WHO Health Guidelines for Indoor Air Quality and National Recommendations/Standards

Lidia Morawska and Wei Huang

Contents

Abstract

This chapter reviews and discusses the World Health Organization (WHO) guidelines related to indoor air quality (IAQ). The WHO IAQ health guidelines are developed and published after systematic reviews of evidence from medical and public health studies, and through extensive panel discussion and expert consultation, which provide an important basis for countries to develop your national indoor air standards. First, a general background is provided for establishing health-based air quality guidelines, followed by a summary of the criteria for the inclusion and exclusion of specific pollutants in these documents and a summary of the values of the numerical guidelines for IAQ. The following

L. Morawska (✉)
International Laboratory for Air Quality and Health, Queensland University Technology, Brisbane, QLD, Australia

Global Centre for Clean Air Research, Department of Civil and Environmental Engineering, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, UK
e-mail: l.morawska@qut.edu.au

W. Huang
Department of Occupational and Environmental Health, School of Public Health, and Institute of Environmental Medicine, Peking University, Beijing, China
e-mail: whuang@bjmu.edu.cn

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is a summary of existing or planned national standards or guidelines for IAQ management, including monitoring, in countries around the world, and discussed in the context of the WHO IAQ guidelines. Globally, only several countries have enacted national indoor air quality standards or health guidelines. The importance of developing a national standard or guideline for indoor air quality based on health evidence is discussed as a measure to reduce indoor exposure.

Keywords

Indoor air quality · Indoor air quality guidelines · Indoor air quality standards · WHO indoor air quality guidelines

Introduction

In this chapter, guidelines and standards for indoor air quality are reviewed and discussed. While the terms "guidelines" and "standards" are often used interchangeably, these are different types of documents, which we explain first. Secondly, we define indoor air quality for the purpose of this discussion. Finally, we outline the scope of this chapter.

An air quality health guideline is any kind of recommendation or guideline on the protection of a human population or receptors in the environment from the adverse effects of air pollution. The guidelines, which are globally considered to be the foundation for the prevention of health effects in relation to air pollution, are those developed by the World Health Organization (WHO). In 1979, the WHO published a criteria document focused on sulfur dioxide (SO_2) and particulate matter (WHO 1979), but the first edition of the guidelines was published by the WHO European Office in 1987 (WHO 1987). Following this, a global edition of the guidelines was published in 2000 (WHO 2000), with the most recent update published in 2021 (WHO 2021). The first edition of the guidelines (1987) included carbon monoxide (CO), lead, nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and total suspended particulate (TSP) matter. The Global and European guidelines published in 2000, as well as the Global guidelines published in 2006, included the same pollutants; however, in 2000, TSP was replaced by $PM_{2.5}$ and PM_{10}, (particulate matter with aerodynamic dimeter <2.5 μm and 10 μm, respectively), albeit without the provision of numerical guideline levels. In addition, the 2000 Global and European guidelines also included the following pollutants: cadmium, carbon disulfide, carbon monoxide, 1,2-dichloroethane, dichloromethane, formaldehyde, hydrogen sulfide, manganese, mercury, platinum, styrene, tetrachloroethylene, toluene, and vanadium. These pollutants were not included in the 2006 updated WHO AQG due to the limited resources available for the project, and therefore their values from the 2000 remain in effect. The new edition of the guidelines includes particulate matter: ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide (WHO 2021). As a general comment, the concept in WHO air quality guidelines has evolved over the years, to include in terms of the method used and environmental protection considerations (WHO 2017).

Health guidelines published by WHO are adopted based on expert panel agreements, following consideration of evidence from medical and public health studies. As stressed in the latest edition of the guidelines, "*The overall objective of these guidelines is to offer quantitative health-based recommendations for air quality, expressed as long- or short-term concentrations of a number of key air pollutants*" (WHO 2021).

Health guidelines are exclusively based on exposure (concentration)-response relationships found in epidemiological, toxicological, and environment-related studies. In general, they are not restricted to a numerical value but can be expressed in different ways. However, air quality guideline values are fixed numerical values corresponding to a defined averaging time. They could be expressed as: pollutant concentration in ambient air, a pollutant deposition level, other physical-chemical value, or a unit risk. In relation to human health, the air quality guideline is a concentration below which no adverse effects are expected, albeit a small individual risk always exists.

Over decades, there have been continued improvements to the meaning of the term "adverse health effects." and improved in the understanding of the distinction between adverse and nonadverse effects (WHO 1972, 1978). These improvements came with the expansion of medical knowledge, including a higher sensitivity of research approaches and the application of biomarkers that can detect even the most subtle perturbation in the human biological system resulting from exposure to air pollution. These expansions were discussed and utilized in the Official Statement of the American Thoracic Society as to "What Constitutes an Adverse Health Effect of Air Pollution," released in 2000 (Samet et al. 2000), thus modifying the previous statement of the Society released in 1985 (Andrews et al. 1985).

