

Article

Challenges in IAQ for Indoor Spaces: A Comparison of the Reference Guideline Values of Indoor Air Pollutants from the Governments and International Institutions

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Abstract: Since people spend most of their time inside buildings, indoor air quality (IAQ) remains a highlighted topic to ensure in the built environment to improve public health, especially for vulnerable users. To achieve a better indoor environment quality (IEQ), some countries' governments or regional institutions have developed and published reference guideline values of various air pollutants to prevent the IAQ from becoming adverse to occupants. Beyond guidelines by World Health Organization (WHO), in some countries, there are specific institutional requirements on the IAQ, and others integrated it into the building regulation for the built environment. This paper is based on the literature research, summarized from previously conducted works by the authors, on the chemical reference values of IAQ-related regulations and guidelines published by several Governments or related institutions from various regions around the World. Despite these efforts at standardization and legislation, many indoor air quality monitoring activities conducted in several countries still fall short of the main indications produced. By comparing the reference values of 35 pollutants, both physical and chemical ones, which are proposed in documents from 23 regions included so far, the IAQ research and prevention actions on progress in different regions should be included in monitoring plans with guidelines/reference values in their current state. The outcome of the paper is to define the current trends and suggest some perspectives on the field of interest for improving the indoor air quality of generic spaces at an international level. It becomes evident that, at the global level, IAQ represents a complex political, social, and health challenge, which still suffers from the absence of a systematic and harmonized approach. This is not a new situation; the issue was raised more than 40 years ago, and despite efforts and a pandemic, the situation has not changed.

Keywords: indoor air quality (IAQ); air pollutants; indoor environment quality (IEQ); reference values; guidelines values; international regulations; built environment; perspectives in IAQ; chemical contaminants

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1. Introduction

1.1. The Present Scenario

Indoor and outdoor air pollution is one of the greatest environmental health risks, affecting everyone in low-, middle-, and high-income countries [1]. People spend on average about 90% of their hours indoors. The development of information and communication technologies has increased the ability to work remotely, and the time spent at home has risen to 100% [1,2].

The scientific community shows that adverse health effects do not only result from acute events but also chronic exposure [3], and most low-level exposures are not perceivable before the symptom is found and have risks to be accumulated during long-term exposure, leading to irreversible health conditions [4–7]. Correspondingly, several guidelines and standards on IAQ are published by many states and several research institutions and professional associations (e.g., related to the ventilation approach) for indoor settings, starting from the documents and guidelines by World Health Organization (WHO) [1,5], with useful suggestions on no impacts on users [8] and best practices for the building managers [9,10].

Currently, several cities started—from their building regulations [11]—to impose the presence of green areas [12], green roofs [13], and other solutions related to green building design for trying to reduce pollution in the built environment. Nowadays, in fact, some companies are developing technologies (paintings, façade solutions, etc.) aimed at improving the quality of indoor and outdoor air, such as the works by Bianchi et al. [14].

The guidelines and standards for IAQ are not only for the target audience of buildings designers who make decisions, such as architects, engineers, internal designers, and construction teams [15], but also for specific users inside the indoor spaces and facility managers who occupied the indoor spaces during the running period in the building lifespan.

Some countries have specific government departments and affiliated or cooperated institutions that independently suggest and publish IAQ reference values based on their national needs, such as Italy [16], France (recently updated on 27.12.2022) [17], Germany [18], Finland [19–21], Denmark [22], Australia [23], Canada [24], New Zealand [25], China [26] and Hong Kong (China) [27], Japan [28], Russian [29], etc. Others include IAQ requirements in the building regulations, guiding the design and construction [30], as one section of the requirements for the built environment, such as the United Kingdom [31,32] and Singapore [33].

Meanwhile, also many international organizations such as the WHO, ISO (International Organization for Standardization), ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), etc., and their working groups regularly provide standards for the IAQ and related guidelines on best practices to help designers, building managers, hygienists, employers, and users to avoid IAQ deterioration. Based on the difference among the geographies, climate conditions, and local features, the presence of industries and developing conditions, as well as the progress of research, the list of pollutants and the reference values vary for each document, lacking a common perspective [34].

In most countries, there is no independent national government authority responsible for IAQ, and the various actions usually lead to an unclear central role of the issue (e.g., prevention activities in offices, schools, hospitals, transportation, and the role of energy efficient interventions).

1.2. Exposure to Chemical Compounds

The exposure to chemical compounds and their health effects in indoor environments have been taken into consideration by several governments and the main environmental and health institutions [35–37].

Exposure to indoor pollutants may cause a significant overall intake of pollutants by users. As a result of long-term work from the 1970s, the WHO has shifted from air quality guidelines on indoor air pollutants, with reports in 1987, 1999, 2000, and 2006, to specific indoor air guidelines, with several documents in 2009, 2010, 2014, and 2016 [34,38]. These guidelines consider many pollutants, including nitrogen dioxide, naphthalene, polycyclic aromatic hydrocarbons (for example, benzo[a]pyrene, etc.), benzene, trichloroethylene, tetrachloroethylene, carbon monoxide, radon, etc. [39], and also dampness and mold [40].

The European Environmental Agency (EEA) defined that IAQ is affected by the quality of ambient air, ventilation systems, construction materials, cleaning products, energy-

saving strategies, users' behavior (such as smoking, E-CIG), etc. [41,42], as well as the activities carried out and the use of construction materials, finishing materials, equipment, furniture, etc. [43–46].

In the international scenario, there is a trend for integrated health promotion related to IAQ issues to drastically decrease the presence of pollutants, even though not all countries have specific regulatory legislation. All the guidelines available internationally constitute a framework that can support it in case of the absence of legislation, scholars, researchers, and experts in the topic and strategies to be applied.

As Settimo highlighted, with a specific focus on the European context, norms, and regulations on indoor air pollution are applied only in some punctual countries [34]. Harmonization of contents and parameters related to indoor air pollution control and monitoring should be implemented [34]. This calls for a review and improvement of the information and problems related to the quantity, nature, and origin of pollutants, starting from the existing protocols and norms.

Starting from these considerations, the ISO and CEN (European Committee for Standardization) institutions have provided a set of specific references on standard operating procedures for IAQ monitoring with EN ISO 16000 [47]. The EC (European Commission) and ECA (European collaborative action) have carried out a multidisciplinary research project, with the collaboration of several experts producing 30 specific documents from 1988 to 2020.

In terms of harmonization, several guidelines and indications on IAQ are also available from the WHO, for which health-based evidence is extracted from the related research on health effects [39,48]. The guidelines define the starting point for establishing reference values and limits adopted by various countries that are subject to regular revisions. In any case, the guidelines related to airborne pollutants are limited due to the large number of indoor compounds.

In general, as Settimo already specified, “reference values permit indoor spaces to be more restrictive than those suggested for industrial workplaces, based on 8-h a day, 5-day a week exposure and for a maximum period of 40 years, and targeted to the protection of workers against professional disease and illnesses” [34]. Identifying the appropriate reference values is critical to making appropriate assessments for the type of exposure. Several countries have applied specific and punctual references and guideline values; for example, the “Plan d'actions sur la Qualité de l'Air Intérieur” in France listed several monitoring and procedures.

At the same time, the deepening of knowledge on the topic has conditioned some countries through the development of multidisciplinary working groups for guideline values for IAQ, such as Germany with the AG IRK/AOLG (Federal Environmental Agency and the States Health), France with CSTB (Scientific and Technical Centre for Building) and AFSSET (French Agency for Environmental and Occupational Health Safety), the United Kingdom with the COMEAP (Committee on the Medical Effects of Air Pollutants), the Netherlands with the RIVM (National Institute for Public Health and the Environment), Finland with the MSAH (Ministry of Social Affairs and Health) commission, the Flemish Region, etc.

They have thus included reference values or limits in their regulation/guideline, including formaldehyde, benzene, trichlorethylene, tetrachlorethylene, carbon monoxide, carbon dioxide, nitrogen dioxide, PM₁₀, PM_{2.5}, etc. Because of the different methods used for determining the guide values, they may differ for the same substances, as compared to the WHO guidelines [39].

Methodologies are a strategic factor, as well as guideline values. In all the regions, values proposed are related to monitoring methods and analysis developed by several institutes (such as the Netherlands Instituut Normalisatie, NEN; British Standards, BS; German Institute for Standardization, DIN; Association Française de Normalisation, AFNOR; Bureau de Normalisation, NBN; Austrian Standards Institute, ASI; Finnish Standards Association, SFS, etc.). Thus, a global framework for pollutants that are taken

into account by several nations and the WHO can be developed with significant technical information from these key institutions.

1.3. Aims and Scope of the Position Paper

This position paper aims to compare the reference values related to physical and chemical pollutants applied in several countries in order to highlight the current trends and perspectives on the field of interest for improving the quality. It is based on the existing standards and guidelines (mostly available and in English) from international countries' governments and regional institutions, as well as starting from a previous research work by Settimo [34].

The comparisons between values from adjacent regions reveal a wide range of values and show the needs of IAQ from the regions. On the other hand, a list of pollutants and reference values is proposed with highest requirement on values from all documents collected so far for achieving higher requirements of IAQ in some specific indoor spaces, such as those with medical needs or as the future targets in some regions.

2. Methodology and Data Collection

2.1. Inclusion of Documents

For defining the current trends in chemical and physical pollutant reference values, the research team selected and compared mandatory and voluntary guidelines and standards of several countries coming from different continents; in particular, the ones considered are the most representative, accessible ones from the webpages. In particular, the analysis aims to give rise to a matrix of analyses, with the list of pollutant types and their reference values.

As shown in Table 1, the documents included in this position paper are mainly about guidelines and standards that defined reference values to guide the intervention to the IAQ to make the comparisons, but not those about measurement standards and strategies' implementations (e.g., ISO 16000). All the references selected were published by international governments, professional associations, affiliated departments, and regional/local institutions. They were collected from published regulations, government websites, national standard departments, and online archives of institutions. In particular, they are collected from the following:

- Existing guidelines and standards with reference values collected in the previous research with the updates if they had;
- Standard or regulation documents from the local government from the countries with research on IAQ and published in English;
- Searches according to the related papers, published documents, mentioned references, and websites.

Among the regions searched so far, the local governments from some regions did not publish any official guidelines, standards, or regulations on the IAQ, such as USA and India. In this case, the documents from local authoritative institutions are included, for example, ASHRAE [49] and the Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) [50].

