
Literature Review on the Correlation Between Indoor Air Quality (IAQ) and Health and Safety

by
CLEAN AIR NETWORK

June 2025

Abstract

Indoor air quality (IAQ) is a critical public health issue in Hong Kong, though it is often overshadowed by concerns about outdoor air pollution. The city's unique high-density urban environment and humid climate significantly exacerbate health risks from a wide range of indoor sources, including combustion from cooking, chemical emissions from building materials, and biological contaminants. These risks translate into severe consequences for residents, including an increased risk of chronic diseases like cancer, impaired cognitive function, and a substantial economic burden around 32.56 billion HKD per year. Crucially, these impacts fall disproportionately on vulnerable groups such as the elderly, children, and low-income workers, particularly those in high-risk environments like subdivided units and schools. Underpinning this entire crisis is a systemic failure: a vicious cycle where policy neglect leads to a lack of research and data, which in turn prevents IAQ from becoming a public priority. Therefore, a concerted effort from both the government and the public is urgently needed to break this cycle and safeguard the health and well-being of all residents.

Key Words: Indoor Air Quality, Indoor Air Pollutants, Health Impact, Economic Impact, Vulnerable Populations

Contents

1. Introduction	1
2. Sources of Poor IAQ	2
2.1 Indoor air pollutants	2
2.1.1 Gaseous Pollutants	2
2.1.2 Volatile Organic Compounds (VOCs).....	3
2.1.3 Particulate Matter and Fibers	4
2.1.4 Biological Pollutants	4
2.2 Physical factors	5
3. Impacts of Poor IAQ	6
3.1 Physiological Impacts	6
3.1.1 Cardiovascular System Disease	6
3.1.2 Respiratory System Disease	6
3.1.3 Infection Diseases	7
3.1.4 Cancer	8
3.1.5 Sick Building Syndrome	8
3.2 Cognitive Impacts	9
4. Economic Burden	10
4.1 International Estimation	10
4.2 Estimate the Economic Impact of poor IAQ in Hong Kong	10
4.2.1 DALYs estimation.....	11
4.2.2 DALY cost calculation	14
4.2.3 Sick Building Syndrome Cost.....	15
4.2.4 Total Economic Burden	15
5. High-Risk Population and Built Environments in Hong Kong	16
5.1 High-Risk Population	16
5.1.1 Elder.....	18
5.1.2 Children	19
5.1.3 Women	21
5.1.4 Staff and workers	22
5.2 Built Environments	23
5.2.1 School	23
5.2.2 Elderly home	24
5.2.3 Office	26
5.2.4 Subdivided Units (SDUs)	26
5.2.5 Hospital and medical institutions	27
6. Discussion	29
6.1 Sources of Poor Indoor Air Quality	29
6.1.1 Combustion and Heating Activities	29
6.1.2 Building Materials, Furnishings, and Chemical Products	29
6.1.3 Biological Contaminants.....	30
6.1.4 Amplifying Factors: Urban Density and Climate.....	30
6.2 The Impacts of Poor Indoor Air Quality	30
6.3 High-Risk Populations and Environments	32
6.3.1 Vulnerable Populations	32
6.3.2 High-Risk Buildings and Environments	32
6.4 Challenges in Hong Kong's IAQ Management	33
7. Conclusion.....	33
Reference.....	35

List of Tables

Table. 1 Gaseous Pollutants and Indoor Sources	2
Table. 2 Volatile Organic Compounds (VOCs) and Indoor Sources.....	3
Table. 3 Particulate Matter and Fibers and Indoor Sources	4
Table. 4 Biological Pollutants and Indoor Sources.....	4
Table. 5 Cardiovascular System Disease Caused by Indoor Air Pollutants	6
Table. 6 Respiratory System Disease Caused by Indoor Air Pollutants	7
Table. 7 Infection Diseases by Indoor Air Pollutants	7
Table. 8 Symptoms of Sick Building Syndrome.....	8
Table. 9 Cognitive Impacts Caused by Indoor Air Pollutants.....	9
Table. 10 Economic Burden Caused by Indoor Air Pollutants	10
Table. 11 Criteria IAP C-R Function Outcomes and DALYs Lost per Incidence.....	11
Table. 12 Mean Indoor Air Pollutant Concentration ($\mu\text{g}/\text{m}^3$).....	12
Table. 13 Age-specific Indoor Activity Patterns of the Hong Kong Population	13
Table. 14 Estimated DALYs Attributable to Different Indoor Environments in Hong Kong (IND)	13
Table. 15 Summary of DALY Factors and Indoor Concentrations for Selected IAPs	13
Table. 16 Demographic and Exposure Parameters for the Hong Kong Population by Age Group	14
Table. 17 Estimated DALYs Attributable to Different IAPs in Hong Kong (ID)	14
Table. 18 High-Risk Population related Indoor Sources	16

1. Introduction

Air quality, as a dominant environmental exposure for humans, has a significant impact on health. According to the IMHE's GBD database, air pollution has become the second largest global health risk, only after high blood pressure [1]. As lifestyles in modern society change, studies from multiple countries indicate that people spend over 80% of their time indoors on average. Against this backdrop, indoor air quality (IAQ) is particularly important [2, 3]. It refers to the air quality inside and around buildings and structures, affecting respiratory health and being closely related to various chronic diseases, directly impacting life quality and work efficiency [4]. IAP is the main cause of IAQ deterioration, with WHO data indicating that IAP in household environments alone causes about 3.2 million deaths annually, including 200,000 children; considering public places, the actual number may be higher [5]. However, despite IAQ's importance, academia and government attention is noticeably lower than that for outdoor air quality [6], and Hong Kong is no exception.

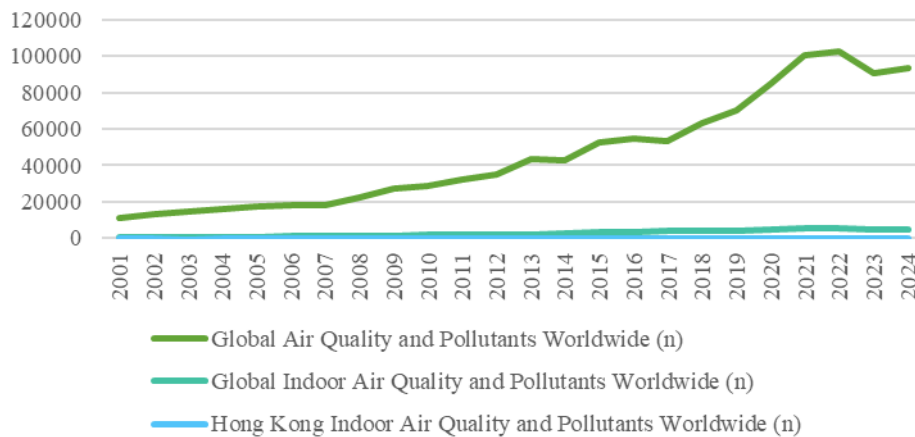


Fig. 1 Trends in Global and Hong Kong Air Quality and Pollutants - Related Research

As a highly urbanized, densely populated international metropolis, Hong Kong's unique urban environment poses greater challenges to indoor air quality. Although the Hong Kong government has achieved significant results in outdoor air quality management, such as implementing the Air Quality Health Index (AQHI) and pollutant concentration monitoring [7, 8]. But indoor air quality management still relies on recommended standards and voluntary participation plans, lacking mandatory regulatory support [9]. Additionally, Hong Kong lacks detailed indoor air quality data and related research, having only rough air quality classification information for buildings certified through government management plans [10], lacking an early warning mechanism for poor indoor air quality, and research in related fields is relatively weak.

Considering the above background, this study aims to integrate international and local research findings on indoor air quality through literature review, with specific objectives including: 1. Fully identifying key pollution sources affecting Hong Kong's indoor air quality and their health impact mechanisms. 2. Identifying high-risk indoor

locations (such as schools, offices, malls, and high-density residences) and vulnerable populations (such as children, the elderly, and chronic disease patients) in Hong Kong's specific environment. 3. Assessing the shortcomings of existing Hong Kong indoor air quality management policies and gaps in the evidence chain. Through this study, it is hoped to enhance public awareness of the importance of indoor air quality, provide a scientific and systematic knowledge base for the Hong Kong government to formulate relevant policies, and ultimately improve the health and well-being of Hong Kong residents.

2. Sources of Poor IAQ

2.1 Indoor air pollutants

Indoor air pollutants (IAP) typically form complex mixtures containing inorganic gases, volatile organic compounds (VOCs), particulate matter (PM), aerosols, and biological contaminants[11]. When released into the air from indoor pollution sources, these compounds become the primary contributors to poor indoor air quality. The specific composition of IAP varies across different building environments due to differences in pollution source types, emission rates, and ventilation conditions. Therefore, identifying air pollutants and their potential sources is critical for effective indoor air quality management [12].

2.1.1 Gaseous Pollutants

Indoor gaseous pollutants vary widely in type and originate from diverse sources. The most common types include carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur oxides (SO_x), which are mainly produced during fossil fuel and biomass combustion. Another significant example is radon (Rn), a radioactive gas formed through the decay of uranium, radium, and other radioactive elements in the Earth's crust [13, 14].

Table. 1 Gaseous Pollutants and Indoor Sources

Gases	Source of emission
CO[14-16]	- Combustion or heating activities: Cooking appliances, heating systems, generators, and gasoline-powered devices - Tobacco smoke - Outdoor air pollution: Vehicle exhaust and industrial emissions

CO ₂ [17]	1. Biological metabolism 2. Combustion or heating activities: Cooking appliances, heating systems, generators, and gasoline-powered devices 3. Tobacco smoke
NO _x [14, 15, 18]	1. Combustion or heating activities: Cooking appliances, heating systems, generators, and gasoline-powered devices 2. Tobacco smoke 3. Outdoor air pollution: Vehicle exhaust and industrial emissions
SO _x [14, 19, 20]	1. Combustion or heating activities: Cooking appliances, heating systems, generators, and gasoline-powered devices 2. Tobacco smoke 3. Outdoor air pollution: Vehicle exhaust and industrial emissions
Radon[14, 15]	1. Building materials: Stone and concrete structures 2. Soil gas emissions 3. Groundwater supply systems

2.1.2 Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are organic chemicals that evaporate at room temperature [21]. These compounds are released from multiple sources, such as building materials, furniture, household chemicals, and tobacco smoke. Generally, their indoor concentrations are much higher than outdoor ones [22], which may cause acute or chronic adverse health effects on residents [23, 24].

Rösch 's research employed principal component analysis and analyzed the specific sources of different VOCs in indoor environments through field measurements [25].

Table. 2 Volatile Organic Compounds (VOCs) and Indoor Sources

VOCs	Source of emission
Aromatic hydrocarbons, nonane	Ventilation/season
Terpenes, 2-heptanone	Wood products (furniture, parquet), personal care and cleansing products
Hexane, heptane, methylcyclopentane, cyclohexane	Solvents, adhesive emissions, PVC
Tri-, tetra-, penta-, hexadecane	Renovation, paints/traffic emissions
Texanol isobutyrate, benzaldehyde, cyclohexanone	Solar radiation/secondary emissions
Decan, un-, do-, tridecan	Renovation, new furniture/traffic emissions
Pentanal, hexanal, octanal, nonanal	Aging of materials

Tetrachloromethane	Background
1-Butanol, 2-ethylhexanol	Indoor climate
Tetrahydrofuran	PVC flooring

2.1.3 Particulate Matter and Fibers

PM refers to inhalable solid and liquid particles floating in the air [26, 27]. Indoor particulate matter pollution is classified into primary and secondary particulate matter pollution according to the source of PM. Primary PM directly comes from combustion and heating activities, smoking, use of daily chemicals, and other indoor activities. Secondary PM includes particles generated by the infiltration of polluted outdoor air, secondary physical dust, or chemical reactions.

Table. 3 Particulate Matter and Fibers and Indoor Sources

PM	Source of emission
Primary PM[28-38]	Combustion or heating activities: Cooking appliances, heating systems, generators, and gasoline-powered devices Tobacco smoke Aging of building materials Human activity
Secondary PM[29]	Outdoor air pollution Transformation of primary gaseous pollutants Secondary dust source

2.1.4 Biological Pollutants

Biological pollutants are organisms in the air or their by-products, mainly composed of microorganisms, dust mites, pollen and dander, etc. [39, 40]. These sources often relate to dampness, human and animal presence, ventilation systems, and the infiltration of outdoor bioaerosols.

Table. 4 Biological Pollutants and Indoor Sources

Biological Pollutants	Source of emission
Molds and fungi[41]	Damp environment
Bacteria and viruses[42]	Human beings and animals Ventilation equipment: Air conditioner, fan, cooler, humidifier
Dust mites and allergens[43]	Clothes and bedding Human beings and animals Plant Pollen Outdoor air pollution

2.2 Physical factors

Despite the indoor air pollutants, several other factors also affect indoor air quality, including humidity, temperature and ventilation. Some countries have incorporated it into the IAQ standards [44-46].

