Journal of Air Pollution and Health (Summer 2023); 8(3): 315-338

Original Article

Available online at http://japh.tums.ac.ir

Indoor air quality control at national-level regulations: A special case in Indonesia

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ARTICLE INFORMATION

Article Chronology:
Received 04 June 2023
Revised 01 July 2023
Accepted 22 August 2023
Published 29 September 2023

Keywords:
Buildings; Indoor air quality (IAQ); Pollutants; Regulations; Standards

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ABSTRACT

Introduction: While many national-level governments have worked to tighten atmospheric air quality standard, the Authors observe, Indoor Air Quality (IAQ) control as part of building-codes have remained understudied and not yet enforced in many national-level regulations. The COVID-19 pandemic seemed to trigger an immediate response worldwide for IAQ control. Indoor air pollutants need to be tightly regulated. International agencies have produced recommendations to cope with the pandemic, however, national-level IAQ standards and building codes have been slow to adapt.

Materials and methods: IAQ regulations from various nations worldwide were studied along with the international standards: The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and World Health Organization (WHO). A comprehensive review was conducted comparing the national-level building codes and regulations as legal implementation instruments. Focus group discussions were also conducted to complement preliminary findings and further analysis.

Results: Except for Indonesia, bacteria and fungi have been categorized as infectious aerosols in many national-level regulations that fare up to the international standards as indoor air pollutants with their acceptable levels. However, while they set thresholds for pollutants, their effectiveness regulating IAQ in public buildings remain unknown. It also found that there is a significant lack of national building codes in Indonesia.

Conclusion: The COVID-19 epidemic raises awareness of IAQ. The health aspect is currently being prioritized, particularly in Indonesia, where the majority of related regulations are still fragmented and prioritize energy conservation over health. This study can inform policymakers with evidence of IAQ control and practices worldwide for applicable regulatory building and implementation, as well as for health emergency and disaster risk management.

Introduction

Atmospheric air quality is an environmental issue that affects the health of the global population, which concerns many national-level governments these days to where they have worked to strengthen

Please cite this article as: Gamal A, Hidayat HY, Raiiaya IGAAKM, Wangkanusa MN, Budihardjo B, Alhamid MI, et al. Indoor air quality control at national-level regulations A special case in Indonesia. Journal of Air Pollution and Health. 2023;8(3): 315-338.

the global atmospheric air quality standard. The European Union (EU) legislation considers improving its legal standards due to the recent level of pollutants exposure that is above the EU standards [1]. Various existing studies also point out that atmospheric air pollution causes health hazards regardless of age [2-4]. More ironically, The United Nations Environment Programme (UNEP) reports that about one-third of nations world-wide have no legally mandated standards on the atmospheric air quality; and if they do, it is often misaligned with the World Health Organization (WHO) guideline [5].

While existing research and legal re-evaluation have focused on the outdoor air quality, the Authors contend that, Indoor Air Quality (IAQ) control as part of the national-level building codes and regulations studies are still limited and have not yet been effectively adopted and enforced on national-level air quality regulations. A study has indicated that there is a lack of proper and detailed scientific studies and focus on IAQ, particularly in most developing and underdeveloped nations worldwide [6]. The UN Environment Programme previously wrote that developing nations are most vulnerable to indoor air pollutants due to the unaffordability of cleaner fuels or relevant technologies [7]. Moreover, various studies have also uncovered the correlation between air quality and health. A study has comprehensively discussed the impact of the IAQ on human health. By focusing on the workplace environment, it specified and analyzed three common indoor pollutants, such as biological, chemical and particles (non-biological) [8]. The outbreak of COVID-19 has highlighted the need to pay more attention to IAQ control due to the physical/social distancing and stay-at-home regulations implemented to prevent virus contamination. An immediate response is needed to re-evaluate IAQ standards and controls through regulations implemented by many nations to discover a properly aligned and widely used prevention strategy for a long-term dealing with the pandemic.

In the current pandemic, studies have also found the correlation between air pollution and the spread of COVID-19. High levels of air pollution and its exposure may increase its transmission risk [9], especially the exposure to the NO_2 and $PM_{2.5}$ [10]. In addition to this, bacteria and fungi have also been the concerns during the pandemic. Researches show the bacteria and fungi infections in COVID-19 patients [11, 12]), which can potentially worsen their conditions. It is studied that more attention must also be placed on the poor communities as they are susceptible from the indoor air pollution exposures [10]. Moreover, various factors can influence the quality of indoor air. It is studied that IAQ can be influenced by the outdoor air quality [13]. In the context of COVID-19, the transmission occurred through close contacts, aerosols, droplets, and vomits [14]. In addition, it is noted that 93% of humans' activities are held inside the room during the pandemic. It is necessary for house owners and office management to maintain the IAQ through filtering, cooling, and heating processes to control the incoming air through doors and windows. Moreover, air circulation and ventilation are essential for self-isolation/quarantine to reduce aerosol COVID-19 transmission. Good air circulation can prevent the fall of oxygen saturation [15], thus, more attention should be paid to IAQ control during the pandemic.

The newly published IAQ guideline from WHO in 2021 is an up-to-date framework of assessment on the impact of air pollution on humans' health. The European Environment Agency notes that the EU air quality standards are less strict compared to the WHO air quality guidelines for all assessed pollutants [16]. It is valuable to uncover the other current national-level IAQ standards and control assessments, as it has been indicated that, in the design and maintenance phases, most developed nations consider and follow IAQ regulations compared to the developing/underdeveloped ones [6]; especially in Indonesia that does not have a national standard for air pollution [17].

This study concerns with IAQ control and practices. It aims to review and compare the national-level IAQ regulations worldwide and investigate their current implementation with a special case in Indonesia. The international IAQ standards published by international agencies, such as WHO and ASHRAE, are also referenced to demonstrate the recommended threshold used globally. With the comprehensive review and comparison of regulations, this study dismantles the current issues on IAQ control and offers a new insight for knowledge advancement. It also not only informs policymakers with scientific evidence, but also provides recommendations for betterment of IAQ policymaking and implementation at national level about health emergency and disaster risk management.