The above example illustrates many steps, which need to be taken before initiating the process of establishing air quality health guidelines – which are "*rigorous scientific tool that can be used by regulatory authorities as a basis for setting standards, taking into account local sociopolitical and economic conditions and prevailing ambient concentrations of air pollutants*" (WHO 2017) – as discussed in section "National Standards," below. The quantification of risk due to environmental exposure to a particular pollutant is always a complex process, since there are numerous other pollutants and environmental factors, which have an impact on the individual at the same time, and the particular exposure investigated is only one of those factors. Such a process is normally initiated when evidence emerges that exposure to the pollutant constitutes a risk to human health. Some of the key subsequent steps in the process include the quantification of both the exposure-response relationship, as well as the impact of the proposed regulations or policy measures on the actual reduction in exposure. The entire process of risk assessment, for the purpose of risk management, encompasses several more steps, in particular, establishing the exposure-dose and dose-response relationships (these two are not always conducted, instead concertation-response is considered), the lifetime individual risk, and the risk to the exposed population (Naugle and Pierson 1991).

By contrast to air quality health guideline, an air quality standard is a level of air pollution (concentration, deposition, etc.), which is promulgated by a regulatory authority and adopted as enforceable. The key elements in formulation of a standard are: (i) effect-based level, (ii) averaging time, (iii) measurement procedure, (vi) definition of compliance parameters corresponding to the averaging times, and (vii) permitted number of exceeding. Ideally, national (state, provincial, etc.) standards should be set at the level (or below) recommended by WHO guidelines. For a range of reasons this is often not possible and a higher-standard values are decided upon and set. Unlike WHO air quality guidelines that are exclusively based on exposure-response relationships, there are two key aspects that are considered by public health regulators when setting standards, which are acceptability of risk and cost-benefits analysis. Acceptability of the risk and thus the standard value selected depend on: (i) the expected incidence and severity of the potential health effects; (ii) the size of the population at risk; and (iii) the degree of scientific uncertainty that the health effect will occur at any given level of air pollution. The acceptability of risk may vary among countries (or even among administrative regions within the countries), because of differences in social norms, degree of adversity, risk perception in the general population and various stakeholders, and how the risk associated with air pollution compares with other risks. Therefore, approaches to derivation of air quality standards from air quality guideline have the objectives of: (i) reducing the risk of adverse effects to a socially acceptable level and (ii) identification of the control actions that achieve greatest net economic benefit or is most economically efficient.

It is important to keep in mind these broad aspects characterizing indoor air quality (IAQ) guidelines and standards when considering these two types of documents. In principle, we *compare* different national standards and discuss how they *relate* to WHO IAQ guidelines.

IAQ is an element of indoor environment quality (IEQ) and is characterized in terms of concertation of pollutants that affect health (discussed in more detail below). IEQ is concerned, in addition to airborne pollutant concentrations, with several other factors, including thermal comfort, lightening, and acoustics. Another critical factor characterizing IEQ is ventilation for acceptable IAQ. Its role in the first instance is to remove from indoor air, and thus lower below acceptable levels (set by guidelines or standards), pollutants generated within the indoor environment. The pollutants are generated by the occupants and sources existing within the indoor environment (for example, mould or wall paint) or operating there (for example, combustion sources). Carbon dioxide (CO_2) requires a specific mention, as is produced by combustion processes in indoor and outdoor environments but is a by-product of the natural metabolism of living organisms. Sampling for CO_2 is often used as a means for screening areas where potential IEQ problems may exist. Importantly, CO_2, that is an indoor pollutant generated by humans, is commonly considered as a measure of perceived air quality, or a proxy for ventilation (Khovalyg et al. 2020).

Considering the above background, the scope of this chapter is:

1. WHO IAQ guidelines: (i) WHO guidelines related to indoor environment – background: (i) criteria for inclusion and exclusion of the specific pollutants and (ii) a summary of the IAQ numerical guideline values.
2. National IAQ standards: summary of the existing numerical national IAQ standards available in English language; (ii) summary of the rationale for selecting specific pollutants and their numerical values by the national health authorities; and (iii) discussion on the relation between national standards and WHO IAQ guidelines.

Outside the scope of the chapter are: (i) any qualitative IAQ guidelines or recommendations; and (ii) analysis of any broader IEQ aspects, in particular ventilation guidelines or standards. The later are critically reviewed, by, for example (Khovalyg et al. 2020).

WHO Indoor Air Quality Guidelines

WHO Guidelines Related to Indoor Environment: Background

There is an added complexity to indoor air pollution, compared to outdoor air pollution, since indoor air contains a mix of pollutants that penetrated from outside and those that were emitted inside; it is the mix of the pollutants that affects human health. This added complexity of relating indoor air quality and health, when compared to the impact of outdoor air, reflected in the WHO approach to develop health guidelines related to both of these environments. While, in relation to the outdoor air, there is two current documents, *WHO Global Air Quality Guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide* (WHO 2021) and for some pollutant and averaging times (WHO 2006), indoor air is covered by three documents. Recommendation for developing separate indoor air quality guidelines came from the working group of the WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006), in recognition that the management of indoor air quality requires approaches different from those used for outdoor air. In the subsequent work, it was acknowledged that while the existing WHO air quality guidelines are applicable to indoor air, a number of chemical substances were also identified for which specific indoor air guidelines were recommended. This led to the development of WHO *Guidelines for Indoor Air Quality, Selected Pollutants* (WHO 2010) – discussed below. In addition, guidelines on two other categories of health risk in indoor environments were also developed: biological agents and indoor combustion of solid fuels. The WHO guidelines on *Dampness and Mould* were published in 2009 (WHO 2009) and later, the *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion* (WHO 2014). These two sets of WHO guidelines do not, however, provide limit values in indoor air but provide qualitative recommendations to manage mould and dampness in buildings and best approaches to reducing household air pollution, respectively. Given our objective is to provide to the reader an overview of existing numerical guideline values for indoor air (regulatory or voluntary), the WHO guidelines on dampness and combustion of solid fuels are out of the scope of this chapter.