Indoor temperature directly affects the pollutant emission from indoor materials and products, as well as the diffusion process of other pollutants [47, 48]. Guo's quantitative formula clearly states that a 10°C increase in indoor temperature can increase the diffusion coefficient by approximately 6% [49]. And indoor temperature is primarily determined by ambient temperature, indoor heat sources, building heat conduction capacity, and ventilation and cooling systems [50-52].

Moisture mainly affects indoor air quality through biological pollutants and triggers a series of chain reactions, posing multiple threats to the indoor environment and human health [53]. In terms of biological pollutants, a humid environment provides excellent conditions for the survival and reproduction of microorganisms, which include various bacteria, fungi, and viruses. In addition to directly infecting humans and causing diseases, they also produce irritating factors such as toxins or allergens, further deteriorating indoor air quality [54, 55]. Besides, humid environment also attracts dust mites, insects, and rodents to inhabit and reproduce [53], which not only carry a large number of germs, but also are important sources of indoor allergens, directly threatening human health [56].

- **Water leakage:** Water intrudes through structural defects in buildings (roofs, exterior walls, pipes) or seeps in after being absorbed by porous building materials.
- **Air infiltration and condensation:** Condensation of moisture in the air.
- **Inadequate ventilation and humidity control:** Poor ventilation in high-humidity areas (bathrooms, kitchens) or dehumidification system failures.

Ventilation is often considered to have a strong connection with IAQ [57, 58]. Because the pollutant concentration in outdoor air is often lower than that in indoor air, strong ventilation tends to mean better indoor air quality, and vice versa. According to previous studies, poor ventilation is often related to terrain and building layout, surrounding pollution sources and obstacles, interior building design, and mechanical ventilation equipment [59, 60].

3. Impacts of Poor IAQ

3.1 Physiological Impacts

3.1.1 Cardiovascular System Disease

The cardiovascular system can be significantly influenced by exposure to poor indoor air quality, with a growing body of evidence linking various IAP to adverse cardiac and circulatory outcomes. These pollutants can instigate a range of physiological responses, including endothelial dysfunction, systemic inflammation, oxidative stress, and alterations in autonomic nervous system balance, which collectively contribute to the pathogenesis or exacerbation of cardiovascular diseases, ranging from chronic conditions like heart disease, congestive heart failure, coronary artery disease, angina, hypertension, and atherosclerosis, to acute and potentially life-threatening events such as heart attack (myocardial infarction), stroke, arrhythmia, and atrial fibrillation.

Table. 5 Cardiovascular System Disease Caused by Indoor Air Pollutants

Indoor air pollutants	Mechanism	Disease
Gaseous[61, 62]	Elevated blood pressure, Decreased HRV	Heart disease
VOCs[63-67]	Elevated blood pressure, Elevated heart rate, Decreased HRV, Decreased HF, Increases in serum CRP and 8-OHdG levels	Congestive heart failure Coronary artery disease Angina Heart attack Stroke
PM[68-72]	Elevated blood pressure, Elevated heart rate, Hemodynamic disorder	Hypertension Atherosclerosis Stroke Myocardial Infarction Arrhythmia Heart Failure Atrial Fibrillation

3.1.2 Respiratory System Disease

The human respiratory system serves as a direct interface with the surrounding air, making it exceptionally vulnerable to the various pollutants present in indoor environments. Exposure to these contaminants can trigger a cascade of adverse reactions, including inflammation of the airways, oxidative stress leading to cellular

damage, compromised immune responses, and direct irritation or injury to lung tissues, culminating in a diverse range of respiratory ailments. Such as Chronic Obstructive Pulmonary Disease (COPD), type II respiratory failure characterized by hypercapnia, acute respiratory infections, asthma, and allergic rhinitis.

Table. 6 Respiratory System Disease Caused by Indoor Air Pollutants

Indoor air pollutants	Mechanism	Disease
Gaseous[73-75]	Increased ventilation	COPD
	Decreased FVC	Type II respiratory failure
	Decreased vital capacity	(hypercapnia)
	Induce oxidative stress	Respiratory infection
	DNA damage	Asthma
VOCs[76-78]	Enhanced airway responsiveness	Asthma
PM[79-84]	Impaired immune function	COPD
	Inflammation	Asthma
	Induce oxidative stress	
	DNA damage	
Biological[85-88]	Bacterial or viral infection	COPD
	Impaired immune function	Respiratory infection
	Inflammation	Asthma
	Induce oxidative stress	Allergic rhinitis
	DNA damage	

3.1.3 Infection Diseases

Biological pollutants in the indoor air cover a wide range of infectious bacteria and viruses. Many diseases are transmitted through air droplets or aerosols containing viruses, bacteria or other infectious particles. Especially those places with high living density or insufficient ventilation often become important storage and transmission sites for pathogenic microorganisms. In addition to the pathogens themselves, their survival and spread are also significantly influenced by indoor air quality parameters such as humidity and ventilation conditions, which are directly related to the risk of residents contracting infectious diseases.

Table. 7 Infection Diseases by Indoor Air Pollutants

Pathogenic microorganism	Disease
Virus [89-97]	Influenza
	SARS
	MERS
	Tuberculosis
	Measles
	Adenovirus disease
Bacteria [98-102]	Tuberculosis

Other [103, 104]	Diphtheria
	Pharyngitis
	Staphylococcal infection
	Psittacosis
	Aspergillus
	Pulmonary infection

3.1.4 Cancer

Long-term exposure to poor indoor air quality is a significant contributor to various cancers, most notably lung cancer. Studies reveal that air pollutants like particulate matter (PM) and volatile organic compounds (VOCs), released from burning solid fuels such as coal and wood for cooking and heating, can quadruple the risk of lung cancer in chronically exposed individuals compared to the general population [105].

This issue is particularly pronounced in East and South Asia, where women traditionally undertake most of the cooking. Due to the prevalent use of solid fuels, lung cancer rates among non-smoking women in these regions surpass those of their male counterparts [106, 107]. Beyond fuel-based pollutants, carcinogens from tobacco smoke and radon are also major risk factors. Furthermore, harmful substances produced by fuel combustion, including polycyclic aromatic hydrocarbons and PM, have been linked to other malignant tumors such as oral, laryngeal, nasopharyngeal, and even breast cancer [14, 108]. A local study found that every 10 µg/m³ increase in residential PM_{2.5} would lead to a higher risk of mortality from all cancers among the elderly, with a Hazard Ratio of 1.22 (95% CI: 1.11–1.34).[109]

3.1.5 Sick Building Syndrome

Besides directly inducing diseases, poor IAQ exposure can also cause some symptoms without a clear cause, related to the overall building environment [110], referred to as Sick Building Syndrome (SBS) [111]. These symptoms emerge once residents spend a certain amount of time in the building and deteriorate over time. Yet once they leave the building, the symptoms gradually subside and disappear [112].

Table. 8 Symptoms of Sick Building Syndrome

Irritation in eyes, nose or throat	Dryness
	Stinging, smarting, irritating sensation
	Hoarseness, changed voice
Skin irritation	Reddening of skin
	Stinging, smarting, itching sensation
	Dry skin
Odor and taste complaints	Changed sensitivity
	Unpleasant odor or taste

Neurotoxic symptoms	Mental fatigue
	Reduced memory
	Lethargy, drowsiness
	Reduced power of concentration
	Headache. Dizziness
	Nausea
	Tiredness

3.2 Cognitive Impacts

Increasing evidence suggests that the quality of indoor air does not only affect physiological health but can also exert a significant influence on cognitive functions, impacting mental performance, concentration, and overall productivity. Even at exposure levels that may not induce overt physical illness, common indoor pollutants can subtly or overtly impair a range of cognitive abilities crucial for learning, work, and daily tasks. Which includes decreased memory recall and retention, heightened difficulty in concentrating and maintaining attention, prolonged reaction times, diminished accuracy in work or task performance, increased feelings of fatigue, episodes of dizziness or headache, a discernible decrease in overall cognitive level or capacity, and ultimately result in decreased productivity.

Table. 9 Cognitive Impacts Caused by Indoor Air Pollutants

Indoor air pollutants		Impacts
Gaseous[113-119]	CO	Decreased memory
	CO ₂	Difficulty concentrating
	NO ₂	Prolonged reaction time
	O ₃	Decreased work accuracy
		Fatigue
		Dizziness, headache
		Decreased cognitive level
VOCs[115, 117, 118, 120, 121]		Decreased productivity
	Aromatic hydrocarbons (benzene, toluene, xylene, ethylbenzene)	Fatigue
	Aldehydes (formaldehyde) Terpenes	Dizziness, headache
	Alcohols	Decreased cognitive level
PM[116, 122, 123]		Decreased productivity
	PM2.5	Decreased cognitive level
	PM10	Decreased productivity

4. Economic Burden

4.1 International Estimation

The societal and economic repercussions of poor indoor air quality (IAQ) are extensive, translating into significant financial burdens through increased healthcare expenditures, productivity losses due to illness and cognitive impairment, and diminished overall quality of life. Numerous international studies and organizations have undertaken efforts to quantify these multifaceted economic impacts, employing diverse methodologies and focusing on various pollution and outcome scopes.

Table. 10 Economic Burden Caused by Indoor Air Pollutants

Region	Pollution scopes	Economic burden	Outcome scopes	Year
France [124]	IAQ	€20 billion	Total economic cost	2004
America [125]	IAQ	\$168 billion	Total economic cost	2004
America [126]	Household damp and mold	\$3.5 billion	Total economic cost	2007
Indonesia [127]	IAP	\$1.4 billion	Value of the lost health	2010
Philippines [127]	IAP	\$86–435 million	Value of the lost health	2010
Timor-Leste [127]	IAP	\$5–20 million	Value of the lost health	2010
California [128]	IAP	\$45 billion	Total economic cost	2005
Developed country [129]	IAQ	\$150,000 per DALYs	Value of the lost health	2018

4.2 Estimate the Economic Impact of poor IAQ in Hong Kong

The Environmental Protection Department (EPD) of Hong Kong used to conduct a study to measure the economic burden caused by IAQ in 1995. Which showed poor IAQ caused economic losses of HK\$12.2 billion, and 32% occupants were unsatisfied with their workplace's IAQ[130]. The Hedley Environmental Index provides the latest data on the economic burden caused by air pollution in Hong Kong [131], indicating that poor air quality resulted in a total loss of HK\$41.8 billion in 2024.

Due to a lack of IAQ monitoring data in Hong Kong, this study aims to provide a preliminary estimate of its economic burden. Based on Hong Kong's "Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places", we selected six key air pollutants for analysis: carbon monoxide (CO), PM2.5, nitrogen dioxide (NO₂), ozone (O₃), formaldehyde (HCHO), and total volatile organic compounds (TVOCs) [132]. The IAP concentrations data and relevant disease incidence data are primarily sourced from local Hong Kong studies since 2000. For the calculation methodology, we first employed the intake-incidence-DALY (IND) and intake-DALY (ID) methods proposed by Logue et al. to calculate the loss of Disability-Adjusted Life Years (DALYs) caused by air pollution [133]. Then DALYs loss was converted into an

economic burden through an estimation model proposed by Louis, C. et al [134].

4.2.1 DALYs estimation

We begin by estimating the healthy life years lost due to CO, PM_{2.5}, NO₂, and O₃ through the IND method. The main formula is shown below:

$$\text{DALY}_s = \frac{\partial \text{DALY}_s}{\partial \text{DI}} \times \text{Incidence} \quad (1)$$

$$\text{Incidence} = -\{y_0[\exp(-\beta \Delta C_{\text{exp}}) - 1]\}p \quad (2)$$

In Formula (1), $\frac{\partial \text{DALY}_s}{\partial \text{DI}}$ represents the healthy life years lost per case of a specific disease caused by a particular IAP, while incidence is the annual rate of new cases caused by that pollutant. In Formula (2), y_0 is the baseline annual incidence rate of the disease; β is the exposure-response coefficient; ΔC_{exp} is the exposure concentration; and p is the size of the exposed population. Our calculation incorporates local Hong Kong data for baseline incidence, population age structure, indoor activity patterns, and pollutant concentrations. Meanwhile, the selections for disease types, the β coefficient, and the $\frac{\partial \text{DALY}_s}{\partial \text{DI}}$ follow the study by Logue et al [133].

Table. 11 Criteria IAP C-R Function Outcomes and DALYs Lost per Incidence.

