Household carbon monoxide poisoning

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1. Introduction

Carbon monoxide (CO) is a toxic gas that is colorless, odorless, tasteless and non-irritating, and thus without warning properties (ATSDR, 2009). CO is produced by the incomplete combustion of carbonaceous materials including vehicle and heating fuels. Without appropriate ventilation, indoor levels of CO can reach harmful or even life-threatening concentrations, sometimes within minutes. CO inhalation leads to tissue hypoxia and toxicity through several mechanisms. The best recognized is the impairment of oxygen transport. CO preferentially binds haemoglobin, which displaces oxygen and adversely affects the delivery of oxygen to the tissues.

CO intoxication is the number one cause of unintentional, non-drug poisoning in developed countries. The case fatality rate is about 3% among persons seeking/receiving hospital care for CO poisoning (Sam-Lai et al., 2003; CDC, 2005). Ambient CO concentration in outside air is not a good predictor of poisoning incidence (diMarco et al., 2005). Instead, accumulations of CO in indoor air are the most common cause of intoxication. In several developed countries, 50-64% of CO poisoning occurs in the home (Sam-Lai et al., 2003; CDC, 2005; Clifton et al., 2001; European Center for Injury Prevention, 2007).

Accordingly, CO is a highly relevant risk related to inadequate housing conditions. Unintentional CO poisoning in the home – as considered in this chapter – is related to inappropriate or faulty heating, cooking or other combustion appliances and the entry of vehicle exhaust from attached garages. Intentional CO inhalation (suicides and suicide attempts), occupational CO inhalation or CO inhalation as a consequence of smoke inhalation due to structure fires are beyond the scope of this chapter.

Individuals with greater susceptibility to CO exposure include pregnant women, infants and small children, the elderly and persons with underlying cardiopulmonary disease. Additionally, certain homes or residential areas (e.g., those with older/poorly maintained heating systems) are at significantly higher risk for both episodic CO elevations and/or chronically higher CO concentrations.

Gas heating and cooking can be significant contributors to CO concentration in homes (Bruinen et al., 2004). The climate of most developed regions is such that heating is used in most homes at least part of the year. Additionally in Europe, for example, the WHO LARES study, which included 3300 homes in 8 European cities (Angers, Bonn, Bratislava, Budapest, Ferreira, Forli, Geneva, and Vilnius), revealed that two thirds (67%) of these houses relied on gas energy for cooking (WHO LARES database). Thus, CO is an important potential household hazard throughout most developed countries.

2. Summary of the method

Data on CO cases are tracked using the International Classification of Disease (ICD-10; T58) and the data on non-drug poisoning use ICD-10 (X47 or Y17).

Death and delayed/persistent neurological effects are the principal adverse health effects used to assess the burden of disease associated with CO exposure. Detailed estimates for the population

attributable fraction (PAF), which is the proportion of disease or death that can be associated with CO are reviewed below. In this context, PAF represents the proportion of CO poisoning in the population that would be prevented if exposure to CO in the home were reduced to the level outdoors. The PAF estimate is then multiplied by the total burden of CO poisoning. This results in an estimate of the proportion of CO cases, deaths and disability adjusted life years (DALYs) that can be ascribed to CO exposure in the home.

The steps required for estimating the household disease and fatality burden from CO is as follows:

- Retrieve available health-care statistics for CO intoxications receiving hospital care;
- Assess the incidence of significant CO poisonings and/or deaths for countries with available data;
- The PAF of CO poisonings associated with the household or housing-related exposures is then calculated by multiplying the incidence of CO poisonings/deaths by 60%. The literature demonstrates that the proportion of unintentional CO poisonings due to housing conditions ranges from 50-64% (Sam-Lai et al., 2003; CDC, 2005; Clifton et al., 2001; European Center for Injury Prevention, 2007).
- Select the health effects or outcomes for study: unintentional poisoning death and delayed/persistent neurologic sequelae (DNS/PNS);
- Apply the mean case-fatality rate of 3% to the incidence of serious CO exposure;
- Apply the rate of DNS/PNS incidence (3-40%) to the incidence of serious CO exposure incidence (Raub et al., 2000).

3. Exposure assessment

This section provides a short overview of typical exposures encountered in Europe.

Table 1 demonstrates examples of typical household CO concentrations as measured in Europe. As expected, average indoor CO levels for a large majority of homes are less than the WHO guidelines of 10 mg/m3 (9 ppm) as an eight-hour, time-weighted average and 35 mg/m3 (30.6 ppm) for 60 minutes.