For the USA, the United States Environmental Protection Agency (USEPA) published Acute Exposure Guideline Levels (AEGl) for Airborne Chemicals [51] to describe the human health effects of once-in-a-lifetime or rare exposure to airborne chemicals. Because those values are not proposed for IAQ but air in general, and during the comparison, they are found to be far higher than the IAQ reference values from other documents; thus, those documents will not be included. Meanwhile, some values from this website of USEPA [51] have been adapted to other documents, such as the values for VOCs from Canada [24,52] and the UK [32], and the adapted values need double checks before comparisons.

Moreover, for the USA, even if USEPA has published the National Ambient Air Quality Standards (NAAQS) for outdoor air quality, there is no such integrated document

published officially for the IAQ. From the website of USEPA [53], there are several concerned pollutants listed with guidelines about how to prevent exposure, including asbestos, biological pollutants, carbon monoxide (CO), formaldehyde/pressed-wood products, lead (Pb), nitrogen dioxide (NO₂), pesticides, indoor particulate matter, secondhand smoke/environmental tobacco smoke, stoves and heaters, fireplaces and chimneys, volatile organic compounds (VOCs), and radon (Rn), but no value proposed for them. Apart from ASHRAE, there are some organizations that are cited for the permissible exposure limit (PEL) or recommended exposure limit (REL) from organizations including the Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH). It is worth mentioning that these limits (i.e., Threshold Limit Value—Time-Weighted Average, TLV[®]-TWA; Threshold Limit Value—Short-Term Exposure Limit, TLV[®]-STEL; and TLV[®]-Ceiling) are related to the industrial field, and therefore they cannot be applied in generic environments. Moreover, for ASHRAE, there are several documents related to the IAQ, including Indoor Air Quality Guide [54] and Standards 62.1 [55] and 62.2 [56], but no reference value proposed officially. Therefore, apart from the specifically proposed values found, such as for CO₂, other documents from the USA are not included.

2.2. Matrix Analysis

The documents found from the existing literature and websites so far are listed in Table 1. The documents are from not only the countries but also from regional organizations, which are applied in the local context, as the WHO document stated [39].

In general, it is well-known that countries' guidelines and standards usually reflect the particular social economic, geographical, and climate conditions of each state. For this reason, the authors of this position paper will take into consideration the different values suggested by the regions to suggest representative values for improving the IAQ performance in indoor spaces.

Table 1. Documents included in the comparison.

Region	Country or Institution	Update Year(s)	Publication Department	Citation
International	WHO	2000	World Health Organization (WHO), Regional Office for Europe	[4,37,39]
		2010		
		2021		
Asia	China	2002	Ministry of Ecology and Environment of the People's Republic of China (MEE)	[26]
	Hong Kong (China)	2019	The Government of the Hong Kong Special Ad- ministrative Region Indoor Air Quality Manage- ment Group	[27]
	Taiwan (China)	2013	Taiwan Environmental Protection Administra- tion (Taiwan EPA)	[57,58]
	India	2019	Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE)	[50]
	Japan	2019	Ministry of Health Labour and Welfare of Japan (MHLWJ)	[28]
	Malaysia	2010	Department of occupational safety and health ministry of human resources Malaysia (DOSH)	[59]
	Singapore	2016	Singapore Standard Council (SSC)	[33]
Europe	Austria	1996 2012 2011 2014	Federal Ministry for Climate Protection, Envi- ronment, Energy, Mobility, Innovation and Technology;	[60–66]

	2013 2011	Association of Ecological Research Institutes (AGÖF); Federal Ministry of Agriculture Regions and Tourism		
Belgium	2018 2019 2022 2017	Flemish government; Federal public service employment labor and social dialogue; Service Public Fédéral Sécurité Sociale; FPS Public Health, Food Chain Safety and Environment of Belgium; Superior Health Council	[67–70]	
Denmark	2010	Danish Building Regulations	[22]	
Finland	2015 2012	Ministry of the Environment Department of Built Environment; Ministry of Social Affairs and Health (STM)	[19–21]	
France	2018 2016 2015 2011 2010	French Agency for Food Environmental and Occupational Health & Safety (ANSES); Légifrance	[17,71–78]	
Germany	2022	Federal Environment Agency (UB)	[18]	
Lithuania	2007	Minister of Health Protection of the Republic of Lithuania	[79]	
Netherlands	2010	Health Council of the Netherlands	[80]	
Norway	2013 1991	Ministry of Labour and Social Inclusion	[81,82]	
Poland	1996	Minister of Health and Social Welfare	[83]	
Portugal	2006 2013	Ministério das Obras Públicas Transportes e Comunicações (MOPTC); Ministério da Economia e do Emprego (MEE)	[84,85]	
Russia	2001	Department of State Sanitary and Epidemiological Supervision of the Ministry of Russia	[29]	
Spain	2021	Instituto Nacional de Seguridad y Salud en el Trabajo (INSST)	[86]	
United Kingdom	2018 2019 2021	Education & Skills Funding Agency; Public Health England; His Majesty's Government	[31,32,87]	
North America	Canada United States	2022 2019	Government of Canada American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	[24,52,88] [49]
Oceania	Australia New Zealand	2021 1990	Commonwealth of Australia and States and Territories of Australia (CASTA) Standards New Zealand (SNZ)	[23] [25]

In the table, the authors also added Hong Kong and Taiwan. Although they are regions in China, the local regulations are usually different from those of the mainland; therefore, they are also included to represent the reference value applied in those regions.

3.2.1. Acetaldehyde

Acetaldehyde is a clear, colorless, fuming liquid with a pungent, fruity odor; it is volatile at ambient temperature and pressure, with a boiling point of 21 °C. Acetaldehyde has a widespread natural occurrence. It occurs in nature as an intermediate product in the respiration of higher plants and can be found in ripening fruit such as apples. Moreover, acetaldehyde is an intermediate product of the fermentation of alcohol and in the metabolism of sugars in the body [89].

The main exposure is from the inhalation of ambient air from urban areas or near sources of combustion. Workers in the organic chemicals industry, with some exposure to fabricated rubber products and biological products industries, have higher risks of exposure to it. Moreover, it is emitted from some building materials, such as rigid polyurethane foams, and some consumer products, such as adhesives, coatings, lubricants, inks, and nail-polish remover [89]. The International Agency for Research on Cancer (IARC) listed acetaldehyde as a Group 1 carcinogen.

The reference values of acetaldehyde are listed in Table 3

Table 3. Reference values for acetaldehyde.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)			
	General	1 h	1 Day	Long Term
AS India	-	-	-	140 (1 y) ¹
Japan	48 (30 ppb)	-	-	-
EU France	-	3000	-	160 (>1 y)
NA Canada	-	1420 (795 ppb)	280 (157 ppb)	-

¹ The values are displayed in “reference value (value in ppm or ppb) (average period if they have) (additional information if they have)”, in which the average period refers to “m” for minutes, “h” for hours, “d” for days, and “y” for years. Values are displayed in the same way in the following tables.

As Table 3 shows, the value from Japan (48 $\mu\text{g}/\text{m}^3$ and 30 ppb) is far lower than the others, probably because the value was assessed based on exposure effects on the nasal olfactory epithelium in the rats’ respiratory tract as criteria, which was adapted from the work published by Appelman et al. in 1986 [90]. Although the final update time of the Japanese document was in 2019, this value was proposed on 22 Jan. 2002 [91] based on the research mentioned above in 1986, and there are no more updates on it.

For the values from Canada, among the comparisons, those values are usually slightly lower (for short- and long-term exposures) than the others, not only in acetaldehyde but also in the following tables, meaning higher requirements in the IAQ. This may be due to the better local natural habitats, as well as the developed social and economic context. Since the deviations of these values from Canada are not so far from those from other regions, they are still considered adaptable values for other regions, but not the first choice.

The reference value to be adopted in the international scenario can be related to the following:

- 1420 $\mu\text{g}/\text{m}^3$ for the 1-hour average and 280 $\mu\text{g}/\text{m}^3$ for 1-day average as the short-term value, as Canada [24] suggests.
- 140–160 $\mu\text{g}/\text{m}^3$ for the 1-year average as the long-term value, as India [50] and France suggest [17,71–78].

3.2.2. Benzene

Benzene is an aromatic hydrocarbon with a pungent and sweet smell that evaporates in the air very quickly, as do all volatile organic compounds (VOCs), and it is a highly flammable substance. It is listed as a Group 1 carcinogen by the IARC.

Lower levels of concentration can cause dizziness, drowsiness, increased heart rate, tremors, confusion, and unconsciousness. Prolonged concentrations over time can impair memory and some psychic abilities, as well as cause disturbances and irritant effects on skin and mucous membranes; it is also a human carcinogen.

It comes from cigarette smoke; incomplete combustion of domestic coal and oil; and vapors released from products that contain it, such as glues, paints, furniture and floor wax, cleaning agents, etc. [92].

The reference values of benzene are listed in Table 4.

Table 4. Reference values for benzene.

Reference	Reference Value ($\mu\text{g}/\text{m}^3$)					
	General	1 h	8 h	Days	Long Term	Additional Info
INT WHO	NSL ¹	-	-	-	-	0.17 ² 1.7 ³
AS	China	-	110	-	-	-
	India	3	-	-	-	-
	Belgium	0.4	-	-	-	20 IV ⁴
	France	-	-	30 (1–14 d)	20 (14 d–1 y) 2 (> 1 y)	0.2 ² 2 ³
	Lithuania	-	-	100	-	-
EU	Netherlands	20	-	-	-	-
	Poland	-	-	20 PO ⁵	10 R ⁵	-
	Portugal	-	-	5	-	-
	UK	NSL ¹	-	-	-	0.17 ² 1.7 ³

¹ NSL means No Safe Level. ² An excess lifetime risk UR/lifetime of 10^{-6} at this value. ³ An excess lifetime risk UR/lifetime of 10^{-5} at this value. ⁴ IV means Intervention Value. ⁵ PO means Public Offices; R means Residential buildings.

From the comparison in Table 4, the data from China ($110 \mu\text{g}/\text{m}^3$ for 1 h average) and Lithuania ($100 \mu\text{g}/\text{m}^3$ for 1-day average) are quite higher than the others, maybe because of the local emission source in the past, and the last updated time of these two documents was in 2002 from China [26] and 2007 from Lithuania [79].

Meanwhile, the values from India ($3 \mu\text{g}/\text{m}^3$), Belgium ($0.4 \mu\text{g}/\text{m}^3$), and Portugal ($5 \mu\text{g}/\text{m}^3$ for 8 h average) are relatively lower than the others, especially in Belgium. These values can be adapted for the future stage, according to the local emission condition.

