atmosphere

Review

Indoor Air Quality (IAQ) Management in Hong Kong: The Way Forward

Tsz-Wun Tsang , Kwok-Wai Mui and Ling-Tim Wong *

Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, Hong Kong, China; hayley.tsang@polyu.edu.hk (T.-W.T.); horace.mui@polyu.edu.hk (K.-W.M.)
* Correspondence: ling-tim.wong@polyu.edu.hk; Tel.: +852-2766-7783

Abstract: There has been an increasing awareness of indoor air quality (IAQ) management in green building designs, driven by the need to mitigate potential health risks and create sustainable and healthy indoor environments. The COVID-19 pandemic has further highlighted the critical role of ventilation and IAQ in reducing the risk of indoor airborne transmission. Governments and organisations worldwide have responded to this growing concern by implementing ventilation requirements and updating IAQ standards and guidelines. In the case of Hong Kong, a developed and densely populated city characterised by high-rise buildings, this study aims to provide a strategic framework for non-governmental agencies to address IAQ issues effectively. A comprehensive review of policies, regulations, and guidelines by international bodies and individual governments, along with an examination of the current IAQ management scheme in Hong Kong, has been conducted. Drawing inspiration from successful IAQ management strategies, the study aims to identify insights and potential pathways for the city's future development of IAQ management strategies. Overall, this research highlights the importance of proactive IAQ management for buildings and offers a roadmap for Hong Kong's pursuit of healthier indoor environments.

Keywords: indoor air quality (IAQ); policies; regulations; management; guidelines

Citation: Tsang, T.-W.; Mui, K.-W.; Wong, L.-T. Indoor Air Quality (IAQ) Management in Hong Kong: The Way Forward. *Atmosphere* **2024**, *15*, 546. https://doi.org/10.3390/atmos15050546

Academic Editors: Marta Gabriel and Manuel Feliciano

Received: 31 March 2024
Revised: 22 April 2024
Accepted: 26 April 2024
Published: 29 April 2024

1. Introduction

In recent years, there has been a significant increase in public awareness and concern regarding indoor air quality (IAQ) due to the substantial amount of time spent indoors [1,2]. The global COVID-19 pandemic has further amplified these concerns, as the inadequacy of building ventilation has been associated with the spread and outbreak of pathogens. The World Health Organisation (WHO) has highlighted the detrimental impact of household air pollution caused by prolonged exposure to high air pollutants from cooking and heating with coal and kerosene. These pollutants were responsible for over 3.2 million deaths worldwide in 2020, primarily attributed to diseases such as ischemic heart disease, stroke, lower respiratory infections, and chronic obstructive pulmonary disease (COPD) [3].

Even in developed countries and cities where solid fuels are rarely used and are discouraged in enclosed environments, IAQ problems continue to threaten public health. Poor IAQ has been associated with a range of health effects, from mild short-term irritations and dizziness to long-term chronic conditions, including cancer [4–11]. In the case of Hong Kong, the high air humidity brought by the summer monsoon from the South China Sea contributes to substantially high levels of airborne bacteria (ABC) and unsatisfactory IAQ in offices [12]. Additionally, the use of volatile organic compound (VOC)-containing products like wall paints and printing inks has made total volatile organic compounds (TVOC) the primary contributor to poor IAQ in the city [12].

The battle against IAQ issues in Hong Kong began in 1989 when the 'White Paper on Pollution' first addressed indoor air pollution. Subsequent research assessed IAQ in 70 air-conditioned offices and street-level shops, revealing the lack of IAQ management and poor

IAQ conditions in Hong Kong in 1990. This research finding led the government to address the health effects and economic losses resulting from poor IAQ in the 'Second Review of the 1989 White Paper on Pollution in Hong Kong' [13,14]. In 1991, the Environmental Protection Department (EPD) proposed the Hong Kong Interim IAQ Guidelines, followed by a consultancy study on IAQ in offices and public places in 1995 [15,16]. The EPD established the Indoor Air Quality Management Group (IAQMG) in 1998 to plan IAQ-related policies and management strategies to improve IAQ overall.

A significant milestone in IAQ management was achieved when the IAQMG introduced an IAQ Management Programme in 1999. This program aimed to raise awareness through educational and publicity campaigns, with the establishment of the cyber IAQ Information Centre to provide public access to IAQ-related information. Since 2003, IAQ objectives, the 'Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places' (hereafter the Guidance Note) and the voluntary 'IAQ Certification Scheme for Offices and Public Places' (hereafter the IAQ Certification Scheme), have been endorsed [17]. In 2019, the EPD updated the IAQ objectives in the Guidance Notes and the IAQ Certification Scheme, incorporating the latest IAQ guidelines from the WHO and introducing additional parameters such as mould and tightened exposure levels for carbon monoxide (CO), dust (PM_{10}), radon (Rn), formaldehyde (HCHO), and nitrogen dioxide (NO_2) [18].

With the financing and insurance sectors contributing significantly to Hong Kong's GDP [19], there is a growing demand for office development in non-traditional business districts and expanding the central business district (CBD). A substantial increase in private office completions is expected in the following years, along with a rise in the number of offices certified under the IAQ Certification Scheme [20]. Luxury offices and the private commercial sector are also seeking alternative ways to monitor IAQ, aiming to provide an indoor environment that exceeds local standards. Major developers in Hong Kong are acquiring building certifications such as the WELL Building Standard (WELL) and Leadership in Energy and Environmental Design (LEED) to enhance their business reputation and improve their Environmental, Social, and Governance (ESG) performance. These initiatives demonstrate their commitment to sustainability and further promote the adaptation of smart solutions for monitoring and improving IAQ.

Currently, the responsibility for initiating IAQ management rests mainly with the building developers. Several building developers have taken the initiative to employ IoT-based real-time air quality sensors for continuous monitoring of environmental parameters such as temperature, relative humidity (RH), carbon dioxide (CO_2), dust, and other relevant pollutants [21–24]. While these systems monitor and understand IAQ conditions, it remains unclear whether the collected data is being effectively analysed to drive further IAQ improvements.

This situation reveals a lack of clear direction in developing IAQ management practices in Hong Kong. While building developers are willing to address IAQ concerns, there is uncertainty about effectively implementing strategies for improvement. Consequently, there is a need for guidance and practical frameworks to assist building developers in utilising the collected IAQ data to drive meaningful IAQ enhancements and achieve their sustainability goals. Given the trend in Hong Kong towards raising IAQ standards beyond the acceptable level, this study aims to provide a strategic framework for non-governmental agencies in the city to address IAQ problems effectively. The paper begins by reviewing policies, regulations, and guidelines issued by selected government bodies and non-governmental organisations worldwide in response to IAQ issues. Countries and cities with similar stages of development and proximity to Hong Kong are chosen for comparison. The current IAQ management scheme in Hong Kong is then examined and evaluated, followed by a discussion on the city's future development of IAQ management strategies.

2. Regional Responses to IAQ Problems

Figure 1 presents a global map highlighting regions with numerical national IAQ standards based on the review by Morawska and Huang [25] and updates from the current review. In addition to previous efforts, this review goes beyond summarising IAQ standards and provides an in-depth understanding of regional responses to the IAQ problem by examining policies, regulations, and guidelines. The relevant information on existing strategies and measures implemented in the selected places is obtained from the literature, corresponding web pages, and other open sources. Tools like Google Translation are adopted to understand non-English or non-Chinese information content. In this section, places including Australia, China, Japan, South Korea, Taiwan, and individual state members of the European Union (EU) are studied, and their tactics for IAQ problems are briefly summarised. The IAQ response from the WHO, an international health agency of the United Nations (UN), is also outlined. Table 1 summarises all the IAQ standards reviewed in this study.

2.1. Australia

The Australian government has put substantial efforts into combating IAQ problems. The National Health and Medical Research Council (NHMRC) had previously recommended 'Interim National Indoor Air Quality Goals' in 1996. [26]. The interim goals suggested maximum permissible levels of indoor air pollutants, including carbon monoxide (CO), formaldehyde (HCHO), lead (Pb), ozone (O_3), radon (Rn), sulphate (${SO_2}^{-4}$), sulphur dioxide (SO_2), total suspended particulates (TSP), and total volatile organic compounds (TVOC). However, these goals were rescinded in 2002 and no longer apply in Australia. In 2001, the Australian government published the 'State of Knowledge Report: Air Toxics and Indoor Air Quality in Australia', which provides information on IAQ problems, the effects of poor IAQ, and IAQ management guidelines [27].

In 2016, the Australian Building Codes Board (ABCB) introduced updates to the 'National Construction Code (NCC)', a mandatory performance-based code that sets the minimum required level for safety, health, amenity, accessibility, and sustainability in buildings. The 2016, the NCC introduced the verification methods for "adequate" or "acceptable" air quality, which consider the occupants' health and comfort [28]. It specifies the minimum acceptable contaminant limits for IAQ covering CO_2, CO, HCHO, nitrogen dioxide (NO_2), particulate matter ($PM_{2.5}$ and PM_{10}), and TVOC, which are used to determine compliance of a building solution with the NCC ventilation performance requirements. The ABCB also issued the 'Indoor Air Quality Verification Methods Handbook' to provide building and construction practitioners with a better understanding of the design, construction, and certification of new buildings using the suggested IAQ verification methods. The handbook has been updated to align with the latest scientific evidence to address the impact of the COVID-19 pandemic on building ventilation requirements [29].

Although the Australian government recognises IAQ problems, there are currently no specific legislated standards for IAQ in the country. However, exposure standards for a range of chemicals in industrial environments have been set by the National Occupational Health and Safety Commission (NOHSC) to ensure a safe working environment. NCC performance requirements provide a clear pathway for compliance with performance solutions, such as delivering outdoor air and controlling odours and harmful contamination using mechanical ventilation. It is worth noting that verification methods are voluntary. Given the variations in the exposed population, including vulnerable groups such as children and elders, these IAQ guidelines are typically more stringent than occupational standards and align with ambient air quality standards.