IAP	Disease ^[133]	β ^[133]	Y_0	$\frac{\partial \text{DALY}_s}{\partial \text{DI}}$
CO	Hospital admissions			4×10^{-4} ^[135]
	Asthma	0.033	$4.44 * 10^{-4}$ ^[136, 137]	
	Lung disease	0.025	$2.47 * 10^{-2}$ ^[138, 139]	
	Heart failure	0.034	$2.85 * 10^{-3}$ ^[140, 141]	
PM2.5	Total mortality	0.058	$7.5 * 10^{-3}$ ^[138]	1.4 (0.14, 14) ^[142, 143]
	Chronic bronchitis	0.091	$4.19 * 10^{-3}$ ^[144, 145]	1.2 (0.12, 12) ^[135, 146]
	Nonfatal stroke	0.025	$3.55 * 10^{-3}$ ^[147, 148]	11.7(11.1,12.4) ^[149]
NO ₂	Hospital admissions			4×10^{-4} ^[135]
	Respiratory issues	0.004	$2.47 * 10^{-2}$ ^[138, 139]	
	Congestive heart failure	0.003	$2.85 * 10^{-3}$ ^[140, 141]	
	Ischemic heart disease	0.003	$3.11 * 10^{-3}$ ^[140, 150]	
O ₃	Mortality	0.001	$7.5 * 10^{-3}$ ^[138]	1.0 (0.1, 10) ^[135]
	Hospital admissions			4×10^{-4} ^[135]
	Asthma	0.003	$4.44 * 10^{-4}$ ^[136, 137]	
	Lung disease	0.003	$1.87 * 10^{-2}$ ^[138, 139]	
	Respiratory infection	0.002	$8.08 * 10^{-3}$ ^[139, 151]	

Table. 12 Mean Indoor Air Pollutant Concentration ($\mu\text{g}/\text{m}^3$)

	Home	Office	School	Shopping mall	Restaurant
CO	943 ^[152]	854.3 ^[153]	187 ^[152]	1031.2 ^[154]	3750 ^[152]
PM _{2.5}	39 ^[155]	13 ^[155]	19 ^[156]	20.1 ^[154]	385 (PM ₁₀) ^[152]
NO ₂	118 ^[152]	18.9 ^[153]	31.98 ^[156]	63.64 ^[153]	718 ^[152]
O ₃	32.26 ^[157]	46 ^[158]	27.47 ^[156]	120 ^[132]	120 ^[132]

Table. 13 Age-specific Indoor Activity Patterns of the Hong Kong Population

	Hours per day (%) ^[152]					n('000) ^[159]
	Home	Office	School	Shopping mall	Restaurant	
Adolescents (6-18)	14.18 (59.08)	0.52 (2.17)	3.15 (13.13)	1.5 (6.25)	0.77 (3.21)	715.6
Adults (18-60)	13.66 (56.92)	3.00 (12.5)	0.68 (2.83)	1.31 (5.46)	0.99 (4.12)	4278.4
Elder (>60)	16.71 (69.63)	0.79 (3.29)	0.08 (0.33)	1.87 (7.79)	0.72 (3.00)	2311.4

Table. 14 Estimated DALYs Attributable to Different Indoor Environments in Hong Kong (IND)

Category of indoor environment	DALYs _i
Home	226956.77
Office	16831.73
School	8680.73
Shopping mall	19275.39
Restaurant	123197.62
Total	394942.24

The ID method is then used to estimate the health impacts of HCHO and TVOC, for which lack of concentration-response data. The main formula is as follows:

$$DALYs_i = C_i V \left[\left(\frac{\partial DALY_{cancer}}{\partial intake} \right)_i ADAF + \left(\frac{\partial DALY_{noncancer}}{\partial intake} \right)_i \right] \quad (3)$$

In Formula (3), C_i is the indoor concentration of pollutant i , obtained from local Hong Kong research data. V is the annual indoor air inhalation volume per person, determined by the average Chinese inhalation rate, local Hong Kong age demographics, and indoor activity patterns. $\left(\frac{\partial DALY_{cancer}}{\partial intake} \right)_i$ and $\left(\frac{\partial DALY_{noncancer}}{\partial intake} \right)_i$ are the respective cancer and non-cancer DALY factors for pollutant i , using toxicological data from Huijbregts et al [160]. ADAF is the Age-Dependent Adjustment Factor for carcinogenic exposure, based on U.S. Environmental Protection Agency (EPA) data [161].

Table. 15 Summary of DALY Factors and Indoor Concentrations for Selected IAPs

IAP	$\frac{\partial DALY_{cancer}}{\partial intake}$ [160]	$\frac{\partial DALY_{noncancer}}{\partial intake}$ [160]	C_i (μg/m ³)
HCHO	$7.6 * 10^{-1}$	$7.6 * 10^{-3}$	112.3 ^[162]
TVOC			
Benzene	$5.8 * 10^{-3}$	$3.1 * 10^{-3}$	8.1 ^[163]
Tetrachloroethylene	$1.0 * 10^{-2}$	$2.8 * 10^{-2}$	5.2 ^[163]
Trichloroethylene	$1.2 * 10^{-3}$	NA	5.6 ^[163]
Naphthalene	$1.1 * 10^{-2}$	$6.1 * 10^{-2}$	10 ^[132]
benzo(a)pyrene	$1.1 * 10$	NA	$1.2 * 10^{-3}$ ^[132]

Table. 16 Demographic and Exposure Parameters for the Hong Kong Population by Age Group

Age group	Population ratio (%)	V (m ³ /y) [164]	ADAF [161]
<2	0.9	1854.2	10
2~17	10.6	3752.2	3
18~44	33.3	6095.5	1
45~59	22.9	6095.5	1
60~79	27	5037	1
80+	5.5	4380	1
Weighted average		5442.15	1.295

Table. 17 Estimated DALYs Attributable to Different IAPs in Hong Kong (ID)

IAP	DALYs _i
HCHO	4428.11
Benzene	3.42
Tetrachloroethylene	8.47
Trichloroethylene	0.35
Naphthalene	29.92
Benzo(a)pyrene	0.68
Total	4470.93

The original ID method does not account for the actual time individuals spend in different settings. To address this limitation, we adjusted the initial results using a weighting method based on population age and activity patterns. This yielded a total indoor time adjustment factor of 82.72% and an office-specific factor of 8.57% [152, 159]. Applying these adjustments resulted in a final total of 3698.35 DALYs, with 383.16 DALYs specifically attributable to office environments.

4.2.2 DALY cost calculation

Following the methodology of Louis, C. et al. [134], the economic burden associated with DALYs is primarily comprised of three components: the cost of a life year, productivity loss, and associated medical costs. However, due to data limitations and significant disparities in healthcare expenditures across different regions, the medical cost component for Hong Kong is excluded from our analysis, as shown in Formula (4). For the productivity loss component, the average cost per person (P_{cost}) in Hong Kong is estimated around 422242 HKD per year [165].

$$DALY\ cost_i = LY_{cost} + P_{cost} \quad (4)$$

$$LY_{cost} = \frac{VSL}{\sum_{t=1}^T (1+r)^{-t}} \quad (5)$$

The cost per life year is calculated using Formula (5), which is adapted from a French report [166]. This formula incorporates the Value of a Statistical Life (VSL) of 15.7 million HKD [167], a social discount rate (r) of 3.5% [168], and an average remaining

life expectancy (T) of 40 years for the Hong Kong population[169] [159].
Based on this calculation, the cost per life year in Hong Kong is 73,5188 HKD.

4.2.3 Sick Building Syndrome Cost

$$SBS_{cost} = P_{cost} * \{(P_{loss} * POPS_2) + (\frac{P_{loss}}{2} * (POPS - POPS_2))\} \quad (6)$$

In Formula (6), P_{cost} is the same as previously defined. $POPS$ and $POPS_2$ are the "Percentage of Occupants Presenting at least 1 or 2 Sick Building Syndrome (SBS) Symptoms from 1 to 3 days a week during the last 4 weeks," set at 55% and 17.9% respectively [170, 171]. P_{loss} is the productivity loss caused by SBS symptoms, which is assumed to be 3% for the $POPS$ group and 6% for the $POPS_2$ group [172]. Using the number of employees (2,721,500) and civil servants (10,627) in Hong Kong [173, 174], the final estimated cost of Sick Building Syndrome is 25,229.64 million HKD.

4.2.4 Total Economic Burden

$$Non - occupational_{cost} = (DALY_{IND} + DALY_{ID}) * LY_{cost} \quad (7)$$

$$Occupational_{cost} = (DALY_{IND} + DALY_{ID}) * (LY_{cost} + P_{cost}) + SBS_{cost} \quad (8)$$

The total economic burden was calculated by dividing costs into two categories. The burden from non-occupational environments is determined by directly multiplying the total DALYs by the cost per life year, as shown in Formula (7). For occupational environments, the calculation additionally included costs from lost productivity and Sick Building Syndrome, as shown in Formula (8).

Finally, the estimated economic burden is 28.04 billion HKD for non-occupational environments and 4.52 billion HKD for occupational environments, resulting in a total economic loss of 32.56 billion HKD.

5. High-Risk Population and Built Environments in Hong Kong

5.1 High-Risk Population

Table. 18 High-Risk Population related Indoor Sources

Population Group	Hong Kong Indoor Sources	Additional International Sources
Elder ^[157, 175-187]	Cooking	Building materials (Rn)
	Tobacco Smoke	Solid Fuel combustion (wood, candle burning)
	Incense burning	Air conditioning system and humidifier
	Heating equipment	Transmission of infectious diseases
	Outdoor air pollution	Hygiene and healthcare products
	Poor ventilation	
	Decoration materials and furniture	
	Household chemicals	
	Damp environments	
	Cleaning activities	
Children ^[156, 157, 175-180, 182, 187-198]	Cooking Activities	Household products
	Heating	Personal care products
	Environmental Tobacco Smoke	Office products
	Incense Burning	The combustion of solid fuels and kerosene
	Poor Ventilation	Soil and rock
	Air Conditioning	Indoor heavy metal dust
	Outdoor Air Pollution Infiltration	Pesticides
	Building Characteristics and Materials	Pets

Women [157, 176, 178-180, 187, 188, 198, 199]	Household Background Emissions	Occupant activities
	Damp environments	Dust mites and pests
	Cooking Activities	Household products
	Environmental Tobacco Smoke	Personal care products
	Incense Burning	Office products
	Poor Ventilation	The combustion of solid fuels and kerosene
	Household Background Emissions	Soil and rock
	Damp environments	Indoor heavy metal dust
	Building Characteristics and Materials:	Pesticides
		Pets
Staff and workers [158, 175, 200-207]		Occupant activities
		Dust mites and pests
		Flame retardants
	Office Equipment	
	Building Materials and Furniture	
	Outdoor Air Pollution Infiltration	
	Mechanical Ventilation and Air-Conditioning (MVAC)	
	Systems	
	Damp Environments	
	E-Waste Recycling	
	Commercial Kitchen	

5.1.1 Elder

Older adults, typically defined as individuals aged 65 and above, represent a significant and growing population in Hong Kong. This demographic often spends a considerable amount of time indoors, a trend further amplified by potential impairments in their daily living activities and a higher prevalence of chronic diseases. Their reduced physiological functions and weaker immune systems make them particularly vulnerable to the harmful effects of poor indoor air quality. In 2023, among Hong Kong residents aged 65 and over, 1,190 deaths were attributed to chronic lower respiratory diseases, 5,950 to heart disease, and 1,523 to dementia.[208]. And indoor air pollution is a significant risk factor for these conditions. Furthermore, older adults who don't reside in elderly care homes are largely confined to their residential environments, leaving them completely exposed and outside the scope of the Hong Kong government's Indoor Air Quality Certification Scheme.

Common indoor pollutants that pose a concern for older adults in Hong Kong include:

- **Pollutant Concentrations:** Indoor PM_{2.5} concentrations in the homes of elderly residents in Hong Kong are significantly higher during winter (averaging around 34.2 $\mu\text{g}/\text{m}^3$) than in summer (averaging around 25.3 $\mu\text{g}/\text{m}^3$), with over half of households exceeding World Health Organization standards. Nitrogen dioxide (NO₂) levels are more stable, averaging between 40.5-43.5 $\mu\text{g}/\text{m}^3$. Formaldehyde (HCHO) concentrations are notably higher in summer (averaging around 26.1 $\mu\text{g}/\text{m}^3$) than in winter (averaging around 15.4 $\mu\text{g}/\text{m}^3$) [179].
- **Cooking Activities:** Cooking is a primary source of indoor PM_{2.5}, PM₁₀, VOCs and NO₂ [175-177]. The use of gas fuels, particularly Liquefied Petroleum Gas (LPG), leads to higher pollutant levels; without mechanical ventilation, cooking with LPG can result in PM_{2.5} concentrations 95% higher than those from other stoves. Using mechanical ventilation, such as a range hood, during cooking is crucial for reducing these emissions [178-180].
- **Heating:** IAPs are also emitted during heating equipment operation, particularly by gas water heaters. [187].
- **Tobacco Smoke:** Since many local smokers are elderly, environmental tobacco smoke remains a widespread threat to older people in Hong Kong, especially in their homes [157, 175]. Even non-smoking seniors can be exposed to secondhand smoke at home.
- **Incense Burning:** Incense burning is another activity that significantly increases indoor PM_{2.5}, NO₂ and VOCs concentrations [178-180]. Of all indoor activities, incense burning contributes the most to overall cancer risk, accounting for up to 46%.[157]
- **Cleaning Activities:** Cleaning methods such as sweeping can also slightly elevate indoor PM_{2.5} levels by resuspending dust particles [178, 179].
- **Household chemicals:** Cleaning and disinfection products, such as laundry detergents and mothballs, are known to release various types of VOCs [182].
- **Damp environments:** Hong Kong's climate, particularly its unstable and humid

springs and hot, humid summers, can create damp indoor environments. These conditions may lead to health issues for the elderly, such as fungal skin problems [181].