For the value from Belgium, $20 \mu\text{g}/\text{m}^3$ for continuous condition is the Intervention Value, and the $0.4 \mu\text{g}/\text{m}^3$ is set for the target value, which is why the value is far lower than the others. The proposed values from Belgium are similar in the following tables.

Although currently there is not a specific guideline value for Benzene, as indicated by the WHO [39], the reference value to be adopted can be related to the following:

- $20 \mu\text{g}/\text{m}^3$ for 1-day average, as the short-term value, as the Netherlands [80] and Poland [83] suggest.
- $2 \mu\text{g}/\text{m}^3$ for 1-year average, as the long-term value, as France [17,71–78] suggests.
- Moreover, the value refers to the Unit Risks (URs) evaluated by the following:
- $1.7 \mu\text{g}/\text{m}^3$ (UR/lifetime) 10^{-6} —WHO values.
- $17 \mu\text{g}/\text{m}^3$ (UR/lifetime) 10^{-5} —WHO values [39].

The Unit Risk factors are toxicity values used for carcinogens, which estimate the increased risk of getting cancer that is associated with the concentration of the chemical in the air. A cancer risk of less than one in a million is usually considered to be negligible.

3.2.3. Benzo[a]pyrene (BaP)

Benzo[a]pyrene, is a crystalline aromatic hydrocarbon consisting of five fused benzene rings and formed during the incomplete combustion of organic matter. It is mainly found in gasoline and diesel exhaust, cigarette smoke, coal tar and coal tar pitch, charcoal-broiled foods and certain other foods, amino acids, fatty acids and carbohydrate pyrolysis products, soot smoke, creosote oil, petroleum asphalt, and shale oils [93].

It is listed as a Group 1 carcinogen by the IARC. In the 18th century, a scrotal cancer of chimney sweepers, the chimney sweep's carcinoma, was already known to be connected to soot.

The reference values of Bap are listed in Table 5.

Table 5. Reference values for BaP.

Region		Reference Value (ng/m ³)			Additional Info
		General	8 h	1 Day	
INT	WHO	-	-	-	0.012 ¹
					0.12 ²
AS	China	-	-	1 (1 d)	-
	Hong Kong (China)	-	1.2	-	-
EU	Lithuania	-	-	1 (1 d)	-
	Netherland	1.2	-	-	-

¹ An excess lifetime risk of 10⁻⁶ at this value. ² An excess lifetime risk of 10⁻⁵ at this value.

From the comparison, generally, apart from those from the WHO, the four values of BaP are close: 1 ng/m³ for 1-day average from China and Lithuania, and 1.2 ng/m³ from Hong Kong and the Netherlands. These are all for short-term exposure, no matter whether they are for 8 h or 1 day, and there are no long-term values found in the documents so far.

Missing currently specific guidelines values from the WHO, the reference value to be adopted can be related to the following:

- 1 ng/m³ for 1-day average, as China [26] and Lithuania [79] suggest. The value refers to the Unit Risks evaluated by the following:
- 0.012 ng/m³ (UR/lifetime) 10⁻⁶—WHO values.
- 0.12 ng/m³ (UR/lifetime) 10⁻⁵—WHO values [39].

3.2.4. Carbon Dioxide [94]

Carbon dioxide (CO₂) is one of the common gaseous substances in the atmosphere. The latest observations reported by the WMO [95] show that globally averaged surface mole fractions for carbon dioxide (CO₂) reached 415.7 ± 0.2 ppm in 2021.

Apart from the listed regions in Table 1, the reference value of CO₂ is also included in the documents for indoor environment and ventilation in other regions, including Brazil (1800 mg/m³–1000 ppm), South Korea (1800 mg/m³–1000 ppm), and Taiwan (China) (1800 mg/m³–1000 ppm). Moreover, in the US, different organizations published different values on CO₂; for example, CDC has 1440 mg/m³ and 800 ppm, ASHRAE has 1800 mg/m³–1000 ppm for the reference value and 1260 mg/m³–700 ppm for the acceptable value [49], and Illinois has 1800 mg/m³ and 1000 ppm [96].

Since CO₂ does not have any direct toxicity, the reference value is usually set to improve the working efficiency in the school and office [87]. The values at 1000 ppm and 1800 mg/m³ are the Intervention Value in most regions; the working environments higher than this value require ventilation for fresh air.

The reference values of carbon dioxide are listed in Table 6.

Table 6. Reference values for carbon dioxide.

Region	Reference Value (mg/m ³)			
	General	8 h	1 Day	Additional Info
China	0.1% ¹	-	-	-
AS	Hong Kong (China)	1440 (800 ppm) EC ²	-	-
		1800 (1000 ppm) GC ²	-	-
Malaysia	1800 (1000 ppm)	-	-	-
Singapore	1000 ppm	700 ppm	-	-
Belgium	-	1620 (900 ppm) (8 h)	-	-
	-	2160 (1200 ppm) (8 h)	-	-
Finland	1350 (750 ppm) S1 ³	1710 (950 ppm) S2 ³	-	-
France	1440 (800 ppm)	1800 (1000 ppm)	-	-
Germany	1800 (1000 ppm)	-	-	<1800 (1000 ppm) (harmless) 1800–3600 (1000–2000 ppm) (high) >3600 (2000 ppm) (unacceptable)
Netherlands	2160	1710 (School)	-	-
EU	Norway	1800	-	-
Portugal	1800 (1000 ppm)	2250	-	-
	2250 (1250 ppm)			
Spain	1440 (800 ppm)	1800	-	-
	1800 (1000 ppm)			
UK ⁴	1000 ppm	-	-	1800 (1000 ppm) (ESB); 2700 (1500 ppm) (RB);
	1500 ppm	-	-	1800 (1000 ppm) (S) occupation;
	2000 ppm	-	-	2700 (1500 ppm) (S) 20 consecutive minutes;
		-	-	3600 (2000 ppm) (S) (20 m) NE
NA	Canada	-	1800 (1000 ppm)	-
	Australia	-	850 ppm	-
OC	New Zealand	1800 (1000 ppm) (continuous)	-	-

¹ 0.1% is 1000 ppm and 1800 mg/m³. ² For Hong Kong, “EC” refers to “Excellent Class”, and “GC” refers to “Good Class”. ³ S1 for individual indoor environment, and S2 for good indoor environment. ⁴ For the UK, “ESB” refers to “Energy Saving Buildings”; “RB” refers to “Refurbished Buildings”; “S” refers to “Schools with natural ventilations”.

Generally, from the comparison, the values vary between 1440 and 2180 mg/m³ and between 800 and 1200 ppm, with the most mentioned value at 1800 mg/m³ and 1000 ppm, no matter whether it is for 8 h, 1 day, or as a general value. In addition, 3600 mg/m³ and 2000 ppm are applied as the Intervention Value, such as in Germany and UK.

The reference value of CO₂ as a real-time level to be adopted can be related to the following:

- 1800 mg/m³ and 1000 ppm, as many of the documents mentioned above suggest;
- 3600 mg/m³ and 2000 ppm as an Intervention Value (IV), as Germany [18] and the UK [31,32,87] suggest.

3.2.5. Carbon Monoxide

Carbon monoxide (CO), which is an odorless, colorless, and tasteless gas that is highly toxic at low concentrations, causing fatigue and pains in the chest for heart patients; at moderate concentrations, it causes coordination problems, headaches, nausea, dizziness, etc.; and, at very high concentrations, it is lethal. The sources that generate it are the incomplete combustion of materials containing carbon or biomass (for heating issues); the malfunction of the gas heating systems, stoves, furnaces, and fireplaces; inadequate ventilation; and also the proximity to roads with high vehicular traffic, as well as garage and parking lots, which can cause a significant impact on the gas concentrations in confined environments [39].

The reference values of carbon monoxide are listed in Table 7.

Table 7. Reference values for carbon monoxide.

Region		Reference Value (mg/m ³)						Additional Info
		General	15 min	30 min	1 h	8 h	1 Day	
INT	WHO	-	100	-	35	10	7	-
	China	-	-	-	10	-	-	-
AS	Hong Kong (China)	-	-	-	-	2 EC 7 GC	-	-
	Malaysia	-	-	-	-	10 ppm	-	-
	Singapore	-	-	-	31 ppm	9 ppm	-	-
EU	Belgium	8	-	-	30 IV	-	5.7	-
	Finland	7	-	-	-	-	-	Instant value
	France	-	100	60	30	10	-	-
	Germany	-	-	6 RWI	-	1.5 RWI ¹	-	-
		-	-	60 RWII	-	15 RWII ²	-	-
	Lithuania	-	-	5	-	-	3	-
	Netherlands	-	100	60	30	10	-	-
	Norway	-	-	-	25	10	-	-
	Poland	-	-	-	25 R	10 PO	-	-
	Portugal	-	-	-	-	10	-	-
Russia	-	-	-	-	-	3	-	
NA	Canada	-	100 (90 ppm)	60 (50 ppm) (30 m)	30 (25 ppm)	10 (10 ppm)	-	-
		-	-	-	28.6 (25 ppm)	-	11.5 (10 ppm)	-
OC	Australia	-	100 (90 ppm)	50 ppm (30 m)	25 ppm	10 ppm	-	For Class 234,569 building
		100 ppm (NE) ³	90 ppm	-	60 ppm	30 ppm	-	For Class 7a building

¹ Guide Value I (RW I—precautionary guideline value) describes the concentration of a pollutant in the indoor air, which, according to the current state of research, is not expected to have any adverse

health effects if the level is maintained or not reached, even with lifelong exposure. ² Guide Value II (RW II—hazard guide value) is an effect-related value that is based on the current toxicological and epidemiological knowledge of the effect threshold of a pollutant. ³ NE means No Exceedance.

From the comparison, most values are in a small range for each average period: 100 mg/m³ and 90 ppm for 15 min average; 60 mg/m³ and 50 ppm for 30 min average; 25–35 mg/m³ and 25–31 ppm for 1 h average; 10 mg/m³ and 9–10 ppm for 8 h average; and 3–7 mg/m³ for 1-day average.

There are several exceptions that are higher or lower than the range mentioned above, for example, Belgium (8 mg/m³), Lithuania (5 mg/m³ for 20–30 min average), Germany (6 mg/m³ for 30 min and 1.5 mg/m³ for 8 h for RWI), and Hong Kong (2 mg/m³ for 8 h EC), which are relatively lower than the others in the same average period.