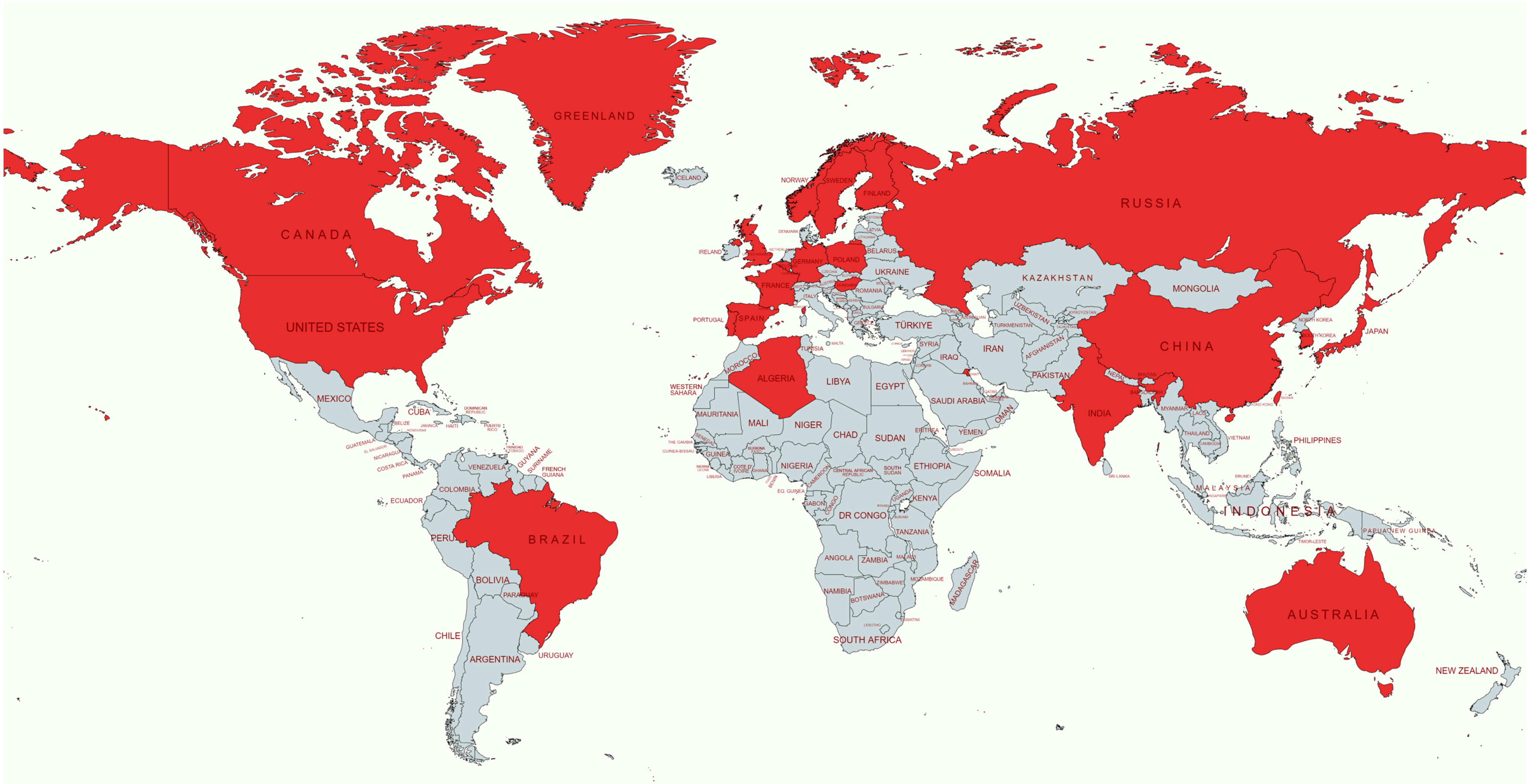

Figure 1. Regions with IAQ standards highlighted in red. Footnote: individual states within the United States may have their own IAQ standards.

Table 1. IAQ management policies and standards.

		Parameter	Temp	RH	Air Velocity	CO_2		CO								O_3		Rn
Place/ Organisation	**IAQ management policies**	unit	°C	%	m/s	ppm	%	µg/m^3				ug/m^3				ppm	µg/m^3	Bq/m^3
		Averaging time	-	-	-	8 h		15 min	1 h	8 h	24 h	15 min	30 min	1 h	8 h	8 h	8 h	8 h
Australia	National Construction Code	-	-	-	-	850		-	-	-	-	90	50	25	10	0.0473	100	-
China	Hygiene Indicators and Limits for Public Places	-	16–20 (winter) 26–28 (summer)	40–65	<0.5	-	0.15	-	-	10,000	-	-	-	-	-	-	160	400
Finland	Classification of Indoor Climate, Construction Cleanliness, and Finishing Materials	Individual indoor climate (S1)	-	-	-	350 above outdoor		-	-	-	-	-	-	-	-	-	-	100
		Good indoor climate (S2)	-	-	-	550 above outdoor		-	-	-	-	-	-	-	-	-	-	100
		Satisfactory indoor climate (S3)	-	-	-	800 above outdoor		-	-	-	-	-	-	-	-	-	-	200
Germany	Indoor Air Guide Values (selected)	Hygiene guide values	-	-	-	1000 [a]		-	-	-	-	-	-	-	10	-	-	-
			-	-	-	1000–2000 [b]		-	-	-	-	-	-	-	-	-	-	-
			-	-	-	>2000 [c]		-	-	-	-	-	-	-	-	-	-	-
Hong Kong	IAQ Certification Scheme	Excellent class	-	-	-	800		-	-	2000	-	-	-	-	1.7	0.025	50	150
		Good class	-	-	-	1000		-	-	7000	-	-	-	-	6.1	0.061	120	167
Japan	Building Sanitation Act	-	18–28	40–70	<0.5	1000		-	-	-	-	-	-	-	6	-	-	-
South Korea	Indoor Air Quality Control Act	Sensitive group	-	-	-	1000 *		-	-	-	-	-	-	-	10 *	-	-	148
		General environment	-	-	-	1000 *		-	-	-	-	-	-	-	10 *	-	-	148
		Apartment complex	-	-	-	-		-	-	-	-	-	-	-		-	-	148
Taiwan	Indoor Air Quality Management Act	-	-	-	-	1000		-	-	-	-	-	-	-	9	0.06	-	-
World Health Organisation	WHO Guidelines for Indoor Air Quality: Selected Pollutants	-	-	-	-	-		100,000	35,000	10,000	700	-	-	-	-	-	-	167 [d]

		Parameter	HCHO						TVOC				Bacteria		Fungi/ Mould
Place/ Organisation	**IAQ management policies**	unit	µg/m^3			ppm			µg/m^3		ppm		CFU/m^3		CFU/m^3
		Averaging time	0.5 h	1 h	8 h	0.5 h	1 h	8 h	1 h	8 h	1 h	8 h	8 h	max	max
Australia	National Construction Code	-	100	-	-	-	-	-	500	-	-	-	-	-	-
China	Hygiene Indicators and Limits for Public Places	-	-	100	-	-	-	-	600	-	-	-	-	4000 (1500 [e])	-
Germany	Indoor Air Guide Values (selected)	Precautionary guide value (GV I)	-	100	-	-	-	-	-	-	-	-	-	-	-
		Hygiene guide values	-	-	-	-	-	-	300 [f]	-	-	-	-	-	-
			-	-	-	-	-	-	300–1000 [g]	-	-	-	-	-	-
			-	-	-	-	-	-	1000–3000 [h]	-	-	-	-	-	-
			-	-	-	-	-	-	3000–10,000 [i]	-	-	-	-	-	-
			-	-	-	-	-	-	>10,000 [j]	-	-	-	-	-	-

Table 1. *Cont.*

		Parameter	HCHO						TVOC				Bacteria		Fungi/ Mould
Place/ Organisation	**IAQ management policies**	unit	μg/m^3			ppm			μg/m^3		ppm		CFU/m^3		CFU/m^3
		Averaging time	0.5 h	1 h	8 h	0.5 h	1 h	8 h	1 h	8 h	1 h	8 h	8 h	max	max
Hong Kong	IAQ Certification Scheme	Excellent class	70	-	0.03	0.057	-	0.024	-	200	-	0.087	500	-	Prescriptive checklist
		Good class	100	-	0.1	0.081	-	0.081	-	600	-	0.261	1000	-	-
Japan	Building Sanitation Act	-	-	100	-	-	0.08	-	-	-	-	-	-	-	-
	Guidelines for Indoor Air Quality (selected)	-	-	100	-	-	0.08	-	400	-	-	-	-	-	-
South Korea	Indoor Air Quality Control Act	Sensitive group	-	80 *	-	-	-	-	400	-	-	-	-	800 *	500
		General environment	-	100 *	-	-	-	-	500	-	-	-	-	-	-
Taiwan	Indoor Air Quality Management Act	-	-	-	-	-	0.08	-	-	-	0.56	-	-	1500	1000
World Health Organisation	WHO Guidelines for Indoor Air Quality: Selected Pollutants	-	100	-	-	-	-	-	-	-	-	-	-	-	-

