoid the adverse health effects of long-term exposure. At tier 5, the concentration of CO is at or below the acute toxicity benchmark concentration of 230 mg/m$^3$ for 99.9% of homes under the default model assumptions. It is important to note that adequate ventilation is essential to reduce the health risks due to exposure to CO.

6.3 Calculation of emission factors from emission rates

Laboratory test results for emissions are reported as "emission factors", in milligrams (mass) per megajoule delivered (useful energy) for PM$_{2.5}$ and in grams per megajoule delivered for CO. Although the laboratory-test protocol yields results for both emission factors and emission rates, emission factors must be used when comparing laboratory test results with a VPT tier. The reasons for using emission factors for determining VPT tiers and the relation between emission rates and emission factors are described further in Box 4.
Box 4. Emission factors and emission rates

In the context of VPTs, an “emission factor” is defined as the ratio of the mass of a pollutant emitted to the useful energy delivered. An “emission rate” is the mass of an air pollutant emitted per unit time.

A low-powered stove may have a low emission rate (per min), giving the appearance of good (clean) performance. Because of its low power, however, it would have to be used longer to complete cooking, resulting in higher overall emissions than from a more powerful stove with a higher emission rate per minute. Thus, emission rates are not used directly in setting VPTs, and the emission factor is used instead, as it is expressed in relation to the amount of useful energy delivered.

“Normalized” emission rates (e.g., mg/min of a pollutant, as referred to in the emissions model in section 6.1.1) are calculated from measured emission factors (e.g., mg/MJ\text{d}) whereby the emission factor is multiplied by the assumed useful energy delivered required for daily cooking (11 MJ), as shown in the equation below (23), divided by the assumed average cooking time (in min/day).

\[
\text{Normalized emission rate (mg/min)} = \frac{[\text{emission factor (mg/MJ\text{d})} \times \text{energy delivered (MJ\text{d})}]}{\text{duration of use (min)}}
\]

In the global default scenario, it is assumed that a stove must deliver 11 MJ of energy within a default time of use of 4.4 h, such that,

\[
\text{Normalized emission rate (mg/min)} = \frac{[\text{emission factor (mg/MJ\text{d})} \times 11 \text{ MJ}\text{d}]}{252 \text{ min}}
\]

For the purpose of establishing the emission factors for the VPTs as a function of emission rates (as depicted in Fig. 5), emission factors were derived from emission rates:

\[
\text{Emission factor (mg/MJ\text{d})} = \frac{[\text{emission rate (mg/min)} \times \text{duration of use (min)}]}{\text{Energy delivered (MJ\text{d})}}
\]

With the same assumptions as above for duration of use and energy delivered,

\[
\text{Emission factor} = \frac{[\text{emission rate} \times (252 \text{ min})]}{11 \text{ MJ}\text{d}}
\]
SETTING NATIONAL VOLUNTARY PERFORMANCE TARGETS FOR COOKSTOVES
Selection of appropriate voluntary performance targets for emissions of $\text{PM}_{2.5}$ and carbon monoxide

7.1 Planning national testing strategies: appropriate emission tiers

When countries are planning a national strategy for testing and applying standards, including VPTs for stove emissions, it is recommended that they review data on the housing characteristics and cooking practices in the country. If such data are not available, information may be available for other countries with similar cooking practices. WHO has established a database of such variables, organized by country and region (see section 10). If no locally appropriate data are available, countries may choose to conduct field measurements to obtain the model input data: air exchange rate, kitchen volume and average daily cooking time. Fig. 6 conceptualizes establishment of national voluntary targets for emissions.
**Fig. 6.** Flowchart for establishing national voluntary performance targets for emissions

**STEP 1**
Determine if data are available

Determine whether data on air exchange rate/ventilation rate, kitchen volume, and duration of stove use per day are available for the country or regional data. Refer to local sources OR Review WHO database of input variables from studies conducted across the world for air exchange rates, kitchen volume and duration of stove use [https://worldhealth.org.shinyapps.io/HAPmodelinputdata/](https://worldhealth.org.shinyapps.io/HAPmodelinputdata/) OR if desired, an additional literature review may be conducted.

No → Are sufficient DATA for ALL THREE VARIABLES available?


**STEP 2**
Develop VPTs for PM\(_{2.5}\) and CO (either ADAPT or ADOPT)

Determine whether default assumptions for air exchange rate (either default, high-ventilation, or low-ventilation), kitchen volume and duration of stove use per day are reasonable for the country/context:

<table>
<thead>
<tr>
<th>Model input variable</th>
<th>Units</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Default” air exchange rate</td>
<td>Number/h</td>
<td>21.0(^a)</td>
<td>11.0</td>
<td>4 - 100</td>
</tr>
<tr>
<td>“High-ventilation” air exchange rate</td>
<td>Number/h</td>
<td>30.0</td>
<td>15.0</td>
<td>4 - 100</td>
</tr>
<tr>
<td>“Low-ventilation” air exchange rate</td>
<td>Number/h</td>
<td>10.0</td>
<td>5.0</td>
<td>4 - 100</td>
</tr>
<tr>
<td>Kitchen volume</td>
<td>m(^3)</td>
<td>28.0(^a)</td>
<td>16.8</td>
<td>5 - 100</td>
</tr>
<tr>
<td>Duration of use</td>
<td>h/day</td>
<td>4.2(^b)</td>
<td>1.5</td>
<td>1 - 8</td>
</tr>
</tbody>
</table>

\(a\) Geometric mean (exponential of the mean of the log-transformed values)

\(b\) Arithmetic mean

Yes → Default assumptions reasonable?

No → ADAPT voluntary performance targets from the ISO Technical Report (2) (Chapter 8)

Develop user-defined emission tiers using WHO Performance Target (PT) model and other resources: [https://www.who.int/tools/performance-target-model](https://www.who.int/tools/performance-target-model)

**STEP 3**
Present VPTs to stakeholders

Present proposed VPTs for PM\(_{2.5}\) and CO emissions to stakeholders. Solicit feedback on whether proposed VPTs are based on appropriate evidence and are aspirational yet achievable in the local context.
Countries can use data for similar settings or local data to determine which set of VPT emission tiers – default VPT tiers, alternative (high- or low-ventilation scenarios) or user-defined tiers (Fig. 7) – is appropriate and representative of national and local conditions. It is important to note that the different VPT tiers and ventilation scenarios apply only to PM$_{2.5}$ and CO emissions. The tiers for other test parameters (thermal efficiency, safety and durability) do not change according to the ventilation in the home.

**Fig. 7.** Types of VPT tiers for PM$_{2.5}$

The **default VPT tiers** are based on input variables (air exchange rate, kitchen volume and duration of stove use) from the literature and provide a generic set of distributions (means, SDs and ranges) for general use. The default tiers are described in detail in section 7.2.

**Alternative ventilation scenarios for VPT tiers** are similar to default tiers, except that an adjustment has been made to the air exchange rate in the model to provide conditions more typical of “high” and “low” ventilation. The other two model input variables (kitchen volume and duration of stove use per day) are the same as the default values. These scenarios are recommended for use if the national or local air exchange rates are similar to those in the alternative scenarios (see section 7.3).

If, however, after a review of the available evidence and any new studies, it is found that the housing characteristics (e.g. air exchange, kitchen volume) or cooking practices (duration of stove use per day) differ substantially from those in the ISO VPT default and alternative scenarios, it may be more appropriate to generate **user-defined tiers** based on more representative data for the setting. Section 8 describes user-defined emission tiers for PM$_{2.5}$ and CO.