The 20–30 min values from Lithuania are the one-time maximum permissible concentration (vienkartinė cheminių medžiagų -teršalų- didžiausia leidžiama koncentracija (DLK)), which is defined to be the concentration of a chemical substance (pollutant) that does not harm human health after exposure for 20–30 min [79], and there is no other citation or interpretation of the values from Lithuania. The 5 mg/m³ for 20–30 min average from the document is much lower, so maybe it is proposed based on the local context and is not a suitable value for other regions, which are similar in the following tables, such as Table 11 for nitrogen dioxide and Table 18 for tetrachloroethylene.

For the values for RWI from Germany, they are much lower than the others because the RWI (Guide Value I) values are proposed to have no adverse health effect if levels are not reached, even after lifelong exposure. Thus, these values are not so helpful to be compared with other values since the meaning and purpose are different, and these values for RWI are the same in the comparison among the following tables.

For Hong Kong, the value of 2 mg/m³ for 8 h is pretty low because it is classified as EC (Excellent Class), adapted from a report from Finland published in 2001 [97], and is implemented as the high-level target. The values for EC from Hong Kong are similar in the following tables and are excluded from the comparison among the general requirements. Moreover, the other value of 7 mg/m³ for 8 h was described to be adapted from the WHO [39], but it should be a value for the 24-hour average, as listed in Table 7, which probably was a mistake.

For Australia, there are values of 60 ppm for the 1-hour average and 30 ppm for the 8-hour average for Class 7a buildings. These less stringent requirements are proposed because Class 7a buildings in Australia are defined as buildings with car park space, so the CO value is allowed to be a bit higher than that in other spaces in the regulation [23].

For carbon dioxide, the 1-day average is considered as the long-term value due to its toxicity, and there is no other long-term average value found in the documents for days or the 1-year average.

The reference values to be adopted can be related to the following:

- 100 mg/m³ for 15 min average; 25 mg/m³ for the 1-hour average; 10 mg/m³ for the 8-hour average as the short-term value, as the WHO [39], Malaysia [59], Belgium [67–70], France [98], the Netherlands [80], Norway [81,82], Poland [83], Portugal [84,85], the UK [31,32,87], and Australia [23] suggest.
- 7 mg/m³ for 1-day average as long-term value, as the WHO [39] suggests.

3.2.6. Dichloromethane

Dichloromethane (DCM), or methylene chloride, is a volatile, colorless liquid with a chloroform-like odor. It is extensively used in numerous industrial settings, such as paint stripping and pharmaceutical and paint remover manufacturing. It irritates the skin and eyes by preventing evaporation, and long-term exposure will cause chemical burns. The main toxic effects of DCM are reversible central nervous system depression (neurophysiological and neurobehavioral disturbances) and carboxyhemoglobin formation extending up to hepatic, renal, cardiovascular, and hematological parameters [99].

The reference values of dichloromethane are listed in Table 8.

Table 8. Reference values for dichloromethane.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)				
	30 min	1 Day	7 Day	Long Term	Additional Info
INT WHO	-	3000	450	-	0.012 ¹ 0.12 ²
EU	Germany	200 RWI	-	-	-
	Lithuania	8800	3000	-	-
	Netherlands	-	-	-	200 (1 y)

¹ An excess lifetime risk of 10^{-6} at this value. ² An excess lifetime risk of 10^{-5} at this value.

From the comparison in Table 8, we can see that the short-term values are from 2000 to 3000 $\mu\text{g}/\text{m}^3$ for the 1-day average and 450 $\mu\text{g}/\text{m}^3$ for the 7-day average. The long-term value can be 200 $\mu\text{g}/\text{m}^3$ for the 1-year average.

The mean outdoor concentrations of DCM are generally below 5 $\mu\text{g}/\text{m}^3$, and only in certain conditions, the indoor concentration of DCM can reach a high level (up to 4000 $\mu\text{g}/\text{m}^3$), such as when using paint stripping solutions or with other outdoor industrial emission sources [37]. Moreover, the WHO [37] indicated that acute inhalation exposure at levels exceeding 1050 mg/m^3 (300 ppm) for short durations will cause impairment of behavioral or sensory responses in humans, and the effects are transient, which is much higher than the normal concentration. Thus, unless it is in a specific working space, such as in a factory, the 1-day average value range of 2000–3000 $\mu\text{g}/\text{m}^3$ is more representative than the 30 min value from Lithuania.

The reference value to be adopted can be related to the following:

- 3000 $\mu\text{g}/\text{m}^3$ for the 1-day average and 450 $\mu\text{g}/\text{m}^3$ for the 7-day average, as the short term, as the WHO suggests [37,39];
- 200 $\mu\text{g}/\text{m}^3$ for the 1-year average, as the long-term value, as the Netherlands [80] suggests.

3.2.7. Formaldehyde

Formaldehyde is a colorless gas with a characteristic pungent odor and a strong irritating power to mucous membranes, eyes, and the respiratory system. It causes conjunctivitis, asthma, contact dermatitis, fatigue, anxiety, headaches, nausea, drowsiness, and dizziness; it is mutagenic and carcinogenic. It is attributable to furniture; fabrics; construction materials; tobacco smoke; and in many everyday products, such as detergents, dyes, disinfectants, plastics, glues, and paint materials [39].

The reference values of formaldehyde are listed in Table 9.

Table 9. Reference values for formaldehyde.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)						
	General	30 min	Hours	8 h	1 Day	Long Term	Additional Info
INT WHO	-	100	-	-	-	-	-
	China	-	100	-	-	-	-
AS	Hong Kong (China)	-	70 EC 100 GC	-	30 EC 100 GC	-	-
	India	-	-	-	30	-	-
	Japan	100 (80 ppb)	-	-	-	-	-

Region	Reference Value ($\mu\text{g}/\text{m}^3$)						Additional Info
	General	30 min	Hours	8 h	1 Day	Long Term	
Malaysia	-	-	-	100 ppb	-	-	-
Singapore	-	100 (80 ppb)	-	-	-	-	-
Austria	-	100	-	-	60 (24 h)	-	-
Belgium	-	10	-	-	-	-	100 (30 m) IV
Denmark	100	-	-	-	-	-	-
Finland	-	100	-	-	-	50 (1 y)	-
France	100 (continuous)	-	50 (2 h)	-	-	10 (1 y)	10 (valid from 2023)
Germany	120	-	-	-	-	-	-
EU Lithuania	-	100	-	-	10 (1 d)	-	-
Netherlands	-	120	-	-	-	10 (1 y)	1.2 (long term)
Norway	-	100	-	-	-	-	-
Poland	-	-	-	100 PO	50 (24 h) R	-	-
Portugal	-	-	-	100	-	-	-
Russia	-	-	-	-	-	10 (1 y)	-
UK	-	100	-	-	-	10 (1 y)	-
NA Canada	-	-	123 (100 ppb)	50 (40 ppb)	-	-	-
OC Australia	-	100	-	-	-	-	-

From the comparison in Table 9, in the short-term average period, we can see that the values are mostly in the range of 70–120 $\mu\text{g}/\text{m}^3$, in which 100 $\mu\text{g}/\text{m}^3$ is mentioned in most of the documents, no matter whether it is for the 30 min average or 1-to-8 h average values. For the 1-day average, an intermedium value in the range of 50–60 $\mu\text{g}/\text{m}^3$ was proposed. For the long-term value, 10 $\mu\text{g}/\text{m}^3$ for the 1-year average is the most mentioned value, although the Netherlands [80] highlights reaching a value of 1.2 for the long term.

The regulation from Denmark did not provide a value on formaldehyde but quoted 0.1 mg/m^3 from the WHO. Moreover, this WHO value was adapted to the 8-hour average value in the document from Hong Kong.

The reference values to be adopted can be related to the following:

- 100 $\mu\text{g}/\text{m}^3$ for the 30 min average as the short-term value, as the WHO [39], Singapore [33], Austria [60–66], Finland [19–21], Lithuania [79], Norway [81,82], the UK [32], and Australia [23] suggested.
- 10 $\mu\text{g}/\text{m}^3$ for 1-year average, as France, the Netherlands, Russia, and the UK suggest [17,29,31,72–78,80].

3.2.8. Naphthalene

Naphthalene is a two-ring aromatic hydrocarbon isolated from coal tar, the volatile organic compound (VOC) polycyclic aromatic hydrocarbon (PAH) with a gas-phase part of 90–100%. Its indoor sources are consumer products such as multipurpose solvents, lubricants, herbicides, charcoal lighters, hair sprays, unvented kerosene heaters/tobacco smoke, rubber materials, naphthalene insect repellents (mothballs), and so on. The outdoor naphthalene sources mainly originate from fugitive emissions and motor vehicle exhaust [39].

The reference values of naphthalene are listed in Table 10.

Table 10. Reference values for naphthalene.

Region		Reference Value ($\mu\text{g}/\text{m}^3$)					
		General	30 min	1 h	8 h	1 day	Long Term
INT	WHO	-	-	-	-	-	10 (1 y)
AS	Hong Kong (China)	-	-	-	10	-	-
	India	-	-	-	9	-	-
	Finland	10	-	-	-	-	-
	France	-	-	-	-	-	10 (1 y)
EU	Germany	10 (RWI)	-	-	-	-	-
		30 (RWII)	-	-	-	-	-
	Lithuania	-	3	-	-	3	-
	Netherlands	25	-	-	-	-	-
	Poland	-	-	-	150 PO	100 R	-
	UK	-	-	-	-	-	3 (1 y)
NA	Canada	-	-	-	-	10 (1.9 ppb)	-

From the comparison in Table 10, apart from the adjacent regions, including Germany, the Netherlands, and Poland, which mentioned the higher values from 25 to 30 $\mu\text{g}/\text{m}^3$, other regions proposed values within the range from 3 to 10 $\mu\text{g}/\text{m}^3$, no matter whether they are for the short term or long term, with 10 $\mu\text{g}/\text{m}^3$ being applied in most of them.

For the value from the UK (3 $\mu\text{g}/\text{m}^3$ for 1-year average), in the document, it is mentioned that this value was adapted from a webpage of the Agency for Toxic Substances & Disease Registry (ATSDR), USA, in 2005, but the page is no longer available. Instead, another document found in the database of ATSDR about the toxicological profile of naphthalene was published in 2005 [100], which provided a review of previous research on the naphthalene measurement, but neither reference values nor the indoor air value was proposed in the document. Thus, this value will be excluded from the comparison before the source is verified.