		Parameter	PM$_{10}$			PM$_{2.5}$		NO$_2$					
Place/ Organisation	**IAQ management policies**	unit	ug/m^3			ug/m^3		ug/m^3			ppm		
		Averaging time	8 h	24 h	1 yr	24 h	1 yr	1 h	8 h	1 yr	1 h	8 h	1 yr
Australia	National Construction Code	-	-	50	20	25	10	200		40	0.099		0.0197
China	Hygiene Indicators and Limits for Public Places	-	-	150	-	-	-	-	-	-	-	-	-
Finland	Classification of Indoor Climate, Construction Cleanliness, and Finishing Materials	Individual indoor climate (S1)	-	-	-	10	-	-	-	-	-	-	-
		Good indoor climate (S2)	-	-	-	10	-	-	-	-	-	-	-
		Satisfactory indoor climate (S3)	-	-	-	25	-	-	-	-	-	-	-
Germany	Indoor Air Guide Values (selected)	Precautionary guide value (GV I)	-	-	-	-	-	-	-	-	0.08	-	-
		Hazard guide value (GV II)	-	-	-	-	-	-	-	-	0.25	-	-
		Hygiene guide values	-	-	-	15	-	-	-	-	-	-	-
Hong Kong	IAQ Certification Scheme	Excellent class	20	-	-	-	-	100	40		0.053	0.021	-
		Good class	100	-	-	-	-	200	150		0.106	0.08	-
Japan	Building Sanitation Act	-	-	150	-	-	-	-	-	-	-	-	-
South Korea	Indoor Air Quality Control Act	Sensitive group	-	75 *	-	35 *	-	-	-	-	-	-	-
		General environment	-	100 *		50 *	-	-	-	-	0.05	-	-

Table 1. *Cont.*

		Parameter	PM_{10}			$PM_{2.5}$		NO_2					
Place/ Organisation	**IAQ management policies**	unit	ug/m^3			ug/m^3		ug/m^3			ppm		
		Averaging time	8 h	24 h	1 yr	24 h	1 yr	1 h	8 h	1 yr	1 h	8 h	1 yr
Taiwan	Indoor Air Quality Management Act	-	-	-	-	-	-	-	-	-	0.1	-	-
World Health Organisation	WHO Guidelines for Indoor Air Quality: Selected Pollutants	-	-	75	-	35	-	200	-	40	-	-	-

[a] hygienically safe; no action. [b] hygienically noticeable; ventilation (outdoor air flow rates or increasing air change) is proof of ventilation habits and improvement. [c] hygienically unacceptable; proof of ventilation options and further measures were reviewed. [d] the radon concentrations associated with an excess lifetime risk of 1/100 and 1/1000 are 67 and 6.7 Bq/m^3 for current smokers and 1670 and 167 Bq/m^3 for lifelong non-smokers, respectively. [e] for sleep and rest area. [f] hygienically safe. [g] hygienically still safe if indoor air guide values are not exceeded for single substances or substance groups. [h] hygienically noticeable. [i] hygienically unacceptable. [j] hygienically alarming. * maintenance standard.

2.2. China

China is one of the few places with mandatory public policies addressing IAQ problems. In 1996, the Chinese government issued the 'Hygienic Standards for Public Places (GB9663–GB9673, 16153-1996)', which governed the sanitary requirements for environmental conditions, IAQ, water quality, mechanical ventilation, and public utilities in various public places such as hotels, swimming pools, sports facilities, libraries, and malls. These standards specified the required exposure limits for parameters such as CO, CO_2, HCHO, TSP, and airborne bacteria (ABC) in public places [30–40]. The 'Hygiene Management Specification for Public Places (GB 37487-2019)', introduced in 2019, replaced the previously separate standards by using a unified 'Hygiene Indicators and Limits for Public Places (GB37488-2019)' to regulate hygiene requirements [41,42]. These standards are legally enforced through laws and administrative regulations to enhance the protection of human health, personal property, and safety.

In 2002, the Chinese government published the 'Indoor Air Quality Standard (GB/T18883-2002)', a recommended national standard to improve China's IAQ management and safeguard public health. This standard included four physical parameters (temperature, RH, air velocity, and fresh air rate), thirteen chemical parameters (such as SO_2, NO_2, CO, CO_2, ammonia (NH_3), O_3, HCHO, benzene (C_6H_6), toluene (C_7H_8), ethylbenzene (C_8H_{10}), PM_{10}, TVOC, and benzo(a) pyrene), one biological IAQ parameter ABC, and one radioactive parameter Rn [43]. The standard also provided comprehensive requirements and protocols for IAQ measurements, including sampling points and locations, sampling methods, and sampling conditions. An updated version of this standard was released in 2022, which introduced amendments to definitions, terminologies, sampling protocols, and the inclusion of $PM_{2.5}$, tetrachloroethylene (C_2Cl_4), trichloroethylene (C_2HCl_3), as well as updates to the exposure limits for specific parameters [44]. These exposure limits cover a broader range of IAQ parameters and are more stringent than those stated in the mandatory standard.

2.3. Europe

In 2007, the Scientific Committee on Health and Environmental Risks (SCHER) of the European Commission (EC) published the 'Opinion on Risk Assessment on Indoor Air Quality' to identify IAQ risk assessment strategies. However, it did not provide guidelines or suggestions for risk management and mitigation [45]. The EC does not establish an official IAQ standard or promulgate any IAQ policy. Instead, the EU adopts the 'WHO guidelines for indoor air quality: selected pollutants' issued by the WHO [18], which will be discussed later. Within the EU, mandatory limits for Rn are the only legally set IAQ requirements.

2.3.1. Finland

Certain EU member states have taken initiatives to address IAQ problems in their respective regions [46]. Finland, for example, issued the first IAQ guideline in 1990, providing guidance on maintaining a suitable living environment in apartment buildings [47]. Under the 'Health Protection Act' and the 'Indoor Air Guidelines' published in 1997, responsible parties must take remedial measures against health hazards caused by poor IAQ. In impoverished IAQ situations, the usage of premises may be prohibited [48,49].

The Finnish Society of Indoor Air Quality and Climate (FiSIAQ), a non-governmental association that promotes healthy and comfortable IAQ and climate, introduced the voluntary-based 'Classification of Indoor Climate, Construction Cleanliness, and Finishing Materials' in 1995. This classification system sets target values for IAQ and climate, provides guidelines for design and construction, and classifies building materials based on their emissions. The system categorises indoor spaces into three categories: S1 (individual indoor climate), S2 (good indoor climate), and S3 (satisfactory indoor climate), with S1 and S2 exceeding the regulatory requirements for new buildings, aiming for better IAQ and climate [50]. This classification system is well-known in the Finnish construction industry, and studies have shown that the target values are realistic and technically and economically achievable [51].

2.3.2. Germany

In Germany, the government addressed IAQ problems and the need for recommended indoor air pollutant values in 1992 by publishing the 'Concept of the German Federal Government for Better Indoor Air Quality'. Subsequently, an ad hoc group was formed to prepare recommendations on IAQ matters [52,53]. While there is legislation controlling only four indoor contaminants (polychlorinated biphenyls (PCBs), phencyclidine (PCP), asbestos fibres, and tetrachloroethene) [54], IAQ-related issues in Germany are managed through building codes, which are regulations designed to protect occupants from health hazards.

The German Committee on Indoor Air Guide Values (AIR) establishes health- and hygiene-based guide values that allow for a health-related assessment of substance concentrations in indoor air. The guide provides two guide values: guide value I (precautionary guide value), which suggests a pollutant value that does not cause adverse health effects under lifelong exposure, and guide value II (hazard guide value), which is an effect-related value based on current toxicological and epidemiological knowledge. Guide value II indicates a concentration at and above which immediate action is required due to potential health threats. Guide value II is correlated with the building codes of the federal states in Germany, which stipulate that structures must be designed to prevent hazards from chemical, physical, or biological impacts. The AIR also derives hygiene and risk-related guide values for selected pollutants without toxicological evidence and carcinogenic chemicals in indoor air. Additionally, it provides odour guide values for addressing odour annoyance and complaints. The guide values are regularly updated based on new scientific and analytical findings, with the most recent updates made in 2023 [55].

2.4. Japan

The Japanese government has recognised the importance of addressing Sick Building Syndrome in indoor environments [56]. To ensure a hygienic environment and promote public health, they have implemented the 'Act on Securing a Hygienic Environment in Buildings' (Act No. 20 of 1970), commonly known as the 'Building Sanitation Act'. This act establishes standards for building environmental sanitation management, including air conditioning and water supply management measures. Its purpose is to maintain specified buildings in good environmental and sanitary conditions. Regarding IAQ, the Building Sanitation Act requires regular air environment measurements to be conducted once every two months to ensure that the IAQ meets the Building Environmental Sanitation Management Standards. Failure to comply with these regulations can result in fines or imprisonment [57].

In addition to legal enforcement, the Ministry of Health, Labour and Welfare manages a study group dedicated to addressing IAQ issues. They have published the 'Guidelines for Indoor Air Quality' to address public complaints and concerns about indoor pollutants, such as solvents in adhesives or paints, insect deterrents, and deodorants. These guidelines cover 14 indoor air pollutants, including HCHO, TVOC, and volatile organic compounds. The guideline values are based on the most recent available toxicological data, with the latest update being in 2019 [58].

2.5. South Korea

South Korea has implemented legislation to regulate IAQ. In 1990, the 'Clean Air Conservation Act' was promulgated to control pollutants emitted from workplaces and vehicles [59]. Recognising the increasing importance of IAQ, the South Korean government revised the 'Air Quality Control in Underground Location Act', initially sanctioned by the Ministry of Environment in 1996, into the 'Indoor Air Quality Control in Public Use Facilities, etc. Act', which came into effect in 2004 [60]. Most recently, in 2024, it was updated and renamed as the 'Indoor Air Quality Control Act'. This act applies to public indoor spaces, including libraries, shopping malls, and medical facilities. It establishes two levels of control: maintenance standards for general indoor facilities and recommended standards for sensitive groups such as elderly care facilities and day-care centres. Penalties are imposed for any violation of the maintenance standards without appropriate improvements within a given period [61].

2.6. Taiwan

Taiwan is another region that has implemented regulations to control and manage IAQ. As early as 2005, the Taiwan Environmental Protection Administration issued the 'Suggested Values for Indoor Air Quality', which provides exposure limits for 10 IAQ parameters [62]. In 2012, the Legislative Yuan passed the third reading to expand the scope of the 'Air Pollution Control Act' to include the 'Indoor Air Quality Management Act'. This extended act applies to nearly all indoor environments, including enclosed and semi-closed spaces. Under the act, building owners and facility managers are responsible for managing and maintaining IAQ. Penalties can be imposed if they fail to comply with the regulations. Public places with high occupant flow, such as shopping malls and sports facilities, are required to install real-time IAQ monitoring systems that display the results at the main entrance or foyer of the buildings [63].