Criteria for Inclusion and Exclusion of the Specific Pollutants

The criteria, which were defined for selecting the compounds to be included in the WHO guidelines for indoor air were:

- The existence of indoor sources.
- The availability of toxicological and epidemiological data.
- Indoor levels exceeding the levels of health concern (NOAEL – no observed adverse effect level and/or LOAEL – lowest observed adverse effect level).

The substances initially selected based on these criteria as requiring specific attention in relation to the indoor environment were: benzene, carbon monoxide, formaldehyde, naphthalene, nitrogen dioxide, particulate matter ($PM_{2.5}$ and PM_{10}), polycyclic aromatic hydrocarbons (especially benzo-[*a*]-pyrene), radon, tetrachloroethylene, and trichloroethylene. Later, however, particulate matter – $PM_{2.5}$ and PM_{10} – was included in the list of the pollutants covered by the same outdoor and indoor air quality guidelines. In this chapter we discuss all these pollutants, including particulate matter, since exposure to particulate matter is one of the most significant environmental risks factors (GBD 2019).

The pollutants covered by the WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006) are regarded as not requiring specific attention in regard to indoor air: O_3, lead, and SO_2. Therefore, the same numerical heath guidelines apply to both outdoor and indoor environments in relation to these pollutants (now provided by [WHO 2021]). While all three of these pollutants also originate from indoor sources, outdoor air is typically their main source in indoor environments, and the chemical structure of their molecules is the same, whether originating from indoor or outdoor sources.

Organic Indoor Air Pollutants

In relation to the impact of the organic air pollutants (benzene, formaldehyde, naphthalene, and polycyclic aromatic hydrocarbons, including especially benzo-[*a]*-pyrene, tetrachloroethylene, and trichloroethylene), the list of effects includes: carcinogenicity, co-carcinogenicity, mucus coagulation, cilia toxicity, increased allergic sensitization, increased airway reactivity, eye, throat or nose irritation, headache, cough, and fatigue. While it is outside the scope of this chapter to discuss these effects in more detail, they are comprehensively covered by the guideline document. The indoor sources of these pollutants include – *benzene*: tobacco smoke, solvents used for hobbies or cleaning, or using building materials that off-gas benzene; *formaldehyde*: particleboard, insulation, furnishing, tobacco smoke, gas stoves, and consumer products; *naphthalene*: naphthalene mothballs, but also the combustion of biomass; *polycyclic aromatic hydrocarbons*: mainly combustion, including cooking smoking, candle burning, etc; *trichloroethylene*: using wood stains, varnishes, lubricants, paint removers, etc; and *tetrachloroethylene*: cleaning solvent and dry cleaning agents.

Inorganic Indoor Gaseous Pollutants: CO and NO_2 and Radon

In contrast, CO was included in the WHO Air Quality Guidelines for Europe, 2nd ed. (WHO 2000), and NO_2 was included in the WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006). The two pollutants were in turn included in the WHO *Guidelines for Indoor Air Quality, Selected Pollutants* (WHO 2010), considering the different nature of exposure to these gases in indoor environments. Briefly, exposure to CO results in a reduction of oxygen delivery to tissues, owing to the formation of carboxyhemoglobin, and its indoor sources include tobacco smoke, faulty appliances (e.g., furnaces and hot water heaters), clogged chimneys, and automobile exhaust in houses with attached garages. Chronic health effects may be present for low concentrations of CO and sudden death can occur at high levels of the gas. Nitrogen dioxide exposure may lead to the occurrence of respiratory health effects, including short-term effects due to peak concentrations, particularly in susceptible individuals (asthmatics), as well as long-term effects on the incidence and prevalence of respiratory disease, primarily among children. Its indoor sources mainly include unvented combustion appliances, such as gas stoves, kerosene heaters, etc.

Radon, mainly ^{222}Rn, is a naturally occurring noble radioactive gas which is classified by the International Agency for Research on Cancer (IARC) as a human carcinogen, which emanates and penetrates to indoor air from rocks, soil, groundwater, and also building materials. The radiation released, mainly from alpha decay of short-lived decay products within the lungs, imparts on the lung a dose to which an increased risk of lung cancer can be attributed. The WHO has identified radon as the highest priority area for reducing environmental radiation risk and in 2009 they launched the *WHO Radon Handbook* which gives a comprehensive overview on the radon problem (Zeeb et al. 2009).