Another point to note is that the WHO and UK proposed only the long-term values due to the lack of reliable human data for long-term inhalation toxicity available, as mentioned in references [32,39]. For the value from Canada, although the value is for a 24-hour average, it is defined as the long-term exposure limit, which is set for health problems that can occur from continuous or repeated exposure over several months or years. The value from Hong Kong is adapted from the WHO [39], but it was adapted from annual data to the 8-hour average value [27].

The reference values to be adopted can be related to the following:

- 10 $\mu\text{g}/\text{m}^3$ for 1-year average, for long-term value, as the WHO and UK (10 $\mu\text{g}/\text{m}^3$) suggest [31,39].

3.2.9. Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a toxic gas with yellow-red color and a strong and pungent odor; it is a highly reactive and corrosive oxidant, and, with great irritant power, it causes disturbances to the lower respiratory system and susceptibility to infections, especially in people with lung diseases. It is generated by high-temperature combustion processes (cooking stoves, heating systems with internal boilers, etc.). The proximity to roads with high vehicular traffic and parking garages can significantly affect gas concentrations in indoor environments because NO_2 is contained in the exhaust gases of motor vehicles [39].

The reference values of nitrogen dioxide are listed in Table 11.

Table 11. Reference values for nitrogen dioxide.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)						Additional Info
	30 min	1 h	8 h	1 Day	7 Day	Long Term	
INT WHO	-	25	-	-	-	10 (1 y)	-
China	-	240	-	-	-	-	-
Hong Kong (China)	-	100 EC 200 GC	40 EC 150 GC	-	-	-	-
AS India	-	-	-	-	-	-	<40 Class A three-time days (18 results for y) <80 Class B three-time days (6 results for y)
Singapore	-	-	40	-	-	-	-
Belgium	-	20 (1 h) 40	-	-	-	-	200 (1 h) IV
France	-	200	-	-	-	40 (1 y)	20 (>1 y)
Germany	350	-	-	-	60 (7 d)	-	Both for WWII
EU Lithuania	85	-	-	40	-	-	-
Netherlands	-	200	-	-	-	40 (1 y)	-
Norway	-	200	-	100	-	-	-
Russia	-	-	-	-	-	40 (1 y)	-
UK	-	288 (150 ppb)	-	-	-	40 (20 ppb) (1 y)	-
NA Canada	-	170 (90 ppb)	-	20 (11 ppb)	-	-	-
OC Australia	-	200 (98.7 ppb)	-	-	-	40 (19.7 ppb) (1 y)	-

In the new guideline from the WHO in 2021, a value of $10 \mu\text{g}/\text{m}^3$ was proposed as the recommended AQG level, also with three interim target values of $40 \mu\text{g}/\text{m}^3$, $30 \mu\text{g}/\text{m}^3$, and $20 \mu\text{g}/\text{m}^3$ respectively. Moreover, for the short term (24-hour average), $25 \mu\text{g}/\text{m}^3$ was proposed as the recommended AQG value, with two interim target values of $120 \mu\text{g}/\text{m}^3$ and $50 \mu\text{g}/\text{m}^3$ [4].

Nitrogen dioxide is also mentioned in the building regulation from Denmark as oxides of nitrogen in general, but there is no reference value given. Because it is a building regulation and is considered to be related to kitchen and gas supply, details are included in Danish Gas Regulations.

Apart from the WHO, in the comparison, it can generally be included in the range from 170 to $288 \mu\text{g}/\text{m}^3$ for the 1-hour average, with more values at $25 \mu\text{g}/\text{m}^3$ as the short-term value, and there can be an intermedium value in the range of $60\text{--}100 \mu\text{g}/\text{m}^3$ for a daily average. Moreover, for long-term values, $40 \mu\text{g}/\text{m}^3$ is the most proposed value for the 1-year average. The ranges of values, no matter whether they are for the short term or for the long term, are at the level of the interim value 1, which is acceptable for the current scenario, but the AQG value from the WHO can be adapted as the target value for the future scenario.

The reference value to be adopted can be related to the following:

- $25 \mu\text{g}/\text{m}^3$ for the 1-hour average as the short-term value, as the WHO's new guidelines 2021 [39] suggest; $10 \mu\text{g}/\text{m}^3$ for the 1-year average as the long-term value, as the WHO [39] suggests.

3.2.10. Ozone

Ozone (O₃) is a poisonous gas, with a penetrating odor and pale blue color. It is present in the troposphere and contributes to air pollution; it is harmful to humans and the environment. As a powerful oxidant, it attacks the organic tissues of the respiratory system, causing breathing disturbances and aggravating asthma episodes. It is emitted by photocopiers, laser printers, ultraviolet lamps, and some air purifiers [101].

For ozone, 100 µg/m³ equals 49.27 ppb at 15 °C, 50.12 ppb at 20 °C, and 50.98 ppb at 25 °C, under a pressure of 1 atmosphere. Thus, generally, in regard to ozone, most documents put forward 100 µg/m³ and 50 ppb, except for Canada and India, which have a lower level, and China, which has a higher level.

The reference values of ozone are listed in Table 12.

Table 12. Reference values for ozone.

Region	Reference Value (µg/m ³)					
	General	1 h	8 h	Long Term	Additional Info	
INT	WHO	-	-	100 *	60 (1 y) **	-
	China	-	160	-	-	-
	Hong Kong (China)	-	-	50 EC 120 GC	-	-
AS	India	-	-	-	-	<50 Class A three-time days (18 results for y) <80 Class B three-time days (6 results for y)
	Malaysia	-	-	50 ppb	-	-
	Singapore	-	-	50 ppb	-	-
EU	UK	100	-	-	-	-
NA	Canada	-	-	40 (20 ppb)	-	-
	Australia	-	-	100	-	-
OC	New Zealand	100 (50 ppb) (continuous)	-	-	-	-

* Average of daily maximum 8-hour mean O₃ concentration in the six consecutive months with the highest six-month running-average O₃ concentration. ** 99th percentile (i.e., 3–4 exceedance days per year).

As Table 12 shows, for the ozone, 50 ppb is around 98.16 µg/m³ in 25 °C and 1 atmosphere conditions. Thus, in the comparison, the short-term values are similar at around 100 µg/m³ and the 50 ppb level for the 8-hour average, except for China and Canada, with 160 (1 h) µg/m³ and 40 (20 ppb) (8 h), respectively. Moreover, for the long-term value, only the WHO proposed a value of 60 µg/m³ for the 1-year average.

The value from China is higher because it is averaged for 1 h, but not 8 h like other values; however, unfortunately, there is no other value to be compared at this average period.

The reference value to be adopted can be related to the following:

- 100 µg/m³ for the 8-hour average, for the short-term value, as the WHO [39], Malaysia [59], Singapore [33], and Australia [23] suggest.
- 60 µg/m³ for the 1-year average, for the long-term value, as the WHO [39] suggests.

3.2.11. Particulate Matters (PM_{2.5} and PM₁₀)

PM₁₀ and PM_{2.5} are constituted by all those solid, liquid, and aerosol particles, with an adequate diameter and weight to remain suspended in the air. It may cause irritating and harmful effects on the respiratory system, obstruction of the pulmonary alveoli, heart diseases, and the possibility of inducing alterations in the immune system. It is generated

by cigarette smoking, burning, outdoor environment, spraying, cooking food, bacteria, spores, pollen, and human activities [102,103].

According to the definition, PM_{2.5} includes particles with a diameter smaller than 2.5 µm, and PM₁₀ are those smaller than 10 µm, so basically PM₁₀ included PM_{2.5} in the concentration measured, and its reference values are also higher than PM_{2.5}.

The reference values of PM_{2.5} and PM₁₀ are listed in Table 13 and Table 14 respectively.

Table 13. Reference values for PM_{2.5}.

Region		Reference Value (µg/m ³)			
		8 h	1 day	Long Term	Additional Info
INT	WHO	-	15	5 (1 y)	-
AS	India	-	-	-	<15 Class A three-time days (18 results for y) <25 Class B and C three-time days (6 results for y)
	Singapore	-	37.5	-	-
EU	Belgium	-	10–25	15 (1 y)	-
	Finland	-	25	-	-
	France	-	20	10 (1 y)	-
	Germany	-	24	-	-
	Lithuania	-	40	-	-
	Netherlands	-	25	10 (1 y)	-
	Norway	40	-	-	-
	Poland	40 R	-	-	-
OC	Portugal	25	-	-	-
	Australia	-	25 (10 (1 y)	-

From the comparison in Table 13, for the short-term value, the values are in the range of 20–40 µg/m³ for 8-hour and 1-day averages, among which 40 µg/m³ for 8-hour and 25 µg/m³ for 1-day are the most mentioned values. For the long-term value, 10 µg/m³ is the most used value, apart from the WHO and Belgium.

The WHO values are lower than those in all the other documents, which can be adapted for the future scenario as the final target.

The reference value for PM_{2.5} to be adopted can be as follows:

- 40 µg/m³ for 8-hour average and 25 µg/m³ for 1-day average as the short-term value, as Norway [81,82] and Poland [83] state;
- 10 µg/m³ for 1-year average as the long-term value, as France [17,71–78], the Netherlands [80], and Australia [23] suggest.

For the future scenario, the WHO values can be applied as the final target:

- 15 µg/m³ for 1-day average, for the short term;
- 5 µg/m³ for 1-year average, for the long term [37,39].

In addition, apart from the PM_{2.5}, the document by Singapore adds a reference value for respirable suspended particles [33], as Table 15 shows. The given definition of this value from the document is for the particles sampled with a median cut-point of 4 µm, which is different from the definition of PM_{2.5} and PM₁₀. Theoretically, they are not comparable, so it is listed separately.

Table 14. Reference values for PM₁₀.

	Region	Reference Value ($\mu\text{g}/\text{m}^3$)			Additional Info
		8 h	1 Day	Long Term	
INT	WHO	-	45	15 (1 y)	-
	China	-	150	-	-
	Hong Kong (China)	20 EC 100 GC	-	-	-
AS	India	-	-	-	<50 Class A three-time days (18 results for y) <100 Class B and C three-time days (6 results for y)
	Malaysia	150	-	-	-
	Belgium	-	40	15 (1 y)	-
	Finland	-	50	-	-
	France	-	50	25 (1 y)	-
EU	Lithuania	500	50 150	-	-
	Netherlands	-	50	20 (1 y)	-
	Norway	90	-	-	-
	Poland	90	-	-	-
	Portugal	50	-	-	-
OC	Australia	-	50	20 (1 y)	-

Table 15. Reference values for respirable suspended particles.