### 7.2  Default values for tiers of PM$_{2.5}$ and carbon monoxide

#### 7.2.1  Rationale for default tiers

The values for VPT tiers of emissions used throughout this section are “default” values. They are termed “default” as they are as representative as possible of all settings. To ensure this, the model input values for air exchange rate, kitchen volume and duration of stove use summarized in Table 9 were derived from studies in the WHO database. In this sub-section, we review derivation of the default tiers and additional
information from reference 1 on interpretation of the tiers. Understanding the basis for and interpretation of the default values will clarify the rationale for the alternative high- and low-ventilation scenarios and indicate the circumstances in which alternative scenarios might be more appropriate than default values.

### 7.2.2 Default emission tiers for PM$_{2.5}$ and interpretation of test results

Table 10 provides additional information on the default values for PM$_{2.5}$ emissions, showing the:

- six tiers (0–5);
- RRs used in the emissions model;
- emission factors (emission per unit of useful energy delivered, in mg/MJ$_d$);
- normalized emissions rates (related to emission factors, as described in section 6.3);
- percentage of homes that would meet each tier level in the emissions model output; and
- equivalent average concentration of PM$_{2.5}$ in the kitchen, as calculated from the emissions model, met by 50% (tiers 0–4) or 90% (tier 5) of homes.

For tiers 1–4, at least 50% of homes should meet the tier threshold value; for tier 5, at least 90% of homes should meet the emission factor cut-off of 5 mg/MJ$_d$. The criterion for tier 5 is stricter, so that most homes (90%) meet the WHO annual average air quality guideline of 10 µg/m$^3$ PM$_{2.5}$. The values shown in bold in the table are discussed in Box 5.

<table>
<thead>
<tr>
<th>Tier</th>
<th>Relative Risk</th>
<th>Emission Factor (mg/MJ$_d$)</th>
<th>Normalized Emission Rate (mg/min)</th>
<th>µg/m$^3$</th>
<th>Percentage of homes meeting the tier level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>≤ 5</td>
<td>≤ 0.2</td>
<td>≤ 10</td>
<td>≥90%</td>
</tr>
<tr>
<td>4</td>
<td>≤ 1.5</td>
<td>≤ 62</td>
<td>≤ 2.7</td>
<td>≤ 50</td>
<td>≥50%</td>
</tr>
<tr>
<td>3</td>
<td>≤ 2.5</td>
<td>≤ 218</td>
<td>≤ 9.5</td>
<td>≤ 170</td>
<td>≥50%</td>
</tr>
<tr>
<td>2</td>
<td>≤ 3.0</td>
<td>≤ 481</td>
<td>≤ 21</td>
<td>≤ 400</td>
<td>≥50%</td>
</tr>
<tr>
<td>1</td>
<td>≤ 3.15</td>
<td>≤ 1031</td>
<td>≤ 45</td>
<td>≤ 800</td>
<td>≥50%</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 3.15</td>
<td>&gt; 1031</td>
<td>&gt; 45</td>
<td>&gt; 800</td>
<td>&lt; 50%</td>
</tr>
</tbody>
</table>

**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.

**Source:** adapted from reference 1, Table 7, bolding added and discussed in the example in Box 5
Box 5. Example of interpretation of a PM$_{2.5}$ test result

- A laboratory test shows that the combined PM$_{2.5}$ emission factor of a tested stove is 1031 mg/MJ$_d$ (column 3). This places it in tier 1 (column 1).
- The equivalent RR is 3.15, implying that risk of a child for ALRI would be more than three times higher than with a concentration at the WHO air quality guideline level of 10 µg/m$^3$ (column 2).
- The normalized emission rate is 45 mg/min (column 4).
- In tier 1, 50% or more of homes meet the emission factor of 1031 mg/MJ$_d$ and a normalized emission rate of 45 mg/min (column 5).
- At this emission rate, half of all kitchens would have an average concentration of PM$_{2.5} \leq$ 800 µg/m$^3$ (column 6). This is well above the WHO annual mean guideline of 10 µg/m$^3$; it is also well above the WHO intermediate target 1 of 35 µg/m$^3$.

7.2.3 Default emission tiers for carbon monoxide and interpretation of test results

Similar principles apply for derivation and interpretation of default values for CO emissions, with some distinct differences. Although the same model input variables (Table 9) were used for CO and similar assumptions apply to the default kitchen characteristics, differences in the mechanisms by which CO affect health lead to some differences in the way in which the tier values for CO are presented in the ISO Technical Report (1) and can be interpreted.

Table 11 provides information on the default emission values for CO, showing the:

- six tiers (0–5);
- emission factors (emissions per unit of useful energy delivered, in g/MJ$_d$);
- normalized emissions rates (related to emission factors as described in section 4.1);
- equivalent 24-h average concentration of CO in the kitchen at 50% coverage (50% of homes at or below this concentration), as calculated from the emissions model;
- concentration during cooking at 50% coverage (50% of homes at or below this concentration), as calculated from the emissions model;
- percentage of homes covered at a daily average of 7 mg/m$^3$, the WHO 24-h air quality guideline for protection against the chronic adverse health effects of long-term exposure to CO; and
- percentage of homes covered at 230 mg/m$^3$ during cooking, the concentration at which people experience minor symptoms (slight headache and impaired judgement) within 2–3 h of the start of exposure.

The values shown in bold in the table are discussed in Box 6.
SETTING NATIONAL VOLUNTARY PERFORMANCE TARGETS FOR COOKSTOVES

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

<table>
<thead>
<tr>
<th>Tier</th>
<th>Emission factor g/MJ&lt;sub&gt;d&lt;/sub&gt;</th>
<th>Emission Rate mg/min</th>
<th>24 hour concentration at 50% coverage mg/m&lt;sup&gt;3&lt;/sup&gt; (ppm)</th>
<th>Cooking event concentration at 50% coverage mg/m&lt;sup&gt;3&lt;/sup&gt; (ppm)</th>
<th>Percent of homes covered at mg/m&lt;sup&gt;3&lt;/sup&gt; daily average&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Percent of homes covered at 230 mg/m&lt;sup&gt;3&lt;/sup&gt; during cooking&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>≤ 3.0</td>
<td>≤ 133</td>
<td>2.3 (2.0)</td>
<td>13.6 (11.9)</td>
<td>≥ 90%</td>
<td>≥ 99.9</td>
</tr>
<tr>
<td>4</td>
<td>≤ 4.4</td>
<td>≤ 190</td>
<td>3.2 (2.8)</td>
<td>19.3 (16.8)</td>
<td>≥ 80%</td>
<td>≥ 99.9</td>
</tr>
<tr>
<td>3</td>
<td>≤ 7.2</td>
<td>≤ 315</td>
<td>5.4 (4.7)</td>
<td>32.6 (28.5)</td>
<td>≥ 60%</td>
<td>≥ 99.3</td>
</tr>
<tr>
<td>2</td>
<td>≤ 11.5</td>
<td>≤ 500</td>
<td>8.8 (7.7)</td>
<td>52.5 (45.8)</td>
<td>≥ 40%</td>
<td>≥ 97.1</td>
</tr>
<tr>
<td>1</td>
<td>≤ 18.3</td>
<td>≤ 800</td>
<td>14.0 (12.2)</td>
<td>84.1 (73.4)</td>
<td>≥ 20%</td>
<td>≥ 90</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 18.3</td>
<td>&gt; 800</td>
<td>14.0 (12.2)</td>
<td>84.1 (73.4)</td>
<td>&lt; 20%</td>
<td>&lt; 90</td>
</tr>
</tbody>
</table>

**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.

<sup>a</sup> WHO 24-hour air quality guideline

<sup>b</sup> Concentration during cooking at which subjects experience slight headache and impaired judgement within 2 h to 3 h from start of exposure

*ppm, parts per million

**Source:** adapted from reference 1, Table 11; bolding added to row for tier 3 and discussed in the example in Box 6

---

**Box 6. Example of interpretation of a CO test result**

- A laboratory test shows that the average CO emission factor of a stove is 7.2 g/MJ<sub>d</sub> (column 2). This places it in tier 3 (column 1).

