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Towards equitable and sustainable indoor air quality guidelines – A perspective on mandating indoor air quality for public buildings

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ABSTRACT

A recent article published in Science urges mandatory indoor air quality (IAQ) standards in public spaces, focusing on protecting public health, especially against diseases such as COVID-19, but also IAQ in general (*1*). Given the significance of this topic to our society, this short communication aims to provide commentary on the article and further discuss the importance of establishing IAQ standards. Citing a lack of legislated standards globally, the authors (*1*) propose numerical limits for four IAQ parameters: particulate matter ($PM_{2.5}$), carbon dioxide (CO_2), carbon monoxide (CO), and ventilation rate (VR). While recognizing that most of the countries do not have any mandatory IAQ standards, it is also noteworthy that IAQ regulations or guidelines exist in more than 40 countries. We like to emphasize that successful IAQ management requires recognizing, sharing, and reviewing openly available, existing regulations and guidelines, while adapting them to regional characteristics.

In 2020, the International Society of Indoor Air Quality and Climate's Scientific and Technical Committee (STC) 34 published an Indoor Environmental Quality (IEQ) guidelines database (www.ieqguidelines.org) [2,3]. The overarching aim of this open database is to help countries develop standards while considering regional characteristics and needs.

The IEQ database [4] comprises data from more than 40 countries and includes over 840 limit values specific for IAQ (Fig. 1).

Of these, 33 % are government regulations, 50 % are governmental guidelines, and 12 % are non-governmental guidelines. In other words, the national limit values in the database are divided into three categories, with only the first category having a regulatory scope, as shown in Table 1. Additionally, a fourth category, 'International Guideline', is included in the database. Most of these values are applicable for public spaces and about 20 % target residential buildings. In addition to over 160 other IAQ parameters (some of which are shown in Table 2), the database contains 8 regulations and 6 guidelines for $PM_{2.5}$, 18 and 16 for CO_2, 16 and 31 for CO, and 17 and 11 for ventilation, excluding values explicit to residential buildings and indutrial settings.

Morawska et al. [1] included only four IAQ parameters ($PM_{2.5}$, CO_2, CO, and VR), largely because compliance monitoring of all 13 pollutants as recommended by the World Health Organization (WHO) [5,6] would be too costly and complex. However, while we recognize the substantial challenges associated with monitoring, we still believe that health-based parameters should not be omitted from mandatory IAQ standards. Indeed, many countries already regulate other chemicals, such as formaldehyde and radon, deploying standardized compliance overseen by public authorities.

Three ($PM_{2.5}$, CO_2, VR) of the four parameters in the Morawska et al.'s article [1] can be considered proxies for infection-related and other common indoor pollutants and correlate with each other. While better ventilation can reduce the airborne transmission of infectious

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diseases, it can also be reflected in CO_2 and $PM_{2.5}$ levels indoors, where the main source of CO_2 is humans and one of the main sources of $PM_{2.5}$ is combustion. Given that reliance on unvalidated proxy parameters may not reduce the level of pollutants or improve health, further research is required to determine which parameters and monitoring protocols best serve as the basis for legislation targeting airborne transmission. For example, Mendell et al. (2024) recommended research identifying VR airflows needed to control key indoor-related health effects and developing practical yet sufficiently accurate strategies for measuring CO_2 to indicate VRs [11]. Further research should also focus on accurately characterizing target pollutant(s) and their relationships to health. Another consideration is whether legislation - and perhaps especially policies- should solely address IAQ parameters or also attend building-occupant behaviors, such as the use of chemicals and personal protective equipment.

Among the four parameters, CO is not associated with virus transmission. CO is commonly regulated based on acute poisoning or death, usually resulting from incomplete combustion in improperly installed or malfunctioning heating and cooking appliances. On the other hand, among other IAQ pollutants, $PM_{2.5}$ is linked to a range of health outcomes [3], supporting its inclusion in IAQ standards designed to protect public health and welfare.

The proposed CO limit values in the article [1] match WHO guidelines [5], except that it excludes the 24-hour limit of 7 mg/m^3, which represents chronic exposure. The article also proposed short averaging times for measuring exposure (e.g.,1 hour for $PM_{2.5}$), assuming that the general population spends about one hour in public spaces. However, the 1-hour limit for $PM_{2.5}$ does not seem to be supported by epidemiological evidence, and even normal occupant activities can cause short term peaks exceeding the proposed limit [7]. In addition, complying with the 1-hour $PM_{2.5}$ limit may be unrealistic in many urban areas where outdoor air concentrations are high, which could inadvertently impose a significant burden on building developers and owners. Instead, it could be more beneficial to focus on building performance criteria aimed at improving air tightness and filtration, while simultaneously regulating outdoor air by requiring actions from those responsible for polluting it, rather than those who are exposed to it.