Materials and methods

This study intends to conduct a comparative study on the national-level IAQ regulations worldwide with a special case in Indonesia. The methodology has focused on the search for information on national-level IAQ regulations implemented in various countries in the last half decade, from which are relevant and reliable to be employed for more appropriate comparison and analysis of regulatory implementation. The IAQ standards issued by international agencies are also reviewed. Originally qualitative research, this employs desk study and Focus Group Discussions (FGDs).

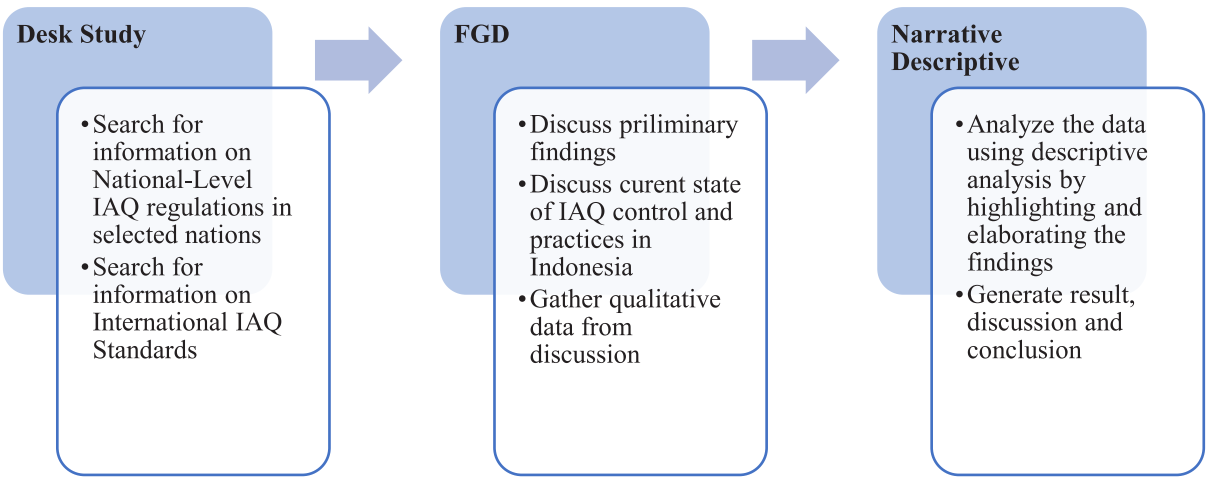

Fig. 1. Methodological flow

The desk study is used to collect available and accessible data, including articles on the internet, focusing on both national level IAQ regulations and international standards. The several nations of Southeast Asia (Indonesia, Vietnam, Thailand Malaysia, Singapore) East Asia (Japan, China, Hongkong [now China] and Taiwan [although disputed]), USA and European Union (Germany, France, Netherlands, Finland, Belgium, and Austria) are selected as the subjects of comparison. In relation to the countries selected and the reasons why not all countries are addressed in this study, it should be noted that the selected ones are representative samples of countries with different geographical locations and climatology. For Asian countries, the Southeast Asian sample represents tropical climate, while East Asian one illuminates sub-tropical climate. These aspects are important and heavily considered for indoor air regulations in each nation, therefore, relevant to this study.

Moreover, to better understand the context of international standards on IAQ, it also conducts a review on standards issued by World Health Organization (WHO), American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and other relevant international organisations. The period of COVID-19 pandemic is referenced considering how it influenced the awareness toward the urgency for regulations on IAQ control.

In addition, the data are also collected from an expert panel through the several designated FGDs. They are held to discuss and collect more data specifically on the Indonesian IAQ control and regulatory practices. They engage various national stakeholders, such as the Director of Technical Development for Settlements and Housing, Director of Building Arrangement of the Ministry of Public Works and Housing, Director of Prevention and Control of Directly Infectious Diseases of the Ministry of Health, National Standardization Agency (BSN), Local government, SMART CITY Universitas Indonesia, Faculty of Public Health, University of Indonesia, ASHRAE Indonesia, Indonesian Association of Sanitary Engineers & Environmental Engineers, Indonesian Association of Building Physicists, Green Building Council (GBC), and the Indonesian Electronics Producers Association (Gabel). Their expertise, roles, and affiliations contribute to the development of this study.

The collected data are mainly compiled and illustrated in tables and graphs and analyzed employing narrative descriptive analysis by highlighting and elaborating the findings.

Results and discussion

Comparison of the parameters of international IAQ Standards

Many international agencies pay special attention to IAQ and have developed standards that can be referred to and adjusted accordingly by many nations worldwide. They include WHO, ASHRAE, American Conference of Governmental Industrial Hygienists (ACGIH), American Society of Heating, Occupational Safety and Health Administration (OSHA), The National Ambient Air Quality Standards (NAAQS), The National Institute for Occupational Safety and Health (NIOSH), and the US Environmental Protection Agency (US EPA).

Studies have indicated that outdoor air quality has an impact on the quality of indoor air and pointed out that the latter can be more dangerous. To this, the international IAQ standards are added to provide complete air pollutant types and their standardized levels relevant to the indoor air, including those originated from outdoor and are now considered indoor. The inclusion of international IAQ standards function for the comparative purpose with the national level IAQ regulations, as many seemed to have [and not] regulated air pollutant types and different levels.

From the review and comparison, it is found that their standards have similarities and differences, depending on the types of pollutants and their permitted pollutant contents limit.

Chemical and Physical Pollutants in the International Organizations' IAQ Standards

The International agencies' IAQ standards are compared based on the regulated pollutant types: Chemical and Physical Pollutants. The comparison of pollutants with each permitted content limits can be seen in the Tables 1 and 2 below.