Particulate Matter: $PM_{2.5}$ and PM_{10}

There are still many questions remaining regarding PM, with one of them being whether there is convincing evidence for a difference in risk caused by PM from indoor sources, as compared with those from outdoors. One complexity is that ambient air is a significant contributor to indoor PM, whereby indoor concentrations are of the order of 50% of ambient concentrations, in the absence of any indoor sources. However, when indoor sources are present, the indoor levels of PM are usually higher than the outdoor levels. A large number of indoor particle sources were identified and emissions from these sources were investigated by many studies reported in the literature, e.g., He et al. (2004). Combustion processes are the main indoor sources of smaller particles, with the majority of them (in terms of number) in the ultrafine size range (<0.1 μm), containing a host of organic and inorganic material (Morawska and Zhang 2002). Other sources or human activities contributing to elevated levels of indoor ultrafine particles include vacuuming, cleaning using detergents, showering, operation of electric motors, and operation of printing and photocopying devises (Monn et al. 1995; Tucker 2000). Resuspension of particles by human movement, on the other hand, contributes to the coarse mode of indoor particles, usually in the supermicrometer size (He et al. 2004). Contributions of different sources to different particle metrics (particle mass or particle number concentration), and different particle size ranges, were reviewed and summarized by Morawska et al. (2017). The analysis of the data available in literature showed that the key source contribution varies between different indoor environments. In particular, the main source of residential PM_{10} and $PM_{2.5}$ is outdoor; ultrafine particles (measured as particles number concentration) are generated predominantly by indoor sources, which is opposite to schools and day cares, for which ultrafine particles originate from outside, but PM_{10} and $PM_{2.5}$ originate from indoor sources, and for offices, particles of all sizes originate mainly from outdoors.

Health effects due to exposure to particulate matter include: decreased lung function, increased respiratory symptoms, increased chronic obstructive pulmonary disease, increased cardiovascular and cardiopulmonary disease, and increased all cause and cause-specific mortality. A large body of evidence on health effects associated with exposure to PM_{10} and $PM_{2.5}$ since publication of WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006), which was used in the current update of the *WHO Global Air Quality Guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide* (WHO 2021).

Summary of the IAQ Numerical Guideline Values

Table 1 summarizes WHO IAQ guideline values based on WHO *Guidelines for Indoor Air Quality, Selected Pollutants* (WHO 2010). Included in the table are also guideline values for $PM_{2.5}$ and PM_{10}, NO_2, and CO based on the *WHO Global Air Quality Guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide* (WHO 2021), as well as NO_2 and CO for the averaging times that are covered by WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006).

National Standards

National air quality standards are enacted based on the potential for health and economic effects of the identified pollutants. We conducted a comprehensive Internet search to identify any existing indoor air quality national standards or guidelines. Unlike literature searches for referred journal papers, we could not use databases such as Web of Science, Scopus, etc. to identify national standards. Our search was also limited to English and Chinese language published documents; countries in

Table 1 Guideline values, as well as critical health outcomes of the indoor air pollutants included in the WHO *Guidelines for Indoor Air Quality, Selected Pollutants* (WHO 2010)(1), on particulate matter, NO_2, and CO averaging times based on the *WHO Global Air Quality Guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide* (WHO 2021)(2), and on NO_2 and CO that are covered by WHO *Air Quality Guidelines: Global Update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide* (WHO 2006)(3)

Pollutant	Guideline value	Critical outcome[a]
Benzene(1)	No safe level of exposure can be recommended Unit risk of leukaemia per 1 μg/m^3 air concentration is 6×10^{-6} The concentrations of airborne benzene associated with an excess lifetime risk of 1/10,000, 1/100,000 and 1/1,000,000 are 17, 1.7, and 0.17 μg/m^3, respectively	Acute myeloid leukemia (sufficient evidence on causality) Genotoxicity
Carbon(1) monoxide Carbon(2) monoxide	15 min – 100 mg/m^3 1 h – 35 mg/m^3 8 h – 10 mg/m^3	Acute exposure-related reduction of exercise tolerance and increase in symptoms of ischemic heart disease (e.g., ST-segment changes)
	24 h – 4 mg/m^3	Association with hospital admissions and mortality from myocardial infarction
Formaldehyde(1)	0.1 mg/m^3–30-min average	Sensory irritation
Naphthalene(1)	0.01 mg/m^3 – annual average	Respiratory tract lesions leading to inflammation and malignancy in animal studies
Nitrogen dioxide(3) Nitrogen dioxide(2)	200 μg/m^3–1 h average	Respiratory symptoms, bronchoconstriction, increased bronchial reactivity, airway inflammation, and decreases in immune defence, leading to increased susceptibility to respiratory infection
	10 μg/m^3 – annual average 25 μg/m^3–24-h average	Nonaccidental mortality, cause-specific, and respiratory mortality
Polycyclic aromatic hydrocarbons(1)	No threshold can be determined, and all indoor exposures are considered relevant to health Unit risk for lung cancer for PAH mixtures is estimated to be 8.7×10^{-5} per ng/m^3 of B[*a*]P The corresponding concentrations for lifetime exposure to B[*a*]P producing excess lifetime cancer risks of 1/10,000, 1/100,000, and 1/1,000,000 are approximately 1.2, 0.12, and 0.012 ng/m^3, respectively	Lung cancer

(continued)

Table 1 (continued)