- **Building Materials and Furniture:** Indoor formaldehyde (HCHO) is primarily released from sources like building materials, wooden furniture, and wallpaper adhesives, with emission rates being highly sensitive to temperature and relative humidity [178, 179].
- **Poor Ventilation:** Poor ventilation is a common problem in residential care homes and is also prevalent in private residences due to ventilation habits and crowded living spaces. Furthermore, opening windows for extended periods may not always be beneficial, as it can increase indoor PM_{2.5} levels by introducing outdoor pollutants. In contrast, using air conditioning appears to help lower indoor PM_{2.5} concentrations [178, 180, 181].
- **Outdoor Air Pollution:** Outdoor air pollution is a decisive factor influencing indoor air quality, as indoor PM_{2.5} and NO₂ concentrations show a strong correlation with outdoor levels. Homes near roads with heavy traffic have significantly higher indoor NO₂ levels, while proximity to odor sources like rubbish collection points can also negatively affect the indoor environment. [178-181]

Furthermore, several indoor air pollutant (IAP) sources identified in international studies have not yet been conclusively established by research in Hong Kong. These include emissions from building materials [185, 186], solid fuel combustion [183, 184], air conditioners and humidifiers [186], the airborne spread of infectious diseases [185], and hygiene and healthcare products [186]. For Hong Kong's elderly, several of these sources are particularly pressing and require local investigation. In older buildings, deteriorating materials and proximity to soil can lead to indoor radon contamination, especially for residents on lower floors. Moreover, aging air conditioning systems in high-density housing can accelerate the spread of biological pollutants among the vulnerable elderly. Finally, the frequent use of hygiene and healthcare products in nursing homes can generate substantial levels of VOCs and bioaerosols, adversely impacting resident health.

5.1.2 Children

Children constitute a population group with heightened susceptibility to the detrimental effects of poor IAQ. Their organs, particularly the lungs, are still developing, meaning that exposure to pollutants during these critical growth periods can lead to more severe and potentially long-lasting health consequences [209, 210]. Children also have higher breathing rates compared to adults, leading to a greater intake of pollutants per unit of body weight [211]. Children typically spend substantial periods indoors—at home, daycare, or school—elevating their cumulative exposure [195]. This situation is potentially intensified in Hong Kong's characteristically dense urban living conditions, where smaller apartment sizes and reliance on mechanical ventilation would lead to higher concentrations of indoor-generated pollutants and increased infiltration of

outdoor pollutants [212]. Notably, an estimated 16% of residents in Hong Kong's SDUs are under the age of 15 [213].

Common indoor pollutants that pose a concern for children in Hong Kong include:

Pollutant Concentrations: In Hong Kong schools, average PM₁₀ concentrations exceed the Hong Kong Air Quality Objectives, with peak indoor levels surpassing 1000 µg/m³. Carbon dioxide (CO₂) levels in classrooms frequently exceed 1000 ppm, reaching as high as 5900 ppm [189]. Various gaseous pollutants, including CO, NO₂, HCHO, and VOCs, have also been detected in indoor environments frequented by children [176, 189, 197]. Additionally, total bacterial counts are relatively high in air-conditioned classrooms, shopping malls, and restaurants, potentially increasing the risk of respiratory infections [189].

Cooking Activities: Cooking is a primary source of indoor IAPs, including PM₁₀, PM_{2.5}, and VOCs. This impact is significantly amplified by open-plan kitchens and poor ventilation, which allow pollutants to migrate from the kitchen to other areas like living rooms, where children spend more time [175-177].

Heating: IAPs are also emitted during heating equipment operation, particularly by gas water heaters. [187]

Environmental Tobacco Smoke: Children continue to be exposed to environmental tobacco smoke (ETS) at home due to smoking by older family members [157, 175].

Incense Burning: Incense burning is a significant source of indoor PM, NO₂, and VOCs in residences, which are primary environments for children [178-180].

Poor Ventilation: Insufficient ventilation is particularly prominent in Hong Kong's classrooms, SDUs, and general residences. High population density, combined with structural building defects, makes it difficult for ventilation rates to meet actual demand [176, 189].

Air Conditioning: Improper use or maintenance of air conditioning can become a source of indoor air pollution, leading to the accumulation of pollutants such as CO, CO₂, and VOCs [182, 197].

Outdoor Air Pollution Infiltration: In school settings, outdoor air pollution is the strongest predictor of indoor PM_{2.5}, PM₁₀, O₃, and NO₂ levels, contributing 90%, 70%, 75%, and 50% of their respective indoor concentrations [156].

Damp environments: This is a common problem in Hong Kong residences that affects all residents and increases the probability of childhood asthma [188].

Building Characteristics and Materials: Building materials and renovation projects in schools and homes release formaldehyde and VOCs. And this problem is often more severe in commercial spaces like restaurants and shopping malls [175].

Household Background Emissions: In Hong Kong residences, studies indicate that even without obvious polluting activities, the indoor environment can be a source of continuous exposure to harmful substances. This may be related to the long-term, slow release from various sources like building materials, furniture, cleaning products, and dust accumulation [157].

In addition to the sources identified in local studies, international research has pointed to other IAP sources, such as household, personal care, and office products [195], the combustion of solid fuels and kerosene [194, 195], soil and rock [196], indoor heavy

metal dust [190], pesticides[191], pets[195], occupant activities[193], and dust mites and pests[192]. Many of these sources are common in Hong Kong. Although the concept of "Household Background Emissions" touches upon many of these, more in-depth research is needed to deepen our understanding of specific sources. Furthermore, moisture in building materials and indoor environments can promote mold and fungal growth and should receive greater attention.

5.1.3 Women

Women, particularly in certain socio-cultural contexts, may have distinct exposure patterns due to traditional household roles involving more time spent indoors and greater involvement in cooking activities [214]. Furthermore, pregnant women are a group that is exceptionally sensitive both physiologically and in terms of environmental exposure. The indoor air pollutants they are exposed to during pregnancy not only affect their own health but can also cross the placental barrier, exerting direct or indirect effects on the developing fetus. Research has confirmed that maternal exposure to PM, NO_x, PAHs, and CO during pregnancy is significantly associated with an increased risk of respiratory diseases in their offspring, including asthma, wheezing, pneumonia, and lower respiratory tract infections [214].

Common indoor pollutants that pose a concern for women in Hong Kong include:

Cooking Activities: Cooking is a primary source of indoor particulate matter, especially with Chinese cooking methods like stir-frying and deep-frying. Moreover, high concentrations of Ultrafine Particles (UFPs) can persist for up to 60 minutes after cooking, significantly extending the exposure time for family members, particularly women who are often responsible for cooking [199].

Environmental Tobacco Smoke: Environmental Tobacco Smoke (ETS) is a major indoor air pollutant in Hong Kong that threatens the health of non-smoking women. The presence of ETS in the home is particularly critical, given the epidemiological finding that up to 64% of female lung cancer patients in Hong Kong are non-smokers [187].

Building Characteristics and Materials: They are common sources of VOCs in the home environment [175].

Damp environments: It is a common problem in Hong Kong residences that affects all residents, and women may be more exposed to damp environments in the home due to household activities [188].

Heating: Gas water heaters also existing in female household environments. [187]

Incense Burning: Incense burning is a significant source of indoor PM, NO₂, and VOCs in residences, which are also primary environments for women [178-180].

Poor Ventilation: Poor ventilation can lead to the accumulation of various air pollutants. For women, this is particularly relevant to the effects of inadequate ventilation in the kitchen during cooking [176].

Household Background Emissions: Among the potential sources of "Household Background Emissions," women may have higher exposure to IAPs generated from

cleaning activities [157].

Other sources of exposure in the home environment mentioned in international studies are consistent with those for children. However, personal care and cleaning products are of particular concern for women. Research from the United States indicates that the use of various household products, including personal care items and cleaning agents, contributes to women's VOC exposure [215]. In daily life, an individual uses at least two personal care products per day, applied 11 times on average within 24 hours, for a total of up to 44 applications daily. Products like dish soap and stove cleaners are used daily. It is estimated that women may be exposed to approximately 168 different chemicals each day through these products [216].

5.1.4 Staff and workers

Staff and workers in various occupational settings, including offices, factories, and commercial buildings, can be exposed to a range of indoor air pollutants for extended durations, leading to increased health risks. In Hong Kong, the thriving tertiary industry means a large share of the workforce works in offices. And studies show that local offices and public buildings often fail to meet IAQ standards, which can lead to "Sick Building Syndrome" (SBS) and significantly reduce productivity. While improvements in some office IAQ parameters like CO₂ and formaldehyde were noted after the implementation of EPD Guidance Notes [217], issues such as elevated TVOC levels persist even in some Grade A offices [218].

Common indoor pollutants that pose a concern for office worker in Hong Kong include:

Building Occupants: Office workers themselves are a primary source of indoor air pollution. Their metabolic processes and activities directly release CO₂ and bioaerosols into the indoor environment [200].

Office Equipment: During operation, office equipment such as printers, photocopiers, and fax machines release various VOCs due to the heating of ink or toner [201].

Building Materials and Furniture: The materials used in office construction, renovation, and furnishings are long-term emission sources of chemical pollutants, particularly formaldehyde and VOCs [175].

Outdoor Air Pollution Infiltration: Outdoor air pollution is another significant factor affecting indoor air quality, especially in commercial premises with poor building sealing or specific ventilation designs [202]. Street-level shops, in particular, are susceptible to traffic-related pollutants like Respirable Suspended Particulates (RSP), CO and NO₂ [202].

Mechanical Ventilation and Air-Conditioning (MVAC) Systems: Poorly maintained HVAC systems are ideal breeding grounds for microorganisms. Moist areas, such as condensation drip pans in air-conditioning ducts, are prone to the growth of bacteria like *Legionella* and various types of mold, which can then be distributed throughout the indoor space via the ventilation system [203].

Damp Environments: The high humidity of Hong Kong's summers provides an excellent environment for bacterial proliferation, leading to very high levels of airborne

bacteria in offices [158].

Special Occupational Exposures:

E-Waste Recycling Workshops: The physical processing of electronic waste, particularly dismantling and desoldering, is a major source of heavy metal pollutants, including cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), mercury (Hg), and zinc (Zn) [219]. These operations release metals contained in electronic components into the air as suspended particulates and dust, which then settle on surfaces and floors, creating multiple exposure pathways through inhalation, dermal contact, and ingestion. Furthermore, chemical additives within the electronic products are also a significant source of pollution, exposing workers to notably higher levels of bisphenol analogues (BPs) [204].

Commercial Kitchens: In the commercial kitchens of Hong Kong, especially in Chinese restaurants, gas combustion is a primary source of indoor air pollution, directly impacting the respiratory health of kitchen staff [205].

Furthermore, international research has highlighted flame retardants, which are common in modern office products and leach out over time. In the office environment, major sources include polyurethane foam in furniture (chairs, partitions), casings of electronic equipment (computers, printers), and carpet padding [206]. These chemicals migrate from the products into indoor dust, making dust a primary reservoir and pathway for exposure.

5.2 Built Environments

5.2.1 School

The "Guidelines on Indoor Air Quality Management for Schools" issued by the Hong Kong government explicitly outlines potential sources of indoor air pollution [220].

Pollutant Sources Infiltrating from Outdoors:

- Exhaust from Surrounding Environments: Schools adjacent to major transportation routes are affected by traffic exhaust. If located near industrial zones, they may face pollution from industrial emissions.
- Particulates from the Natural Environment: Pollen and dust from playgrounds or surrounding green belts, as well as mold spores from old building exteriors or damp corners, can easily be blown indoors by the wind.
- Odors from Adjacent Facilities: Trash cans or garbage collection stations on or near campus are primary sources of unpleasant odors.

Various Pollutant Sources Originating from within the Campus:

Mechanical Ventilation and Air Conditioners (MVAC): As the primary ventilation equipment in spaces where students conduct their daily activities, MVAC systems can circulate mold, dust, and debris accumulated within them if not properly cleaned and maintained, affecting all students and staff.