Table 1. Chemical pollutants of international organizations' standards

Chemical Pollutants	Permitted chemical pollutants content limit				
	ACGIH	ASHRAE	NAAQS/EPA	NIOSH	OSHA
Carbon Monoxide (CO)	-	9 ppm [8 h]	35 ppm [1 h] 9 ppm [8 h]	35 ppm [8 h] 200 ppm [exposed] 1.347 µg/m³ [dangerous]	50 ppm [8 h]
Carbon Dioxide (CO_2)	30.000 ppm [15 mins] 5.000 ppm [8 h] 600 ppm [comfort limit]	<700 ppm [outdoor condition]	800 ppm	600 ppm [comfort limit] 30.000 ppm [15 mins] 5.000 ppm [8 h]	5.000 ppm [8 h]
Formaldehyde (HCHO)	0,3 ppm	0,081 ppm [30 mins] 76 ppb [1 h] 27 ppb [8 h]	0,4 ppm	0,1 ppm 0,016 ppm [10 h exposed] 24.540 µg/m³ [dangerous]	2 ppm [15 mins] 0,75 ppm [8 h exposed]
Nitrogen Dioxide (NO_2)	5 ppm [15 mins] 3 ppm [8 h exposed]	-	0,05 ppm [1 yr]	1 ppm [15 mins] 37,600 µg/m³ [dangerous]	5 ppm
Ozone (O_3)	0,05 ppm [exposed 1 day–heavy work] 0,08 ppm [exposed 1 day–medium work] 0,1 ppm [exposed 1 day – light work]	0,05 ppm [8 h]	0,12 ppm [1 h] 0,08 ppm [8 h] 0,1 ppm	0,1 ppm	0,1 ppm [8 h]
Sulfur Dioxide (SO_2)	5 ppm [15 mins] 2 ppm [8 h]	0,5 ppm [3 h] 0,14 ppm [24 h] 80 µg/m³ [1 year]	0,14 ppm [24 hrs] 0,03 ppm [1 year]	5 ppm [15 mins] 2 ppm [8 h]	5 ppm [5 h]
Lead (Pb)	0,05 µg/m³	-	1,5 mg/m³ [3 mons]	0,05 µg/m³	0,05 µg/m³

Notes: The [] signifies the average time of IAQ measurements. For example: 9 ppm [8 hours] shows the indoor air pollutant levels should not exceed 9 ppm for 8 hours average measurement.

Table 2. Physical Pollutants of International Organizations' Standards

Physical Pollutants	Permitted Physical Pollutants Content Limit			
	ACGIH	ASHRAE	NAAQS/EPA	OSHA
Particulate Matter ($PM_{2.5}$)	3 μg/m³ [8 h]	65 μg/m³ [24 h]	35 μg/m³ [24 h] 15 μg/m³ [1 yrs]	5 μg/m³ [8 h]
Particulate Matter (PM_{10})	10 μg/m³ [24 h]	150 μg/m³ [24 h]	150 g/m³ [24 h] 50 g/m³ [1 yrs]	-
Total Suspended Particles (TSP)	-	-	-	15 μg/m³ [8 h]
Temperature	-	22,5–26,0 °C Summer 20,0–23,5 °C Winter	-	-
Relative Air Humidity	-	40 - 60% Summer 30 - 60% Winter	-	-

Note: The signifies the average time of IAQ measurements. For example: 9 ppm [8 h] shows the indoor air pollutant levels should not exceed 9 ppm for 8 h average measurement.

As seen, almost all agencies listed above highly consider and regulate the content limits of the chemical pollutants. Only ACGIH and ASHRAE do not have a content limit of one of the chemical pollutants. The former does not regulate CO content limit, while the latter does not regulate the content limit of Pb.

For the physical pollutants, moreover, it is seen that only ASHRAE does regulate almost all physical pollutants, except for the Total Suspended Particle. Similarly, the ACGIH and NAAQS/EPA also do not have the Total Suspended Particle content limits in addition to their lack of regulation on the Temperature and Relative Air Humidity content limits.

Moreover, WHO has also been developing and annually updating its air quality standard. In 2005, it specifically issued IAQ guidelines [18] and it recently published a newly updated the guidelines in 2021 [19]. It does not differentiate pollutant types into chemical and physical categories but includes several pollutants that are listed in Tables 1 and 2. The pattern of changes on the regulated pollutants content levels in the 2005 and 2021 guidelines is seen in the Fig. 2 below

It is seen that the permitted content limit of the ozone, Nitrogen dioxide and carbon monoxide were not regulated in the 2005 WHO Air Quality guidelines. These changes, however, are not directly related to the on-going COVID-19 pandemic. According to an expert, Dr. Maria Neira, on WHO's new Air Quality Guidelines that there are key pollutants that the exposures are recommended to be lowered in order to protect peoples' health particularly for the $PM_{2.5}$ which could save about 80% of the total number of deaths due to air pollution, therefore in the current COVID-19 pandemic, the relationship between air pollution and COVID-19 infections is obvious [20].

Comparison of the pollutants level regulated at national level

The comparison of the pollutant levels at national level regulations includes Indonesia, Thailand, Taiwan, USA and Europe. The detailed comparison is shown on Table 3 below.