Pollutant	Region	Reference Value ($\mu\text{g}/\text{m}^3$)
Respirable suspended particles	Singapore	50 (24 h)

As Table 15 shows, in the document from Malaysia, although the value is under the name of respirable suspended particles, the given definition is suspended airborne particles with an aerodynamic diameter of 10 μm or less, the same as PM₁₀.

From the comparison, except for the values from China (150 $\mu\text{g}/\text{m}^3$ for 1 day) and Lithuania (500 $\mu\text{g}/\text{m}^3$ for 8 h and 150 $\mu\text{g}/\text{m}^3$ for 1 day), others are inside the range of 50 to 150 $\mu\text{g}/\text{m}^3$ for the 8-hour average and 40–50 $\mu\text{g}/\text{m}^3$ for the 1-day average as the short-term value, as well as 15–25 $\mu\text{g}/\text{m}^3$ for the 1-year average as the long-term values.

The reference value for PM₁₀ to be adopted can be as follows:

- 90 $\mu\text{g}/\text{m}^3$ for 8-hour average and 50 $\mu\text{g}/\text{m}^3$ for 1-day average as the short-term values, as Norway [81,82], Poland [83], France [17,71–78], the Netherlands [80], and Australia [23] suggest;
- 20 $\mu\text{g}/\text{m}^3$ for 1-year average as the long-term value, as the Netherlands [80] and Australia [23] suggest.

For the future scenario, the WHO values can be adapted:

- 45 $\mu\text{g}/\text{m}^3$ (1-day), for the short term;
- 15 $\mu\text{g}/\text{m}^3$ (1-year), for the long term [37,39].

3.2.12. Radon

Radon, which has several isotopes, is a naturally occurring colorless and odorless radioactive noble gas. It is also an important source of ionizing radiation of natural origin and a major contributor to the ionizing radiation dose received by the general population. It is a member of the uranium-238 (238U) decay series and its immediate parent is radium-226 (226Ra), which is around 1–3 ppm in all rocks [39].

The main source of indoor radon is the radon produced by the decay of radium in the soil subjacent to a house. Meanwhile, building materials with high concentrations of radium, such as alum shale concrete, and Water supply from the underground water are the potential indoor source of radon [39].

The reference values of radon are listed in Table 16.

Table 16. Reference value for radon.

Region	Reference Value (Bq/m ³)			
	General	8 h	Long Term	Additional Info
INT	WHO	-	-	0.6 ¹ 15 ²
	China	400 IV	-	-
AS	Hong Kong (China)	-	150 (8 h) EC 167 (8 h) GC	-
	Singapore	-	100 (8 h)	-
EU	Denmark ³	100–200 EB 100 NB	-	200 IV
NA	Canada	200	-	-
OC	New Zealand	-	-	100 (1 y)

¹ An excess lifetime risk of 10^{-6} at this value. ² An excess lifetime risk of 10^{-5} at this value. ³ For Denmark, “EB” refers to “Existing Building”; “NE” refers to “New Building to be constructed”.

From the comparison on Table 16, we can see that the values are in the range of 100 to 200 Bq/m³. The value of 400 from China is an Intervention Value (IV) when the intervention is urgently needed.

The reference value to be adopted can be as follows:

- 100 Bq/m³ for 8-hour and 1-year averages as short- and long-term values, as Singapore [33] and New Zealand [25] suggest.

The value refers to the Unit Risks evaluated by the following:

- 0.6 Bq/m³. (UR/lifetime) 10^{-6} —WHO values.
- 15 Bq/m³. (UR/lifetime) 10^{-5} —WHO values [39].

3.2.13. Styrene

Styrene is primarily a synthetic chemical pollutant that is used extensively in the manufacture of plastics, rubber, and resins. The health effects of styrene include irritation of the skin, eyes, and upper respiratory tract. Acute exposure may also result in gastrointestinal effects. Chronic exposure affects the central nervous system, showing symptoms such as depression, headache, fatigue, and weakness, and may cause minor effects on kidney function [104].

Styrene present in residential indoor air can arise from multiple indoor and outdoor sources, such as automobile exhaust; tobacco smoke; certain consumer, office, and household products; and building and furnishing materials. Moreover, apart from the natural existence inside food, it can be intake from the packaging of the food and drinking water with a certain level of styrene [105].

The reference values of styrene are listed in Table 17.

Table 17. Reference values for styrene.

Region		Reference Value ($\mu\text{g}/\text{m}^3$)						
		General	30 min	1 h	8 h	1 Day	7 Days	Long Term
INT	WHO	-	70 ¹	-	-	-	260 ²	-
	India	-	-	-	-	-	-	900 (1 y)
AS	Japan	220 (50 ppb)	-	-	-	-	-	-
	Austria	-	-	10	-	-	40	-
	Finland	40	-	-	-	-	-	-
	Germany	-	-	-	-	-	30 RWI	-
		-	-	-	-	-	300 RWII	-
	EU	Lithuania	-	40	-	-	2	-
Netherlands		900	-	-	-	-	-	-
Poland		-	-	-	30 PO	20 R	-	-
Russia		2	-	-	-	-	-	-
UK		-	-	-	-	-	-	850 (1 y)
NA	Canada	850	-	-	-	-	-	-

¹ This value is based on sensory effects or annoyance reactions. ² This value is based on effects other than cancer or odor/annoyance.

As Table 17 shows, for the value from the WHO, the 70 $\mu\text{g}/\text{m}^3$ for 30 min was based on sensory effects or annoyance reactions, with the given recognition threshold to the smell of styrene at around 210–280 $\mu\text{g}/\text{m}^3$. The document added that these values were set to protect the public from the smell, and it is lower than the level which can cause adverse effects to health; and the value of 260 $\mu\text{g}/\text{m}^3$ for 7-day average is defined as the level at the lowest concentration at which adverse effects are observed [37].

The value from Canada (850 $\mu\text{g}/\text{m}^3$) [52] was adapted from the Toxicological Profile for Styrene [106], which was published by ATSDR in 2010, but this value of 850 $\mu\text{g}/\text{m}^3$ is not found in the ATSDR document. Instead, other American national regulations on the styrene in the air were listed together, including values from ACGIH, American Industrial Hygiene Association (AIHA), USEPA, NIOSH, and OSHA. The details of them can be seen in the document from ATSDR [106]. Just taking the EPA value as an example, Acute Exposure Guideline Levels (AEGl)-1,2,3, three levels were provided as a reference, in which the AEGl-1 provided the lowest values among the three levels, and the value for this level is 85 mg/m^3 for all average periods, far higher than the 0.26 mg/m^3 from the WHO.

Meanwhile, the value from the UK (850 $\mu\text{g}/\text{m}^3$ for 1 year) was adapted from Canada, which means the origin is also from ATSDR [106].

The value from India was not interpreted with much additional information in the document from ISHRAE [50]; instead, the document mentioned that the sampling methods were based on ISO16000-5. Since there is no another citation for this value, it is presumed to be proposed according to the local research in the Indian context. Moreover, similar to styrene, other VOCs' values from India that are shown in the following table with large variations may be due to this reason.

The reference value to be adopted can be related to the following:

- The range between 40 and 70 $\mu\text{g}/\text{m}^3$ for 30 min average as the short-term value to avoid the smell, as the WHO [39], Lithuania [79], and Austria [60–66] suggest;
- 260 $\mu\text{g}/\text{m}^3$ for 7-day average as the long-term value for health, as the WHO [39] suggests.

3.2.14. Tetrachloroethylene

Tetrachloroethylene (PCE) is a readily volatile, colorless liquid with an ether-like smell. The major industrial applications of PCE are as a synthetic raw material of

hydrochlorofluorocarbon, a dry-cleaning agent, a degreaser for manufactured metal parts, and an industrial solvent, as well as consumer products for dry cleaning, drinking water, and food [39].

By breathing in the air containing a large amount of tetrachloroethylene, people will feel dizzy or sleepy, develop headaches, and become uncoordinated; or they can become unconscious. Long-term exposure may have changes in mood, memory, attention, reaction time, or vision [107].

The reference values of tetrachloroethylene are listed in Table 18.

Table 18. Reference values for tetrachloroethylene.

	Region	Reference Value ($\mu\text{g}/\text{m}^3$)						
		General	30 min	1 h	8 h	1 Day	Days	Long Term
INT	WHO	-	8000 ¹	-	-	-	-	250 (1 y) ²
AS	Hong Kong (China)	-	-	-	250	-	-	-
	India	-	-	-	-	-	-	35 (1 y)
	Austria	-	-	-	-	-	250 (7 d)	-
	Belgium	100	-	-	4–38	-	-	-
	France	-	-	-	-	-	1380 (1–14 d)	250 (1 y)
EU	Germany	-	-	-	-	-	100 (7 d) RWI 1000 (7 d) RWII	-
	Lithuania	-	500	-	-	60	-	-
	Netherlands	250	-	-	-	-	-	-
	Portugal	-	-	-	250	-	-	-
	UK	-	-	-	-	40	-	-
NA	Canada	40	-	-	-	-	-	-

¹ This value is based on sensory effects or annoyance reactions. ² This value is based on effects other than cancer or odor/annoyance.

Similar to the value of styrene, as Table 18 shows, the values from the WHO apply to different conditions: 8 mg/m³ for 30 min applies to the smell recognition with the given recognition threshold to the smell of tetrachloroethylene at around 24–32 mg/m³, and the value of 250 $\mu\text{g}/\text{m}^3$ is applied as the level at the lowest concentration at which adverse effects are observed [37].

For the value from France, 1380 $\mu\text{g}/\text{m}^3$ is proposed for the acute health effect during 1 to 14 days, and this value is adapted from ATSDR as the short-term value. Moreover, the 250 $\mu\text{g}/\text{m}^3$ for 1-year average is adapted from the WHO document, and the value for RWII from Germany is based on the toxicological and epidemiological knowledge of the effective threshold of a pollutant; thus, the value is close to that of France.

For the values of 40 $\mu\text{g}/\text{m}^3$ from the UK and Canada, the document of the UK is cited from Canada and USEPA [28], but the value is only found in the document from Canada [52]. Then the document of Canada is adapted from USEPA and ASTDR [108]. Similar to the condition for styrene, the value is also not found from ATSDR, but there are many other American organizations listed, which are not comparable.