Specific Pollutant Sources from Teaching Activities:

- Science Laboratory Supplies: During chemistry or biology experiments, the

volatilization of chemical reagents and gases produced from heating reactions are pollutant sources unique to laboratory areas.

- Vocational and Art Supplies: Pigments, spray paints, solvents, and glues used in art rooms, as well as various materials used in craft classes, release specific chemical substances during use.
- Dry-Erase Markers and Similar Pens: Whiteboard markers, used frequently by teachers in class, continuously release organic solvents and are one of the most direct and common sources of pollution inside the classroom.

Building Materials and Furniture: In new school buildings, newly renovated classrooms, or with newly purchased desks and chairs, materials such as paint, caulk, adhesives, and varnishes will persistently release harmful substances like formaldehyde in their initial stages. Damp environments on campus (such as changing rooms and restrooms) are breeding grounds for mold.

Pollution from Daily Operations and Maintenance:

- Office and Cleaning Equipment: Printers and copiers in staff rooms, as well as high-power cleaning equipment used by janitorial staff, produce ozone and fine particles during operation.
- Cleaning Materials and Air Fresheners: Cleaners and air fresheners used to maintain hygiene and freshness on campus (especially in restrooms and canteens) are a significant source of chemical pollutants.
- Emissions from Rubbish: Trash cans in classrooms, canteens, and public areas are major sites for garbage odors and bacterial growth, especially after lunchtime.
- Pesticides: Regular or ad-hoc spraying for pest control on campus can leave chemical residues.
- Personal Care Products: Hand soaps used by students or perfumes and hairsprays used by teachers can also release various VOCs.

The guidelines may have overlooked certain IAP sources. Some primary and secondary schools in Hong Kong have already implemented tablet-based teaching, and research suggests that the cumulative VOC emissions from high-density personal electronic devices should not be ignored [221]. Students and teachers are themselves sources of pollution; this includes CO₂ from respiration, shed skin flakes, and particle resuspension caused by movement, all of which contribute to air contamination [222]. Furthermore, classrooms located on the ground floor may be affected by radon gas emanating from the soil and rock beneath [223].

5.2.2 Elderly home

The "Guidelines on Indoor Air Quality Management for Residential Care Homes for the Elderly" issued by the Hong Kong government explicitly outlines potential sources of indoor air pollution [224].

Outdoor pollutants can enter the care home through doors, windows, and ventilation systems, affecting the baseline quality of indoor air:

- Influence of Surrounding Environments: Many residential care homes in Hong

Kong are located near roads, making them susceptible to traffic exhaust from adjacent roadways and potential industrial emissions.

- Natural Environmental Factors: Pollen, outdoor dust, and mold spores are common triggers for seasonal allergies and respiratory discomfort.
- Odors from Adjacent Facilities: This includes, for example, unpleasant odors emanating from nearby garbage collection points.

The internal operations and facilities of the care home also generate sources of pollution: Mechanical Ventilation and Air-Conditioning (MVAC) Systems: If filters and ducts are not cleaned properly, they can become a source and distribution channel for mold, dust, and debris, continuously circulating pollutants into the living spaces of residents.

Building Materials and Furniture:

- During partial renovations, repairs, or when new furniture is introduced, materials like paint, caulk, adhesives, and varnishes release volatile organic compounds (VOCs).
- When the care home environment is damp (e.g., in bathrooms, laundry rooms, or from wall leaks), building materials and furniture are more prone to mold growth, significantly impacting air quality.

Pollution from Daily Operations and Care Activities:

- Cleaning Materials and Air Fresheners: The frequent use of detergents, disinfectants, and air fresheners to maintain hygiene and a pleasant smell is a significant source of chemical pollutants.
- Personal Care Products: Soaps, body powders, and other products used for or by residents can lead to an accumulation of chemical substances in both personal and common areas.
- Office and Cleaning Equipment: Printers and copiers in offices, as well as specific equipment used during cleaning, can release fine particles and exhaust gases during operation.
- Emissions from Rubbish: Daily waste generated within the home—including nursing care waste, kitchen scraps, and general refuse—can produce foul odors and breed bacteria if not disposed of in a timely manner.
- Pesticides: Spraying to control pests like mosquitoes, insects, and rodents can leave residual chemicals suspended in the air.
- However, the guidelines may have overlooked some potential indoor IAP sources relevant to elderly homes in Hong Kong. These include bioaerosols generated from human breathing, talking, and coughing, which can carry viruses and bacteria [225]. Cleaning activities, such as sweeping and making beds, can resuspend large quantities of particulate matter, skin flakes, and microorganisms [226]. Furthermore, many residential care homes in Hong Kong are located on lower floors, making elderly residents more susceptible to radon gas emanating from the underlying soil and rock [223].

5.2.3 Office

The IAQ guidelines for offices and public places introduced by the Hong Kong government propose the following indoor IAP sources [132]:

Building Materials and Furniture: This includes formaldehyde released from pressed wood products like plywood and particleboard; volatile organic compounds (VOCs) from paints, adhesives, carpets, and various synthetic materials; asbestos-containing materials that may be present in older buildings; and radon gas released from granite and concrete in building materials, as well as from the soil and rock surrounding the building.

Office Equipment: This includes devices such as photocopiers, laser printers, and fax machines, the operation of which releases ozone, VOCs, and dust.

Biological Activities: This primarily refers to carbon dioxide (CO₂) from occupants' respiration, human body odors and shed skin flakes, and viruses carried by individuals. It also includes bacteria, mold, and dust mites that thrive in damp office environments.

External Sources: Pollutants entering the indoor environment through gaps in doors and windows or via fresh air intake systems, such as vehicular exhaust, industrial emissions, pollen, dust, and cooking fumes.

Maintenance, Cleaning, and Pest Control: Chemical products like cleaning agents and pesticides are sources of VOCs. Furthermore, pests and their by-products (such as insect fragments) are also considered a source of particulate matter.

Defects in HVAC (MVAC) Systems: Damp areas within the system can foster the growth of mold and bacteria, while unclean ventilation ducts can spread dust and microbial contaminants.

Indoor Plants: Indoor plants (especially strongly scented flowering plants) can cause allergies and distress to sensitive individuals, triggering asthma or hay fever symptoms. Their pollen is also a source of particulate matter.

Some potential pollutant sources may not have been mentioned in the guidelines. First are air purifiers and humidifiers. Some staff and office managers may choose to purchase air purifiers to improve office air quality. However, certain air purifiers with ozone generators can have negative effects, as ozone is largely ineffective below safe concentration levels and can harm the respiratory system either directly or through secondary reactions with other chemicals [227]. Due to the intensive use of air conditioning in Hong Kong offices, some staff members might purchase small humidifiers, which can lead to the generation of harmful aerosols (particulate matter, bacteria, and mold) [228]. Food heating activities in pantries, such as using microwaves and coffee machines, also produce particulates and VOCs [229].

5.2.4 Subdivided Units (SDUs)

Subdivided units (SDUs) represent one of the most acute IAQ challenges in Hong Kong. These are typically small flats partitioned into several tiny, self-contained units, often with a floor area of merely 9.3 m² and frequently lacking a properly partitioned kitchen

and window [176]. Approximately 210,000 people, or 2.9% of Hong Kong's population, reside in such units. These conditions pose severe health risks, including respiratory diseases, allergies, and potentially cancer, particularly for children who are disproportionately represented in SDUs. There is a clear lack of comprehensive IAQ data, government-led studies and more rigorous regulatory measures.

IAQ monitoring in Hong Kong SDUs has revealed alarming pollutant levels [176, 197]. Among them, PM₁₀ was measured at 22 µg/m³ and VOCs at 794 µg/m³, exceeding Hong Kong's IAQ objectives by 1.10 and 3.89 times, respectively. During open-kitchen cooking, peak concentrations of PM₁₀ and PM_{2.5} can exceed standards at 1000 µg/m³ and 500 µg/m³, respectively. Furthermore, during air conditioner use, CO₂, CO, and VOCs increased by 86%, 312%, and 22%, respectively.◦

Research has also identified the following IAP sources in SDUs:

Inadequate Ventilation: The installation of additional partition walls severely inhibits air circulation. Some units have no windows, or their windows open into narrow gaps between buildings, leading to restricted ventilation. In some extremely crowded units, accumulated clothing and clutter also obstruct airflow.

Cooking Activities: As most SDUs lack separate kitchens, residents cook directly in their living spaces. This leads to the diffusion of cooking fumes (rich in PM₁₀ and PM_{2.5}) throughout the entire unit.

Air Conditioning Use: When using air conditioning, doors and windows are kept closed, leading to a rapid accumulation of CO₂ from human respiration and VOCs continuously released from various sources. When an air conditioner is turned on for the first time in the hot season, dust (PM) and adsorbed CO and VOC molecules that have collected on the filter and evaporator are blown into the room, causing a sudden spike in the concentrations of these pollutants. Research speculates that CO molecules may be adsorbed onto the air conditioner's metal evaporator due to electrostatic forces.

Other Indoor Sources:

- **Volatile Organic Compounds (VOCs):** Primarily from building materials, paint, furniture, household items, and clothes being dried indoors (laundry detergents can release various VOCs).
- **Moth-proofing Products:** Some residents use mothballs, which release VOCs such as naphthalene and 1,2-dichlorobenzene, leading to elevated VOC concentrations.
- **Damp Environments:** Inadequate ventilation and small toilets in SDUs often lead to high air humidity, with average relative humidity commonly exceeding 80%, especially in the summer.

5.2.5 Hospital and medical institutions

The indoor air quality in hospitals is unique due to frequent cleaning, disinfection, and healthcare activities, particularly the inherent contradictions in maintaining a hygienic environment. On the one hand, hospitals must carry out strict and frequent disinfection to control pathogens and prevent healthcare-associated infections [230]. This is a

necessary measure to protect the health of patients and healthcare workers. However, on the other hand, the chemical agents used for disinfection are themselves sources of VOCs (volatile organic compounds) and may generate harmful disinfection by-products (DBPs) during the disinfection process [231]. This ultimately leads to patients and staff inhaling these chemicals. As a unique setting where IAP characteristics differ significantly from other environments, and where patient populations are generally more physically vulnerable and sensitive to poor air quality, hospitals require dedicated indoor air guidelines from the government, accompanied by regular air quality monitoring and regulatory action. Furthermore, there is a severe lack of local research in this area in Hong Kong, necessitating government-led studies or increased investment in relevant scientific research to provide support for policymaking. Hospital indoor air pollutants primarily originate from microorganisms and chemical substances [232].

Sources of Microbial Pollutants:

- **Tuberculosis (TB) Bacteria:** Droplets containing TB bacteria are generated when patients with active tuberculosis cough, sneeze, or speak.
- **Legionella Bacteria:** A common source in hospitals is the water aerosol discharged from cooling towers, which is then drawn into the indoor environment through outdoor air intakes. Other potential sources include evaporative condensers, drinking water systems, and hot water systems.
- **Staphylococcus aureus:** This bacterium is present on the skin and in the nose, blood, and urine of infected patients. Microbial aerosols can be generated during certain surgical procedures.
- **Aspergillus Spores:** Hospital renovations or nearby construction projects are major sources of aerosolized Aspergillus spores. Additionally, fungal spores from soil, plants, animals, and dust can adhere to the clothing of healthcare staff or visitors.

Chemical and Other Pollutants:

- **Waste Anesthetic Gases:** One source of nitrous oxide is the waste gas generated during anesthesia.
- **Latex Gloves:** Latex allergens can originate from gloves used by healthcare personnel.
- **Construction and Renovation:** Construction and renovation work generates dust and chemical substances.
- **Materials and Equipment:** Cleaning products, building materials, furniture, and medical equipment can all release chemical pollutants.

Furthermore, international research has also identified aerosolized medications [233], chemical solvents from laboratories [234], and radioactive isotopes released from drugs and procedures in nuclear medicine [235] as sources of IAPs in hospitals.

6. Discussion

6.1 Sources of Poor Indoor Air Quality

The sources of poor indoor air quality (IAQ) are more complex than those of outdoor air pollution. Pollutants originate not only from indoor environments and activities but are also significantly influenced by outdoor air. Indoor air pollutants can be broadly divided into four categories: gaseous pollutants, volatile organic compounds (VOCs), particulate matter and fibers, and biological contaminants.

6.1.1 Combustion and Heating Activities

A primary source is combustion, which generates various gaseous pollutants and particulate matter. While solid fuels like coal and wood are no longer common in Hong Kong, the widespread use of gas stoves and the nature of Chinese cooking still place a heavy burden on indoor air in homes and restaurants. Gas-powered water heaters and space heaters also contribute to this problem. While it is difficult to change these fundamental activities, we can encourage residents to improve ventilation during cooking and heating to mitigate the impact.