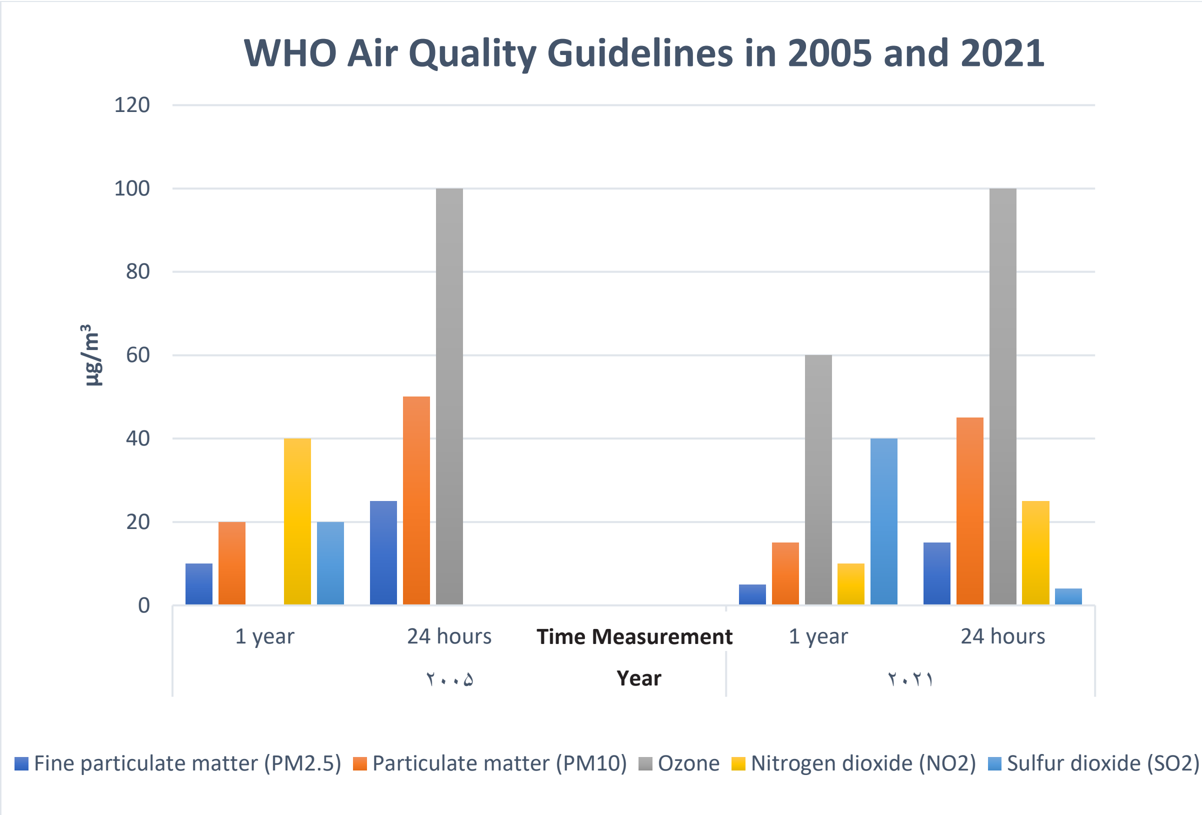

Fig. 2. Parameter pollution of the air quality standard of WHO in 2005 and 2021

As seen, the USA regulates the levels of most pollutants listed above. While almost all compared nations have pollutants levels for $PM_{2.5}$, PM_{10}, CO_2, CO and HCHO, Europe does not. For Indonesia, its regulations do not have levels for several pollutants, such as O_3, NO, Lead, Total Volatile Organic Compounds (TVOC), Total of Bacteria Count. In addition, the level of bacteria in Taiwan is the highest compared to other countries; while for fungi, Indonesia and Taiwan are at the same level and are the highest compared to Thailand.

Comparison of the $PM_{2.5}$, bacteria and fungi regulations at national level

The table below compares $PM_{2.5}$ levels in Indonesia, Vietnam, Singapore and WHO standards. It is seen that, by referring to the Regulation of the Indonesian Ministry of Health, Indonesia's maximum limit is 35 g/m^3 per 24 hours, lower than WHO's target, but slightly higher than Vietnam and Singapore. Field tests are needed to adjust the amount of contaminant according to application level.

Table 3. Comparison of the pollutant levels regulations at national levels

Types of Pollutant	Indonesia	Thailand	USA	Taiwan	Europe
$PM_{2.5}$	35 (max. 24 h)	35 (avg. 8 h)	65 µg/m^3 [24 h]	35	
PM_{10}	≤70 (max. 24 h)	50 (avg. 8 h)	150 µg/m^3 [24 h]	75	
CO_2	1000 (max. 8 h)	1.000 (max. 8 h)	<700 ppm [outdoor condition]	1000 (8h)	
CO	9 (max. 8 h)	9 (avg. 8 h)	9 (avg 8 h)	9 (8h)	90 ppm [15 mins] 50 ppm [30 mins] 25 ppm [1 h] 10 ppm [8 h]
O_3		0.1 (avg. 8 h)	0,05 ppm [8 h]		
SO_2	0.1 (max. within 24 h)	-	0,5 ppm [3 h] 0,14 ppm [24 h] 80 µg/m^3 [1 yr]	-	-
NO	-	-	-	-	-
NO_2	-	-	200 µg/m^3 (annual mean)	-	0,1 ppm [1 h] 0,02 ppm [1 yr]
Formaldehyde	0.1 ppm	-	0,081 ppm [30 min] 76 ppb [1 h] 27 ppb [8 h]	-	0,1 mg/m^3 (0,001 ppm) [15 mins]
Lead	-	-	-	-	0,5 µg/m^3 [1 yr]
HCHO	0.1 (max. 30 secs)	0.1 (avg. 8 h)	0,081 ppm [30 mins] 76 ppb [1 h] 27 ppb [8 h]	0,08	-
TVOC	-	3 (avg. 8 h)	200 µg/m^3	0,56	-
Total of Bacteria Count (CFU/m^3)	-	500	-	1500	-
Total of Fungi Count (CFU/m^3)	1000	300	-	1000	-
Ozone	0.5 (max.)	-	-	0,06	0.064 ppm [1 h] (120 µg/m^3) (8 h)
Total Particles	-	-	-	-	-

*Each country should add the information, such as the standard, unit, and duration.

The table below shows the regulations on the bacteria and fungi as indoor pollutants from Indonesia, Singapore, Vietnam and USA. As seen, there is no specific regulation or guidelines for regulating adhesive bacteria and fungi. Studies have shown that bacteria and fungi are correlated with the COVID-19 [11, 12]), and they can increase the risk of its transmission. Therefore, it is necessary to have additional regulations related to adhesive bacteria and fungi, for example by referring to the measurement standard named JEM1467 in Japan. Performance measurement methods to suppress virus transmission can be done by air purifiers or by measurement of adhesive bacteria, viruses, and/or fungi.

Table 4. The Comparison of $PM_{2.5}$ at national level

	Indonesia	Vietnam	Singapore	WHO
Standard	Ministry of Health Regulation No. 1077/Per/V/2011	TCVN xxx:2020	Singapore Code of Practice for indoor air quality for air-conditioned buildings (SS 554:2016)	WHO Air Quality Guideline 2021 update
Scope	Guidance for households, developers, central-local government, to establish healthier air quality.	Residentials and State buildings to use certain air conditioning equipment.	To all air-conditioned spaces (temporarily or continuously), except housings, factories, hospitals, polyclinics, and laboratories.	WHO Specific Regulation on each pollutant.
$PM_{2.5}$	Max. 35 $\mu g/m^3$ (24 h)	50 $\mu g/m^3$ (avg. 8 h for office buildings. avg. per 24 h for residentials)	max. 37.5 $\mu g/m^3$ (24 h/avg)	avg. 24 h Temp. Target 1: Max. 75 $\mu g/m^3$ Temp. Target 2: Max. 50 $\mu g/m^3$ Temp. Target 3: Max. 37,5 $\mu g/m^3$ WHO AQG (*): Max. 15 $\mu g/m^3$