While average CO concentrations in the home are quite low, significant short-term CO exposures can develop quickly with changes in conditions, such as: turning on a heating system; the blockage of a vent or a chimney; some other appliance malfunction; and the use of supplemental heating appliances or use of electrical power generators indoors following a power outage. Significant exposures are episodic and predominantly occur during autumn and winter months. Certain types of housing are at much higher risk for these episodic CO elevations.

Risk factors include: older/poorly maintained heating systems; combustion-powered space heaters; and housing found in low-income areas. In a survey of gas appliances in low-income English homes, 23% had some type of problem with a gas appliance; 5% were at high risk of CO exposure and 3% were at “very” high risk (Croxford, 2006). Furthermore, 0.7% of appliances were deemed “immediately dangerous” and disconnected on the spot. Almost 20% of homes had CO concentrations that exceeded the current WHO 8-hour limit of 10 mg/m^3 (9 ppm) as a time-weighted average at least once during the monitoring period, and about 4% exceeded the previous 2000 WHO short-term, 30 minute guideline of 60 mg/m^3 (52 ppm) (WHO, 2000).

Table 1: Typical household CO concentrations.

Reference	Country	Type of housing; Surveyed exposure parameters	Mean concentration [mg/m^3]	Maximum concentration [mg/m3]	Percentage of households with CO > 10 mg/m^3
Bruinen de Bruin et al., 2004	Italy	Homes of 46 Milan office workers: ▪ No home CO source; ▪ Gas cooking in home; ▪ 1 hour maximum cooking exposures	 2.1 +/- 1.5 2.8 +/- 1.7	 21*	0% (8 hour exposure)* 30% (1 hour exposure)*
Raw et al., 2004	United Kingdom (England)	830 randomly selected homes 14 day average concentrations Gas cooking oven; winter	0.45 (bedrooms) 0.54 (kitchen)	4.5 (bedrooms) 5.1 (kitchen)	Short-term peaks not measured
Croxford, 2006	United Kingdom (England)	Indoor CO monitored in 270 homes. Appliances examined in 597 low income homes for CO, estimation made that ~6% of homes will exceed WHO 1hour guideline.	2.0 +/- 1.8	95	18% (exceeded for an 8 hour exposure at least once during monitoring period of 1 – 4 weeks) (4% > 60 mg/m^3 for a 30 minute exposure)
Willers et al., 2004	Nether-lands	72 homes (kitchens) 7 day average	0.5 +/- 1.2	6.0	Not reported
diMarco et al., 2005	Finland	Mean of > 250 000 one minute CO exposures in homes based on personal sampling from 201 residents in Helsinki area	1.2 +/- 0.6	2.3 (95%ile)	Not reported

*Based on personal sampling.

4. Exposure-risk relationship for CO and adverse health

There is a direct correlation between the concentration of CO in ambient air and the carboxyhaemoglobin saturation (COHb%) in the human body (Table 2). However, the measured COHb% does not reliably predict individual clinical presentations, especially the incidence of neurologic sequelae. Susceptible persons (see above) may experience more serious health effects, up to and including death, at lower levels of exposure than shown in the table. However, the table provides examples of probable health effects in "average" adults for each range of increasing exposure.

Based on the exposure-response relationship, serious health effects due to housing-related CO poisoning are most likely to occur in two situations of "very significant exposures":

- the acute production of several hundred to thousand mg/m^3, and
- chronic exposures of 80-230 mg/m^3 (75-200 ppm).

A functioning warning system (e.g. CO detector or alarm) would be expected to prevent the consequences of such exposure scenarios, otherwise, they are expected to result in poisonings of varying severity when occupants are present (~100% incidence).

Table 2: Health effects associated with increasing CO concentrations

CO inhaled mg/m^3 (ppm)	COHb% Saturation	Health Effects
1.2-3.4 (1-3)	0.49-0.81	None expected
8-58 (7- 50)	1.46- 8	Reduced time to angina, arrhythmia and/or ischaemia in adults with coronary heart disease.
80-115 (70-100)	11-14	Diminished performance of complex tasks, cardiac ischaemia in susceptible persons, mild headache.
115- 230 (100-200)	15-25	Severe headache, nausea, vomiting, syncope
345-575 (300-500)	33-45	Confusion; collapse on exercise
805-1150 (700-1000)	54-62	Seizures, coma, loss of consciousness, death

Adapted from Stewart (1975) and Beckett (1998). This table assumes that equilibration of haemoglobin with CO has occurred after constant exposure for 5 or more hours.

Reliable data on the population's exposure to episodically elevated household CO levels are not available. Therefore, we do not recommend using a relative risk in an exposure-based approach for estimating the PAF.