Furthermore, activities like burning incense and smoking, though less common, still have a significant impact, particularly among middle-aged and older populations. These activities release not only gaseous pollutants and particulates but also high levels of VOCs, posing serious health risks. The Hong Kong government has successfully implemented smoking bans in public places, but smoking within private homes remains unregulated. Continued education and public awareness campaigns are needed to encourage voluntary smoking cessation. Tackling incense burning is more complex. As a practice tied to cultural and religious beliefs, and with its health risks less widely understood than those of smoking, changing public behavior in the short term is a significant challenge.

Outdoor sources also play an indirect role. In Hong Kong, the close proximity of road networks to buildings, combined with a vehicle fleet still dominated by gasoline and diesel cars, allows exhaust fumes to affect occupants, especially in lower-level buildings. The city's electricity generation also relies heavily on fossil fuels. Controlling these external sources depends on government initiatives in energy transition and air quality management, where considerable progress has been made in recent years.

6.1.2 Building Materials, Furnishings, and Chemical Products

A second major source is building and renovation materials, furniture, and everyday chemical products like personal care items, cleaners, and pesticides. These all release various VOCs. To address this, two strategies are effective: source control and enhanced

ventilation. Consumers can choose low-toxicity, environmentally friendly products. For newly renovated spaces or new furniture, it's crucial to allow for a period of natural ventilation before use. Similarly, consciously increasing air exchange with the outdoors before and after using chemical products is important.

6.1.3 Biological Contaminants

The third primary source is biological activity. This includes humans, indoor plants and animals, and pests, along with their metabolic byproducts. These sources can generate mold, fungi, bacteria, viruses, dust mites, and allergens that compromise indoor air. Regular cleaning is essential. It is also important to ensure good ventilation during cleaning to prevent the secondary pollution of dislodged particles.

6.1.4 Amplifying Factors: Urban Density and Climate

Finally, while not direct sources themselves, Hong Kong's high-density urban environment and humid climate significantly amplify the harm from existing indoor sources. High-density living translates to more indoor activity per unit of area, accelerating the rate at which pollutants are generated. In Hong Kong's subdivided units (SDUs), for instance, residents often perform all daily activities—cooking, washing, sleeping—within a space of about 10 square meters. Furthermore, the small living quarters and minimal space between buildings lead to poor ventilation. This traps pollutants indoors, allowing them to accumulate and cause long-term harm.

6.2 The Impacts of Poor Indoor Air Quality

Exposure to poor IAQ can trigger a range of health issues, from minor sensory irritation to life-threatening diseases.

Health Consequences:

- **Cardiovascular and Respiratory Diseases:** Abundant evidence shows that pollutants like particulate matter (PM), VOCs, and gaseous pollutants can cause or worsen conditions such as heart disease, stroke, chronic obstructive pulmonary disease (COPD), and asthma by triggering systemic inflammation, oxidative stress, and autonomic nervous system dysfunction. In Hong Kong, respiratory and circulatory diseases rank fourth and fifth for hospital admissions, placing a significant strain on the healthcare system [236]. Poor air quality is likely a major contributor to this burden.
- **Cancer Risk:** Long-term exposure to poor IAQ is a significant cancer risk factor. PM, VOCs, and polycyclic aromatic hydrocarbons (PAHs) from combustion are known to cause lung, oral, laryngeal, nasopharyngeal, and even breast cancer. Cancer is currently Hong Kong's largest disease burden, accounting for 15.3% of all hospital discharges and deaths in 2023, with lung

and breast cancer being the most common [236, 237]. This underscores the severe disease burden imposed by poor IAQ.

- **Infectious Disease Transmission:** Poor air quality, especially in poorly ventilated and humid conditions, creates a favorable environment for airborne pathogens like influenza, tuberculosis, and SARS to spread. This risk is particularly pronounced in Hong Kong, given its experience with COVID-19 and SARS and its high-density population. Local studies have found that common air-conditioned environments in the city have relatively high total bacterial counts, increasing the risk of respiratory infections. This should be a key concern for schools, nursing homes, and offices.
- **Sick Building Syndrome (SBS):** SBS refers to a collection of symptoms like headaches, fatigue, and irritation of the eyes, nose, or throat that are linked to time spent in a specific building but have no clear cause. Studies in Hong Kong's office environments have already shown high levels of employee dissatisfaction with IAQ. Some buildings fail to meet official IAQ standards, and the conditions in most remain unknown. This suggests SBS may be a widespread problem affecting the health and well-being of Hong Kong's workforce, potentially impacting an economy dominated by finance and trade.

Cognitive Impacts:

Research clearly indicates that common indoor pollutants like CO₂, VOCs, and PM can impair cognitive function, leading to memory loss, difficulty concentrating, slower reaction times, and reduced productivity.

This is particularly alarming when connected to real-world data from Hong Kong. For example, CO₂ levels in the city's classrooms frequently exceed the recommended limit of 1000 ppm and can reach as high as 5900 ppm [162]. Even in Grade A office buildings, total volatile organic compound (TVOC) levels are often elevated [193]. These findings suggest that Hong Kong's students and office workers may be studying and working in environments that compromise their cognitive abilities, representing a significant potential loss for both individuals and the city's economy.

Economic Impacts:

Poor Indoor Air Quality (IAQ) not only impairs public health and cognitive performance but also carries significant economic consequences for Hong Kong. Globally, studies in the U.S. and France have shown that the economic damage from indoor air pollution exceeds 1% of their GDP [124, 125]. A similar finding was observed in Hong Kong in the late 1990s, with an estimated annual economic loss of HK\$12.2 billion, equivalent to 1.1% of its GDP at the time [130]. According to our estimation, poor IAQ causes an economic loss of 32.56 billion HKD. It also exceeds 1% of the 2024 GDP even before considering medical costs, highlighting the significant impact of poor IAQ on the city's development.

Data and Research Gaps:

However, current estimate of Hong Kong's IAQ economic burden is heavily reliant on foreign data and numerous assumptions, which undermines its credibility and policy influence. There are significant data gaps, including:

- **Exposure Assessment:** A lack of long-term monitoring data for key pollutants

across Hong Kong's typical indoor environments (homes, schools, offices).

- **Health Risk Quantification:** A shortage of local epidemiological studies to establish dose-response relationships or relative risks between IAQ and various health outcomes.
- **Economic Valuation:** A lack of locally derived VSL figures, detailed data on direct medical costs for IAQ-related diseases, and quantified data on productivity losses from SBS and other related conditions.

6.3 High-Risk Populations and Environments

The negative effects of poor IAQ in Hong Kong are not distributed evenly; they disproportionately affect specific groups.

6.3.1 Vulnerable Populations

- **The Elderly, Children, and Women:** These groups are more vulnerable due to physiological reasons and social roles. The elderly and children have weaker immune systems and often spend more time in potentially polluted environments like nursing homes and schools. Despite government guidelines for these locations, studies show their air quality is often suboptimal, likely due to higher occupancy density or ventilation limits. In homes, small living spaces and closely packed buildings can restrict airflow, a problem worsened in elderly households that may have more clutter. Due to traditional gender roles, women are often primarily responsible for cooking and cleaning, leading to higher exposure to cooking fumes and cleaning chemicals.
- **Workers:** Certain occupations face extremely high exposure risks. This includes workers in commercial kitchens and e-waste recycling facilities. Additionally, cleaners and dockworkers are among those likely exposed to poor IAQ long-term. These roles are often filled by low-income workers who have less power to advocate for better working conditions, linking the IAQ issue to socioeconomic status.

6.3.2 High-Risk Buildings and Environments

Existing guidelines are insufficient for many high-risk environments. Even for schools, nursing homes, and offices where guidelines exist, the recommendations are often incomplete and need updating.

Many other high-risk locations lack government guidance entirely. The most critical among these are subdivided units (SDUs), a product of Hong Kong's unique social landscape. SDUs are a concentration of IAQ risk factors: extremely poor ventilation, open kitchens, high occupant density, and the continuous release of harmful substances from cheap construction materials. These risks converge upon a low-income,

vulnerable population with few alternatives, creating one of Hong Kong's most severe IAQ challenges. Hospitals are another overlooked environment, facing the inherent conflict of needing to control both airborne pathogens and chemical pollution, yet lacking dedicated local research and guidance.

6.4 Challenges in Hong Kong's IAQ Management

The challenges in managing Indoor Air Quality (IAQ) in Hong Kong stem from interconnected deficiencies at both the policy and research levels.

Policy:

The Hong Kong government currently gives low priority to IAQ. Compared to outdoor air quality, there is a significant gap in policy planning and data monitoring for indoor air. This is mainly due to a lack of sufficient research to confirm the importance of IAQ. Furthermore, the government's primary management approach for IAQ relies on a voluntary program—"Indoor Air Quality Certification Scheme for Offices and Public Places." It is designed for commercial buildings, hard to protect vulnerable groups like the elderly and children in high-risk non-commercial areas. This represents a critical gap as our estimates show significantly higher health and economic costs from poor IAQ in non-office environments. Additionally, the scheme has long intervals between inspections and relies on passive testing rather than active spot-checks, which may lead to discrepancies between a building's certified results and its actual air quality..

Research:

There is a limited amount of research on indoor air quality in Hong Kong, and the lack of scientific evidence makes it difficult to capture governmental attention and advocate for policy change. There is an urgent need for systematic research to identify local IAQ sources, define the affected populations, and quantify the adverse outcomes. Furthermore, scientific guidance is required to raise public awareness and to develop effective methods for improving indoor air quality.

Ultimately, we need to take action to break the vicious cycle between "low government priority" and "a lack of research and data". This is the core objective of the current project by our organization, the Clean Air Network.

7. Conclusion

Indoor air quality (IAQ) in Hong Kong is a severely underestimated issue with major public health, economic, and social equity implications. This problem is driven by a range of indoor pollutants from sources like combustion and chemical emissions, including harmful gases (CO, CO₂, NO_x), volatile organic compounds (VOCs), and particulate matter (PM). Exposure to these contaminants directly increases residents' risks of cardiovascular disease, cancer, and infectious illnesses, while also causing Sick Building Syndrome and reducing productivity, which in turn causes economic burden around 32.56 billion HKD per year. Crucially, this health burden is not distributed

evenly. Vulnerable populations like the elderly and children, along with those in high-risk environments like subdivided units (SDUs) and schools, bear a disproportionate share of the harm. Despite this clear inequality, Hong Kong's current policy framework, which relies on voluntary certification, fails to protect the populations and places that need it most. This challenge is rooted in a vicious cycle where government inaction and a gap in local scientific data reinforce each other, hindering effective governance. Therefore, to break this cycle, we strongly urge the government to establish an IAQ management system built on mandatory regulations and supported by evidence-based research. Such a step is not just a public health necessity; it is a fundamental requirement for achieving social equity and ensuring the city's sustainable development.

Reference

1. IHME. *Global Burden of Disease (GBD)*. 2025 [cited 2025 12 May]; Available from: <https://www.healthdata.org/research-analysis/gbd>.
2. Phillips, L.J. and J. Moya, *Exposure factors resources: contrasting EPA's Exposure Factors Handbook with international sources*. Journal of Exposure Science & Environmental Epidemiology, 2014. **24**(3): p. 233-243.
3. Duan, X., *Exposure factors handbook of Chinese population*. China Environmental Science Press, 2013.
4. EPA. *Introduction to Indoor Air Quality*. 2025 [cited 2025 12 May]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality>.
5. WHO. *Household air pollution*. 2024 [cited 2025 12 May]; Available from: <https://www-who-int.eproxy.lib.hku.hk/en/news-room/fact-sheets/detail/household-air-pollution-and-health>.
6. Sundell, J., *On the history of indoor air quality and health*. Indoor air, 2004. **14**.
7. EPD. *Data & Statistics*. 2025 [cited 2025 12 May]; Available from: https://www.epd.gov.hk/epd/english/environmentinhk/air/data/air_data.html.
8. Hedley, A.J., JP. *Hedley Environmental index*. 2025 [cited 2025 12 May]; Available from: <https://hedleyindex.hku.hk/en>.
9. EPD. *IAQ Certification Scheme*. 2021 [cited 2025 12 May]; Available from: https://www.iaq.gov.hk/en/iaq-certification-scheme-background/#new_iaqo-triangle-anchor.
10. EPD. *Map of Certified Premises*. 2025 [cited 2025 12 May]; Available from: <https://www.iaq.gov.hk/en/iaq-certification-scheme-map-of-certified-premises/>.
11. EPA. *Indoor Pollutants and Sources*. 2024 [cited 2025 13 May]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/indoor-pollutants-and-sources>.
12. Tran, V.V., D. Park, and Y.-C. Lee, *Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality*. International journal of environmental research and public health, 2020. **17**(8): p. 2927.
13. Soreanu, G., M. Dixon, and A. Darlington, *Botanical biofiltration of indoor gaseous pollutants—A mini-review*. Chemical engineering journal, 2013. **229**: p. 585-594.
14. Kumar, P., et al., *Critical review on emerging health effects associated with the indoor air quality and its sustainable management*. Science of The Total Environment, 2023. **872**: p. 162163.
15. Organization, W.H., *WHO guidelines for indoor air quality: selected pollutants*. WHO guidelines for indoor air quality: selected pollutants, 2010.
16. EPA. *Carbon Monoxide's Impact on Indoor Air Quality*. 2025 [cited 2025 13 May]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality>.
17. Szczurek, A., et al., *Dynamics of carbon dioxide concentration in indoor air*. Stochastic Environmental Research and Risk Assessment, 2015. **29**: p. 2193-2199.
18. Manisalidis, I., et al., *Environmental and health impacts of air pollution: a review*. Frontiers in public health, 2020. **8**: p. 14.