Table 5. Regulations on bacteria and fungi as indoor pollutants at national level

Countries	Indonesia			Singapore		Vietnam
Standard	The Ministry of Health Regulation No. 1077/Per/V/ 2011 [21]	The Ministry of Health Regulation No. 48, 2016. [22]	Governor's Regulation Air Quality Standard No. 54/2008 [23]	Code of Practice for air-conditioning and mechanical ventilation in building (SS 553:2016 +A1:2017) [24]	Code of Practice for indoor air quality for air-conditioned buildings (SS 554:2016) [25]	TCVN xxx:2020 (draft) [26]
Scope	Guide for households, developers, and central government.	Regulations related to Health and Work Safety	New building and Green Buildings	All offices, commercial buildings, and State buildings, except the health facility.	Buildings with air conditioning, except housing, factories, production, hospitals, laboratories, and others.	Residentials and State buildings that use air conditioning.
Airborne: a. Bacteria b. Fungi	1). 700 cfu/m^3 2). Undefined	1). 700 cfu/m^3 2). 1000 cfu/m^3	1). 700 cfu/m^3 2). Undefined	Undefined	1).1000 cfu/m^3 2) Undefined	1). -Public 1000 cfu/m^3 -Residential 1500 cfu/m^3 2) -Public 700 cfu/m^3 -Residential 500 cfu/m^3
Adhesive a. Bacteria b. Fungi	Undefined	Undefined	Undefined	Undefined	Visual based inspection of fungal pollutants	Undefined

Focus group discussions result

FGDs are conducted specifically to discuss current Indonesian IAQ control and practices, and simultaneously collect data from experts and stakeholders relevant to foci of indoor air. It is revealed that several national-level regulations in Indonesia control IAQ, ranging from the highest which is Indonesian Law to the lowest in Governor level. These regulations are elaborated in Table 6 below.

Table 6. Indonesian Regulations on IAQ

Types of Regulation	Specific Regulations	Subjects
The Indonesian Law	The Indonesian Law No.28/2002	Buildings [27]
	The Indonesian Law No. 06/2017	Architects [28]
	The Indonesian Law No. 11/2020	Job Creation [29]
The Indonesian Government Regulation	The Indonesian Government Regulation No. 16/2021	Law Implementation [30]
	Indonesian President Regulation No. 73/2011	State Buildings Construction [31]
The Regulation of the Indonesian Ministry	The Indonesian Ministry of Health No. 1077/2011	Guidelines on indoor air health improvement [21]
	The Indonesian Ministry of Health No. 48/2016	The Standards of the Office Occupational Safety and Health [22]
	The Indonesian Ministry of Public Works and Housing No. 22/PRT/M/2018	State Building Construction [32]
	The Indonesian Ministry of Public Works and Housing No. 29/PRT/M/2006	Building Technical Requirements Guidelines [33]
	The Indonesian Ministry of Public Works and Housing No. 01/2015	Cultural heritage [34]
	The Indonesian Ministry of Public Works and Housing No. 02/2015	Green building [35]
Governor's Regulation	The Governor Regulation of DKI Jakarta No. 38/2012 on Green Buildings	Green Building [36]
	The Governor Regulation of DKI Jakarta No. 52 /2006	Indoor Air Quality Guidelines (KUDR) [37]
	The Governor Regulation of DKI Jakarta No. 54/2008	Indoor Air Quality Standard (KUDR) [38]

It is also uncovered that these regulations are too general and do not specify air quality parameters that manage indoor pollutants. Almost all of these regulations focus on the comfort of the buildings' occupants, rather than other important aspects, such as health. This has led to the central consideration of health aspects during the FGDs.

The General Chairman at the FGD: Study of the State Buildings' Indoor Air Quality Control in Indonesia, mentioned that health has not yet become the major concern in Indonesia and that a building is not only intended to provide comfort, but also to ensure the health of its occupants. The Regulation of the Indonesian Ministry of Public Works and Housing No. 22/2018 stipulates that in the technical specifications of buildings, the aspects related to air conditioning need to be budgeted as they have approximately 6-10% of the total budget. An adequate ventilation system can ensure the circulation of fresh air in the room and building; therefore, the State Buildings' ventilation must meet the previously regulated system. If it is impossible for the ventilation system installation, it is encouraged to consider applying energy conservation principles. For the placement of ventilation equipment, it should not interfere with the shape of the building and should be adjusted to the function of the building.

Moreover, the FGD General Chairman and a Sub-Coordinator of State Development of the Indonesian Ministry of Public Works and Housing discussed the importance of geographical area for the types of buildings in Indonesia. They suggested that proper tropical buildings with mechanical, natural, and hybrid ventilation systems can be used to reduce the outbreak of COVID-19. Additionally, Sub-Coordinator of State Development of the Indonesian Ministry of Public Works and Housing provided several alternative efforts to ensure the quality of the indoor air in state buildings:

Table 7. The IAQ control efforts in the state building

Control effort	Definition
Building construction approval (PBG)	This permit is granted to building owners to build new, modify, expand, reduce, and/or maintain buildings in accordance with building technical standards.
Functional eligibility certificate (SLF)	This certificate is given by the local government to inform that a building has been guaranteed from the aspect of functional feasibility. This certificate must be obtained by the building owner before use.
Green building certification (BGH)	Green building certification with an area of more than 5,000 m^2 must apply the principles of Green Building.
Technical management	Every State Building construction conducted by the Ministry/institution or regional apparatus organizations must receive technical assistance from the Minister in the form of technical management.

In addition, the implementation of the SLF can be extended if the intended building or building already exists, the process is through an inspection of the function of the building by a Technical Assessment Service Provider for Simple Building. Another effort is by assessing the performance of BGH (Green Building) from seven principles, there are two principles that are most relevant to efforts to control IAQ, namely energy use efficiency and IAQ. These two principles are elaborated in the Table 8 below.