Pollutant	Guideline value	Critical outcome[a]
Radon[(1)]	The excess lifetime risk of death from radon-induced lung cancer (by the age of 75 years) is estimated to be 0.6×10^{-5} per Bq/m^3 for lifelong nonsmokers and 15×10^{-5} per Bq/m^3 for current smokers (15–24 cigarettes per day); among ex-smokers, the risk is intermediate, depending on time since smoking cessation The radon concentrations associated with an excess lifetime risk of 1/100 and 1/1000 are 67 and 6.7 Bq/m^3 for current smokers and 1670 and 167 Bq/m^3 for lifelong nonsmokers, respectively	Lung cancer suggestive evidence of an association with other cancers, in particular leukemia and cancers of the extra thoracic airways
Trichloroethylene[(1)]	Unit risk estimate of 4.3×10^{-7} per $\mu g/m^3$ The concentrations of airborne trichloroethylene associated with an excess lifetime cancer risk of 1:10,000, 1:100,000, and 1:1,000,000 are 230, 23, and 2.3 $\mu g/m^3$, respectively	Carcinogenicity (liver, kidney, bile duct, and non-Hodgkin's lymphoma), with the assumption of genotoxicity
Tetrachloroethylene[(1)]	0.25 mg/m^3 – annual average	Effects in the kidney indicative of early renal disease and impaired performance
$PM_{2.5}$[(2)]	1 year, 5 $\mu g/m^3$ 24 h, 15 $\mu g/m^3$	All-cause, cardiovascular, respiratory, and lung cancer mortality
PM_{10}[(2)]	1 year, 15 $\mu g/m^3$ 24 h, 45 $\mu g/m^3$	All-cause, cardiovascular, respiratory, and lung cancer mortality

[a]Besides these outcomes, there are other health effects of the exposure to each of the considered pollutants. The critical outcomes were selected for the risk assessment of the exposure to given pollutant with the assumption (based on available evidence) that the reduction of exposure to prevent this critical health outcome prevents other health outcomes of the exposure as well

which English is not spoken will not necessarily have their standards published in English (but some European Union [EU] countries have). While our search was comprehensive, we cannot exclude that we missed some countries' national regulations due to, for example, different terminology used or the indoor air regulations being imbedded into other types of broader regulations.

Based on the Internet search, we found that not all countries have their own national standards or guidelines. There is no directive guideline or standard at the EU level, but there are national guidelines in some European countries, including the guideline or target values in the UK (Shrubsole et al. 2019), France (France 2020), Germany (Bundesamt 2021), and Belgium (De Brouwere et al. 2020). Table 2 presents a summary of national standards or guidelines for IAQ management or monitoring and Table 3 tabulates pollutants and their limit values for the countries that have national standards, guidelines, or targets.

We have also separately listed the countries which state that they do not have national standards. Those countries in alphabetic order include: Albania, Algeria, Andorra, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Bahamas, Barbados, Belarus, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brunei, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Capo Verde, Central African Republic, Chad, Chile, Colombia, Comoros, Congo, Cote d'Ivoire, Croatia, Cyprus, Czech Republic, Democratic Republic of Congo, Denmark, Djibouti, Ecuador, Egypt, Equatorial Guinea, Eritrea, Estonia, Eswatini, Ethiopia, Falkland Islands, Finland, French Guiana, Gabon, Gambia, Georgia, Ghana, Greece, Guinea, Guyana, Iceland, Iran, Ireland, Italy, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyzstan, Latvia, Laos, Lebanon, Lesotho, Liberia, Libya, Liechtenstein, Lithuania, Luxembourg, Madagascar, Malawi, Maldives, Mali, Malta, Mauritania, Mauritius, Mayotte, Moldova, Monaco, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, the Netherlands, New Zealand, Niger, Nigeria, North Macedonia, Oman, Pakistan, Paraguay, Peru, Philippines, Qatar, Réunion, Romania, Rwanda, Saint Helena, San Marino, Sao Tome and Principe, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Slovakia, Slovenia, Somalia, South Africa, South Sudan, Sri Lanka, State of Palestine, Sudan, Suriname, Switzerland, Syria, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Trinidad and Tobago, Tunisia, Turkmenistan, Turkey, Uganda, Ukraine, United Arab Emirates, Uruguay, Venezuela, Vietnam, Western Sahara, Zambia, Zimbabwe, etc.

Although there are no specific policies in these countries, in some of the countries actions are being taken to comply with other countries' air quality standards or other type of indoor air regulations. For example, in Singapore, building owners, facility managers, and occupants all have liability in maintaining indoor air quality for the health and comfort of occupants in buildings. In Bahamas, the government regularly compare local air quality levels with the US air quality index values.

Different environments in different countries, as well as different factors considered in health and economic assessments of the impact of indoor air pollution, can result in different pollutants to be included in national standards or guidelines across countries. Most national guideline or standard threshold values are enacted in consideration with exposure level that is undesirable for health; however, the numerical values for the same pollutant can be different across countries. For example, in Germany, Guide value II (RW II) is an effect-related value based on current toxicological and epidemiological evidence of a substance's effect threshold with uncertainty factors considered. Guide value I (RW I) represents the concentration of a substance in indoor air for which, when considered individually, there is no evidence at present that even lifelong exposure is expected to bear any adverse health impacts. In India, three levels of threshold values have been defined as aspirational (Class A), acceptable (Class B), and marginally acceptable (Class C).