- The equivalent normalized emission rate is 315 mg/min (column 3).

- At this emission rate, half of all kitchens would have an average 24-h concentration of CO ≤ 5.4 mg/m<sup>3</sup> (or 4.7 ppm) (column 4); this is well below the WHO 24-h guideline of 7 mg/m<sup>3</sup>.

- Thus, over half of all kitchens would meet the WHO 24-h guideline level (column 6), which was designed to protect against the chronic effects of long-term exposure.

- During cooking, the concentration of CO would be about 33 mg/m<sup>3</sup> (28.5 ppm) (column 5); this is well below the concentration of 230 mg/m<sup>3</sup>, the level at which mild symptoms of CO toxicity are seen after 2–3 h of exposure.

- Thus, most kitchens would have concentrations below the level at which acute toxicity is experienced during the time usually spent in cooking (column 7).

---

For the default emission rate tiers, the values were derived from the emissions model, with “global” average values for air exchange, kitchen volume and duration of stove use from all the available studies. As the default values may not be representative of all settings, we examined the tier values for the two
alternative scenarios presented in the ISO Technical Report (1), with different assumptions (and model input data) for air exchange.

7.3 Alternative scenarios for emission tiers: high and low ventilation

7.3.1 Rationale

The alternative scenarios apply only to tiers of emission rates; those for thermal efficiency, safety and durability remain the same.

Although the inputs to the emissions model include distributions of values for air exchange, kitchen volume and duration of stove use, the mean value determines where the distribution of each variable is “located” and hence each tier value. For example, the geometric mean (SD) of air exchange rates used in the default values shown in Table 9 was 21.0 (11.0) per hour, with a range of 4–100, while the geometric mean for the kitchen volume was 28.0 (16.8) m$^3$ with a range of 5–100.

If the stove being tested is to be used in a warm, low-altitude setting where kitchens are wide open and ventilation is greater than average, such as 30 exchanges per hour, this value is included in the default range but is about one SD above the mean. Thus, the “average” situation is not well represented. In a higher altitude region during the cold season, for example, ventilation may be much reduced, to, for example, 10 exchanges per hour; this is one SD below the default mean and again does not represent the “average”. These contrasted settings are illustrated in Fig. 8.

Fig. 8.  Left, low ventilation (photo credit: Nigel Bruce); right, high ventilation (photo credit: Nigel Bruce)

For more flexible VPTs, reference 1 provides two alternative ventilation scenarios, with the following distributions of the air exchange rate:
• high-ventilation scenario: geometric mean, 30; range, 4–100; SD, 15
• low-ventilation scenario: geometric mean, 10; range, 4–100; SD, 5

The kitchen volume and duration of cooking are not changed in these two scenarios. If local data indicate that the default values of these two variables or the air exchange rates in either the default or the alternative scenarios are not sufficiently representative, the online WHO PT emissions model can be used to set the tier values, as described in section 8.

7.3.2 Alternative scenarios for PM$_{2.5}$ emissions and interpretation of test results

Table 12 presents the following information for the alternative scenarios for PM$_{2.5}$ emissions:

• tiers (0–5) (column 1);
• RRs for ALRI in children; these values are the same as in the default scenario (column 2);
• kitchen concentration of PM$_{2.5}$ at 50% coverage for each tier (column 3);
• emission factors and normalized emission rates in the high-ventilation scenario (column 4); and
• emission factors and normalized emission rates in the low-ventilation scenario (column 5).

Note that the percentages of homes that meet the specified criteria (not shown here) are the same as in the default scenario, i.e. 90% for tier 5, 50% for tiers 1–4 and < 50% for tier 0.

Table 12. Tiers for high- and low-ventilation scenarios for PM$_{2.5}$ emission factors and rates$^a$

<table>
<thead>
<tr>
<th>Tier</th>
<th>Relative Risk</th>
<th>µg/m$^3$</th>
<th>Emission factor (mg/MJ$_{d}$)</th>
<th>Normalized Emission Rate (mg/min)</th>
<th>Emission factor (mg/MJ$_{d}$)</th>
<th>Normalized Emission Rate (mg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>≤ 10</td>
<td>≤ 7</td>
<td>≤ 0.3</td>
<td>≤ 2</td>
<td>≤ 0.1</td>
</tr>
<tr>
<td>4</td>
<td>≤ 1.5</td>
<td>≤ 50</td>
<td>≤ 92</td>
<td>≤ 4</td>
<td>≤ 32</td>
<td>≤ 1.4</td>
</tr>
<tr>
<td>3</td>
<td>≤ 2.5</td>
<td>≤ 170</td>
<td>≤ 321</td>
<td>≤ 14</td>
<td>≤ 115</td>
<td>≤ 5</td>
</tr>
<tr>
<td>2</td>
<td>≤ 3.0</td>
<td>≤ 400</td>
<td>≤ 733</td>
<td>≤ 32</td>
<td>≤ 252</td>
<td>≤ 11</td>
</tr>
<tr>
<td>1</td>
<td>≤ 3.15</td>
<td>≤ 800</td>
<td>≤ 1 489</td>
<td>≤ 65</td>
<td>≤ 550</td>
<td>≤ 24</td>
</tr>
<tr>
<td>0</td>
<td>&gt; 3.15</td>
<td>&gt; 800</td>
<td>&gt; 1 489</td>
<td>&gt; 65</td>
<td>&gt; 550</td>
<td>&gt; 24</td>
</tr>
</tbody>
</table>

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 10.

Source: Adapted from reference 1, Table 9; bolding added and discussed in the example in Box 7.
The emission factors (and rates) in each tier are substantially higher in the high-ventilation scenario than in the default scenario (Table 4), while those in the low-ventilation scenario are substantially lower. This reflects the fact that greater air exchange rate in the kitchen removes pollutant emissions faster, and thus a higher stove emission rate can result in the same kitchen concentration and RR. The example in Box 7 should facilitate interpretation of the alternative tier values.

Box 7. Interpreting PM$_{2.5}$ test results in high- and low-ventilation scenarios

High-ventilation scenario:
- A laboratory test of a stove in a highly ventilated setting shows a combined PM$_{2.5}$ emission factor (column 4) of 321 mg/MJ$_d$. This places it in tier 3 (column 1).
- In Table 4, showing the default scenario, the emission factor threshold for tier 3 is 218 mg/MJ$_d$ (column 3), which is considerably lower. This difference is consistent with the fact that a higher emission rate in a kitchen that is better ventilated can result in the same concentration of PM$_{2.5}$.

Low-ventilation scenario:
- A laboratory result for a stove in a low-ventilation setting shows a combined PM$_{2.5}$ emission factor (column 5) of 115 mg/MJ$_d$. This also places it in tier 3 (column 1).
- In Table 4, the emission factor threshold for tier 3 is 218 mg/MJ$_d$, which is considerably higher. This difference is consistent with the fact that, in a kitchen that is less well ventilated, a lower emission rate is required to result in the same concentration of PM$_{2.5}$ in the room.

7.3.3 Alternative scenarios for carbon monoxide emissions and interpretation of test results

Table 13 shows the following information for the alternative scenarios for CO:
- tiers 0–5 (column 1);
- 24-h concentration of CO at 50% coverage (column 2);
- concentration of CO during cooking at 50% coverage (column 3);
- emission factors and normalized emission rates for the high-ventilation scenario (column 4); and
- emission factors and normalized emission rates for the low-ventilation scenario (column 5).