Table 8. Ventilation efficiency and indoor air condition

Ventilation efficiency	Indoor air condition
Ventilation System: Buildings that have rooms with planned air conditioning, without conditioning part or all of passive spaces such as corridors, lobbies, elevators, toilets, and others; and parts of the room equipped with natural and mechanical ventilation, will be able to meet the thermal comfort.	*No Smoking Provision:* There is a commitment from the building management to become a smoke-free building. There are warnings and signs prohibiting smoking in all parts of the building. If a smoking area is available, it is necessary to provide a special area. *Carbon Dioxide (CO_2) and Carbon Monoxide (CO) Control:* -Every room, including a room equipped with an air conditioning system with a ventilation system according to the requirements of SNI 03-6572-2001 or the latest edition, consider measuring the CO_2 and/or CO supply. -Every closed indoor space that has a high density and/or has the potential to cause CO_2 accumulation must be equipped with an alarmed CO_2 sensor and a mechanical ventilation system that operates automatically to keep the comfort threshold of CO_2 concentration (1000 ppm) from exceeding the limit. -Every closed parking area with wall openings of less than 3 sides must be equipped with an alarmed CO sensor and a mechanical ventilation system that operate automatically to keep and maintain the comfort threshold from passing
Air Conditioning System: There is a standard for using Air Conditioning (AC) with a minimum room temperature of 25°C±1°C and a room relative humidity of 60% ±10%. The equipment used is based on SNI 6390:2020 or the latest standard.	*Freezer Control:* -The room is designed not to use air conditioning with refrigerants. -In buildings designed to use cooling devices: If it is a must, choose a machine that uses refrigerant with an Ozone Depletion Potential (ODP) value equal to zero. Air conditioners use refrigerants with the highest Global Warming Potential (GWP) of 700.

The recent FGD: Indoor Air Quality Parameters Testing held on January 14th, 2023, highlighted the need for improved national IAQ management and control due to the current regulations not comprehensively regulating the IAQ parameters. New updated regulations with standardized parameters are needed to be implemented for better national IAQ management and control. GBCI representative highlighted that there is no single IAQ regulation in Indonesia that is considered 'vicious enough'. Indonesia is still dependent on contractors running tests, so it is necessary to review the current national-level IAQ regulations and attempt to revise them according to the acceptable standardized regulation worldwide.

International-level IAQ standards

IAQ has been both an international and national concern. Many International agencies and national-level governments have set their own standards and regulations to control the IAQ implementations. The International agencies, such as ACGIH, ASHRAE, OSHA, NAAQS, NIOSH, US EPA, and WHO, have long been regulating the parameters of indoor air pollutants with each tolerable content level.

Many international agencies conduct quinquennial reviews and updates of IAQ standards. However, it is likely that their standards can also be reviewed and updated based on the current peculiar situation, such as the pandemic. In 2020, ASHRAE specifically developed and updated IAQ guidelines for reducing the risk of COVID-19 transmission [39]. It covers indirect spread risk through resuspension, but other transmission prevention efforts include controlling transmission, optimizing air-flow patterns, pressure zones, ventilation, indoor clean air systems, exhaust ventilation, personal ventilation, at-source local exhaust ventilation, centralized filtration systems, UVGI, and controlling indoor air temperature and humidity. ASHRAE is responsible for designing and operating health facilities and the HVAC (Heating, Ventilation, and Air Conditioning) system modification for non-health facilities. The impact of the HVAC system depends on the source location, strength of the source, spread of aerosol release, droplet size, air distribution, temperature, humidity, and filtration. In 2021, ASHRAE published Recommendations for COVID-19 [40], which not only concerns with ventilation, filtration and air cleaning/purification, but also guidelines for residential buildings considering variations of the residential building constructions, HVAC systems, and climate. The guideline differentiates two types of housing: House with Mechanical Ventilation System and Multi-families House with different provided recommendations. This shows the urgency of IAQ during the outbreak.

Moreover, WHO also published the 2021 IAQ guidelines, which is an updated version of the 2005 guidelines. The parameters in the 2005 guidelines are now irrelevant for the current situation, and the WHO has tightened the threshold for air pollutants by tightening the parameters that can be tolerated from pollutants types that affect the quality of the IAQ. The 2021 WHO air quality guidelines have lower tolerable levels than the 2005 guideline. This is due to the COVID-19 pandemic, which has raised health issues as the main factor in regulating the IAQ. The WHO data accumulated that there are approximately 7 million deaths caused by both indoor and outdoor air pollution, with the highest mortality occurring in Southeast Asia and the Western Pacific. The reduction of air pollution contributes to reducing the impact of climate change and strengthening the quality of health in the community. Although WHO does not specifically update its guidelines for the pandemic, its content is referred and applicable for coping with the current situation.

Both ASHRAE and WHO demonstrate immediate responses toward the current COVID-19 pandemic by keeping updating their guidelines to be more properly applicable to the current global situation. During the pandemic, it is seen that the health aspect in international IAQ standards is highly considered.

National-level IAQ standards and implementation

In terms of the national-level IAQ standards on pollutant levels, several countries worldwide have set their own standards and regulations. The comparative review on Indonesia, Thailand, Taiwan, USA and Europe considering the types of pollutants, such as: $PM_{2.5}$, PM_{10}, CO_2, CO, O_3, SO_2, NO, NO_2, Formaldehyde, Lead, HCHO, TVOC, Total of Bacteria Count, Total of Fungi Count, Ozone and Total Particles, indicates that USA regulates almost all the pollutants level. It is also shown that the USA has the highest $PM_{2.5}$ and PM_{10} for 24 hours pollutants level. In Asian countries, only Thailand and Taiwan regulate the pollutant levels of both Bacteria and Fungi, while Indonesia only covers the Fungi pollutant levels. Europe is the one that does not have much data available, as it only regulates five pollutant levels out of sixteen listed pollutants. Indonesia must refer to the Japanese measurement standard, JEM 1467 [41], which focuses on the adhesive bacteria and fungi, and adjust and adopt other national-level standards particularly on the fungi and bacteria, which have been perceived as infectious aerosols.

Besides the pollutant levels, it is necessary to look at the implementations of the IAQ standards at national level as well. The systematic review includes Indonesia, Malaysia, Singapore, China and Hong Kong (now China), Japan, and European Union, such as: Germany, France, Netherlands, Finland, Belgium, and Austria.