2.7. World Health Organisation

WHO published the 'WHO Guidelines for Indoor Air Quality: Selected Pollutants' in 2020. These guidelines offer essential guidance for preventing health risks associated with exposure to indoor air pollutants. They serve as a scientific foundation for decision-making in environmental and public health management, as well as the design and management of individual facilities. The standards outlined in the guidelines address commonly found hazardous chemicals in enclosed environments, such as C_6H_6, CO, HCHO, and more. The booklet provides detailed information on their indoor sources, toxicities, exposure pathways, and health risk guidelines for controlling pollutant levels [18].

In addition, the WHO also published the 'WHO Guidelines on Dampness and Mould' in 2009 [64] and the 'WHO Guidelines for Indoor Air Quality: Household Fuel Combustion' in 2014 [65]. These two guides offer qualitative recommendations for managing mould and dampness in buildings and provide the best approaches for reducing household air pollution [25].

2.8. Summary of Regional IAQ Policies

Most reviewed IAQ standards are legally binding, except for in Finland and Germany. In some cases, the standards apply only to specific indoor environments or new and renovated buildings, as seen in Australia's National Construction Code. Legal requirements typically mandate regular or periodic checking of IAQ, and only Taiwan has legislation specifically requiring the installation of real-time IAQ monitoring systems. In addition to legislation, government departments or non-governmental professional bodies sometimes issue voluntary-based recommended IAQ standards. These voluntary standards provide more comprehensive coverage of IAQ parameters and offer multiple levels of compliance.

It is important to note that not all standards and guides provide recommendations for sampling protocols and methods, as shown in the Supplementary Materials. Additionally, the requirements for instrument specifications, detection method, and calibration for sampling are not always detailed.

Among the IAQ parameters of concern, comfort parameters such as temperature, RH, and air velocity are only included in Japan's Building Sanitation Act as part of the IAQ evaluation. CO_2 requirements are established in most standards, except for the WHO guidelines, based on health risks associated with pollutants. Rn is the second most addressed IAQ parameter, followed by PM_{10} and $PM_{2.5}$.

It is worth noting that different IAQ standards and guidelines utilise different units and averaging times, making direct comparisons challenging. Nonetheless, this review provides an overview of the progress in IAQ management within the selected regions, serving as guidance for establishing a framework in Hong Kong.

3. Review of the Guidance Notes and the IAQ Certification Scheme

3.1. Background

The Guidance Notes are valuable for facility management and building owners of places equipped with mechanical ventilation and air-conditioning (MVAC) systems. These guidelines provide non-legally binding technical advice based on international standards for managing and improving IAQ. The document covers various aspects of IAQ management, including ventilation system management, IAQ assessment, and strategies for IAQ management. It also comprehensively discusses multiple approaches to achieve IAQ objectives in case IAQ problems are identified [66]. Overall, the Guidance Notes serve as blueprints for individual IAQ management, allowing commercial and industrial sectors to proactively manage and enhance IAQ at their own expense.

One of the core tasks in the Guidance Notes is the IAQ Certification Scheme, which is implemented by the IAQMG. The IAQ Certification Scheme is a voluntary program with two levels of accreditations: excellent class and good class. It benchmarks premises equipped with MVAC systems against the IAQ Objectives for Office Buildings and Public Places. The current IAQ objectives cover eight indoor air pollutants, including CO_2, TVOC, PM_{10}, CO, NO_2, O_3, HCHO, and Rn, and two biological agents, ABC and mould [67]. Table 1 provides the standards for the two classes.

Despite the comprehensive IAQ management strategies outlined in the Guidance Notes, there has been an increase in IAQ complaints received by the government over the years, as indicated in Table 2 [68]. The data presented does not include complaints from individual building management regarding IAQ issues, as such data is generally not publicly available. It is also concerning to note the low participation in the IAQ Certification Scheme, with only 2394 certified premises in 2024. Among these, more than 40% of the applicants are government bodies. It is worth mentioning that 3% of the accredited locations are common areas such as lift lobbies, corridors, and main entrances, where people stay temporarily. Table 3 presents the statistics of certified premises as of 26 March 2024, obtained from the official database of the IAQ Certification Scheme [68]. It is important to note that the IAQ Certification Scheme does not disclose the detailed IAQ data for each certified premises. Only limited information is available to the public, such as the building's name, address, type of premises, certified location, and the obtained certification class.

Table 2. IAQ complaints data in Hong Kong.

	2012	2014	2017	2022
Poor ventilation	161	110	185	134
Temperature	182	385	567	409
Dust	26	70	16	6
Odour	134	114	48	83
Toxic chemicals	21	14	11	11
Fungi/mould	17	7	13	2
Without specific nature	17	6	30	31
Total	558	706	870	676

The low participation rate in the IAQ Certification Scheme indicates a lack of incentive to conduct IAQ assessments and effectively manage IAQ. This weak motivation can be attributed to various reasons suggested in the existing literature, which are detailed in the next section.

Table 3. Statistics of certified premises as of 26 March 2024.

Certification Class	**Number**	**Percentage**
Excellent	648	27%
Good	1745	73%
Type of applicant		
Government	978	41%
Non-government bodies	1205	50%
Education	104	4%
Statutory body	40	2%
Subverted body	66	3%
Type of certified premises		
Commercial sector (Shopping mall, Restaurant, Hotel, Bank)	395	17%
Education sector (School)	99	4%
Recreational facilities (Leisure and sports facility, Exhibition/Convention, Clubhouse, Theatre, Cultural facility, Library)	434	18%
Government and Public Service Facilities (Police station, Fire and ambulance facility, Law court, Correctional facility, Social welfare facility, Community hall, Post office)	270	11%
Healthcare facilities	39	2%
Transport facility	7	0%
Office spaces	1097	46%
Residential premises	30	1%
Others	22	1%

3.2. Voluntary Basis, High Implementation, and Improvement Cost

The IAQ Certification Scheme operates voluntarily without a guaranteed benefit to the business, which presents challenges in motivating participation. Implementing the certification process incurs significant costs. Burnett estimated that certifying a 40-storey building could cost around HKD 40,000 [69]. While IAQ assessments have become less expensive over time, with some certifying agencies offering competitive pricing per sampling point, the certification process still demands substantial resources and time. The expenses can be particularly burdensome for small- and medium-sized enterprises (SMEs). Businesses may be less inclined to participate in the scheme without financial support or incentives.

On the other hand, improving IAQ can come at a significant cost. For example, a common IAQ issue in Hong Kong is elevated CO_2 levels due to high occupancy. However, reducing 200 ppm from the existing indoor CO_2 level by increasing the air change rate to introduce fresh air requires an additional 5–10% of operational energy [12]. These substantial costs associated with IAQ improvements can hinder SMEs from adopting effective IAQ management strategies.

3.3. Stringent IAQ Standards

Doubts and questions have been raised regarding the standards adopted in the IAQ Certification Scheme. The rationale behind the selection of IAQ parameters and exposure limits is not clearly defined. For specific parameters like CO_2, exceeding the exposure limit in the standard does not necessarily imply a health hazard. Failing the IAQ Certification Scheme does not necessarily indicate a health impact. While the amended standards have removed parameters related to human comfort [70], some values have become even more stringent than before.

3.4. Lack of Flexibility in the Assessment Procedure

The industry has criticised the lack of flexibility in the measurement method used for IAQ assessments. Technical difficulties and uncertainties in the assessment process have been reported. Lengthy sampling durations and high sampling point densities may disrupt occupants during the assessment period. Alternatively, some new offices undergo the certification process before tenants move in to avoid disturbances, which may not fully reflect the IAQ conditions during occupancy caused by human activities. Various research studies have proposed alternative sampling schemes with shorter durations and simplified procedures [71,72]. These alternative methods have demonstrated accurate assessment results with fewer resources invested.

4. Potential Future Development of IAQ Policy in Hong Kong

4.1. Implementing Territory-Wide IAQ Screening

Implementing territory-wide IAQ screening is crucial in developing an effective IAQ policy for Hong Kong. There are three primary reasons for conducting IAQ screening:

1. Preliminary identification of places with potential IAQ problems: IAQ screening helps identify locations with underlying IAQ issues, allowing for targeted investigations and interventions.
2. Establishment of an IAQ profile for different indoor environments: Conducting screening across various indoor environments in Hong Kong helps create an IAQ profile specific to each setting. This profile provides valuable insights into the general IAQ conditions and can guide policy decisions and interventions.
3. Identification of specific IAQ problems in individual environments: IAQ screening enables the identification of specific IAQ issues present in each particular environment, allowing for focused mitigation strategies and interventions.

Simple yet effective and repeatable screening tools can be incorporated into a territory-wide IAQ screening program instead of investing extensive resources into exhaustive IAQ investigations. Well-developed IAQ screening tools are available and are believed to reduce the resources required for managing IAQ effectively. Two approaches are proposed for IAQ pre-assessment:

1. The indicator approach utilises key IAQ indicators to represent the overall air quality in an indoor environment. Measuring indicators such as CO_2, TVOCs, and particulate matter provides information about general IAQ conditions and helps identify potential issues.
2. The health-risk approach evaluates the potential health risks associated with the IAQ in a particular environment. It considers factors such as the level of specific pollutants, toxicology and epidemiological data, and the associated health effects.

4.2. IAQ Index with Surrogate Indicators (IAQSI)

The use of indicators for diagnosing problematic cases is prevalent in various fields. In disease control management, indicators and biomarkers are often measured to identify individuals at high risk of acquiring certain diseases, as conducting full-body checks can be expensive and inefficient. For example, liver enzymes Alanine transaminase (ALT) and Aspartate transaminase (AST) are commonly used medical indicators for diagnosing liver disorders [73,74]. Similarly, the oxygen isotope ratio ($^{18}O/^{16}O$ ratio) is an indicator in environmental research that provides insights into ancient water temperature and climate [75].