Note that the percentages of homes that meet the specified criteria (not shown here) are the same as in the default scenario (section 6.2).
Table 13. Tiers for high- and low-ventilation scenarios for CO emission factors and rates

<table>
<thead>
<tr>
<th>Tier</th>
<th>24 hour concentration at 50% coverage mg/m³ (ppm)</th>
<th>Cooking event concentration at 50% coverage mg/m³ (ppm)</th>
<th>High ventilation</th>
<th>Low ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tier 5</td>
<td>Tier 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3 (2.0)</td>
<td>3.2 (2.8)</td>
<td>≤ 4.4</td>
<td>≤ 1.4</td>
</tr>
<tr>
<td></td>
<td>13.6 (11.9)</td>
<td>19.3 (16.8)</td>
<td>≤ 190</td>
<td>≤ 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better performance</td>
<td>Tier 3</td>
<td>5.4 (4.7)</td>
<td>19.3 (16.8)</td>
<td>≤ 6.2</td>
</tr>
<tr>
<td></td>
<td>32.6 (28.5)</td>
<td></td>
<td>≤ 450</td>
<td>≤ 95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tier 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8.8 (7.7)</td>
<td>52.5 (45.8)</td>
<td>≤ 16.0</td>
<td>≤ 5.5</td>
</tr>
<tr>
<td></td>
<td>52.5 (45.8)</td>
<td></td>
<td>≤ 700</td>
<td>≤ 240</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tier 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.0 (12.2)</td>
<td>84.1 (73.4)</td>
<td>≤ 26.9</td>
<td>≤ 9.9</td>
</tr>
<tr>
<td></td>
<td>84.1 (73.4)</td>
<td></td>
<td>≤ 1175</td>
<td>≤ 430</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tier 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.0 (12.2)</td>
<td>84.1 (73.4)</td>
<td>&gt; 26.9</td>
<td>&gt; 9.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt; 1175</td>
<td>&gt; 430</td>
</tr>
</tbody>
</table>

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.

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

Source: Adapted from reference 1, Table 12 (bolding added and discussed in the example in Box 8)

As in the case of PM$_{2.5}$, the emission factors and rates for each tier are substantially higher in the high-ventilation than in the default scenario (Table 4), while those in the low-ventilation scenario are substantially lower.

The example in Box 8 should facilitate interpretation of the alternative tier values.

Box 8. Interpreting CO test results in high- and low-ventilation scenarios

High-ventilation scenario:
- A laboratory test of a stove in a high-ventilation setting shows an average CO emission factor (column 4) of 6.2 g/MJ$_d$. This places it in tier 4 (column 1) in Table 13.
- In Table 4 for the default scenario, the emission factor threshold for tier 4 is 4.4 g/MJ$_d$ (column 2), which is considerably lower. This difference is consistent with the fact that a higher emission rate in a kitchen that is well ventilated can result in the same concentration of CO.
- Even in a high-ventilation scenario, the proportion of kitchens at 7 mg/m³ and 230 mg/m³ remain at 80% and 99.9%, respectively (see Table 11).

Low-ventilation scenario:
- A test of a stove for a low-ventilation setting shows that the average CO emission factor (column 5) of the stove is 2.2 g/MJ$_d$. This also places it in tier 4 (column 1).
- In Table 4 for the default table, the emission factor threshold for tier 4 is 4.4 g/MJ$_d$, which is considerably higher. This difference is consistent with the fact that, in a less well-ventilated kitchen, a lower emission rate is required to achieve the same concentration of CO in the room.
- As in the high-ventilation scenario, the proportions of kitchens at 7 mg/m³ and 230 mg/m³ are unchanged (see Table 11).
7.4  Emission tiers defined by users

In some countries, data on housing characteristics (air exchange rate, kitchen volume) and cooking practices (duration of stove use per day) may indicate that the default and alternative scenarios differ substantially from the local conditions. In such cases, user-defined tiers based on locally representative data may be more appropriate. The online WHO PT model has been developed to help countries define local conditions for their national testing strategies. Application of the model is described, with examples, in section 8.
SELECTION OF APPROPRIATE VOLUNTARY PERFORMANCE TARGETS FOR EMISSIONS OF PM2.5 AND CARBON MONOXIDE
Emission tiers defined by users according to the WHO Performance Target model

8.1 Application of the WHO Performance Target model for defining tiers

The online WHO PT model (https://www.who.int/tools/performance-target-model) has been created to support countries in developing tiers based on locally representative data when these are more appropriate than the default or alternative scenarios described in section 7. Such situations may arise:

- when the conditions in a country differ in important respects from those defined in the default and alternative scenarios; or
- when there are marked differences within a country, such as sub-regions that differ geographically and therefore in climate, housing and cooking conditions.

This section addresses two scenarios of application of the PT model to kitchen characteristics and cooking practices that differ substantially, in two settings:

- scenario A: relatively low air-exchange rates, small kitchens and long stove use each day, as might be found in mountainous areas with cold winters and nights;
- scenario B: relatively high air-exchange rates, large kitchens and short stove use each day, as might be found in windy, warm areas where houses are quite open.

Scenario A is more demanding, as the conditions will require lower cookstove emissions to meet air quality targets.

8.1.1 Application to PM$_{2.5}$ tiers

Application of the PT model to obtain tier values for PM$_{2.5}$ in these two contrasting scenarios requires the input data shown in Table 14.
### Table 14. Input data used in applying the WHO PT model to contrasting kitchen characteristics and cooking conditions

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Variable</th>
<th>Units</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>Shape of distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Duration of cooking</td>
<td>Min/day (24-h period)</td>
<td>480.0</td>
<td>150.0</td>
<td>90.0 - 720.0</td>
<td>Normal</td>
</tr>
<tr>
<td>A</td>
<td>Rate of air change&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Changes per hour</td>
<td>10.0</td>
<td>5.0</td>
<td>4.0 - 100.0</td>
<td>Log normal</td>
</tr>
<tr>
<td></td>
<td>Kitchen volume&lt;sup&gt;a&lt;/sup&gt;</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>18.0</td>
<td>12.5</td>
<td>5.0 - 75.0</td>
<td>Log normal</td>
</tr>
<tr>
<td>B</td>
<td>Daily cooking time</td>
<td>Min/day (24-h period)</td>
<td>180.0</td>
<td>51.0</td>
<td>60.0 - 390.0</td>
<td>Normal</td>
</tr>
<tr>
<td>B</td>
<td>Rate of air change&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Changes per hour</td>
<td>30.0</td>
<td>15.0</td>
<td>4.0 - 100.0</td>
<td>Log normal</td>
</tr>
<tr>
<td></td>
<td>Kitchen volume&lt;sup&gt;a&lt;/sup&gt;</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>38.0</td>
<td>22.0</td>
<td>8.0 - 110.0</td>
<td>Log normal</td>
</tr>
</tbody>
</table>

<sup>a</sup> Geometric mean for log normal distribution

<sup>b</sup> The values for air exchange used in these examples are the same as those used for ISO VPT low- and high-ventilation scenarios.

**Input screen and distributions:** Before entering data into the fields for duration of stove use, rate of air change and kitchen volume, ensure that the pollutant choice tab (near the top of the input screen) is set to “PM” in the drop-down menu.

Fig. 9 shows the model input screen, with data for scenario A entered into the relevant fields. Note that:

- the duration of cooking is entered in min/day;
- air exchange is entered in number of exchanges per hour;
- kitchen volume is entered in m<sup>3</sup>;
- distributions should be set for each variable as shown in Table 14; and
- emissions mixing should be left at the default value of 1.0.