19. Perez, P., *Prediction of sulfur dioxide concentrations at a site near downtown Santiago, Chile*. Atmospheric Environment, 2001. **35**(29): p. 4929-4935.
20. Hänninen, O. and P. Goodman, *Outdoor air as a source of indoor pollution*. 2019.
21. CFR, U., *Code of Federal Regulations Title 40: Protection of Environment*. Chapter I—US Environmental Protection Agency, Subchapter I—Solid Wastes, see Parts, 2009: p. 261-268.
22. Batterman, S., C. Jia, and G. Hatzivasilis, *Migration of volatile organic compounds from attached garages to residences: a major exposure source*. Environmental research, 2007. **104**(2): p. 224-240.
23. *Volatile Organic Compounds' Impact on Indoor Air Quality*. 2024 [cited 2025 13 May]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality>.
24. EPD. *Volatile Organic Compounds and Smog*. 2023 [cited 2025 14 May]; Available from: <https://www.iaq.gov.hk/wp-content/uploads/2021/04/leaflet-volatile-organic-compounds-and-you-final.pdf>.
25. Rösch, C., et al., *Relationship between sources and patterns of VOCs in indoor air*. Atmospheric Pollution Research, 2014. **5**(1): p. 129-137.
26. Adams, K., et al., *Particulate matter components, sources, and health: Systematic approaches to testing effects*. Journal of the Air & Waste Management Association, 2015. **65**(5): p. 544-558.
27. WHO. *Air quality, energy and health*. 2025 [cited 2025 14 May]; Available from: <https://www-who-int.eproxy.lib.hku.hk/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants>.
28. Semmens, E.O., et al., *Indoor particulate matter in rural, wood stove heated homes*. Environmental research, 2015. **138**: p. 93-100.
29. Weschler, C.J. and W.W. Nazaroff, *Dermal uptake of organic vapors commonly found in indoor air*. Environmental science & technology, 2014. **48**(2): p. 1230-1237.
30. Yu, K.-P., et al., *Indoor air pollution from gas cooking in five Taiwanese families*. Building and Environment, 2015. **93**: p. 258-266.
31. Huboyo, H.S., S. Tohno, and R. Cao, *Indoor PM_{2.5} characteristics and CO concentration related to water-based and oil-based cooking emissions using a gas stove*. Aerosol and Air Quality Research, 2011. **11**(4): p. 401-411.
32. Liao, C.-M., et al., *Contributions of Chinese-style cooking and incense burning to personal exposure and residential PM concentrations in Taiwan region*. Science of the total environment, 2006. **358**(1-3): p. 72-84.
33. Drago, G., et al., *Relationship between domestic smoking and metals and rare earth elements concentration in indoor PM_{2.5}*. Environmental Research, 2018. **165**: p. 71-80.
34. Braun, M., et al., *Particulate matter emissions of four different cigarette types of one popular brand: influence of tobacco strength and additives*. International journal of environmental research and public health, 2019. **16**(2): p. 263.
35. Kumar, R., et al., *Monitoring of indoor particulate matter during burning of mosquito coil, incense sticks and dhoop*. Indian Journal of Allergy, Asthma and Immunology, 2014. **28**(2): p. 68-73.
36. Schneider, J., et al., *Pleural mesothelioma associated with indoor pollution of asbestos*. Journal of cancer research and clinical oncology, 2001. **127**: p. 123-127.

37. Perez, A.L., et al., *A meta-analysis of airborne asbestos fiber concentrations from work with or around asbestos-containing floor tile*. International Journal of Occupational and Environmental Health, 2018. **24**(3-4): p. 134-148.
38. Branis, M., P. Rezacova, and M. Domasova, *The effect of outdoor air and indoor human activity on mass concentrations of PM10. PM2*, 2005. **5**: p. 143-149.
39. EPD. *What are biological pollutants, how do they affect indoor air quality?* 2024 [cited 2025 14 May]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/what-are-biological-pollutants-how-do-they-affect-indoor-air-quality>.
40. Karri, R.R., et al., *Classification, sources, and occurrence of outdoor air pollutants: a comprehensive overview*. Health and Environmental Effects of Ambient Air Pollution, 2024: p. 1-34.
41. Brambilla, A. and A. Sangiorgio, *Mould growth in energy efficient buildings: Causes, health implications and strategies to mitigate the risk*. Renewable and Sustainable Energy Reviews, 2020. **132**: p. 110093.
42. Baldacci, S., et al., *Allergy and asthma: effects of the exposure to particulate matter and biological allergens*. Respiratory medicine, 2015. **109**(9): p. 1089-1104.
43. Hulin, M., et al., *Respiratory health and indoor air pollutants based on quantitative exposure assessments*. European Respiratory Journal, 2012. **40**(4): p. 1033-1045.
44. Neto, F.R.A. and L.F.G. Siqueira. *GUIDELINES FOR INDOOR AIR QUALITY IN OFFICES IN BRAZIL*. 2000.
45. Administration, C.N.S. *Indoor Air Quality Standard (GB/T 1883–2002)*. 2022 [cited 2025 19 May]; Available from: <http://www.mee.gov.cn/image20010518/5295.pdf>.
46. (JORF), J.o.d.l.R.f. *Décret n° 2012-14 du 5 janvier 2012 relatif à l'évaluation des moyens d'aération et à la mesure des polluants effectuées au titre de la surveillance de la qualité de l'air intérieur de certains établissements recevant du public*. 2012 [cited 2025 19 May]; Available from: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000025105291#JORFTEXT000025105291>.
47. Zhou, C., et al., *Combined effects of temperature and humidity on indoor VOCs pollution: Intercity comparison*. Building and Environment, 2017. **121**: p. 26-34.
48. Salthammer, T. and G.C. Morrison, *Temperature and indoor environments*. Indoor air, 2022. **32**(5): p. e13022.
49. Guo, Z., *Review of indoor emission source models. Part 2. Parameter estimation*. Environmental Pollution, 2002. **120**(3): p. 551-564.
50. Wang, Y., et al., *Measurement and evaluation of indoor thermal environment in a naturally ventilated industrial building with high temperature heat sources*. Building and Environment, 2016. **96**: p. 35-45.
51. Hou, Y., et al., *Relationship between indoor and outdoor temperatures in winter in the Hot Summer and Cold Winter Zone of China-Considering two sources of outdoor temperatures and different indoor heating methods*. Journal of Building Engineering, 2024. **87**: p. 109136.
52. Ponni, M. and R. Baskar, *A study on indoor temperature and comfort temperature*. International Journal of Engineering Science Invention, 2015. **4**(3): p. 7-14.
53. Heseltine, E. and J. Rosen, *WHO guidelines for indoor air quality: dampness and mould*. 2009.
54. Alves, C., et al., *Air quality in a school with dampness and mould problems*. Air Quality,

- Atmosphere & Health, 2016. **9**: p. 107-115.
55. Juel Holst, G., et al., *Household dampness and microbial exposure related to allergy and respiratory health in Danish adults*. European clinical respiratory journal, 2020. **7**(1): p. 1706235.
 56. Sarwar, M., *House Dust Mites: Ecology, Biology, Prevalence, Epidemiology*. Parasitology and Microbiology Research, 2020: p. 271.
 57. Wargocki, P., *Ventilation, indoor air quality, health, and productivity*. Ergonomic workplace design for health, wellness, and productivity, 2016: p. 39-72.
 58. Persily, A. and H. Levin. *Ventilation measurements in IAQ studies: problems and opportunities*. in *Proceedings of Indoor Air 2011, 12th International Conference on Indoor Air Quality and Climate*. 2011.
 59. Reshetniak, E., *Mechanical Supply and Exhaust Ventilation in Residential Building*. 2014.
 60. Fobiri, G., et al., *Critical Factors Contributing to Poor Natural Ventilation of Residential Buildings*. vol, 2023. **8**: p. 65-84.
 61. Kim, K.-H., S.A. Jahan, and E. Kabir, *A review of diseases associated with household air pollution due to the use of biomass fuels*. Journal of hazardous materials, 2011. **192**(2): p. 425-431.
 62. Nie, T., et al., *Effects of Indoor Air Quality on Human Physiological Impact: A Review*. Buildings, 2025. **15**(8): p. 1296.
 63. Ma, C.-M., et al., *Volatile organic compounds exposure and cardiovascular effects in hair salons*. Occupational medicine, 2010. **60**(8): p. 624-630.
 64. Chuang, W.-Y., L.-Y. Lin, and K.-J. Chuang, *Indoor air quality and cardiovascular effects in the Taiwanese general population: Generalized additive mixed models analysis*. in *Proceedings of the World Congress on Engineering & Computer Science*. 2013.
 65. Chen, R.-Y., et al., *Houseplant, indoor air pollution, and cardiovascular effects among elderly subjects in Taipei, Taiwan*. Science of the Total Environment, 2020. **705**: p. 135770.
 66. Han, S., et al., *Associations between specific volatile organic chemical exposures and cardiovascular disease risks: insights from NHANES*. Frontiers in Public Health, 2024. **12**: p. 1378444.
 67. Cao, Q., et al., *Dissecting the connection between volatile organic compounds and cardiovascular disease: immune cell-mediated mechanism*. Ecotoxicology and Environmental Safety, 2025. **298**: p. 118297.
 68. Lin, L.Y., et al., *The effects of indoor particles on blood pressure and heart rate among young adults in Taipei, Taiwan*. Indoor air, 2009. **19**(6): p. 482-488.
 69. Peters, A., et al., *Air pollution and incidence of cardiac arrhythmia*. Epidemiology, 2000. **11**(1): p. 11-17.
 70. Singh, A., et al., *Indoor air pollution and its association with poor lung function, microalbuminuria and variations in blood pressure among kitchen workers in India: a cross-sectional study*. Environmental Health, 2017. **16**: p. 1-13.
 71. Sun, Q., et al., *Long-term air pollution exposure and acceleration of atherosclerosis and vascular inflammation in an animal model*. Jama, 2005. **294**(23): p. 3003-3010.
 72. Kampfrath, T., et al., *Chronic fine particulate matter exposure induces systemic vascular dysfunction via NADPH oxidase and TLR4 pathways*. Circulation research, 2011. **108**(6): p. 716-726.