• *Indonesia*

The existing regulations related to IAQ in Indonesia are still fragmented into several levels of national regulations and seem to be separated from one another, such as: The Indonesian Law, The Indonesian Government Regulations, The Indonesian Ministry Regulations, and The Governor's Regulations. They are divided based on the level of governmental structures. The current system and policy-making tendency seem to affect the situation that is until today, they are not fully regulated in detail, enforced, and controlled. Beyond this, the current Indonesian regulations on IAQ still focus on the energy conservation rather than health aspect. The awareness toward health issues on IAQ has just recently been affected by COVID-19 outbreak.

• *Malaysia*

The Malaysian Ministry of Human Resources through The Department of Occupational Safety and Health (DOSH) issued an Indoor Air Quality Code of Practice in 2005, which was followed by a 2010 Indoor Air Quality Code of Practice. The latter focuses on the establishment of acceptable exposure limits for chemical and biological contaminants; determination of acceptable level for certain physical parameters; description of procedures and mechanisms for identifying, evaluating, and controlling the indoor air contaminants; and the other provisions of the appropriate occupational safety and health measures.

The Malaysian Ministry of Health and the Ministry of Human Resources have issued IAQ guideline/s during the COVID-19 pandemic for non-residential buildings. This guide was developed based on the 2010 Industrial Code of Practice on Indoor Air Quality published by the Department of Occupational Safety and Health [42]. There are also other published IAQ guidelines as Malaysian national-level response to the pandemic, such as Guidance Note on Ventilation and Indoor Air Quality for

Residential Setting During COVID-19 Pandemic [43], Guidance Note on Ventilation and Indoor Air Quality for Public Area During COVID-19 Pandemic [44], and Guidance Note on Ventilation and Indoor Air Quality For Healthcare Facilities Setting During COVID-19 Pandemic [45], as well as Guidance Note on Ventilation and Indoor Air Quality For Non-Residential Setting During COVID-19 Pandemic [46].

• *Singapore*

The Government of Singapore has issued a guideline or standard on IAQ, the Singapore Standard Code of Practice for the Indoor Air Quality for The Air-Conditioned Buildings SS 554: 2016. This Code of Practice is currently in the stage of amendment [25]. During the COVID-19 pandemic, the Singaporean Ministry of Health in collaboration with the Agency Building and Development and the Agency National Environment issued guidelines related to air quality with recommended IAQ parameters, their acceptable limits and methods of measurements.

• *China*

China started regulating IAQ in the 1970s focusing on health quality in the working environment as issued in the 1979 Hygienic Standard for Industrial Enterprises Designing (TJ36-1979), which regulated the standards of 111 toxic substances' concentration limits and 9 types of dust. This was then followed by the regulation on the Hygiene Standard of 12 public places issued by the Chinese Ministry of Health in 1988. This, however, does not include the pollutants' concentration limits [47]. Due to the rapid economic development of the 1990s, moreover, another standard on 7 types of pollutants was published: formaldehyde, bacteria, CO_2, PM_{10}, NOx, SO_2, and benzo(a)pyrene issued in 1995.

In 2001, the Chinese Ministry of Health published the Three Hygienic Norms regarding IAQ standards, formaldehyde in wood panels, and solvents and coatings. Subsequently, on January 1, 2002, GB 50352-2001 was promulgated which was the first building code to regulate pollutant levels in buildings. The following year, on March 1, 2003, the government adopted the GB 18883-2002 standard as the first standard related to IAQ and replaced the Hygiene Norms, which is noted that this standard is still valid today in 2021. Standard GB 18883-2002 is an IAQ standard published in collaboration with three agencies, namely the State Administration of Quality Supervision-Inspection-Quarantine, the Ministry of Health and the State Administration of Environmental Protection. This standard was published on November 19, 2002, and came into force on March 1, 2003. This standard is equipped with four attachments, namely technical instructions related to IAQ monitoring, testing methods for benzene concentrations by capillary gas chromatography, testing methods for TVOC by thermal desorption/capillary gas chromatography and methods for examining bacterial colonies in the air (GB/T 18883-2002 Standard for Indoor Air Quality, 2003). The most common pollutant is formaldehyde which is sourced from building materials. Pollution from formaldehyde has been reduced in recent years by limiting the use of HCHO in wood materials through the standard GB 18580 – 2001 In-door decorating and refurbishing materials – Limit of formaldehyde emission of wood-based panels and finishing products. The measurement in 2010-2011 showed that most of the tested materials met the standards [47].

Volatile Organic Compounds (VOC) are commonly found in Chinese buildings. The majority of VOC pollutants encountered were benzene, toluene, and xylene (BTX). The pollution from benzene has been drastically reduced after the enactment of GB 50325-2001, GB 18581-2001, and GB 18583-2001 [48-50]. However, pollution from toluene and xylene is still common, even with concentrations far above the standard due to the absence of strict rules regarding these pollutants [51].

The IAQ in China is also affected by outdoor air. Coal-based industries, power plants, and motorized vehicles produce particulate emissions, such as PM_{10}, which have become a major problem since 2000. PM_{10} can enter buildings through cracks or holes in the building envelope, and the presence of pollutant sources in the room can also cause high concentrations. In winter, heating with fuel can increase the concentration of PM_{10} to a higher value than outside air. PM_{10} and $PM_{2.5}$ are two types of pollutants that have received attention in China. $PM_{2.5}$ is more dangerous than PM_{10} because it can enter the lungs and circulate in the bloodstream. Biological pollutants have also become a concern in the management of IAQ in China, especially after the SARS out-break in 2003. The main focus of the standard is the concentration of biological pollutants in air conditioning and central ventilation systems, considering that these systems can be a means of spreading pathogenic microorganisms. Since 2006, the government has issued hygiene regulations for central air conditioning systems [51].

• *Hongkong (Now China)*

The Government of the Hong Kong Special Administrative Region issued Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places in January 2019. These Guidance Notes provide background information and practical guidance to enable users to prevent and troubleshoot IAQ issues.