The reference value to be adopted can be related to the following:

- 1000 $\mu\text{g}/\text{m}^3$ for 7-day average, as short-term value, as Germany [18] suggests;
- 250 $\mu\text{g}/\text{m}^3$ for 1-year average, as long-term value, as the WHO [37] and France [17,71–78] suggest;
- In addition, the value of 8000 $\mu\text{g}/\text{m}^3$ for 30 min average to avoid sensory effects, as the WHO [37,39] suggests.

3.2.15. Toluene

Toluene is a clear, colorless liquid with a distinctive smell. Toluene occurs naturally in crude oil and the tolu tree. It is also produced in the process of making gasoline and other fuels from crude oil and coke from coal. Toluene is used in making paints, paint thinners, fingernail polish, lacquers, adhesives, and rubber and in some printing and leather-tanning processes. The primary effect of toluene on the nervous system can cause tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, and loss of appetite at low-to-moderate levels [109].

For generic people, the primary route of exposure for the general population is from inhalation of vehicle exhaust, and possible exposure with the use of paints, varnishes, lacquers, shoe polishes, and cigarette smoke. The occupational people who are exposed frequently to vehicles and work in nail salons, gasoline service stations, paint stripping, the printing industry, or other occupations that use toluene may be exposed to higher concentrations [109].

The reference values of toluene are listed in Table 19.

Table 19. Reference values for toluene.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)						
	General	30 min	1 h	8 h	1 Day	7 Day	Long Term
INT	WHO	-	1000 ¹	-	-	-	260 ²
	China	-	-	200	-	-	-
AS	Japan	260 (0.07 ppm)	-	-	-	-	-
	Austria	-	-	75	-	-	-
	Belgium	5000–140,000	-	-	-	-	-
	France	20,000	-	-	-	-	-
	Germany	300 RWI	-	-	-	-	-
		3000 RWII	-	-	-	-	-
	EU	Lithuania	-	600	-	-	600
Netherlands		-	-	-	-	-	200 (1 y)
Poland		-	-	-	250 PO	200 R	-
Portugal		-	-	-	250	-	-
UK		-	-	-	15,000	2300	-
NA	Canada	-	-	-	15,000 (4.0 ppm)	2300 (0.6 ppm)	-

¹ This value is based on sensory effects or annoyance reactions. ² This value is based on effects other than cancer or odor/annoyance.

As Table 19 shows, the values from the WHO, similar to the previous section, are $1000 \mu\text{g}/\text{m}^3$ for sensory effects with the given recognition threshold to the smell at around $10 \text{ mg}/\text{m}^3$ and $260 \mu\text{g}/\text{m}^3$ for adverse effects on health [37].

The value from France ($20,000 \mu\text{g}/\text{m}^3$) is defined for both the short term and long term [71], because TRV (valeurs toxicologiques de référence) for 24 h and the chronic are 21 and $19 \text{ mg}/\text{m}^3$, respectively, which are practically equivalent [98]. Moreover, these values were adapted from the research by Kobald et al. in 2015 [110] for the short term and Zavalic et al. in 1998 [111,112] for the long term, even if the measured values are always far lower than these levels. In addition, the document also mentioned $1000 \mu\text{g}/\text{m}^3$ as the olfactory threshold.

Furthermore, the values from the UK and Canada are also not comparable due to the reason for adaptation from USEPA mentioned in Section 3.2.14.

Apart from the values mentioned above, which vary a lot, the others are inside the range from 200 to $260 \mu\text{g}/\text{m}^3$, with $600 \mu\text{g}/\text{m}^3$ from Lithuania and $75 \mu\text{g}/\text{m}^3$ from Austria.

The reference value to be adopted can be related to the following:

- 260 $\mu\text{g}/\text{m}^3$ (7 days), for the long-term, as the WHO [37,39] suggests.

3.2.16. Total Volatile Organic Compounds (TVOCs)

Volatile organic compounds (VOCs) are compounds emitted as gases from certain solids or liquids that have a high vapor pressure and low water solubility, including a variety of chemicals, some of which may have short- and long-term adverse health effects [113]. Since there are too many types of VOCs, for the monitoring of air quality, TVOC is applied to sum up the total concentration of VOCs.

Generally, the pollutant mentioned in previous chapters, including acetaldehyde, benzene, BaP, dichloromethane, formaldehyde, naphthalene, styrene, toluene, trichloroethylene, and tetrachloroethylene, as well as other organic air pollutants list in Section 3.3.1, can also be included in the list of VOCs. Some organic pollutants are well-studied and highly related to the generic population, so they are proposed with a suitable reference value for IAQ intervention. However, there are still many other compounds that are not proposed with values or listed in addition to non-compulsory regulations or standards, because of the local industries, research focus, and progress.

The reference values of TVOC are listed in Table 20.

Table 20. Reference values for TVOC.

Region	Reference Value ($\mu\text{g}/\text{m}^3$)				
	General	1 h	8 h	Long Term	
China	-	-	600	-	
AS	Hong Kong (China)	-	200 EC	-	
		-	600 GC	-	
Japan	400	-	-	-	
Singapore	-	-	1000 ppb	-	
EU	Austria ¹	300 R	-	-	
		1000 Z	-	-	
	Belgium	-	300	-	1000
	Netherlands	-	-	-	200 (1 y)
	Norway	400	-	-	-
	Poland	400 R	-	-	-
	Portugal	-	-	600	-
OC	UK	-	-	300	-
Australia	-	500	-	-	

¹ For Austria, “R” refers to “Richtwert” as the reference value; “Z” refers to “Zielwert” as the target value.

Because TVOCs contain multiple pollutants and their composition of them varies a lot according to the local emission condition and the specific usage of indoor spaces, the values from different regions may not be comparable.

As Table 20 shows, for the value from Singapore (1000 ppb for 8-hour average), in the document, the given information indicates the measured TVOCs are photo-ionizable (10.6 eV) calibrated to the isobutylene equivalent, which has the molecular weight of 56.106 g/mol. In this way, 1000 ppb can be converted to around 2290 $\mu\text{g}/\text{m}^3$ at 25 °C and 1 atmosphere condition, and this value is still quite higher than the others.

From the comparison, and according to EN ISO 16000—Part 6, the values to be adopted can be related to a range of 200–600 $\mu\text{g}/\text{m}^3$, but it is not possible to use/recommend any reference value because the reference values do not take into account the toxicological effects of the different substances.

The reference values of trichloroethylene are listed in Table 21.

Table 21. Reference values for trichloroethylene.

	Region	Reference Value ($\mu\text{g}/\text{m}^3$)							Additional Info
		General	30 min	1 h	8 h	1 Day	7 Day	Long Term	
INT	WHO	-	-	-	-	-	-	-	2.3 ¹ 23 ²
AS	Hong Kong (China)	-	-	-	230	-	-	-	-
	India	-	-	-	-	-	-	600 (1 y)	-
	Belgium	0.2–2.5	-	-	-	-	-	-	-
	France	-	-	50	-	-	-	800 (14 d–1 y)	2 ¹ 20 ²
EU	Germany	-	-	-	-	-	1000 RWII 100 RWI	-	-
	Lithuania	-	4000	-	-	1000	-	-	-
	Poland	-	-	-	200 PO	150 R	-	-	-
	Portugal	-	-	-	25	-	-	-	-
	UK	-	-	-	-	-	-	-	2.3 ¹ 23 ²

¹ An excess lifetime risk of 10^{-6} at this value. ² An excess lifetime risk of 10^{-5} at this value.

3.2.17. Trichloroethylene

Trichloroethylene (TCE) is a widely used industrial solvent. It is a volatile, colorless liquid with a sweet ethereal (chloroform-like) smell. The main indoor sources are ground-water and drinking water: water ingestion/dermal absorption when showering; breathing indoor air—use of wood stains, varnishes, finishes, lubricants, adhesives, typewriter correction fluid, paint removers, and certain cleaners, where TCE is used as a solvent; and food with TCE as the solvent [39].

As Table 21 shows, for Hong Kong, since there is no guideline value from the WHO, the value of $230 \mu\text{g}/\text{m}^3$ was adapted from the value with an excess lifetime cancer risk of 1:10 000.

The value from Belgium [70] is adapted from USEPA [114], in which The RfC (inhalation reference concentration) of 0.0004 ppm (0.4 ppb or $2 \mu\text{g}/\text{m}^3$) was proposed based on route-to-route extrapolated results from oral studies for the critical effects of heart malformations (rats) and immunotoxicity (mice) for noncancer effects [114].

For the document from France about trichloroethylene, there is one confusing point about the lifetime risk value: the given values are 2 and $20 \mu\text{g}/\text{m}^3$ in the summary and conclusion, but in Chapter 7, “Conclusions of the working group” (“Conclusions du groupe de travail”), the values are 2.3 and $23 \mu\text{g}/\text{m}^3$ [115]. Since there is no particular reason declared in the document, and the values did not vary much, it may be an adaptation.

The value to be adopted can be related to the following:

- A range between 600 and $800 \mu\text{g}/\text{m}^3$ as the long-term value as India [50] and France [17,71–78] state.

Due to missing currently a specific guideline value from the WHO [39], the values of Unit Risks can be those from France, which is more restrictive.

- $2 \mu\text{g}/\text{m}^3$ (UR/lifetime) 10^{-6} ,
- $20 \mu\text{g}/\text{m}^3$ (UR/lifetime) 10^{-5} , as France [17,71–78] suggests.

3.3. Other Pollutants

3.3.1. Organic Pollutants Listed but Only in Limited Documents

Apart from the listed values in Table 22, in other countries or regions, there are also lists of reference values on the detailed organic pollutants, such as in Germany [18] and Lithuania [79]. However, considering many other documents included in TVOC, rather than listed separately, the detailed values are not listed in this paper.

Table 22. Reference values for organic pollutants.