The lower part of the input screen (Fig. 9) (after a short delay during processing), labelled “simulated parameters”, displays the distributions of each variable calculated by the model. The distributions are created from basic information on the average value (mean), the spread (SD) and the range (minimum and maximum values), which are reflected in the shape, position and scale of each of the four graphs (histograms). The histogram for duration of stove use per day is fairly symmetrical about the mean, as this is a normal distribution, while those for air exchanges per hour and kitchen volume are right (positively) skewed, as these are log normal distributions. They are drawn out to the right, and the mean is not close to the middle but nearer the lowest values. The distribution for the mixing fraction has a single value, 1.0, reflecting the assumption that emissions into the room are completely mixed.
Running the model: Once the data input has been completed and checked, click the menu item “Run the model” on the left (or the tab in the main part of the screen under “Kitchen volume”). As the model makes a large number of calculations by Monte Carlo simulation (10 000), it may take a few minutes to process the data, depending on the computer processing speed. The output of the model is then displayed as shown in Fig. 10.

Fig. 9. Example for scenario A (data from Table 14): Input screen for PM$_{2.5}$ emissions
Output: Emission rates and emission factors by tier

First, it should be noted that, when the model is run several times with the same input values, it will give slightly different output values, because the Monte Carlo simulation repeatedly samples values at random from the distributions of the three variables. Thus, the values that users may obtain when duplicating these exercises with the suggested input values will probably be slightly different from the values shown in the screen shots. The output is therefore summarized in Table 15, and the information in each column is explained.
Table 15. Outputs of the WHO PT model with scenario A data input values and tier 5 (10 µg/m³ PM$_{2.5}$, the WHO air quality guideline) as the level of protection, the default value for the model (also shown in Fig. 10)

<table>
<thead>
<tr>
<th>ISO VPT tier</th>
<th>Equivalent PM$_{2.5}$ concentration (µg/m$^3$)</th>
<th>Kitchen coverage (%)</th>
<th>Emission rate (mg/min)</th>
<th>Emission factor (mg/MJ $d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>User input</td>
<td>10</td>
<td>50</td>
<td>0.33</td>
<td>14.4</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>90</td>
<td>0.19</td>
<td>8.3</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>50</td>
<td>1.6</td>
<td>69.8</td>
</tr>
<tr>
<td>3</td>
<td>170</td>
<td>50</td>
<td>5.7</td>
<td>248.7</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>50</td>
<td>13.4</td>
<td>584.7</td>
</tr>
<tr>
<td>1</td>
<td>800</td>
<td>50</td>
<td>26.8</td>
<td>1169.5</td>
</tr>
</tbody>
</table>

- Column 1 shows the ISO-VPT tiers and the “user input” for the level of protection, which, by default, is set at tier 5, that is 10 µg/m³ PM$_{2.5}$, the WHO annual average air quality guideline value. Another example is given below on setting the user input to a different value. Column 1 includes the equivalent concentration of PM$_{2.5}$ for each tier.

- Column 2 shows the normalized emission rate required for the stated percentage of homes (coverage in column 3) to achieve the stated PM$_{2.5}$ concentration (column 1) for each tier.

- Column 3 shows the assumed coverage for each tier in the model, that is, the percentage of homes that will achieve air quality at or better than the threshold value for each tier. Tier 5 has a coverage of 90% to show the emission rate required for most homes to achieve the WHO guideline. The coverage for all the other tiers, including the user input level of protection, is set at 50%. The remaining model output (below) shows that required emission rates can also be set for 75% and 90% coverage of all tiers and the user input level of protection.

- Column 4 shows the emission factors expressed as mass (mg) of PM$_{2.5}$ emitted per MJ of energy delivered for cooking, measured in laboratory tests to rate stoves for tiers.

Output: Fraction of homes protected at various emission rates

The graph on the lower left of the output screen in Fig. 10 shows the fraction of homes (kitchens) that are protected (i.e. that meet the tier target) at different emission rates. This example illustrates the emission rate necessary for 50% of homes to meet tier 1. It can be seen that, if a larger percentage of homes is to meet the tier threshold, a lower normalized emission rate will be required. This information is also provided for selected percentages (50%, 75% and 90%) for all tiers and the user input level of protection in the lower table on the model output screen (Fig. 11).
**Fig. 11.** Graphic display in model output, shown in Fig. 10, illustrates the normalized emission rates required for varying fractions (from zero to all) of homes to meet each tier threshold concentration of PM$_{2.5}$.

The text boxes and arrows identify the emission rate required for 50% of homes to meet tier 1 (blue line), namely 7.2 mg/m$^3$. The key indicates the equivalent RRs for ALRI in children, as explained in section 6.1.3 of this document.

**Output: Graph of the distribution of PM$_{2.5}$**

The graph in the lower right of the output screen (Fig. 10), labelled “distributions of 24-hour concentrations for user-selected target”, shows the distribution of PM$_{2.5}$ concentrations for the user input level of protection. In the case illustrated, this is the default tier 5. The distribution can be seen to be consistent with 50% of homes meeting the 10 µg/m$^3$ PM$_{2.5}$ threshold required for tier 5.

**Output: Setting the level of protection**

The box “Level of protection” located below the graphs can be used to change the level of protection from the default value for tier 5. Any one of the five ISO-VPT tiers can be selected from the drop-down box. In addition, a specific PM$_{2.5}$ concentration can be entered into this box. The example shown in Fig. 12 is for a level of protection of 35 µg/m$^3$ PM$_{2.5}$, the WHO intermediate target 1 for the annual average concentration of this pollutant. In this example, the “User input” value in the upper table of the output screen is between tier 5 and tier 4, and the PM$_{2.5}$ concentration of 35 µg/m$^3$ is shown in column 2. Coverage remains at 50% regardless of the concentration target entered. The emission rate required for 50% of homes to meet this threshold is 0.31 mg/m$^3$. As expected, this lies between the emission rates required for tier 4 (higher emission rate) and tier 5 (lower emission rate). The left-hand graph now shows the “User input” selection line (pink) lying between tiers 4 and 5, and the lower table shows the emission rates required for coverage rates of 50%, 75% and 90%.
Fig. 12. Re-setting the “level of protection” for scenario A: Output screen for PM$_{2.5}$ emissions

In this screen shot, the level of protection has been re-set to 35 g/m$^3$ (the WHO intermediate target-1 level of PM$_{2.5}$) by typing 35 in the box “Level of protection”.

![Image of screen shot showing re-setting of level of protection]

Type 35 here.

New user input level (35 µg/m$^3$) now shown here.

![Image of screen showing household meeting targets and distribution of 24-hour concentrations for user selected target]
**Scenario B: settings with more ventilation and less stove use**

The model was then run for scenario B (see Table 14), which has better ventilation and thus more air exchanges per hour, a larger kitchen volume and shorter duration of stove use per day. The screen shots of the model inputs and outputs are not shown here as the format is exactly the same as for scenario A. The main output, with emission rates and factors for each tier, is shown in Table 16. As in scenario A, the default level of protection is tier 5.

**Table 16. Outputs of the WHO PT model with input values for scenario B and a level of protection of tier 5 (10 µg/m$^3$ PM$_{2.5}$, the WHO air quality guideline), the default value for the model**

<table>
<thead>
<tr>
<th>ISO VPT tier</th>
<th>Equivalent PM$_{2.5}$ concentration (µg/m$^3$)</th>
<th>Kitchen coverage (%)</th>
<th>Emission rate (mg/min)</th>
<th>Emission factor (mg/MJ$_{d}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>User input</td>
<td>10</td>
<td>50</td>
<td>1.5</td>
<td>24.5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>90</td>
<td>0.51</td>
<td>8.3</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>50</td>
<td>7.5</td>
<td>122.7</td>
</tr>
<tr>
<td>3</td>
<td>170</td>
<td>50</td>
<td>25.7</td>
<td>420.5</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>50</td>
<td>60.5</td>
<td>990.0</td>
</tr>
<tr>
<td>1</td>
<td>800</td>
<td>50</td>
<td>100.0</td>
<td>1636.4</td>
</tr>
</tbody>
</table>

**Comparison of scenarios A and B**

We can now compare the emission rates and factors required in the two contrasting scenarios in order to meet the tier thresholds for the specified percentage coverage of homes (Table 17).