5. Total burden of disease from CO

While reliable data on the population's exposure to episodically elevated household CO levels are not available, serious cases of CO poisoning are almost always recorded in health-care statistics, such as emergency department or hospital discharge data. Here, the approach for estimating the disease burden of CO poisoning uses the rates of serious neurologic complications and the case fatality rate. The incidence rates of serious CO poisoning from various countries are conservative estimates based on health care statistics for persons seeking hospital care for CO poisoning. The best estimate of the case-fatality rate for cases receiving hospital care is 3% based on United States and French data (Sam-Lai et al., 2003; CDC, 2005). In addition, some severe CO exposures will result in DNS/PNS. This permits an estimate of longer term disease burden, in addition to deaths. DNS/PNS refers to persons who survive CO intoxication, but suffer longer term neurologic complications ranging from more subtle deficits of cognition and/or affective disorders to severe neurologic impairment. The incidence of DNS/PNS has been assessed by various studies and varies widely (3-40%) in the literature depending on how it is defined (including only more severe cases or also including cases with only subtle deficits).

6. Environmental burden of housing-related CO poisoning in Europe

The steps required for estimating household disease burden from CO following the alternative approach are summarized below, based on the work by the Apollo project (European Center for Injury Prevention, 2007):

- Retrieve available health-care statistics for CO intoxications receiving hospital care;
- Assess the incidence of significant CO poisonings and/or deaths for countries with available data;

- Adjust for the proportion of CO poisonings associated with the household or housing-related exposures (PAF) by applying a factor of 0.6, based on the findings in the literature that the proportion of unintentional CO poisonings due to housing conditions ranges from 50-64%;
- Select the health effects or outcomes for study: unintentional poisoning death and DNS/PNS;
- Apply the mean case-fatality rate of 3% to the incidence of serious CO exposure;
- Apply the rate of DNS/PNS incidence (3-40%) to the incidence of serious CO exposure incidence.

As a result of unintentional, very significant household CO exposures, 27-366 per 100 million people (0.03 – 0.4/100 000) will suffer delayed or persistent neurologic sequelae; and on average 27 ± 23 persons will die of their poisoning (0.03 ± 0.02 deaths/100 000) (Table 3). The best estimate of the PAF is that household exposures account for 50-64% of CO poisoning.

Table 3. Estimates of non-fatal and fatal cases of CO poisoning due to inadequate housing conditions in western and central Europe

Country	**Reference**	**Serious CO exposures*/year (cases)**	**Non-fatal DNS/PNS**/year (cases)**	**Mortality***** **/year (cases)**
France	Sam-Lai et al., 2003	2300†	69-920	69
Bulgaria	European Center for Injury Prevention, 2007	541	16-216	16
Denmark	European Center for Injury Prevention, 2007	2101	63-840	63
Hungary	European Center for Injury Prevention, 2007	1857†	56-743	56
Latvia	European Center for Injury Prevention 2007	78	2-31	2
Malta	European Center for Injury Prevention, 2007	0	0	0
Norway	European Center for Injury Prevention, 2007	655	20-262	20
Portugal	European Center for Injury Prevention, 2007	587	18-235	18
Slovenia	European Center for Injury Prevention, 2007	1111	33-444	33
Spain	European Center for Injury Prevention, 2007	579	17-232	17
Sweden	European Center for Injury Prevention, 2007	553	16-221	16
Netherlands	European Center for Injury Prevention, 2007	620	19-248	19
Total	**Mean (SD)**	**915 (765)**	**27 (23)-366 (306)**	**27 (23)**

* Estimates are based on standard populations of 100 million and reported proportion of household cases († France and Hungary) or using 60% to estimate household incidents.

**Assumes 3-40% incidence rate for DNS/PNS among the cases in the adjacent column.

***Assumes 3% case fatality rate.

7. Uncertainty

The principal sources of uncertainty in the assessment include the following:

- Lack of data for most countries: mortality, poison center calls, hospital discharges and other statistics that might allow a direct estimate of disease burden due to CO poisoning are often not available or cannot easily be located.
- For countries with some available information: the sensitivity of the statistic or study for capturing the actual number of serious CO poisoning cases, as well as their associated rates of mortality, DNS/PNS and the proportion attributable to inadequate housing. For example regarding the European data, Hungary was the only country in the APOLLO project with an estimate (50%) for the proportion of cases that are household-related (European Center for Injury Prevention, 2007).

Uncertainty could be reduced by mandating CO poisoning as a reportable disease to public health authorities, as household cases almost always justify some type of public health response.