The CO_2 threshold proposed in the article [1] aligns with numerous voluntary guidelines [4] that have themselves generated divergent

Table 1
Number of governmental regulations, governmental guidelines, and non-governmental guidelines included in the database* by country (entries for residential buildings and industrial settings are excluded).

Country	Governmental regulations	Governmental guidelines	Non-governmental guidelines
Australia	0	11	0
Belgium	6	1	0
Brazil	5	0	0
Bulgaria	67	0	0
China	0	32	0
Czech Republic	3	0	0
Denmark	1	7	0
Estonia	13	1	0
Finland	9	4	5
France	1	10	0
Germany	0	61	0
Greece	1	0	0
Hong Kong	0	15	0
Hungary	1	0	0
India	0	0	41
Italy	2	1	0
Japan	1	16	0
Lithuania	11	0	0
Malaysia	12	0	0
Netherlands	1	0	16
New Zealand	0	1	0
Nigeria	11	0	0
Norway	9	18	0
Poland	0	35	0
Portugal	9	0	0
Romania	4	0	0
Singapore	0	15	0
Slovenia	8	0	0
South Korea	28	5	0
Spain	14	0	0
Sweden	6	1	0
Thailand	0	12	0
United Arab Emirates	0	8	0
United Kingdom	10	39	0
United States of America	16	11	34

* ISIAQ STC34, Indoor Environmental Quality Guidelines Database, September 2020. Accessed ieqguidelines.org: 29 April 2024.

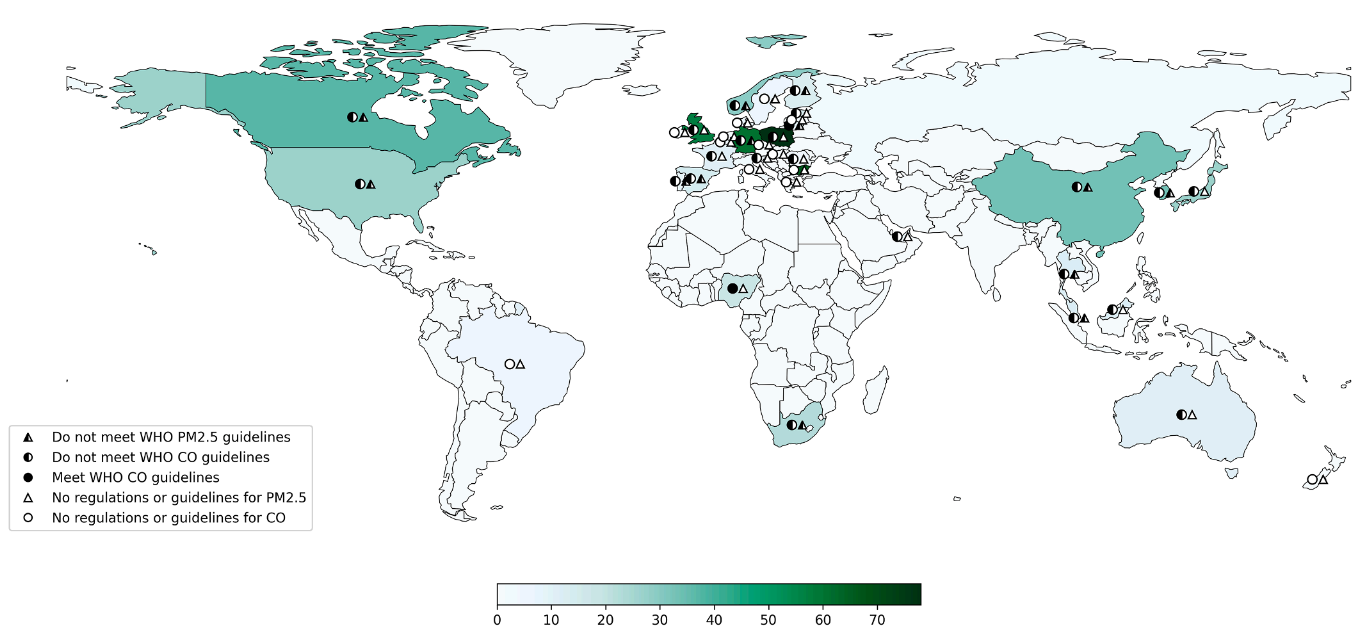

Fig. 1. Number of governmental regulations or guidelines by country included in the IEQ database as of April 2024. Symbols indicate whether regulations or guidelines for CO and/or $PM_{2.5}$ meet WHO guidelines [5]. Note: some countries have multiple entries for each pollutant.

Table 2
Number of governmental regulations and guidelines included in the database* by pollutants with five or more data entries (entries for residential buildings and industrial setting are excluded).