In the context of IAQ, the investigation of using surrogate indicators for preliminary assessment has been conducted. This approach provides a simple diagnostic tool when it is not practical, feasible, or economical to measure the levels of all relevant exposure parameters. An exposure index can be computed by balancing the weighted sum of selected air pollutant levels, assuming no interaction between pollutants. These selected pollutants should represent all other air parameters, as they can reflect the indoor situation. The IAQ can be determined by maintaining a constant relative ratio between the indicator and the component [76].

For instance, CO_2 is commonly utilised as an indicator of building ventilation. However, it is essential to acknowledge that the indicator approach for predicting overall IAQ has limitations in identifying specific problem sources. Nevertheless, the results obtained from a screening test using IAQ indicators can indicate potential problematic IAQ and identify premises at a higher risk of poor IAQ. This approach prompts further and more comprehensive investigations, ultimately saving costs and time.

In an investigation of using the Express Assessment Protocol for IAQ assessment in air-conditioned offices, Hui et al. [12] found that 96% of the offices that failed in the IAQ Certification Scheme could be identified by measuring only TVOC, PM_{10}, and HCHO. Furthermore, measuring the top five IAQ most-contributing parameters (TVOC, ABC, RH, HCHO, and O_3) instead of fully assessing the 12 IAQ parameters from the original standard was sufficient to screen out offices with good class IAQ. The study also revealed that most offices failed in the IAQ Certification Scheme due to exceeding the exposure limit of TVOC [71]. Additionally, Mui et al. demonstrated that a professional selection of sampling locations can improve the accuracy of IAQ assessment results [77]. Wong et al. showed that, even with assessment equipment of lower accuracy, problematic premises can still be effectively identified by adjusting the assessment thresholds accordingly [78]. These studies suggest that a pre-assessment protocol for IAQ screening is feasible and can significantly reduce the required resources.

As mentioned, selecting typical and representative IAQ parameters in indoor environments is crucial to establishing a preliminary IAQ assessment tool. It is worth noting that the chosen parameters should be independent while closely correlated with other relevant but unselected parameters. Measurements of CO_2, PM_{10}, and TVOC are proposed to be used for predicting the levels of the other nine IAQ parameters in the IAQ Certification Scheme, as they indicate occupant load and ventilation rate, system filtration performance, indoor activities, and emissions from building materials and finishes, respectively [79].

Developed by Wong et al., the IAQ index θ is computed using Equation (1), where ϕ_j* represents the average fractional dose of the average level ϕ_j to the exposure limit $\phi_{j,0}$ of the good class in the IAQ Certification Scheme for N selected surrogate parameters j [79].

$$\theta = \frac{1}{N}\sum_{j=1}^{N} \varphi_j^*; \phi_j^* = \frac{\phi_j}{\phi_{j,0}} \quad (1)$$

The IAQ index differentiates premises with satisfactory and unsatisfactory IAQ among 422 offices. It has been reported that the IAQ index for the satisfactory group ranges from 0.08 to 0.77 (mean = 0.37), while the unsatisfactory group ranges from 0.46 to 1.92 (mean = 0.76). A statistically significant difference in the means of the IAQ index between the two groups was observed (*t*-test, *p*-value < 0.0001).

Furthermore, the likelihood ratio L_r is utilised to provide information about the reliance of the test result, indicating how likely a positive outcome is to demonstrate an actual problematic case. Evidence-based medicine often uses it to make treatment decisions [80–82]. Multilevel likelihood ratios of L_r = 10 (or L_r = 0.1) are considered sensitive and specific enough for diagnosing a disease [83]. The same concept can be adopted in diagnosing 'diseased' premises with poor IAQ.

A likelihood ratio of $L_r > 1$ suggests a high risk of having unsatisfactory IAQ and vice versa. Likelihood ratios within the screening level range $\alpha \leq \theta \leq \beta$ can be calculated using Equation (2), where TP and TN represent the test-positive count (fail count) and test-negative count (pass count) concerning the good class standard in the IAQ Certification Scheme, and n_{TN} and n_{TP} represent the total pass and fail counts.

$$L_r = \frac{TN}{TP} \times \frac{n_{TP}}{n_{TN}} \quad (2)$$

To calculate the post-test probability P'_d of having poor IAQ, the pre-test probability P_d, which represents the prevalence of unsatisfactory IAQ in Hong Kong, can be obtained from the collective IAQ assessment of similar buildings. Equations (3) and (4) outline the calculations for P_d, pre-test odds O_d (the ratio of the probability of having satisfactory

IAQ to not having it), post-test odds O'_d, and post-test probability P'_d (the probability of having a positive outcome as suggested by the diagnostic test). N_d represents the number of unsatisfactory IAQ samples in N regional IAQ samples.

$$P_d = \frac{N_d}{N}; O_d = \frac{P_d}{1 - P_d} \tag{3}$$

$$P'_d = \frac{O'_d}{1 + O'_d}; O'_d = O_d \times L_r \tag{4}$$

According to a feasibility study conducted by Mui et al. [84], the effectiveness of different combinations of surrogate IAQ parameters in the IAQ index for predicting unsatisfactory IAQ in offices was investigated [85]. The studied combinations were as follows:

1. IAQ index θ_1—CO_2;
2. IAQ index θ_2—CO_2 and PM_{10};
3. IAQ index θ_3—CO_2, PM_{10} and TVOC.

For practical purposes, verbal probability expressions (VPEs) describe the post-test probability of unsatisfactory IAQ [86]. As illustrated in Figure 2, a step-wise IAQ screening protocol is proposed for screening and decision-making in IAQ management. The results indicate that a screening test with more surrogate IAQ parameters can better identify indoor environments with lower and higher risks of having poor IAQ (but not the intermediate risk group). Therefore, it offers higher resolution than an IAQ index with fewer parameters [85]. It provides guidelines for IAQ management when there is a need to balance resource investment and the effectiveness of IAQ management strategies. The proposed IAQ screening protocol is believed to be suitable and cost-effective for implementing a large-scale IAQ screening program.

It is important to note that the current IAQ management strategies in Hong Kong focus only on workplaces and public places serviced by MVAC systems. Indoor spaces with window-type or split-type air conditioners, natural ventilation, and private compartments are excluded from the program. It is crucial to extend the coverage of IAQ policies to all indoor environments, including but not limited to apartments, elderly centres, institutions, etc., to protect the health of all Hong Kong citizens. One advantage of using the IAQ index is that it can be applied to all environments with a suitable baseline limit (i.e., $\phi_{j,0}$). Therefore, for future development of IAQ policies in Hong Kong, territory-wide IAQ screening in all indoor environments is strongly encouraged to establish an IAQ database for immediate mitigation and remedial actions to improve overall IAQ in Hong Kong.

Establishing such a database requires collaborative efforts from various stakeholders such as government or non-governmental agencies, building developers, premises owners, tenants, and occupants. Real-time monitoring systems utilising low-cost IAQ sensors have proven reliable and accurate for general IAQ monitoring purposes [87,88]. However, a significant challenge lies in determining the party responsible for data maintenance and analysis to facilitate future IAQ improvements. Fortunately, with the advancements in cloud database technologies, maintaining such a massive database has become more manageable and cost-effective [89]. Furthermore, with sufficient data transparency, such a publicly available database could hold significant value for academics and building professionals. It would provide valuable insights into the IAQ situation in Hong Kong and enable the development of targeted mitigation strategies for different types of premises.

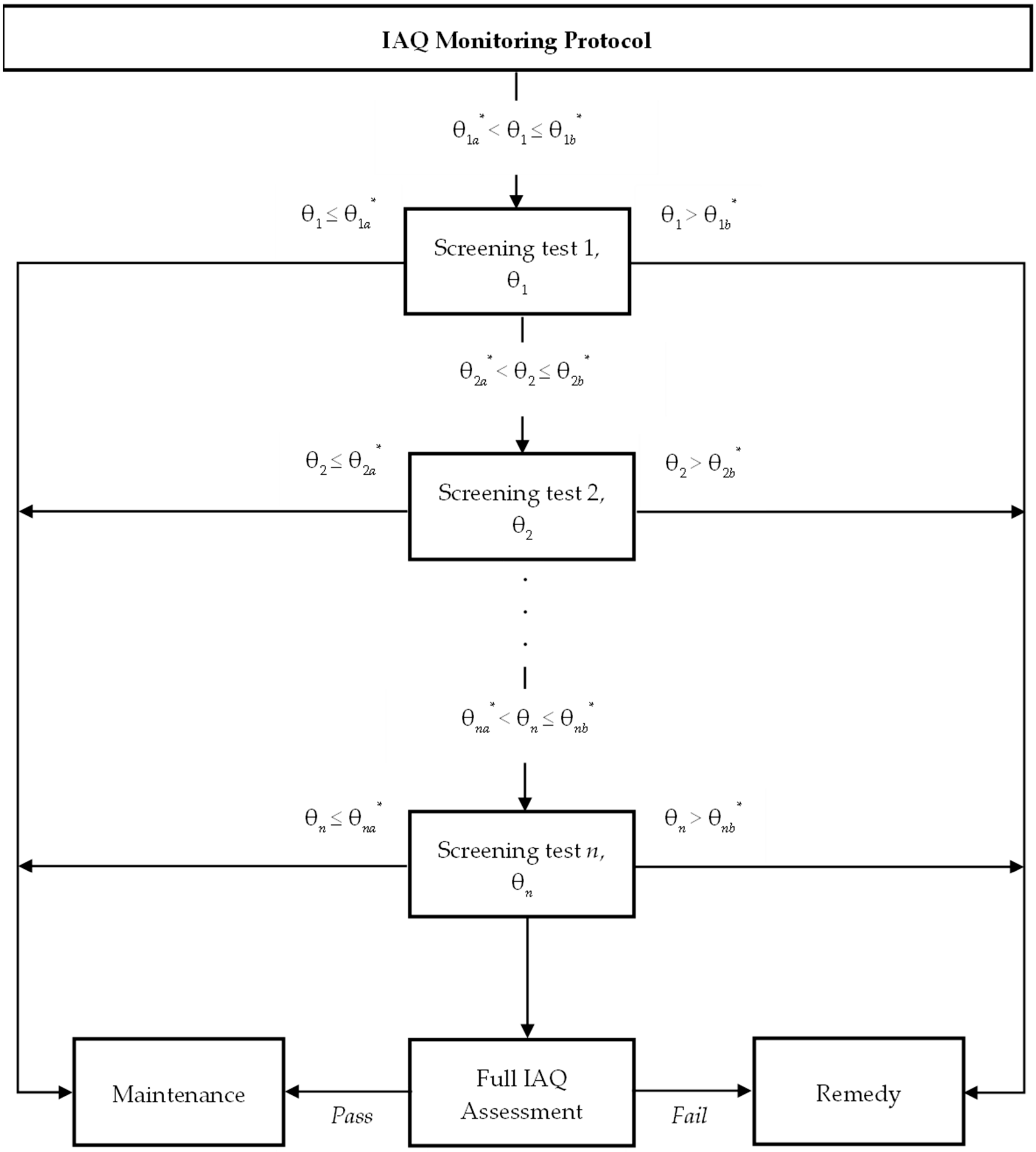

Figure 2. A step-wise IAQ screening protocol proposed by Wong et al. for screening and decision-making in IAQ management [85].