8. Conclusions

While CO poisoning is relatively rare, it has a high case-fatality rate, is highly preventable and therefore, is an important concern in developed countries. The CO data show that 27-366 people per 100 million people will suffer delayed or persistent neurologic sequelae and 27 ± 23 persons will die of their poisoning. The best estimate of the PAF is that household exposures account for 50-64% of CO poisoning (Table 4). To better estimate the total disease burden caused by CO, health care facilities, fire and emergency medical services, and utility companies (e.g. gas companies) should be mandated to report significant CO exposures. Additionally, improved collection, synthesis and analysis of this exposure information at the national and international levels are also needed.

Table 4. Summary of EBD of housing-related CO poisoning

Housing exposure	Indoor exposure to CO		
Health outcome	Headache, nausea, cardiovascular ischaemia/insufficiency, seizures, coma, loss of consciousness, death		
Summary of EBD evidence	As a result of unintentional, very significant household CO exposures, 114 – 1545 persons (27-366 per 100 million population) will suffer delayed or persistent neurologic sequelae per year in Euro A*; and on average 114 ± 97 persons will die of their CO poisoning.		
	Level	**Geographic scope**	**Source of information**
(a) Exposure risk relationship	Case-fatality rate of 3% to the incidence of serious CO exposure DNS/PNS incidence (3-40%) to the incidence of serious CO exposure	Euro A*	Based on Raub et al., 2000; Sam-Lai et al., 2003; CDC, 2005
(b) Exposure assessment	Varies largely by country	Euro A*	For details, see Table 1 and WHO, 2010
(c) PAF	50-64%	Euro A*	See section 6
(d) Total EBD from CO poisoning	Not available		See section 5.

(e) EBD from indoor CO poisoning	114 – 1545 persons with delayed or persistent neurologic sequelae (0.03 – 0.4/100 000) 114 ± 97 deaths (0.03 ± 0.02/100 000)	Euro A*	Extrapolated for Euro A population based on section 6
Main areas of uncertainty	The principal sources of uncertainty relate to the lack of data in many countries, and – in case of data being available – the difficult association with health effects. Data on real exposure to CO in European homes is also rare. Available data for western Europe cannot be extrapolated to the eastern part of the region.		
Main implications	Effective policy measures and regulations need to be installed, such as laws and economic incentives regarding the use of CO detectors in residential units. Periodic testing and maintenance of combustion-powered heating systems and home appliances capable of emitting CO is necessary as well.		

* The list of countries for the European subregions is provided by Table 1 of the Introduction chapter

9. Policy implications and prevention measures

Prevention measures at the policy level

While there is still a need for research examining the effectiveness of household CO detectors as a prevention measure, effective policy measures may include laws and economic incentives favoring the proper placement and maintenance of CO detectors in residential units. Another useful policy would require periodic testing and maintenance of combustion-powered heating systems and home appliances capable of emitting CO.

When an incident is discovered or when a patient reaches the health-care system due to CO exposure, checking for other victims and corrective actions regarding the appliance or other source of CO exposure are necessary actions.

Prevention measures at the household level (CDC, 2005)

- A qualified technician should service the heating system, water heater and every other gas, oil, or coal burning appliance annually.
- Battery-operated CO detectors should be placed in the home (batteries should be checked twice a year). When a detector alarms, the home should be left immediately and the appropriate emergency number should be called.
- Upon suspicion of CO poisoning and feeling dizzy, light-headed, or nauseous, seek urgent medical attention.
- Never use a generator, charcoal grill, camp stove, or other gasoline or charcoal-burning device inside the home, basement, garage or near a window.
- Never run (idle) a car or truck inside a garage attached to the house, even if the garage door is open.
- Never burn anything in a stove or fireplace that is not vented.
- Never heat your house with a gas oven.

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Environmental burden of disease associated with inadequate housing

A method guide to the quantification of health effects of selected housing risks in the WHO European Region