Pollutant	Region	Reference Value ($\mu\text{g}/\text{m}^3$)	
Acrolein	France	6.9 (1 h)	0.8 (>1 y)
	Canada	38 (1 h)	0.44 (24 h)
Ammonia	China	200 (1 h)	-
Chlordane	New Zealand	5/0.3 ppb (continuous)	
Chlorpyrifos	Japan	1.0 (0.07 ppb)	0.1 (0.007 ppb) (Children)
Diazinon	Japan	0.29 (0.02 ppb)	-
Di-n-butyl phthalate	Japan	17 (1.5 ppb)	-
Di-2-ethylhexyl phthalate	Japan	100 (6.3 ppb)	-
Ethylbenzene	France	22,000 (24 h)	15,000 (>1 y)
	Japan	3800 (880 ppb)	-
Fenobucarb	Japan	33 (3.8 ppb)	-
Nicotine	Singapore	<0.01 (8 h)	-
Paradichlorobenzene	Japan	240 (40 ppb)	-
Polycyclic aromatic hydrocarbons	WHO	No threshold	
	China	200 (1 h)	-
Xylenes	Japan	200 (50 ppb)	-
	Canada [88]	7200 (1 h)	150 (24 h)

As Table 22 shows, although polycyclic aromatic hydrocarbons (PAHs) are included in this list and the WHO did not propose a reference value for it, BaP and naphthalene are both inside the definition of PAH with proposed values (see Tables 5 and 10, respectively).

3.3.2. Less Common Indoor Pollutants

- Asbestos

Asbestos is the name given to six minerals that occur naturally in the environment as bundles of fibers that can be separated into thin, durable threads for use in commercial and industrial applications. When asbestos fibers are breathed in, they may get trapped in the lungs and remain there for a long time. Over time, these fibers can accumulate and cause scarring and inflammation, which can affect breathing and lead to serious health problems like shortness of breath, coughing, and permanent lung damage [116].

The reference values of asbestos are listed in Table 23.

Table 23. Reference value for asbestos.

Pollutant	Region	Reference Value
Asbestos	Singapore	0.01 fiber/cm ³ (8 h)
	Finland	0.01 fiber/cm ³ ¹

¹ 1cc equals 1 cm³.

As Table 23 shows, asbestos is also mentioned in the regulation from Denmark [22], which remarked that “Materials containing asbestos are not to be used”, with no value provided.

- Sulfur dioxide

Sulfur dioxide (SO₂) is a colorless and nonflammable gas that is highly soluble in water; it has a pungent smell; it irritates the skin, eyes, and mucous membranes; and it contributes to asthma, bronchitis, and tracheitis. This gas is also produced by combustion processes. The value of sulfur dioxide is only found in the document from China, maybe because it is more of a typical outdoor air pollutant with less indoor sources in generic spaces. Table 24 shows the value defined by China.

The reference values of sulfur dioxide are listed in Table 24.

Table 24. Reference values for sulfur dioxide.

Pollutant	Region	Reference Value (µg/m ³)
Sulfur dioxide	China	500 (1 h)

- Hydrocyanic acid (HCN)

Hydrogen cyanide, whose solution in water is called hydrocyanic acid or prussic acid, is a metabolic poison [117]. At atmospheric pressure, it occurs over the temperature range from −14 °C to +26 °C; it is a colorless gas or bluish-white liquid [118]. Its toxins ultimately act by blocking electron transfer to molecular oxygen during the oxidative phosphorylation of adenosine triphosphate (ATP), leading to a decrease in the unloading gradient for oxyhemoglobin [119].

It causes dyspnea and headache at a low level; immediate and progressive sense of warmth (due to vasodilation) with visible flushing; prostration, followed by nausea, vomiting, headache, difficulty in breathing, and a feeling of tightness around the chest at a medium level; loss of consciousness; and pain in the back of the neck and chest at the high level [118].

As Table 25 shows, although it is mentioned in the document from France [71], no reference value was proposed, probably due to its high toxicity.

Table 25. Reference values for hydrocyanic acid.

Pollutant	Region	Reference Value
Hydrocyanic acid	France	No short-term IAQGs proposed

4. Conclusions: Trends and Perspectives

4.1. Sum Up of the Current Trends and Reference Values for Common Perspectives

The pollutant can be put up with a reference value in the higher requirement for current and future scenarios.

In conclusion, supported by existing norms and guideline values by the WHO and international scenarios, a summary table of the main chemical guideline values can be synthesized, as Table 26 lists.

Table 26. Guidelines' values for chemical compounds for generic environments.

Pollutant	Reference Value		Reference	Additional Info
	Value	Period		
Acetaldehyde	1420 (1 h) µg/m ³	Short term	[24]	
	280 (1 d) µg/m ³			
	140–160 µg/m ³	Long term		
Benzene	20 (1 d) µg/m ³	Short term	[17,71–78,80,83]	1.7 µg/m ³ (UR/lifetime) 10 ^{−6}
	2 (1 y) µg/m ³	Long term	[17,71–78]	17 µg/m ³ (UR/lifetime) 10 ^{−5}
Benzo[a]pyrene	1 (1 d) ng/m ³		[26,79]	0.012 ng/m ³ (UR/lifetime) 10 ^{−6}
				0.12 ng/m ³ (UR/lifetime) 10 ^{−5}
Carbon dioxide	1000 ppm		[18,31,32,37,87], etc.	2000 ppm as Intervention Value

Carbon monoxide	100 (15 m) mg/m ³	Short term	[23,31,32,39,59,67–70,80–85,87,98]	
	25 (1 h) mg/m ³			
	10 (8 h) mg/m ³			
	7 (1 y) mg/m ³	Long term	[39]	
Dichloromethane	3000 (1 d) µg/m ³	Short term	[37,39]	
	450 (7 d) µg/m ³			
	200 (1 y) µg/m ³	Long term	[80]	
Formaldehyde	100 (30 m) µg/m ³	Short term	[19–21,23,32,33,39,60–66,79,81,82]	
	10 (1 y) µg/m ³			
		Long term	[17,29,31,72–78,80]	
Naphthalene	10 (1 y) µg/m ³	Long term	[31,39]	
Nitrogen dioxide	25 (1 h) µg/m ³	Short term	[39]	
	10 (1 y) µg/m ³			
		Long term		
Ozone	100 (8 h) µg/m ³	Short term	[23,33,39,59]	
	60 (1 y) µg/m ³			
		Long term	[39]	
PM _{2.5}	40 (8 h) µg/m ³	Short term	[81–83]	For the future scenario: 15 (1 d) µg/m as short term 5 (1 y) µg/m ³ as long term
	25 (1 d) µg/m ³			
	10 (1 y) µg/m ³			
		Long term	[17,23,71–78,80]	
PM ₁₀	90 (8 h) µg/m ³	Short term	[17,23,71–78,80–83]	For the future scenario: 45 (1 d) µg/m as short term 15 (1 y) µg/m ³ as long term
	50 (1 d) µg/m ³			
	20 (1 y) µg/m ³			
		Long term	[23,80]	
Radon	100 (8 h) Bq/m ³	Short term	[33]	0.6 Bq/m ³ . (UR/lifetime) 10 ⁻⁶ 15 Bq/m ³ . (UR/lifetime) 10 ⁻⁵
	100 (1 y) Bq/m ³			
		Long term	[25]	
Styrene	40–70 (30 m) µg/m ³	Short term	[39,60–66,79]	
	260 (7 d) µg/m ³			
		Long term	[39]	
Tetrachloroethylene	1000 (7 d) µg/m ³	Short term	[18]	8000 µg/m ³ (30 m) for sensory effects 1000 µg/m ³ (30 min) for sensory effects
	250 (1 y) µg/m ³			
		Long term	[17,37,71–78]	
Toluene	260 (7 d) µg/m ³	Long term	[37,39]	
TVOC	No Safe Level			Highly depending on the regions
Trichloroethylene	600–800 µg/m ³	Long term	[17,50,71–78]	2 µg/m ³ (UR/lifetime) 10 ⁻⁶ 20 µg/m ³ (UR/lifetime) 10 ⁻⁵

4.2. Limitations and Next steps

In the current research stage, there are several limits to the comparison result. One aspect is that only the parts of documents from several countries and regional governments are referred to. Some guidelines for green buildings or institutions for ventilation are also instructive. However, it is not clear if these guidelines or standards are officially applied to the in situ evaluation or not.

On the other hand, even though all the collected reference values are compared together in this work, the best reference values for each region are depending on the local condition, including geographical environments, local industries, native cultures and lifestyles, etc. The values collected from the near regions during the comparison may be more suitable depending on the readers' regions, and the proposed reference value is provided as a reference for better practice, such as for healthcare requirements.

Although these documents have been published for many years in their regions, more efforts are still needed to implement those reference values into the actual living space with the intervention to the IAQ deterioration in many regions. For example, in China, the IAQ standard has been published since 2002; however, there is no specific benchmark or regulation about how the IAQ should be evaluated and intervened for

improvement in real situations. In this way, even if the architects, the designers, the construction teams, the manager of buildings, the occupants of the indoor space, etc., are different stakeholders in this problem, none of them is required to take this responsibility due to the lack of related regulations on IAQ. Eventually, only the real users, who have less awareness of IAQ, are exposed to those “designed spaces” without a single evaluation during the whole occupied time. Thus, how these reference values can benefit the generic living space is an essential question to be considered. In the evaluations, it is necessary not to stop at the comparison with the specified guide or reference value but to take into account the conditions of use, frequency, age, etc.

A few values from the documents are found to be adapted or cited from other documents or some previous research. However, during the adaptation, the values were exactly maintained, but the average period or the application condition changed. There is no indication if it is adapted according to the local condition or if it is just a human error. For this reason, the reference values have to be updated, especially those published more than 2 or 3 decades ago.

Some values, such as those for benzene and trichloroethylene from Belgium and styrene from Lithuania and Russia, have a quite large deviation from the values proposed by other documents, but unfortunately, there is no detailed information or explanation found in their sources. They are worth deep research on the reason why and how those values were set in the past.

Different from thermal comfort and energy consumption, the poor IAQ consumes users in an invisible and unperceivable way through long-term exposure. Thus, the application of those reference values to the IAQ monitoring is necessary to raise users’ awareness of the IAQ and further lead to ABs improving it.

In addition, it is worth considering European reference documents drafted by (inter) national accreditation institutions (ISO, CEN, AFNOR, and UNI). Such organizations have been involved in the definition of strategies and technical solutions regarding the methods for conducting monitoring, analysis, and assessments. Currently, EN norms define monitoring methods and strategies for air pollution dilution. The main norms for the monitoring activity of IAQ parameters are 33, as shown in Table 2 [34].

The study and knowledge of the indoor air levels of different pollutants are important to identify possible solutions and strategies to improve mitigation and prevention interventions. In addition, it is important to remember that there is a constant evolution of the data by the states concerning the health status of populations. The authors’ aim is to refer to the general strategies of the WHO and to be more and more conservative with the scope of guaranteeing healthier living, working, etc., spaces.

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