**Table 17. Emission rates and factors derived from the WHO PT model with input variables representing scenarios A and B, as set out in Table 7**

<table>
<thead>
<tr>
<th>ISO VPT tier</th>
<th>Equivalent PM$_{2.5}$ concentration (µg/m$^3$)</th>
<th>Scenario A</th>
<th>Scenario B</th>
</tr>
</thead>
<tbody>
<tr>
<td>User input</td>
<td>10</td>
<td>0.09</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>0.03</td>
<td>0.51</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>0.45</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>170</td>
<td>1.50</td>
<td>25.7</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>3.60</td>
<td>60.5</td>
</tr>
<tr>
<td>1</td>
<td>800</td>
<td>7.20</td>
<td>100.0</td>
</tr>
</tbody>
</table>
As expected, the emission rates required to meet each tier threshold are considerably higher for the “better ventilated, less stove use” scenario B.

**Interpretation and cautions**

Use of the model in this way should not be used as justification for accepting higher levels of pollution in some settings than in others. All being equal and given differences in air exchange rates, stove use time and kitchen volume, a normalized emission rate of 0.45 mg/m$^3$ in scenario A would result in the same concentration of PM$_{2.5}$ (50% meeting tier 4, 50 µg/m$^3$) as an emission rate of 7.5 mg/m$^3$ in scenario B.

Great care must be taken to ensure that the values of the input variables are truly representative. It would be unacceptable, for example, for the higher ventilation values in scenario B to represent circumstances only in warmer seasons, when people are out in the fields and cooking less, and not the conditions during colder, wetter seasons, when houses are much less ventilated and cooking times are longer. In such a case, stoves and fuel thought to meet the target tier thresholds for PM$_{2.5}$ might do so in seasons with better ventilation and less stove use but would probably result in unacceptably high levels during colder times of year with more stove use.

Further guidance on assessing and recording the circumstances for which measurements of the three model input variables are made is provided in section 8.2.

### 8.1.2 Application to carbon monoxide tiers

The WHO PT model can also be used to estimate the emission rates required to achieve the tiers defined for CO in the ISO VPTs. The process is essentially the same as for PM$_{2.5}$. The steps, the appearance of the model output and the interpretation of results are described below.

The first step on opening the model is to set the “Pollutant” drop-down menu (near the top of the input page) to CO. For this example, we have used the model input variables for scenario A, as presented in Table 7. Otherwise, the input page for running the model with CO looks the same as that for PM$_{2.5}$ (Fig. 9) and is not repeated here. The output screen for CO is similar in most respects to that for PM$_{2.5}$, but, as there are also some important differences, screen shots of the output are presented in Fig. 13.
Output: Emission rates and factors by tier

First, we note again that, if the model is run multiple times with the same input values, it will give slightly different output values, because the Monte Carlo simulation repeatedly samples values at random from the distributions of the three variables. As for PM$_{2.5}$, the first output table, with emission rates and the factors necessary to meet the ISO VPT tier thresholds for CO, is shown in Table 18.
### Table 18. Outputs of the emissions model with input data for scenario B and tier 5 (CO concentration, 2.3 mg/m$^3$) as the level of protection, the default value for the model

<table>
<thead>
<tr>
<th>ISO VPT tier</th>
<th>Equivalent CO concentration (mg/m$^3$)</th>
<th>Kitchen coverage for each tier (%)</th>
<th>Emission rate (mg/min)</th>
<th>Emission factor (mg/MJ$_d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>User input</td>
<td>2.3$^a$</td>
<td>50</td>
<td>21</td>
<td>916.4</td>
</tr>
<tr>
<td>5</td>
<td>2.3$^a$</td>
<td>50</td>
<td>21</td>
<td>916.4</td>
</tr>
<tr>
<td>4</td>
<td>3.2</td>
<td>50</td>
<td>29</td>
<td>1265.5</td>
</tr>
<tr>
<td>3</td>
<td>5.4</td>
<td>50</td>
<td>50</td>
<td>2181.8</td>
</tr>
<tr>
<td>2</td>
<td>8.8</td>
<td>50</td>
<td>81</td>
<td>3534.5</td>
</tr>
<tr>
<td>1</td>
<td>14.0</td>
<td>50</td>
<td>130</td>
<td>5672.7</td>
</tr>
</tbody>
</table>

$^a$ At a mean concentration of 2.3 mg/m$^3$, 90% of homes will be protected at or below the WHO 24-h air quality guideline of 7 mg/m$^3$.

- Column 1 shows the five ISO-VPT tiers and also the “User input” for the level of protection. By default, the model sets the level of protection at tier 5, that is, for 90% of homes to meet the WHO 24-h air quality guidelines value of 7 mg/m$^3$. The level of protection can be changed as shown below.
- Column 2 shows the equivalent concentration of CO for each tier, as explained in section 4.2.
- Column 3 shows the assumed coverage at each tier, that is, the percentage of homes that will achieve air quality at or better than the threshold value for each tier. These are all set at 50%. The remaining model output also includes the emission rates required for 75% and 90% coverage of all tiers and the user input level of protection.
- Column 4 shows the emission rates required for 50% of homes (coverage) to achieve the equivalent concentration of CO stated (column 2) for each tier and for the user input level.
- Column 5 shows the emission factors expressed as mass (mg) of CO emitted per megajoule of energy delivered (MJ$_d$) to the cooking vessel, the parameter measured in laboratory tests.

### Fraction of homes protected at various emission rates

The graph on the left of the output screen shows the fraction of homes (kitchens) protected (i.e. that meet the tier level target) at varying emission rates, as was the case for PM$_{2.5}$. Unlike for PM, however, the health risk (RR) is not shown for each CO tier, as the equivalent evidence for CO is not available (see section 6.2 of this guidance for an explanation of how the tiers of CO have been related to health risks).

### Graph of the distribution of CO

The graph on the bottom right of the output screen (Fig. 13) shows the distribution of CO concentrations associated with the user input level of protection. In the case illustrated, this is the default tier 5. As the scale is in µg/m$^3$, it should be divided by 1000 to convert it to mg/m$^3$. This distribution is consistent with 50% of homes meeting the 2.3 mg/m$^3$ threshold required for tier 5.
Setting the level of protection

As for PM$_{2.5}$, the dialogue box “Level of protection” located in the middle of the screen can be used to change the level of protection for CO from the default value of tier 5.

8.2 Caution to be exercised in use of user-generated tiers

The online WHO PT model provides useful flexibility for ensuring that the targets set for performance are appropriate to circumstances in the country or in specific parts of the country. At the same time, however, as mentioned in section 8.1.1, it is important to ensure that the values of the input variables are justified for comparing the PM$_{2.5}$ tier threshold values for scenarios A and B. Inappropriate values may result in performance targets that do not protect households as intended by the ISO standards.

Section 8.1.1 showed that the model will give higher (less stringent) emission factors when the air exchange rates entered are higher (whether user-defined or those in the ISO VPT high-ventilation scenario), the kitchen volumes are greater or cooking times are shorter than in the default model input values. It is therefore strongly recommended that local input data be reported in full when used in the WHO PT model.

Table 19 gives an example of reporting of local input data, including a comparison of local data with ISO VPT default values. Local values should be accompanied by a summary of the methods used (which should be consistent with the protocols described in section 10.3.6) and a narrative justification of why those values are more relevant to the setting than the ISO default or high- or low-ventilation scenarios.