4.3. IAQ Profile Updating for an Individual Environment

While there is still a long way to go for Hong Kong to establish a comprehensive IAQ database for all types of environments, it is possible to update and customise the IAQ profile of a specific environment with limited IAQ information, particularly in settings characterised by distinct building or functional characteristics.

The use of Bayesian inference is proposed to update the IAQ profile when the IAQ situation of an environment is known. Bayes' theorem connects the probability of belief before and after acquiring new information based on prior knowledge of conditions that may contribute to the occurrence of an event. The advantage of employing a Bayesian approach for updating is that it incorporates the statistical significance of field data, regardless of the sample size, into an existing belief with weighted importance. A similar approach has been utilised by Mui et al. to evaluate the impact of IAQ policies in Hong Kong, using a dataset of IAQ measurement results before and after the implementation of IAQ policies and the IAQ Certification Scheme [90].

The IAQ is considered unsatisfactory if the parameter level θ_i exceeds the exposure limits $\theta_{i,e}$ within the range $\theta_i \in [k, \infty]$, where k represents the minimum possible level. The unsatisfactory rate U_i is assumed to follow a normal distribution, denoted as $U_{i,m}\sim N(\mu_m, \sigma_m{}^2)$. The posterior estimate of the unsatisfactory rate, denoted as $U_{i,1}\sim N(\mu_1, \sigma_1{}^2)$, can be calculated using Equations (5) and (6), where $U_{i,0}\sim N(\mu_0, \sigma_0{}^2)$ represents the prior understanding of the unsatisfactory rate, p denotes the probability, and μ_0, μ_m, μ_1, $\sigma_0{}^2$, $\sigma_m{}^2$, and $\sigma_1{}^2$ represent the mean and variance for the prior, measured, and posterior unsatisfactory rates, respectively.

$$p(U_{i,1}|U_{i,m}) = p(U_{i,0})p(U_{i,m}|U_{i,0}) \quad (5)$$

$$\mu_1 = \frac{\mu_0\sigma_m{}^2 + \mu_m\sigma_0{}^2}{\sigma_0{}^2 + \sigma_m{}^2};\ \sigma_1{}^2 = \frac{\sigma_0{}^2\sigma_m{}^2}{\sigma_0{}^2 + \sigma_m{}^2} \quad (6)$$

With the updated mean and variance values, the unsatisfactory rate U_i can be estimated using the following integral Equations (7) and (8), considering the distribution G of a pollutant.

$$U_i = 1 - \int_k^{\theta_{i,e}} G(\theta_i)d\theta_i \quad (7)$$

$$G(\theta_i) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(\theta-\mu)^2}{2\sigma^2}} \quad (8)$$

4.4. IAQ Health Index (IAQHI)

IAQ control and management strategies in Hong Kong should be implemented to protect the general public's health. The IAQ Health Index (IAQHI) is proposed to provide information about the health risks associated with specific indoor environments to ensure a comprehensive approach to identifying potential health problems. In Hong Kong, the Air Quality Health Index (AQHI) is a health-risk-based index for monitoring ambient air pollution. The AQHI for the current hour is calculated by summing the percentage of added health risk (%AR) of daily hospital admissions due to respiratory and cardiovascular diseases attributed to the 3 h moving average concentrations of four air pollutants: SO_2, NO_2, O_3, and PM_{10}. The %AR of each pollutant is determined based on concentration and risk factor data derived from local health statistics and air pollution data [91–93]. Equations (9) and (10) demonstrate the calculation of the AQHI, where $\beta(c)$ represents the regression coefficient of the health risk factor associated with pollutant c, and C(c) is the 3 h moving average concentration ($\mu g/m^3$) of pollutant c.

$$\%AR = \sum \%AR(c) \quad (9)$$

$$\%AR(c) = \{\exp[\beta(c) \times C(c)] - 1\} \times 100\% \quad (10)$$

Based on the concept of AQHI, IAQHI is proposed by expanding the coverage of the index. The dominating IAQ parameters or standard IAQ parameters that are found to cause hazardous health effects should be incorporated in the calculation of the %AR. Including indoor parameters allows the index to apply to any environment with air pollutants, providing the risks of breathing in surrounding gases regardless of the environment. While it would be ideal to include the risks associated with every air pollutant in the health index calculation, it is not feasible and cost-effective to measure the levels of all parameters. Therefore, dividing daily environments into these two major groups with distinctive features helps streamline the assessment process by prioritising the measurement of dominant pollutants in specific environments. This decision aims to strike a balance between resource allocation and the accuracy of the index in identifying health risks.

For indoor spaces, it is recommended to consider health risks associated with VOCs, HCHO, $PM_{2.5}$, PM_{10}, and O_3 in the calculation of the IAQHI. These pollutants are commonly found indoors and can pose health problems at high concentrations. Although CO_2 is a common IAQ pollutant, its typical levels in indoor environments do not cause noticeable health effects, except at extremely high levels [94]. From a health perspective, TVOC may not be a suitable indicator, as reviews on TVOC and health risks have yielded inconclusive results [4,76,94]. Certain VOCs are suspected human carcinogens and are linked to adverse health effects such as cancer, while others may only cause unpleasant feelings and discomfort [4,8,95]. Moreover, the concept of TVOC has been questioned due to ambiguous definitions and interpretations, as well as the varying effects of individual VOCs on different individuals. Therefore, it is recommended to focus on VOCs instead of TVOCs in the calculation of IAQHI.

It is important to acknowledge that the proposed IAQHI is currently in a preliminary stage, as identifying health risks associated with individual chemicals requires extensive health-based research and collective health assessment studies. Evaluating health risks from exposure to specific chemicals poses challenges due to limited knowledge regarding the combined effects of multiple pollutants. Furthermore, individuals can exhibit varying responses to chemical exposures influenced by age, gender, health status, and genetics. Nonetheless, the ultimate goal of IAQ research in Hong Kong is to establish a robust and reliable indicator and reference for IAQ management by establishing the linkages between IAQ and health. While developing our local health statistics and air pollution data in Hong Kong may take time, it is worth considering the adoption of toxicology-based standards from reviewed places to expedite the process.

4.5. Establishing IAQ Benchmarks

To effectively monitor and improve the overall IAQ situation in Hong Kong, it is crucial to implement a scheme or accreditation system that provides monetary and non-monetary rewards to incentivise IAQ management. It is worth noting that benchmarking premises with good IAQ can foster friendly and non-hostile competition among building owners, encouraging them to strive for better IAQ standards. To develop a comprehensive IAQ benchmark for Hong Kong, a territory-wide IAQ database for different types of indoor environments needs to be established and maintained. Extensive IAQ assessments should be conducted in representative buildings with diverse usage to generate an exclusive IAQ profile for Hong Kong. Territory-wide IAQ screening can provide a preliminary IAQ profile for consideration in situations with limited resources. With a collective IAQ database, five-star IAQ benchmarking systems can be established for different types of buildings, such as apartments, institutions, and offices. Annual collection of IAQ data is essential for continuous updates of the profile, serving as a track record to evaluate the effectiveness of IAQ policies in improving the IAQ situation in Hong Kong.

Benchmarking systems have proven successful in enhancing the quality of buildings [96]. Examples like BEAM and LEED recognise buildings that demonstrate significant efforts in promoting sustainable building development and operation. Similarly, a recognition system can be implemented to acknowledge premises with good IAQ and their commitment to maintaining a healthy and comfortable indoor environment. Policymakers need to strike a balance between financial benefits and quality outcomes. The cost incentives should be significant enough for the IAQ benchmarking system to be effective while ensuring that the system is not exploited as a profit-making tool for IAQ assessment providers.

4.6. IAQ Policies, Future Pandemics, and Building Ventilation Energy

The COVID-19 pandemic has significantly increased public awareness regarding building ventilation, airborne transmission, and IAQ-related issues. This situation has led to utilising building ventilation beyond the need for maintaining IAQ and minimising the risk of airborne transmission. Adequate ventilation is crucial in mitigating transmission risks, a significant topic requiring attention in the field.

It is important to note that the ventilation regulations for airborne transmission control are beyond the scope of this review and we have no intention of evaluating such policies. Nevertheless, balancing acceptable IAQ, minimising infection risks, and optimising building ventilation energy consumption is essential when formulating IAQ management strategies.

For this purpose, developing multiple management frameworks that prioritise different concerns is recommended. During epidemics or pandemics, infection risk and health considerations must be of utmost importance, and IAQ management policies should primarily focus on minimising infection risks.