Table 2 Summary of National Standards or Guidelines for Indoor Air Quality Management or Monitoring in individual countries, or indicated as potential standards/guidelines(*)

Country	Document title	Links to the document
Belgium	Establishing target and intervention guidance values for indoor air in dwellings and publicly accessible buildings: The Flemish approach	https://doi.org/10.1016/j.ijheh.2020.113579
Brazil*	Guidelines for Indoor Air Quality (IAQ) in Nonindustrial and Nonspecialized Settings	https://www.semanticscholar.org/paper/GUIDELINES-FOR-INDOOR-AIR-QUALITY-IN-OFFICES-IN-Neto-Siqueira/b8e2fe3fbe093c81542947377ef0caecf8682e29
Canada	Residential Indoor Air Quality Guidelines	https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html
China	Indoor Air Quality Standard (GB/T 1883–2002)	http://www.mee.gov.cn/image20010518/5295.pdf (in Chinese)
France	Indoor Air Quality Action Plan	https://www.ecologie.gouv.fr/sites/default/files/Plan_QAI__23_10_2013.pdf (in French)
German	German Committee on Indoor Guide Values	https://www.umweltbundesamt.de/en/topics/health/commissions-working-groups/german-committee-on-indoor-guide-values
Hong Kong China	Indoor Air Quality Monitoring Guideline for Office and Public Buildings (2003)	https://www.iaq.gov.hk/media/8688/certguide-chi.pdf (in Chinese)
Hungary	National Indoor Air Quality Action Plan (Version 1, 2018)	https://www.interreg-central.eu/Content.Node/InAirQ/National-IAQ-Action-Plan-Hungary.pdf
India	Indoor Environmental quality Standard(2nd Version:2018–2019)	https://ishrae.in/Content/Download/ISHRAE_IEQ_Feb_26_2019_public_draft.pdf
Japan	Law of Maintenance of Sanitation in Building	To be found
Korea	Issues on indoor air quality in Korea	http://www.zyaura.com/quality/Archives/Recently%20issues%20on%20Indoor%20air%20quality%20in%20Korea%5B1%5D.pdf
Kuwait	Indoor air pollution and exposure assessment of the gulf cooperation council countries: A critical review	https://www.sciencedirect.com/science/article/pii/S0160412018318142
Norway*	Guidelines for indoor air in Norway – a practical approach Recommended Guidelines for Indoor Air Quality	http://lodel.irevues.inist.fr/pollutionatmospherique/docannexe/file/3772/245_becher.pdf
Poland	Indoor Air Quality Action Plan – School Environment (Version 5.0, 2019)	https://www.interreg-central.eu/Content.Node/InAirQ/National-IAQ-Action-Plan-Poland.pdf
Portugal*	Indoor Air Quality in Portugal: Technical, Institutional, and Policy Challenges in the	https://www.witpress.com/Secure/elibrary/papers/AIR07/AIR07056FU1.pdf

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Table 2 (continued)

Country	Document title	Links to the document
	Implementation of the Directive on the Energy Performance of Buildings (work in progress)	
Russia*	Standards and Laws for Indoor Air Quality in Russia	https://doi.org/10.1159/000463337
Spain*	Indoor air quality regulations: The Spanish case	https://www.aivc.org/resource/indoor-air-quality-regulations-spanish-case
Sweden*	Sweden Air Quality Policies	https://wedocs.unep.org/bitstream/handle/20.500.11822/17118/Sweden.pdf?sequence=1&isAllowed=y
UK	Indoor Air Quality Guidelines for selected volatile organic compounds (VOCs) in the UK	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831319/VO__statement_Final_12092019_CS__1_.pdf

An important question is how the national indoor air quality guideline or standard values for individual pollutants relate to the WHO guideline values for these pollutants. To answer this question, in Fig. 1a, b, we compare national threshold values to the WHO ones, for PM ($PM_{2.5}$ and PM_{10}) and CO, respectively. An interesting observation from Fig. 1a is that while for PM_{10} the regulatory threshold for four out of six countries that have regulations, significantly exceed the WHO values, for $PM_{2.5}$ by contrast, only in one out of six countries the national threshold value exceeded this of WHO, while in four countries, the national thresholds are lower than the WHO ones. However, CO national guideline/standard values are all but one (out of nine countries) higher than WHO guideline levels.