**Table 19. Example of a comparison of locally sourced model input data with the default ISO VPT values (local data to be added)**

<table>
<thead>
<tr>
<th>Model input variable</th>
<th>Units</th>
<th>Model input values</th>
<th>Mean (see footnotes)</th>
<th>Standard deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air exchange rate</strong></td>
<td>Number per hour</td>
<td>ISO Default</td>
<td>21.0$^a$</td>
<td>11.0</td>
<td>4, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO High ventilation</td>
<td>30.0$^a$</td>
<td>15</td>
<td>4, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO Low ventilation</td>
<td>10.0$^a$</td>
<td>5</td>
<td>4, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Local</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kitchen volume</strong></td>
<td>Metres$^3$</td>
<td>ISO Default</td>
<td>28.0$^a$</td>
<td>16.8</td>
<td>5, 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Local</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Duration of use</strong></td>
<td>Hours per day</td>
<td>ISO Default</td>
<td>4.2$^b$</td>
<td>1.5</td>
<td>1, 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Local</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: reference 1

$^a$ Geometric mean (exponential of the mean of the log-transformed values)

$^b$ Arithmetic mean
Incorporating voluntary performance targets into a national strategy on clean cooking

Application of the ISO VPTs, including use of the WHO PT model where appropriate to adapt tier threshold values, should be part of a coordinated strategy of transition to clean household energy. The WHO CHEST toolkit (24), the purpose and content of which are summarized in section 10.1, has been designed to support this process.

Before VPT tier values are applied in national plans, an assessment should be made of the best tiers of performance that can reasonably be achieved for a given population. When possible, the goal should be to promote fuels and devices that meet the highest tiers. Depending on the development of markets for clean, efficient, safe fuels and on purchasing power and financial assistance, national assessment should include consideration of what is appropriate and achievable for sub-regions and/or different communities within the country. The assessment of what is reasonable and achievable should be justified, including why devices and fuels with better performance in all the VPT parameters (efficiency, emissions, safety and durability) cannot currently be introduced, including factors such as household needs, costs, supply issues and location. In making such assessments, demanding but realistic goals should be set, even if the highest tiers of performance are not currently considered achievable. This is particularly relevant in countries where households cannot yet make the transition to exclusive use of a clean, safe fuel and continue to use traditional fuels for some of their needs, a practice known as “stacking”. The performance of more traditional devices and fuels should not be ignored if stacking remains prevalent, which is typically the case. Use of the WHO Household Multiple Emission Sources (HOMES) model (25), which allows assessment of the contributions of multiple sources of emissions and also of ambient (i.e. outdoor) pollution, will be valuable in this regard.

Such assessments should not be static; rather, an assessment made at any one time should be seen as a step in a transition towards improved performance, unless the highest tier is already being achieved. Fig. 14 represents schematically the different rates and patterns of transition that may be occurring in different socioeconomic and geographically defined groups in a country.
Fig. 14. Schematic representation of household energy transitions from traditional fuels over time in groups defined by different socioeconomic status and geography

Source: adapted from reference 9.

Both consumers and those involved in marketing and promoting cleaner, more efficient devices and fuels should consider the most effective labelling. It will be based on the results of testing and the VPT tiers but should be clear and easy to understand. Any labelling strategy should be accompanied by awareness-raising, and correct application in practice should be monitored and regulated. Provision should be made in strategic planning for periodic review of what is considered reasonable and achievable in order to ensure that progress is made. Reviews every 3–5 years are recommended. The strategy should be formalized in a statutory mechanism to ensure accountability.
WHO and ISO resources available to support countries

10.1 WHO CHEST toolkit for application of WHO guidelines for indoor air quality

WHO has developed the CHEST Toolkit (24) to help health sector professionals and policy-makers implement the recommendations in the WHO GIAQ/HFC. CHEST resources include guidance, training materials, tools and databases to guide planning of household energy, with six modules for designing an action plan for a household energy policy (Fig. 15).

The first module is “stakeholder mapping and situational assessment”, followed by five other modules. Module III addresses standards and testing and explains how ISO deliverables and associated WHO tools can contribute to the development and implementation of national strategies for cleaner household energy.

This document and documents by the ISO TC285 are referenced in module III of the CHEST toolkit.
Fig. 15. Schematic summary of the six modules of the CHEST toolkit

The component modules of the WHO Clean Household Energy Solutions Toolkit (CHEST)
A step-by-step guide and tools to support the implementation of the WHO Guidelines.

I. STAKEHOLDER MAPPING AND SITUATIONAL ASSESSMENT
Identify key stakeholders and assess the household energy situation
- Household Energy Assessment Rapid Tool (HEART)
- WHO Global Health Observatory
- WHO Household Energy Database
- WHO Database of Household Air Pollution Measurements

II. IDENTIFICATION OF TECHNOLOGICAL AND POLICY INTERVENTIONS
Identify and assess intervention options
- WHO Benefits of Action to Reduce Household Air Pollution (BAR-HAP)
- WHO Household Multiple Emission Sources (HOMES) Model
- WHO Household Energy Policy Database
- AirQ+
- Clean Cooking Alliance: Clean Cooking Catalog
- HAPIT: Household Air Pollution Intervention Tool

III. GUIDANCE ON STANDARDS AND TESTING
Develop or apply existing standards and testing
- WHO Performance Target (PT) Model
- International Organization for Standardization (ISO) Technical Committee 285: Clean cookstoves and clean cooking solutions
- WHO Setting national voluntary performance targets for cookstoves

IV. MONITORING AND EVALUATION
Create a monitoring and evaluation framework
- National Household Surveys
- WHO Core Questions on Household Energy Use: A Catalog of Methods (2008), updates underway
- Measuring energy access: A guide to using the Core Questions
- Pictorial Energy Use Guide

V. ENGAGING THE HEALTH COMMUNITY
Empower the health sector to tackle household air pollution
- Training toolkit on air pollution and health for the health workforce
- Air Pollution and Child Health: Prescribing Clean Air report
- UN Habitat and other educational documents

VI. COMMUNICATION AND RAISING AWARENESS
Develop a plan to raise awareness and establish communications
- BreatheLife Campaign
- Air pollution and health video series

Action plan for Household Energy Policy
(to implement the WHO Guidelines at a regional or country level)
10.2 Resources provided in WHO CHEST module III

Implementation of the ISO standards and VPTs for cookstoves and clean cooking solutions, in line with the WHO CHEST toolkit, can be supported by six resource documents and tools, summarized in Fig. 16; further explanation of each of these components is provided below.

**Fig. 16. Summary of resources available to countries and agencies for implementing the ISO VPTs and using the CHEST toolkit**

- **Component #1**
  ISO Protocol for Harmonized Laboratory testing, including of thermal efficiency, emissions (PM$_{2.5}$ and CO), safety and durability.

- **Component #2**
  ISO Voluntary Performance Targets (VPTs); tiered levels for all five parameters listed in component #1.

- **Component #3**
  ISO protocol for field testing in homes, covering usage, usability, fuel consumption, energy consumption, power, safety, and durability. Optional measurement of kitchen ambient PM$_{2.5}$ and CO, and exposure.

- **Component #4**
  WHO database of studies providing model input values of air exchange rates, kitchen volume and duration of device use per day.

- **Component #5**
  WHO Performance Target (PT) model available online for generating locally relevant emission rates with user-defined input values.

- **Component #6**
  WHO protocols for measuring model input values of air exchange rates, kitchen volume and duration of device use per day.

10.3 Contributions of each resource to meeting voluntary performance targets

10.3.1 Component 1: ISO laboratory testing protocol

In this guidance, the ISO laboratory testing protocol and parameters are presented in section 3, and an example of laboratory test results and their relation to default VPT tiers is given in section 5.