5. Conclusions

There is an urgent need to enhance the IAQ policy in Hong Kong to align with world-class standards established by other places. The existing IAQ management strategies and the IAQ Certification Scheme have been reported to have limitations and drawbacks that require improvement. It is essential to take the initiative to promote IAQ management among facility management and building owners to address the issue of poor IAQ. Ongoing tasks in IAQ development should continuously improve IAQ objectives to ensure they are updated, relevant, and achievable. Additionally, the immediate implementation of territory-wide IAQ screening, followed by periodic assessments, is necessary to gain a comprehensive understanding of the overall IAQ situation in Hong Kong and to maintain an up-to-date IAQ profile specific to the region. The suggested IAQ Index with Surrogate Indicators (IAQSI) and IAQ Health Index (IAQHI) can be utilised to minimise resource requirements. Furthermore, establishing an IAQ benchmark as a rebate scheme can enhance the incentive for premise owners to manage IAQ actively. These developmental goals are believed to promote and optimise the development of IAQ management and monitoring policies in Hong Kong. Nonetheless, it is essential to consider multiple IAQ management frameworks that prioritise aspects such as IAQ, infection risk, and building ventilation energy consumption to cater to varying needs over time. Lastly, it is crucial to recognise that public education on the importance of IAQ should always remain a key component in raising awareness about IAQ issues and potential health risks among the general public. This soft-power approach can significantly enhance incentives and facilitate the effective management of IAQ, ultimately contributing to the overall improvement of IAQ in Hong Kong.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos15050546/s1, Table S1: Recommended measurement methods for IAQ parameters in reviewed IAQ management policies and standards.

Author Contributions: Conceptualisation, T.-W.T., K.-W.M. and L.-T.W.; methodology, T.-W.T., K.-W.M. and L.-T.W.; software, T.-W.T.; formal analysis, T.-W.T.; investigation, T.-W.T.; resources, K.-W.M. and L.-T.W.; data curation, T.-W.T.; writing—original draft preparation, T.-W.T.; writing—review and editing, K.-W.M. and L.-T.W.; visualisation, T.-W.T.; supervision, K.-W.M. and L.-T.W.; project administration, K.-W.M. and L.-T.W.; funding acquisition, K.-W.M. and L.-T.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was jointly funded by the Collaborative Research Fund (CRF) COVID-19 and Novel Infectious Disease (NID) Research Exercise; the Research Grants Council of the Hong Kong Special Administrative Region, China (project number PolyU P0033675/C5108-20G and PolyU P0037773/Q86B); PReCIT Seed Funding Scheme, Policy Research Centre for Innovation and Technology (PReCIT), PolyU (project number PolyU P0043831); and Carbon Neutrality Funding Scheme, PolyU (project number PolyU P0043713).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Klepeis, N.E.; Nelson, W.C.; Ott, W.R.; Robinson, J.P.; Tsang, A.M.; Switzer, P.; Behar, J.V.; Hern, S.C.; Engelmann, W.H. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *J. Expo. Anal. Environ. Epidemiol.* **2001**, *11*, 231–252. [CrossRef]
2. Burroughs, H.E.; Hansen, S.J. *Managing Indoor Air Quality*; Fairmont Press: Lilburn, GA, USA, 2001.
3. *Household Air Pollution*; World Health Organization: Geneva, Switzerland, 2023. Available online: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health#:~:text=Household%20air%20pollution%20exposure%20leads,(COPD)%20and%20lung%20cancer (accessed on 26 March 2024).
4. Andersson, K.; Bakke, J.V.; Bjorseth, O.; Bornehag, C.; Clausen, G.; Hongslo, J.K.; Kjellman, M.; Kjærgaard, S.; Levy, F.; Mølhave, L.; et al. TVOC and health in non-industrial indoor environments. Report from a Nordic scientific consensus meeting at Långholmen in Stockholm, 1996. *Indoor Air* **1997**, *7*, 78–91. [CrossRef]
5. Apte, M.G.; Fisk, W.J.; Daisey, J.M. Associations between indoor CO_2 concentrations and Sick Building Syndrome Symptoms in U.S. office buildings: An analysis of the 1994–1996 BASE study data. *Indoor Air* **2000**, *10*, 246–257. [CrossRef] [PubMed]
6. Joshi, S. The sick building syndrome. *Indian J. Occup. Environ. Med.* **2008**, *12*, 61. [CrossRef]
7. Kampa, M.; Castanas, E. Human health effects of air pollution. *Environ. Pollut.* **2008**, *151*, 362–367. [CrossRef] [PubMed]
8. Mølhave, L. *Volatile Organic Compounds and the Sick Building Syndrome. Environmental Toxicants, Human Exposures and Their Health Effects*, 2nd ed.; Wiley-Interscience: New York, NY, USA, 2000; pp. 889–903.
9. Seppanen, O.A.; Fisk, W.J.; Mendell, M.J. Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. *Indoor Air* **1999**, *9*, 226–252. [CrossRef] [PubMed]
10. Tchepel, O.; Penedo, A.; Gomes, M. Assessment of population exposure to air pollution by benzene. *Int. J. Hyg. Environ. Health* **2007**, *210*, 407–410. [CrossRef]
11. Hoskins, J.A. Health effects due to indoor air pollution. *Indoor Built Environ.* **2003**, *12*, 427–433. [CrossRef]
12. Hui, P.S.; Wong, L.T.; Mui, K.W. Feasibility study of an Express Assessment Protocol for the Indoor Air Quality of Air-conditioned Offices. *Indoor Built Environ.* **2006**, *15*, 373–378. [CrossRef]
13. Liao, S.; Bacon-Shone, J.; Kim, Y. Factors influencing indoor air quality in Hong Kong: Measurements in offices and shops. *Environ. Technol.* **1991**, *12*, 737–745. [CrossRef]
14. *The Hong Kong Environment: A Green Challenge to the Community: Second Review of the 1989 White Paper, Pollution in Hong Kong: A Time to Act*; Government Secretariat (Hong Kong), Planning, Environment and Lands Branch (PELB): Hong Kong, China, 1993.
15. *The Hong Kong Interim Indoor Air Quality Guidelines and Hong Kong Air Quality Objective*; Hong Kong Environmental Protection Department: Hong Kong, China, 1994.
16. Ng, D.; Lai, W.Y. *Final Report: Consultancy Study on Indoor Air Pollution in Offices and Public Places in Hong Kong (Agreement No. CE 14/95)*; EHS Consultants Limited and HKEPD Air Services Group: Hong Kong, China, 1995.
17. Indoor Air Quality Information Center. Available online: http://www.epd.gov.hk/epd/english/environmentinhk/air/indoorair_quality/air_indoorair.html (accessed on 26 March 2024).
18. *WHO Guidelines for Indoor Air Quality: Selected Pollutants*; World Health Organization: Geneva, Switzerland, 2010.
19. *2023 Gross Domestic Product by Economic Activity*; Census and Statistics Department: Hong Kong, China, 2023.
20. *Hong Kong Property Review 2019*; Rating and Valuation Department: Hong Kong, China, 2019.
21. *Annual Report 2023—Corporate Sustainability*; New World Development Company Limited: Hong Kong, China, 2023.
22. *Introduction to Pacific Place's New IAQ Monitoring System*; Swire Properties: Hong Kong, China, 2020. Available online: https://iaq.pacificplace.com.hk/en/introduction (accessed on 26 March 2024).
23. *Sustainability Report 2021/22*; Sun Hung Kai Properties Limited: Hong Kong, China, 2022.
24. Morawska, L.; Huang, W. WHO health guidelines for indoor air quality and national recommendations/standards. In *Handbook of Indoor Air Quality*; Zhang, Y., Hopke, P.K., Mandin, C., Eds.; Springer: Singapore, 2022; Volume 19, pp. 1–20.
25. *Interim National Indoor Air Quality Goals Recommended by the National Health and Medical Research Council*; National Health and Medical Research Council: Canberra, Australia, 1996.
26. *State of Knowledge Report: Air Toxics and Indoor Air Quality in Australia*; Environment Australia: Canberra, Australia, 2001.
27. *National Construction Code 2016*; The Australia Building Codes Board: Canberra, Australia, 2016.
28. *Indoor Air Quality Verification Methods Handbook*; The Australia Building Codes Board: Canberra, Australia, 2023.
29. *GB9663-1996*; Hygienic Standard for Hotel. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
30. *GB9664-1996*; Hygienic Standard for Public Place of Entertainment. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
31. *GB9665-1996*; Hygienic Standard for Public Bathroom. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
32. *GB9666-1996*; Hygienic Standard for Barber Shop and Beauty Shop. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
33. *GB9667-1996*; Hygienic Standard for Swimming Place. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
34. 34. *GB9668-1996*; Hygienic Standard for Gymnasium. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
35. *GB9669-1996*; Hygienic Standard for Library, Museum, Art Gallery and Exhibition. Ministry of Health of the People's Republic of China: Beijing, China, 1996.