Pollutant	Governmental regulations	Governmental guidelines
Acetaldehyde	1	4
Airborne mold	7	5
Ammonia	4	3
Asbestos	12	4
Benzene	2	3
Carbon dioxide (CO_2)	**18**	**16**
Carbon monoxide (CO)	**16**	**31**
Formaldehyde	18	21
Naphthalene	1	4
Nitrogen dioxide (NO_2)	14	17
Ozone (O_3)	10	11
Particulate matter (PM_{10})	11	7
Particulate matter ($PM_{2.5}$)	**8**	**6**
Radon	13	11
Relative humidity	9	10
Styrene	2	4
Temperature	21	12
Toluene	2	6
Total airborne bacteria	6	5
Total Volatile Organic Compounds (TVOCs)	5	14

* ISIAQ STC34, Indoor Environmental Quality Guidelines Database, September 2020. Accessed ieqguidelines.org: 29 April 2024.

views. Some experts advocate even stricter standards to safeguard public health, arguing that the cost of improved IAQ is minimal compared to the toll of polluted air on health and productivity. Conversely, others caution against mandating the proposed CO_2 standard year-round, citing sustainability concerns due to the need for substantially increased air exchange or occupancy control. The proposed ventilation rate (14 l/s-person) is approximately double what many countries require for schools and other public spaces and 40 % higher than the WHO's standard for improving indoor ventilation in the context of COVID-19 [8]. Further on, space conditioning already accounts for a significant proportion of energy use in developed countries, comprising half of building energy use and one fifth of total national energy use [9]. In less developed countries, achieving the proposed ventilation rate would pose an even greater challenge given that most buildings rely on natural ventilation through opening windows, which could compromise thermal conditions and increase occupants' exposure to unfiltered outdoor pollutants. Indeed, the complex relationship between CO_2 and health may explain why the WHO, unlike many occupational health authorities, has not issued health-based CO_2 guidelines.

We agree with the authors [1] in that guidelines typically are not enforceable unless incorporated into legislation, and legislated levels will vary by country and jurisdiction, reflecting local circumstances. In our view, the more beneficial and successful approach may be for countries to adopt internationally agreed guidelines (e.g., WHO) or standards (e.g., ISO) and modify them to suit regional characteristics and needs [10]. This strategy is supported by our previous analysis [3], which revealed that WHO guidelines are commonly adopted as national regulations. Deviations from these values indicate that health-based guidelines may not be universally accepted by regulatory bodies, possibly due to environmental and economic factors, such as the cost of implementing new technologies. A further complication is that the WHO's 2021 air quality guidelines primarily target outdoor air; while they allegedly also apply indoors, the dearth of IAQ epidemiological studies hampers consensus on acceptable levels for many harmful indoor air pollutants.

Adding to the complexity, there are instances where national guidelines may lack internal coherence and fail to align with the latest understanding of exposure and health implications. To help international and national authorities achieve better consensus, scientists could leverage the global IEQ database when assessing the effectiveness for improving IAQ and health of governmental regulations compared to voluntary guidelines. Continuous collaboration between scientists and policymakers has the potential to establish knowledge-based guidelines that support equitable and sustainable air quality worldwide. Leading by example, the scientific community should set achievable goals and embrace an open process of collecting, sharing, and rigorously reviewing data based on proven principles. Such a process should allow for consideration of regional variations in climate, building types, occupant characteristics, and cultural differences, factors that can impact the perception, applicability, and feasibility of adopting international standards.

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CRediT authorship contribution statement

Ulla Haverinen-Shaughnessy: Writing – review & editing, Writing – original draft, Supervision, Investigation, Conceptualization. **Marzenna Dudzinska:** Writing – review & editing, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, or other organizations.

Data and materials availability

The data that support the findings of this article are available at www.ieqguidelines.org.

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Corrigendum to "Towards equitable and sustainable indoor air quality guidelines – A perspective on mandating indoor air quality for public buildings" [Indoor Environ. 2 1 (2025) 100070]

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The authors regret that the CRediT authorship contribution statement was only partially included in the article. The correct statement is as follows:

CRediT authorship contribution statement

Ulla Haverinen-Shaughnessy: Writing – review & editing, Writing – original draft, Supervision, Investigation, Conceptualization. Marzenna Dudzinska: Writing – review & editing, Investigation, Conceptualization. Samy Clinchard: Visualization, Writing – review & editing. Sani Dimitroulopoulou: Writing – review & editing. Xiaojun Fan: Writing – review & editing. Piet Jacobs: Writing – review & editing. Henna Maula: Writing – review & editing. Amelia Staszowska: Writing – review & editing. Oluyemi Toyinbo: Writing – review & editing. Ju-Hyeong Park: Writing – review & editing.

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