Another important question is the enforcement of indoor air quality national regulations. The first element of enforcement is compliance monitoring of the concentration levels of the regulated pollutants. Compliance monitoring of ambient air pollution is conducted at networks of air monitoring stations, usually operated by the relevant authorities, or be organizations mandated to do so. Measurements from a set number of central monitoring stations are considered for this purpose as representative of the entire area the network covers. In contrast, compliance monitoring of indoor air quality would require monitoring to be conducted in every building or in several locations within the building, as no central indoor monitoring would be representative of air quality in the entire local building stock. Therefore, indoor air monitoring is usually not conducted on a routine manner, which means there is no enforcement of indoor air quality regulations (UNEP 2021). A particularly difficult case regarding enforcement is, if the pollutant in question is generated predominantly outdoors, from where it penetrates indoors. This is the case in relation to $PM_{2.5}$ and PM_{10}, in homes, and offices, as discussed above, based on a review by Morawska et al. (2017). This is also the case in many air pollution episodes, such as bushfires are haze episodes. In such situations controlling indoor air quality may be

Table 3 Summary on threshold or guideline values for common pollutants in National Indoor Air Quality Standards or Guidelines[a]

Country	$PM_{2.5}$	PM_{10}	Ozone, O_3	Nitrogen dioxide, NO_2	Sulfur dioxide, SO_2	Carbon dioxide, CO_2	Carbon monoxide, CO
Belgium	Lifetime exposure – 10 μg/m³		Lifetime exposure – 40 μg/m³	Lifetime exposure – 20 μg/m³			24 h – 8 mg/m³ intervention value
Canada	As low as possible		8 h – 40 μg/m³	24 h – 20 μg/m³ 1 h – 170 μg/m³			24 h – 11.5 mg/ m³ 1 h – 28.6 mg/m³
China		24 h – 150 μg/m³	1 h – 160 μg/m³	1 h – 240 μg/m³	1 h – 500 μg/m³	24 h – 0.10%	1 h – 10 mg/m³
German				1 h – GVI: 80 μg/m³; GVII: 250 μg/m³			
Hong Kong China		8 h – 180 μg/m³	8 h – 120 μg/m³	8 h – 150 μg/m³		8 h – 1000 ppm	8 h – 10 mg/m³
Hungary	24 h – 25 μg/m³	24 h – 50 μg/m³	7 days –80 μg/m³ 24 h – 50 μg/m³	7 days – 40 μg/m³ 24 h – 100 μg/m³ 1 h – 200 μg/m³		7 days – 1500 ppm	7 days – 80 mg/m³ 24 h – 30 mg/m³

India	Class A: 15 μg/ m^3 Class B: 25 μg/m^3 Class C: 25 μg/m^3	Class A: 50 μg/m^3 Class B: 100 μg/m^3 Class C: 100 μg/m^3	Class A: 50 μg/m^3 Class B: 100 μg/m^3	Class A: 40 μg/m^3 Class B: 80 μg/m^3	Class A: 40 μg/m^3 Class B: 80 μg/m^3	Class A: Ambient +350 ppm Class B: Ambient +500 ppm Class C: Ambient +700 ppm	Class A: 2 ppm Class B: 9 ppm Class C: 9 ppm
Japan		150 μg/m^3	120 μg/m^3			1000 ppm	10 ppm
Korea		150 μg/m^3	0.06 ppm	0.05 ppm		1000 ppm	10 ppm
Kuwait	8 h – 40 μg/m^3		1 h – 235 μg/m^3 8 h – 200 μg/m^3 24 h – 120 μg/m^3 1 year – 60 μg/m^3	30 min – 660 μg/m^3 1 h – 200 μg/m^3 24 h – 100 μg/m^3	8 h – 50 μg/m^3	1 h – 9689 mg/m^3 24 h – 2713 mg/m^3 1 year – 581 mg/m^3	30 min – 60 mg/m^3 1 h – 30 mg/m^3 8 h – 10 mg/m^3
Norway	24 h – 20 μg/m^3						
Poland	10 μg/m^3					1200 ppm	