36. *GB9670-1996*; Hygienic Standard for Shopping Center and Book Store. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
37. *GB9671-1996*; Hygienic Standard for Hospital Waiting Room. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
38. *GB9672-1996*; Hygienic Standard for Waiting Room of Public Transit Means. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
39. *GB9673-1996*; Hygienic Standard for Public Means of Transportation. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
40. *GB16153-1996*; Hygienic Standard for Dining Room. Ministry of Health of the People's Republic of China: Beijing, China, 1996.
41. *GB37487-2019*; Hygienic Management Specification for Public Places. National Health Commission of the People's Republic of China: Beijing, China, 2019.
42. *GB37488-2019*; Hygienic Indicators and Limits for Public Places (GB37488-2019). National Health Commission of the People's Republic of China: Beijing, China, 2019.
43. *GB/T18883-2002*; Indoor Air Quality Standard. The Administration of Quality Supervision, Inspection, and Quarantine; Ministry of Health. Ministry of Environmental Protection: Beijing, China, 2002.
44. *GB/T18883-2022*; Indoor Air Quality Standard. National Health Commission of the People's Republic of China: Beijing, China, 2022.
45. *Opinion on Risk Assessment on Indoor Air Quality*; Scientific Committee on Health and Environmental Risks, Europe Commission: Brussels, Belgium, 2007.
46. Husman, T.M. The Health Protection Act, national guidelines for indoor air quality and development of the national indoor air programs in Finland. *Environ. Health. Perspect.* **1999**, *107* (Suppl. S3), 515–517. [CrossRef]
47. Murtomaa, M.; Aurola, R. *Guide on Living Conditions and Maintenance of Apartment Buildings*; Finnish National Board of Health: Rauma, Finland, 1990. (In Finnish)
48. *Indoor Air Guidelines*; Ministry of Social Affairs and Health: Helsinki, Finland, 1997. (In Finnish)
49. *The Classification of Indoor Climate, Construction, and Finishing Materials*; The Finnish Society of Indoor Air Quality and Climate (FiSIAQ): Finland, 2018.
50. Tuomainen, M.; Pasanen, A.L.; Tuomainen, A.; Liesivuori, J.; Juvonen, P. Usefulness of the Finnish classification of indoor climate, construction and finishing materials: Comparison of indoor climate between two blocks of flats in Finland. *Atmos. Environ.* **2001**, *35*, 305–313. [CrossRef]
51. *Concept of the German Federal Government for Better Indoor Air Quality*; Federal Environment Ministry: Berlin, Germany, 1992. (In German)
52. Ad-hoc-Arbeitsgruppe IRK-AGLMB. Guideline values for indoor air: General Scheme. *Bundesgesundheitsblatt* **1996**, *39*, 422–426. (In German)
53. Fromme, H.; Debiak, M.; Sagunski, H.; Röhl, C.; Kraft, M.; Kolossa-Gehring, M. The German approach to regulate indoor air contaminants. *Int. J. Hyg. Environ. Health* **2019**, *222*, 347–354. [CrossRef]
54. *German Committee on Indoor Air Guide Values*; German Environment Agency (UBA): Berlin, Germany, 2023.
55. Azuma, K.; Uchiyama, I.; Ikeda, K. The regulations for indoor air pollution in Japan: A public health perspective. *J. Risk. Res.* **2008**, *11*, 301–314. [CrossRef]
56. *Act on Securing a Hygienic Environment in Buildings (Act No. 20 of 1970)*; Ministry of Health, Labor and Welfare: Tokyo, Japan, 1970.
57. *Interim Report Summary up to the 23rd Issue*; Ministry of Health, Labor and Welfare: Tokyo, Japan, 2019.
58. *Clean Air Conservation Act (Presidential Decree No. 21325)*; Korea Legislation Research Institute: Seoul, Republic of Korea, 2009.
59. *Indoor Air Quality Control in Public Use Facilities, etc. Act (Act No. 10789)*; Ministry of Environment: Seoul, Republic of Korea, 2011.
60. *Indoor Air Quality Control Act (Act No. 19663)*; Ministry of Environment: Seoul, Republic of Korea, 2024.
61. *Suggested Values for Indoor Air Quality*; Environmental Protection Administration Executive Yuan R.O.C. (Taiwan): Taipei City, Taiwan, 2005.
62. *Indoor Quality Management Act (Presidential Order No. 10000259721)*; Ministry of Environment: Taipei City, Taiwan, 2011.
63. *WHO Guidelines for Indoor Air Quality: Dampness and Mold*; World Health Organization: Geneva, Switzerland, 2009.
64. *WHO Guidelines for indoor air quality: Household fuel combustion*; World Health Organization: Geneva, Switzerland, 2014.
65. *Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places*; Indoor Air Quality Management Group: Hong Kong, China, 2019.
66. *A Guide on Indoor air Quality Certification Scheme for Offices and Public Places*; Indoor Air Quality Management Group: Hong Kong, China, 2019.
67. *Indoor Air Quality (IAQ) Complaint Received by the Government*; Environmental Protection Department: Hong Kong, China, 2022.
68. *Certified Premise List*; Environmental Protection Department: Hong Kong, China, 2024. Available online: https://www.iaq.gov.hk/en/iaq-certification-scheme-certified-premises-list/ (accessed on 26 March 2024).
69. Burnett, J. Indoor air quality certification scheme for Hong Kong buildings. *Indoor Built Environ.* **2005**, *14*, 201–208. [CrossRef]
70. Mui, K.W.; Wong, L.T. Evaluation on different sampling schemes for assessing indoor radon level in Hong Kong. *Atmos. Environ.* **2004**, *38*, 6711–6723. [CrossRef]

71. Mui, K.W.; Wong, L.T.; Ho, W.L. Evaluation on sampling point densities for assessing indoor air quality. *Build. Environ.* **2006**, *41*, 1515–1521. [CrossRef]
72. Lee, T.H.; Kim, W.R.; Poterucha, J.J. Evaluation of elevated liver enzymes. *Clin. Liver. Dis.* **2012**, *16*, 183–198. [CrossRef] [PubMed]
73. Aithal, G.P.; Guha, N.; Fallowfield, J.; Castera, L.; Jackson, A.P. Biomarkers in liver disease: Emerging methods and potential applications. *Int. J. Hepatol.* **2012**, *2012*, 437508. [CrossRef]
74. Jouzel, J.; Koster, R.D.; Suozzo, R.J.; Russell, G.L. Stable water isotope behavior during the last glacial maximum: A general circulation model analysis. *J. Geophys. Res.* **2014**, *99*, 25791.
75. Mølhave, L. Organic compounds as indicators of air pollution. *Indoor Air* **2003**, *13* (Suppl. S6), 12–19. [CrossRef] [PubMed]
76. Mui, K.W.; Wong, L.T.; Hui, P.S. A new sampling approach for assessing indoor air quality. *Indoor Built Environ.* **2006**, *15*, 165–172. [CrossRef]
77. Wong, L.T.; Mui, K.W.; Hui, P.S. A statistical model for characterizing common air pollutants in air-conditioned offices. *Atmos. Environ.* **2006**, *40*, 4246–4257. [CrossRef]
78. Wong, L.T.; Mui, K.W.; Hui, P.S. Screening for indoor air quality of air-conditioned offices. *Indoor Built Environ.* **2007**, *16*, 438–443. [CrossRef]
79. Swets, J.A. The relative operating characteristic in psychology: A technique for isolating effects of response bias finds wide use in the study of perception and cognition. *Science* **1973**, *182*, 990–1000. [CrossRef] [PubMed]
80. Pauker, S.G.; Kassirer, J.P. Therapeutic decision making: A cost-benefit analysis. *N. Engl. J. Med.* **1975**, *293*, 229–234. [CrossRef] [PubMed]
81. Thornbury, J.R.; Fryback, D.G.; Edwards, W. Likelihood ratios as a measure of the diagnostic usefulness of excretory urogram information. *Radiology* **1975**, *114*, 561–565. [CrossRef]
82. Sackett, D.L. *Evidence-Based Medicine: How to Practice and Teach EBM*, 2nd ed.; Churchill Livingstone: Edinburgh, UK, 2001.
83. Mui, K.W.; Hui, P.S.; Wong, L.T. Diagnostics of unsatisfactory indoor air quality in air-conditional workplaces. *Indoor Built Environ.* **2011**, *20*, 313–320. [CrossRef]
84. Wong, L.T.; Mui, K.W.; Tsang, T.W. Evaluation of indoor air quality screening strategies: A step-wise approach for IAQ screening. *Int. J. Environ. Res. Public Health* **2016**, *3*, 1240. [CrossRef]
85. Reagan, R.T.; Mosteller, F.; Youtz, C. Quantitative meanings of verbal probability expressions. *J. Appl. Psychol.* **1989**, *74*, 433–442. [CrossRef] [PubMed]
86. Saini, J.; Dutta, M.; Marques, G. A comprehensive review on indoor air quality monitoring systems for enhanced public health. *Sus. Environ. Res.* **2020**, *30*, 6. [CrossRef]
87. Sá, J.P.; Alvim-Ferraz, M.C.M.; Martins, F.G.; Sousa, S.I. Application of the low-cost sensing technology for indoor air quality monitoring: A review. *Environ. Technol. Innov.* **2022**, *28*, 102551. [CrossRef]
88. Arora, I.; Gupta, A. Cloud databases: A paradigm shift in databases. *Int. J. Comput. Sci. Issues* **2012**, *9*, 77.
89. Mui, K.W.; Wong, L.T.; Hui, P.S.; Law, K.Y. Epistemic evaluation of policy influence on workplace indoor air quality of Hong Kong in 1996–2005. *Build. Serv. Eng. Res. Technol.* **2008**, *29*, 157. [CrossRef]
90. Wong, T.W.; Tam, W.W.; Yu, I.T.; Lau, A.K.; Pang, S.W.; Wong, A.H. Developing a risk-based air quality health index. *Atmos. Environ.* **2013**, *76*, 52–58. [CrossRef]
91. The New AQHI System—Purpose and Use. Available online: http://www.aqhi.gov.hk/en/what-is-aqhi/about-aqhi.html (accessed on 26 March 2024).
92. Robertson, D. The rise in the atmospheric concentration of carbon dioxide and the effects on human health. *Med. Hypotheses* **2001**, *56*, 513–518. [CrossRef]
93. Mølhave, L.; Clausen, G.; Berglund, B.; Ceaurriz, J.; Kettrup, A.; Lindvall, T.; Maroni, M.; Pickering, A.C.; Risse, U.; Rothweiler, H.; et al. Total Volatile Organic Compounds (TVOC) in indoor air quality investigations. *Indoor Air* **1997**, *7*, 225–240. [CrossRef]
94. Hoskins, J.A. Health Effects Due to Indoor Air Pollution. In *Survival and Sustainability*; Gökçekus, H., Türker, U., LaMoreaux, J.W., Eds.; Springer: Berlin/Heidelberg, Germany, 2003; pp. 665–676.
95. *WHO Guidelines for Indoor Air Quality*; World Health Organization: Geneva, Switzerland, 2000.
96. *BEAM Plus New Buildings (Version 1.2)*; BEAM Society Limited: Hong Kong, China, 2012.