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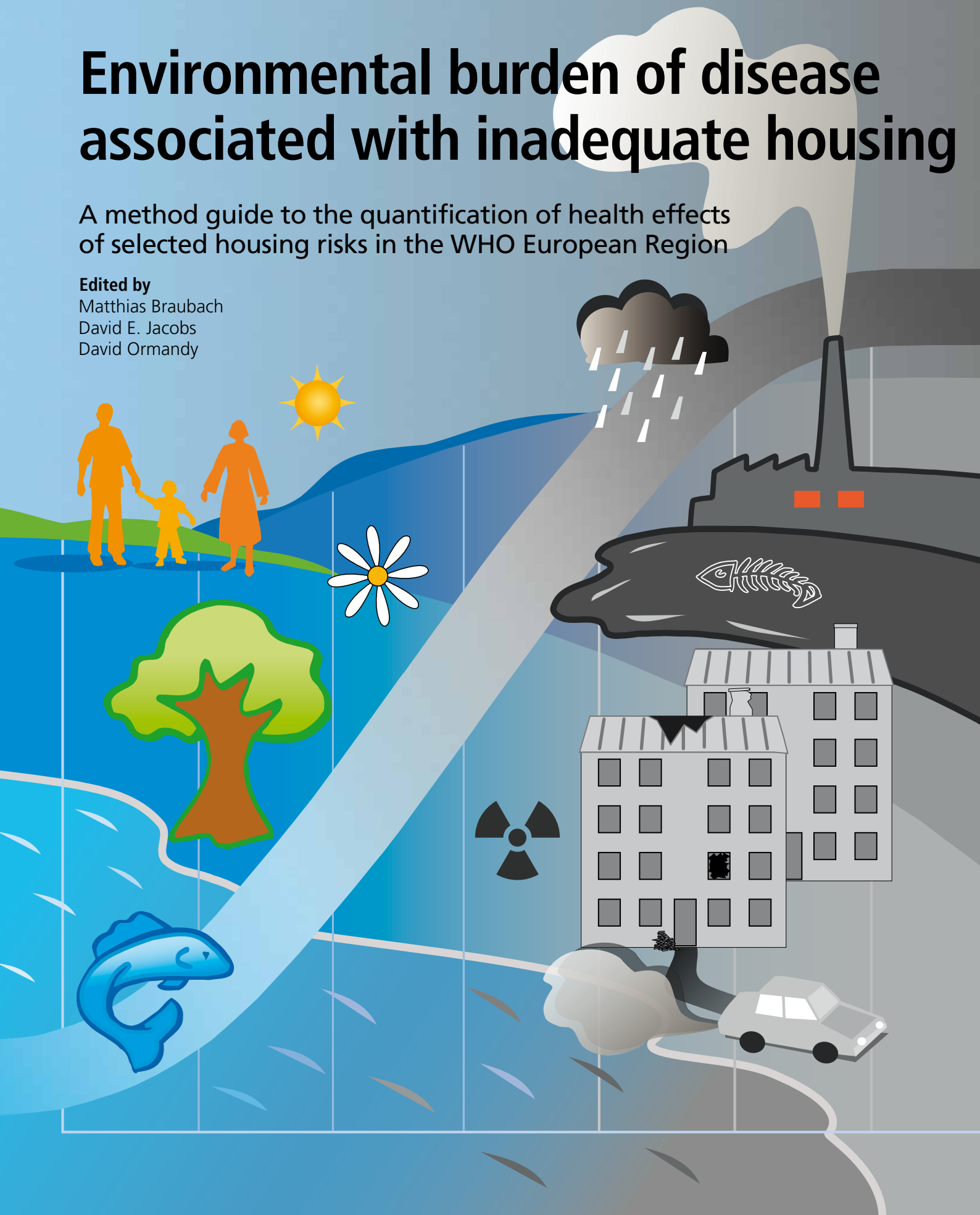

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Environmental burden of disease associated with inadequate housing

Methods for quantifying health impacts of selected housing risks in the WHO European Region

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The WHO European Centre for Environment and Health, Bonn Office, WHO Regional Office for Europe coordinated the development of this report.

ABSTRACT

This guide describes how to estimate the disease burden caused by inadequate housing conditions for the WHO European Region as well as for subregional and national levels. It contributes to the WHO series of guides that describe how to estimate the burden of disease caused by environmental and occupational risk factors. An introductory volume to the series outlines the general methodology.

In this context, the WHO Regional Office for Europe took up the challenge to quantify the health effects of inadequate housing and convened an international working group to quantify the health impacts of selected housing risk factors, applying the environmental burden of disease (EBD) approach.

The guide outlines, using European data, the evidence linking housing conditions to health, and the methods for assessing housing impacts on population health. This is done for twelve housing risk factors in a practical step-by-step approach that can be adapted to local circumstances and knowledge. This guide also summarizes the recent evidence on the health implications of housing renewal, and provides a national example on assessing the economic implications of inadequate housing.

The findings confirm that housing is a significant public health issue. However, to realize the large health potential associated with adequate, safe and healthy homes, joint action of health and non-health sectors is required.

Keywords

HOUSING – standards
RISK FACTORS
RISK ASSESSMENT – methods
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