[a]The units are listed exactly as they are provided in the National Standards

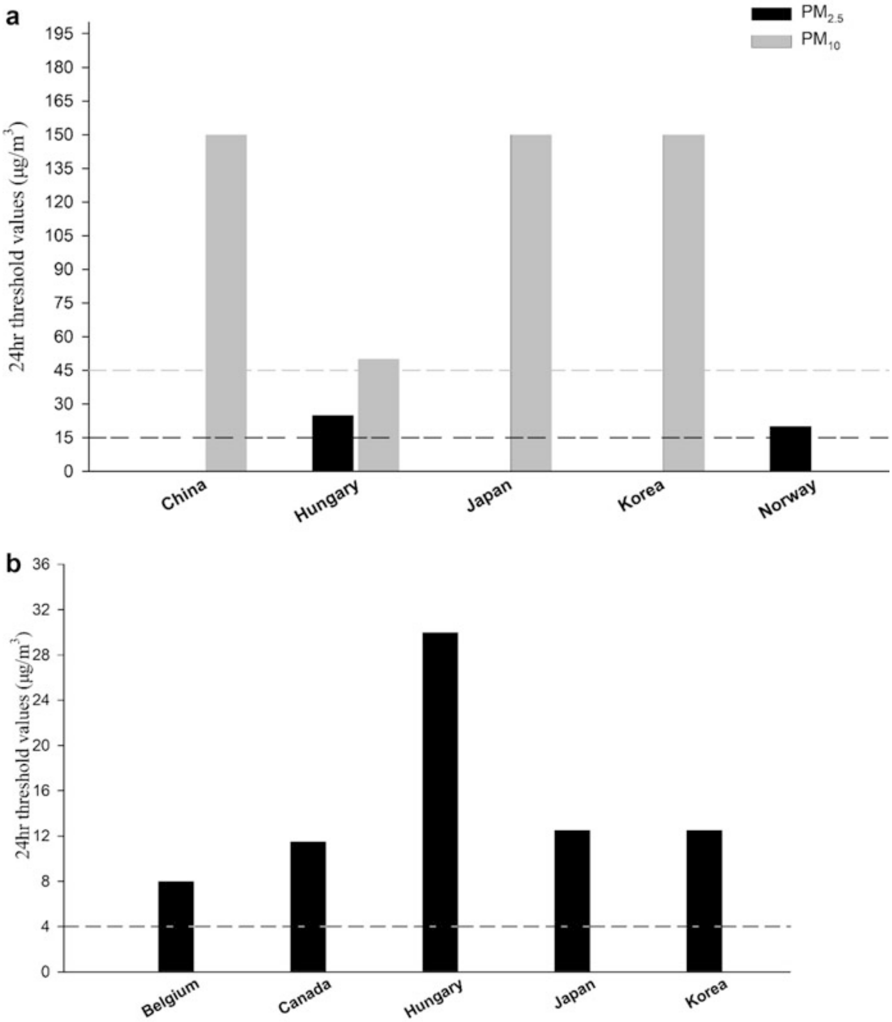

Fig. 1 (**a**) The 24 h threshold or guideline values for $PM_{2.5}$ and PM_{10} in several national indoor air quality standards in comparison with WHO guidelines of 15 μg/m^3 for $PM_{2.5}$ and 45 μg/m^3 for PM_{10}. (**b**) The 24 h threshold or guideline values for CO in several national indoor air quality standards in comparison with WHO guidelines of 4 mg/m^3

difficult or impossible, if the building does not have an efficient mechanical ventilation system.

It is somewhat easier to compare regulatory values and the averaging times for the so-called criteria pollutants (PM and gaseous pollutants: CO, NO_x, O_3, and SO_2), then for organic compounds. Due to the complex structure and toxicity of organic matter in indoor environments, we have summarized national standards of major organic compounds considered by WHO indoor guidelines in Table 4. As radon has been identified as the highest priority for reducing indoor environmental radiation

Table 4 Summary on threshold or guideline values for organic and radioactive pollutant of national indoor air quality standards or guidelines

Country	Benzene	Formaldehyde	Naphthalene	Trichloroethylene	Tetrachloroethylene	PAHs	TVOCs	Radon
Belgium	0.4 μg/m³ Intervention value	100 μg/m³ Intervention value	3 μg/m³	0.2 μg/m³	4 μg/m³	0.012 ng/m³	300 μg/m³	
Canada	As low as possible	8 h – 50 μg/m³ 1 h – 123 μg/m³			40 μg/m³			200 Bq/m³
China	1 h – 110 μg/m³	1 h – 100 μg/m³					8 h –600 μg/m³	400 Bq/m³
German		GVI: 100 μg/m³			GVI: 100 μg/m³; GVII: 1000 μg/m³		GVI: 200–300 μg/m³; GVII: 1000–3000 μg/m³	250
Hong Kong China	16.1 μg/m³	8 h – 100 μg/m³		770 μg/m³	250 μg/m³		8 h – 600 μg/m³	200
Hungary	7 days – 5 μg/m³ 24 h – 10 μg/m³	7 days – 30 μg/m³ 24 h – 50 μg/m³		7 days – 10 μg/m³	7 days – 250 μg/m³			400

(continued)

Table 4 (continued)

Country	Benzene	Formaldehyde	Naphthalene	Trichloroethylene	Tetrachloroethylene	PAHs	TVOCs	Radon
India	3 μg/m^3	30 μg/m^3	9 μg/m^3	600 μg/m^3	35 μg/m^3		Class A: 200 μg/m^3 Class B: 400 μg/m^3 Class C: 500 μg/m^3	
Japan		0.08 ppm					400 μg/m^3	
Korea		0.1 ppm					500 μg/m^3	
Kuwait		30 min – 120 μg/m^3 8 h – 52.9 μg/m^3				1 h – 5000 ppm 24 h – 1400 ppm		
Norway								200
Poland	1.7 μg/m^3	10 μg/m^3						
United Kingdom	As low as possible	30 m – 100 μg/m^3 1 year – 10 μg/m^3	1 year – 3 μg/m^3	As low as possible	24 h – 40 μg/m^3			200

risk in many countries, we have also included the threshold values of radon in Table 4.

Reviewing the information presented in Table 4, it can be seen firstly that only a relatively small number of 14 countries has national regulations regarding indoor organic airborne pollutants. Secondly, the threshold values differ significantly between countries. However, it is outside the scope of this work to analyze in detail the differences and the rationale of different countries to select specific values.

Summary

Health guidelines for indoor air quality that developed and published by WHO following systematic reviews on evidence from medical and public health studies and through extensive expert panel discussion and consultation have provided an important foundation for countries to develop their national indoor air standards. Nevertheless, globally, only several countries have promulgated national indoor air quality standards or health guidelines, and in many cases the threshold values are higher than the current WHO guideline levels. Given the importance of air quality in indoor environments where people spend most of their time, developing health evidence–based national indoor air quality standard or guideline development to reduce indoor exposure is of paramount significance in terms of public health protection, particularly in low- and middle-income countries (LIMCs) with poorer indoor air quality.

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