This Guidance Notes applies to all buildings or enclosed areas with mechanical ventilation and air conditioning systems for human comfort, except: 1) Household buildings; 2) Medical buildings; 3) Industrial buildings; 4). Any areas or a building part that is constructed, used or intended to be used for: domestic, medical or industrial purposes. 5) Every part of the closed building with no Air Conditioning System, such as storage rooms, factory rooms and electrical rooms. This guidance notes, more-over, must be used as the general guideline document for: the formulation of IAQ policy; designs and services of the buildings for the acceptable IAQ; Operational setting and maintenance procedures; IAQ complaints investigations; IAQ issues reduction if they arise. In addition, this guidance note is not a ventilation standard or detailed manual for assessing indoor air contaminants [52].

• *Japan*

Japan has been paying special attention to indoor air quality since the 1990s due to health issues caused by chemical indoor air pollutants. The IAQ standard regulations of 13 types of chemical pollutants were issued by the Ministry of Health, Labour and Welfare (MHLW) from 1997 to 2002 based on scientific discussions at the Committee on Indoor Air Pollution (CIAP). In 2012, MLWH started to set new IAQ guidelines and CIAP was relaunched. The Japanese Government also issued regulations for emission control and ventilation installation systems in the Standard Building Regulation 2003. Control on air concentration containing chemicals in newly built residentials is regulated in the 2002 housing quality assurance regulation and formaldehyde concentrations in buildings and schools are regulated in the 2002 building sanitation regulation.

• *European Union (EU)*

The European Union resolution on March 13, 2019 highlighted the importance of IAQ due to the majority of people spending 90% of their activities indoors. Research related to IAQ in Europe began to bloom, with France, Italy, Germany, and UK being the countries with the largest contribution. WHO has provided standard IAQ guidelines that describe the number of particular pollutants, such as benzene, nitrogen dioxide, polycyclic aromatic hydrocarbons, naphthalene, carbon monoxide, radon, and trichlorethylene. Other basic elements, such as exposure conditions and population vulnerability, have not been considered for risk assessment purposes.

The European Union has adopted several IAQ standard guidelines, such as NIOSH and OSHA. These standards are often used in the industrial sphere of the EU, such as France, Portugal, Austria, Belgium, Germany, the Netherlands, and Lithonia.

The International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have developed a specific standard EN ISO 1600: Indoor Air, which describes the analytical method of sampling VOC of indoor pollutants. This has resulted in an increase in the exact comparative value of the IAQ data generated at the European countries level, suggesting the importance of guiding IAQ standards. Authors should discuss the results and how they can be interpreted from the perspective of previous studies and working hypotheses. Future research directions may also be highlighted.

Table 9. The IAQ standards and implementations in European countries

Countries	Organizations	Implementation methods
Germany	Federal environmental agency	*Lowest observed adverse effect level* (LOAEL)
	States' health authorities	*Lower level of exposure to a toxic pollutant*
France	French scientific Technical center for construction French agency for environmental and occupational health safety	Develop a standard for 8 types of pollutants, such as *hydrogen cyanide, carbon monoxide, benzene, formaldehyde, trichlorethylene, tetrachlorethylene, naphthalene,* PM_{10} and $PM_{2.5}$. Implementing a fine system. Monitoring is carried out for at least 7 years, if the environment has a high pollutant level, then monitoring is carried out every two years.
Netherlands	The national institute for public health and the environment	*Maximum Permissible Risk* (MPR)
Finland	Ministry of the environment, housing and building department D2 national building code of Finland	Applied formula: $\sum (Ci/(HTP)i) > 0.1$, which *Ci* is the measured concentration of a single pollutant, and HTP is the pollutant exposure limit. Identify target values which are divided into 3 types: S1(individual indoor environment), S2(good indoor environment), S3(satisfactory indoor environment)
Belgium		Develop standard for 15 pollutants: *acetaldehyde, formaldehyde, total aldehyde, benzene, asbestos, carbon dioxide, nitrogen dioxide, toluene, ozone, carbon monoxide, volatile organic compounds, trichlorethylene, tetrachlorethylene,* PM_{10} and $PM_{2.5}$
Austria	The Austrian ministry of environment - The Austrian academy of sciences	Method of the *No-Observed-Adverse-Effect-Level* (NOAEL)

Conclusion

This study found that COVID-19 pandemic lights up the awareness of global IAQ control, particularly in Indonesia. Many national-level governments have started to re-evaluate and renew their air quality control and regulations, and recognized bacteria and fungi as infectious aerosols. The focus is then shifted to health focus, as studies have shown that bacteria and fungi infections on individuals with COVID-19 may lead to fatal health impacts. However, current Indonesian policy on IAQ is fragmented in several national level regulations. They are not specific, often too general, and focus more on energy saving than on the aspect of health. As a result, these types of pollutants have not yet been regulated in Indonesia.

Learning from the pandemic, Indonesia is recommended to consider the potentially applicable IAQ control and regulations implemented in other nations, and the international IAQ standards such as from ASHRAE and WHO which are now considered the Gold Air Quality Standards. They have significant regulatory frameworks that can be referenceable and used to build and develop national-level IAQ control in Indonesia. As suggested to focus more on the health aspect, the IAQ measurement regulation in Japan namely JEM1467, which pays special attention to adhesive bacteria and fungi, can be useful for Indonesia. In addition, Indonesia must consider geographical and climate zone differences when deciding the types of buildings and their codes or standards. International standards and national-level regulations may be slightly or completely different, but they are important for consideration points for regulations that are suitable for Indonesian context.

This article can be a valuable reference that informs policymakers with evidence of IAQ control and practices worldwide for applicable regulatory building and implementations, as well as for health emergency and disaster risk management.

Financial supports

This research was entirely self-financed by the authors.

Competing interests

The authors declare no potential conflict of interest affecting this research.

Authors' contributions

Conceptualization, A.G. and H.H.; methodology, I.M and M.I.A.; validation, H.Y.D., I.M. and B.; formal analysis, N. and B.; investigation, M.I.A. and N; resources, I.M.; data curation, M.N. and M.I.A.; writing—original draft preparation, A.G and M.N.W.; writing—review and editing, A.G. and M.N.W.; supervision, A.G., and H.H.; project administration, H.Y.H.; funding acquisition, A.G. and H.H All authors have read and agreed to the published version of the manuscript.

Acknowledgements

The authors would like thank to SMART CITY Universitas Indonesia by providing facilities for this research.

Ethical considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc.) have been completely observed by the authors.

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