The protocol lists the information and results to be reported as specified in the ISO standard (Box 10).
Box 10. ISO Laboratory test report includes

- description of the cookstove system tested (type of cookstove, materials, cooking vessel, fuel and operating procedure);
- test results for efficiency and emissions at high, medium and low power;
- results of safety test;
- results of durability test;
- interpretation and limitations;
- quality assurance and quality control; and
- discussion (if necessary).

10.3.2 Component 2: ISO voluntary performance targets

The ISO Technical Report (1) lists six tiers, graded from 0 (poorest performance) to 5 (best performance), for five test parameters measured and reported in the laboratory-test protocol (component 1), as shown in Table 3. Tiers for the five parameters should be reported separately. The relation of test results to tier values is described, with an example of the default values table, in section 5.

In this guidance, section 4 describes derivation of default VPT tiers for all five parameters of stove performance; section 5 provides an example of laboratory test results and their relation to default VPT tiers; section 6 provides details of the development of the VPT tiers; section 7 explains the selection of appropriate VPT tiers for emissions; and section 8 describes development of user-defined tiers for PM$_{2.5}$ and CO.

10.3.3 Component 3: ISO field testing protocol

ISO Standard 19869:2019 (17) provides methods for evaluating cooking system performance in real-world conditions. It includes a standardized method for measuring and reporting the performance of cookstoves in sample homes. The measurements include usage, usability, fuel and energy consumption, power emissions, safety and durability; kitchen PM$_{2.5}$ and CO concentrations and personal exposure to these two pollutants may also be measured.

In contrast to the standard laboratory test sequence, field testing may also include cooking of typical food in a controlled and an uncontrolled “cooking test”, which provides performance data for cooking tasks that closely resemble the everyday use intended for the stove in the home setting. The ISO field testing protocol provides requirements and guidance to enable informed comparison of results.

The field-testing protocol is available on the ISO website (for purchase) and also from some national standards bodies.

Field testing is inevitably more demanding in terms of time and resources than laboratory testing, as the team and equipment must travel to homes rather than bringing a stove to an established laboratory. In addition, wide variation among homes means that samples must be obtained from many households in
each setting in order to obtain statistically useful results. The settings and technologies selected for field testing should therefore be chosen carefully to maximize the value of the investment and to complement laboratory testing most effectively.

10.3.4 Component 4: WHO online Performance Target model

An online version of the emissions model described in section 2.4 (the WHO PT model) is available for setting national performance target tiers. The model, with technical guidance on its use, is available at: https://worldhealthorg.shinyapps.io/who_pt/. The model allows users to generate their own target tier values from input data (duration of use, air change, kitchen volume) that they consider to be more representative of their settings than the “default” values (see section 4.2) and those of the alternative scenarios (see section 7.3) used in the ISO Technical Report (1). The input variables for the online WHO PT model can be obtained from the two other WHO information resources shown in Fig. 1: surveys in an online database (component 5) or new data (component 6). Application of the WHO PT model is described in section 5, with examples.

10.3.5 Component 5: WHO database of model input variables

This WHO database (https://worldhealthorg.shinyapps.io/HAPmodelinputdata/) holds information from studies conducted in Africa, Asia and Latin America on air exchange rates, kitchen volume and duration of stove use that can be used as inputs for the WHO PT model. The data held include information on study settings, sample size, data required for the WHO PT model (mean, SD, minimum and maximum)\(^1\) and the reference of the publication.

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\(^1\) The coefficient of variation (the ratio of the SD to the mean) is also provided, although this is not required for the WHO PT model.
10.3.6 Component 6: Protocols for local measurement of model input variables

Countries may wish to make their own measurements of the model input variables, such as air exchange rate, kitchen volume and duration of stove use, if the studies listed in the database do not provide data that are sufficiently representative of the setting under consideration. For example, there are relatively few studies from sub-Saharan Africa and currently none on duration of stove use in that region.

As the measurements should be consistent with those in previous studies and in other settings, WHO has developed protocols for collecting this data (23). An overview of the relevant protocols is provided in Table 20.
### Table 20. Protocols available from WHO for standardized measurement of the inputs required for the WHO Household Multiple Emission Sources (HOMES) and Performance Target (PT) emissions models

<table>
<thead>
<tr>
<th>Protocol and application</th>
<th>Overview of content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input parameter protocol – kitchen volume</td>
<td>This protocol defines what is considered to be a kitchen and the circumstances in which an adjoining area of a house should be included. The necessary equipment is described and guidance given on the dimensions to be used for kitchens and houses of different shapes. Diagrams (see below) help the user to obtain the correct volume measurements based on the type and shape of the kitchen.</td>
</tr>
</tbody>
</table>

![Diagram of a kitchen and a house](image-url)
This protocol explains how the air exchange rate can be calculated from the rate at which the concentration of a tracer gas (for example, CO or CO₂) declines after it has been introduced into the kitchen. The diagram below (from the protocol) illustrates this method, as the gas (CO₂) introduced at 14:33 rapidly reaches a peak and then decreases over the next 20 min.

Sample ARMS trace from a single measurement period in a single kitchen

Calculation of air exchanges and the log-transformed period of linear decay is fully described, with the equipment required and the detailed, step-by-step method.

An annex provides an alternative method for estimating the air exchange rate during measurement of air pollutant concentrations. This relies, however, on the assumption that emissions (e.g. from a stove) cease after a peak, which may be difficult to confirm.

This protocol refers to the three methods for measuring duration of device use per day. Because of the potential for substantial bias in reliance on observation or recall from surveys, the protocol emphasizes sensor-based methods, with brief guidance on other options. The equipment required is described, covering a range of sensor types and manufacturers; however, all rely on measurement of temperature fluctuations as the stove is used. Advice is given on the important practical issue of how best to place different types of sensors.

An annex gives detailed instructions on preparation and data download procedures for the iButton sensor, one of the most commonly used types.

This protocol provides guidance on measuring stove performance, the fraction of emissions entering a room and background air pollution and estimating personal exposure. None of these parameters are required for the WHO PT model, but they are used in the WHO HOMES model.
References


**Annex.** Versions of the box model used in the International Workshop Agreement, WHO guidelines, the voluntary performance targets and online WHO resources designed to support use of the CHEST toolkit and related work

<table>
<thead>
<tr>
<th>Model type</th>
<th>Application and key features</th>
<th>Version and name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-source model</td>
<td>International Workshop Agreement for generating target emission rate tiers for PM$_{2.5}$ and CO</td>
<td>ISO IWA model</td>
</tr>
<tr>
<td></td>
<td>WHO GIAQ/HFC for generating guideline emission rates for PM$_{2.5}$ and CO</td>
<td>WHO Indoor Air Quality Guidelines model</td>
</tr>
<tr>
<td></td>
<td>ISO Voluntary Performance Targets for generating target emission rate tiers for PM$_{2.5}$ and CO</td>
<td>ISO VPT model</td>
</tr>
<tr>
<td></td>
<td>WHO online guidance for generating target emission rate tiers for PM$_{2.5}$ and CO with user-defined model inputs for values for air exchange, kitchen volume and duration of device use per day.</td>
<td>WHO PT model</td>
</tr>
<tr>
<td>Multiple-source model</td>
<td>WHO online guidance for generating target emission rate tiers for PM$_{2.5}$ and CO with:</td>
<td>WHO Household Multiple Emission Sources (HOMES) model</td>
</tr>
<tr>
<td></td>
<td>• multiple sources of emissions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• user-defined model inputs for values for air exchange, kitchen volume and duration of device use per day.</td>
<td></td>
</tr>
</tbody>
</table>