73. Chen, Y.-C. and T.-C. Hsiao, *Physiological responses to different CO₂ levels in poor ventilation room*. in *6th European Conference of the International Federation for Medical and Biological Engineering: MBEC 2014, 7-11 September 2014, Dubrovnik, Croatia*. 2015. Springer.
74. Mishra, A.K., et al., *Respiratory performance of humans exposed to moderate levels of carbon dioxide*. *Indoor Air*, 2021. **31**(5): p. 1540-1552.
75. Kajtár, L. and L. Herczeg, *Influence of carbon-dioxide concentration on human well-being and intensity of mental work*. *QJ Hung. Meteorol. Serv*, 2012. **116**(2): p. 145-169.
76. Unwin, J., et al., *An assessment of occupational exposure to polycyclic aromatic hydrocarbons in the UK*. *Annals of Occupational Hygiene*, 2006. **50**(4): p. 395-403.
77. Tsai, W.-T., *An overview of health hazards of volatile organic compounds regulated as indoor air pollutants*. *Reviews on environmental health*, 2019. **34**(1): p. 81-89.
78. Rumchev, K., et al., *Association of domestic exposure to volatile organic compounds with asthma in young children*. *Thorax*, 2004. **59**(9): p. 746-751.
79. Smith-Sivertsen, T., et al., *Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala*. *American journal of epidemiology*, 2009. **170**(2): p. 211-220.
80. Regalado, J., et al., *The effect of biomass burning on respiratory symptoms and lung function in rural Mexican women*. *American journal of respiratory and critical care medicine*, 2006. **174**(8): p. 901-905.
81. Ceylan, E., et al., *Increased DNA damage in patients with chronic obstructive pulmonary disease who had once smoked or been exposed to biomass*. *Respiratory medicine*, 2006. **100**(7): p. 1270-1276.
82. Noonan, C.W. and T.J. Ward, *Asthma randomized trial of indoor wood smoke (ARTIS): rationale and methods*. *Contemporary clinical trials*, 2012. **33**(5): p. 1080-1087.
83. McCormack, M.C., et al., *In-home particle concentrations and childhood asthma morbidity: Environmental health perspectives*, 2009. **117**(2): p. 294-298.
84. Breyse, P.N., et al., *Indoor air pollution and asthma in children*. *Proceedings of the American Thoracic Society*, 2010. **7**(2): p. 102-106.
85. Grief, S.N., *Upper respiratory infections*. *Primary care*, 2013. **40**(3): p. 757.
86. Simkovich, S.M., et al., *The health and social implications of household air pollution and respiratory diseases*. *NPJ primary care respiratory medicine*, 2019. **29**(1): p. 12.
87. Jary, H., et al., *Household air pollution and acute lower respiratory infections in adults: a systematic review*. *PloS one*, 2016. **11**(12): p. e0167656.
88. Yang, J., et al., *The impact of bacteria-derived ultrafine dust particles on pulmonary diseases*. *Experimental & molecular medicine*, 2020. **52**(3): p. 338-347.
89. Li, Y., et al., *Multi-zone modeling of probable SARS virus transmission by airflow between flats in Block E, Amoy Gardens*. *Indoor air*, 2005. **15**(2).
90. Niu, J. and T. Tung, *On-site quantification of re-entry ratio of ventilation exhausts in multi-family residential buildings and implications*. *Indoor air*, 2008. **18**(1).
91. Myatt, T.A., et al., *Modeling the airborne survival of influenza virus in a residential setting: the impacts of home humidification*. *Environmental Health*, 2010. **9**: p. 1-7.
92. Chen, S., C. Chang, and C. Liao, *Predictive models of control strategies involved in containing indoor airborne infections*. *Indoor Air*, 2006. **16**(6): p. 469.

93. Jiang, Y., et al. *Investigating a safe ventilation rate for the prevention of indoor SARS transmission: An attempt based on a simulation approach*. in *Building Simulation*. 2009. Springer.
94. Beggs, C.B., S.J. Shepherd, and K.G. Kerr, *Potential for airborne transmission of infection in the waiting areas of healthcare premises: stochastic analysis using a Monte Carlo model*. BMC infectious diseases, 2010. **10**: p. 1-8.
95. Wan, G.-H., et al., *Detection of common respiratory viruses and Mycoplasma pneumoniae in patient-occupied rooms in pediatric wards*. Medicine, 2016. **95**(14): p. e3014.
96. Sung, M., et al., *Airflow as a possible transmission route of middle east respiratory syndrome at an initial outbreak hospital in Korea*. International journal of environmental research and public health, 2018. **15**(12): p. 2757.
97. Chen, S.-C. and C.-M. Liao, *Modelling control measures to reduce the impact of pandemic influenza among schoolchildren*. Epidemiology & Infection, 2008. **136**(8): p. 1035-1045.
98. International Conference on Indoor Air, Q., et al., *Indoor Air 2005 : proceedings of the 10th International Conference on Indoor Air Quality and Climate, September 4-9, 2005, Beijing, China*. 2005, [China]: Tsinghua University Press.
99. Langer, V., et al., *Rapid quantification of bioaerosols containing L. pneumophila by Coriolis® μ air sampler and chemiluminescence antibody microarrays*. Journal of aerosol science, 2012. **48**: p. 46-55.
100. Smets, W., et al., *Airborne bacteria in the atmosphere: presence, purpose, and potential*. Atmospheric Environment, 2016. **139**: p. 214-221.
101. Blaise, G., et al., *Corynebacterium-associated skin infections*. International journal of dermatology, 2008. **47**(9): p. 884-890.
102. Shiraiwa, M., et al., *Aerosol health effects from molecular to global scales*. Environmental science & technology, 2017. **51**(23): p. 13545-13567.
103. Brown, G.D., et al., *Hidden killers: human fungal infections*. Science translational medicine, 2012. **4**(165): p. 165rv13-165rv13.
104. Ghajari, A., et al., *Fungal airborne contamination as a serious threat for respiratory infection in the hematology ward*. Tanaffos, 2015. **14**(4): p. 257.
105. Mu, L., et al., *Indoor air pollution and risk of lung cancer among Chinese female non-smokers*. Cancer causes & control, 2013. **24**: p. 439-450.
106. Kurmi, O.P., et al., *Lung cancer risk and solid fuel smoke exposure: a systematic review and meta-analysis*. European Respiratory Journal, 2012. **40**(5): p. 1228-1237.
107. Sun, S., J.H. Schiller, and A.F. Gazdar, *Lung cancer in never smokers—a different disease*. Nature reviews cancer, 2007. **7**(10): p. 778-790.
108. White, A.J., et al., *Indoor air pollution exposure from use of indoor stoves and fireplaces in association with breast cancer: a case-control study*. Environmental Health, 2014. **13**: p. 1-12.
109. Wong, C.M., et al., *Cancer mortality risks from long-term exposure to ambient fine particle*. Cancer Epidemiology, Biomarkers & Prevention, 2016. **25**(5): p. 839-845.
110. Baselt, R., *Encyclopedia of toxicology*. 2014, Oxford University Press.
111. Marmot, A., et al., *Building health: an epidemiological study of “sick building syndrome” in the Whitehall II study*. Occupational and environmental medicine, 2006. **63**(4): p. 283-289.
112. Guo, P., et al., *Sick building syndrome by indoor air pollution in Dalian, China*. International journal of environmental research and public health, 2013. **10**(4): p. 1489-1504.

113. Maula, H., et al., *The effect of low ventilation rate with elevated bioeffluent concentration on work performance, perceived indoor air quality, and health symptoms*. Indoor air, 2017. **27**(6): p. 1141-1153.
114. Tsai, D.-H., J.-S. Lin, and C.-C. Chan, *Office workers' sick building syndrome and indoor carbon dioxide concentrations*. Journal of occupational and environmental hygiene, 2012. **9**(5): p. 345-351.
115. Allen, J.G., et al., *Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments*. Environmental health perspectives, 2016. **124**(6): p. 805-812.
116. Laurent, J.G.C., et al., *Associations between acute exposures to PM_{2.5} and carbon dioxide indoors and cognitive function in office workers: a multicountry longitudinal prospective observational study*. Environmental Research Letters, 2021. **16**(9): p. 094047.
117. Zamani, M.E., J. Jalaludin, and N. Shaharom, *Indoor air quality and prevalence of sick building syndrome among office workers in two different offices in Selangor*. Am. J. Appl. Sci, 2013. **10**(10): p. 1140-1147.
118. Sakellaris, I., et al., *Association of subjective health symptoms with indoor air quality in European office buildings: The OFFICAIR project*. Indoor Air, 2021. **31**(2): p. 426-439.
119. Glas, B., et al., *Exposure to formaldehyde, nitrogen dioxide, ozone, and terpenes among office workers and associations with reported symptoms*. International archives of occupational and environmental health, 2015. **88**: p. 613-622.
120. Wallenius, K., et al., *Volatile organic compounds in Finnish office environments in 2010–2019 and their relevance to adverse health effects*. International Journal of Environmental Research and Public Health, 2022. **19**(7): p. 4411.
121. Liu, N., et al., *Indoor exposure levels and risk assessment of volatile organic compounds in residences, schools, and offices in China from 2000 to 2021: a systematic review*. Indoor air, 2022. **32**(9): p. e13091.
122. Wu, J., et al., *The synergistic effect of PM_{2.5} and CO₂ concentrations on occupant satisfaction and work productivity in a meeting room*. International Journal of Environmental Research and Public Health, 2021. **18**(8): p. 4109.
123. Zhou, J., et al., *Short-term exposure to indoor PM_{2.5} in office buildings and cognitive performance in adults: An intervention study*. Building and Environment, 2023. **233**: p. 110078.
124. Boulanger, G., et al., *Socio-economic costs of indoor air pollution: A tentative estimation for some pollutants of health interest in France*. Environment international, 2017. **104**: p. 14-24.
125. Solutions, N.E. *The True Cost of Poor Indoor Air Quality*. [cited 2025 May 26]; Available from: <https://www.novaenvironmentalsolutions.com/the-true-cost-of-poor-indoor-air-quality/>.
126. Mudarri, D., *Public health and economic impact of dampness and mold*. 2007.
127. Arcenas, A., et al., *The economic costs of indoor air pollution: new results for Indonesia, the Philippines, and Timor-Leste*. Journal of Natural Resources Policy Research, 2010. **2**(1): p. 75-93.
128. Schwarzenegger, A., *Indoor air pollution in California*. California EPA, 2005.
129. Walker, I., M. Sherman, and B. Jones, *Economics of Indoor Air Quality*. 2018.
130. Leung, M., C. Liu, and A. Chan, *Indoor Air Quality for Printing Plants*. 2005, Occupational

- Safety and Health Council.
131. Health, L.F.o.M.S.o.P. *Hedley Environmental Index, HEALTH & ECONOMIC LOSS*. 2025 [cited 2025 26 May]; Available from: <https://hedleyindex.hku.hk/en/health-economic-loss>.
 132. Group, I.A.Q.M., *Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places*, EPD, Editor. 2019.
 133. Logue, J.M., et al., *A method to estimate the chronic health impact of air pollutants in US residences*. *Environmental health perspectives*, 2012. **120**(2): p. 216-222.
 134. Louis, C. and J. LAVERGE. *A Methodology to assess economical impacts of poor IAQ in office buildings from DALY and SBS induced costs*. in *CLIMA 2022 conference*. 2022.
 135. Lvovsky, K., et al., *Environmental costs of fossil fuels: a rapid assessment method with application to six cities*. 2000.
 136. Department, C.a.S. *Mid-year Population for 2014*. 2014 [cited 2025 26 August]; Available from: <https://www.info.gov.hk/gia/general/201408/12/P201408120596.htm>.
 137. Mason, T.G., et al., *An evaluation of the air quality health index program on respiratory diseases in Hong Kong: an interrupted time series analysis*. *Atmospheric Environment*, 2019. **211**: p. 151-158.
 138. Health, D.o., *Health Facts of Hong Kong 2024 Edition*. 2024.
 139. Department, C.a.S. *Mid-year Population for 2022*. 2022 [cited 2025 26 August]; Available from: <https://www.info.gov.hk/gia/general/202208/11/P2022081100393.htm>.
 140. Department, C.a.S. *Mid-year Population for 2009*. 2009 [cited 2025 26 August]; Available from: <https://www.info.gov.hk/gia/general/200908/13/P200908130199.htm>.
 141. Hai, J.-J., et al., *Clinical characteristics, management, and outcomes of hospitalized heart failure in a Chinese population—The Hong Kong Heart Failure Registry*. *Journal of cardiac failure*, 2016. **22**(8): p. 600-608.
 142. Pope III, C.A., *Mortality effects of longer term exposures to fine particulate air pollution: review of recent epidemiological evidence*. *Inhalation toxicology*, 2007. **19**(sup1): p. 33-38.
 143. Pope III, C.A., M. Ezzati, and D.W. Dockery, *Fine-particulate air pollution and life expectancy in the United States*. *New England journal of medicine*, 2009. **360**(4): p. 376-386.
 144. Department, C.a.S. *Mid-year Population for 2016 [11 Aug 2016]*. 2016 [cited 2025 26 August]; Available from: https://www.censtatd.gov.hk/en/press_release_detail.html?id=3867.
 145. Protection, C.f.H. *Non-Communicable Diseases Watch*. 2018; Available from: https://www.chp.gov.hk/files/pdf/ncd_watch_november_2018.pdf.
 146. Melse, J.M., et al., *A national burden of disease calculation: Dutch disability-adjusted life-years*. *Dutch Burden of Disease Group*. *American journal of public health*, 2000. **90**(8): p. 1241.
 147. Department, C.a.S. *Mid-year Population for 2023*. 2023 [cited 2025 26 August]; Available from: <https://www.info.gov.hk/gia/general/202308/15/P2023081500251.htm>.
 148. Protection, C.f.H. *Cerebrovascular Disease*. 2025 [cited 2025 26 August]; Available from: <https://www.chp.gov.hk/en/healthtopics/content/25/58.html>.
 149. Hong, K.-S., et al., *Years of optimum health lost due to complications after acute ischemic stroke: disability-adjusted life-years analysis*. *Stroke*, 2010. **41**(8): p. 1758-1765.
 150. Chau, P., M. Wong, and J. Woo, *Trends in ischaemic heart disease hospitalisation and case fatality in the Hong Kong Chinese population 2000–2009: a secondary analysis*. *BMJ open*, 2013. **3**(8): p. e002963.

151. *Pneumonia*. 2025 [cited 2025 26 August]; Available from: https://www.healthyhk.gov.hk/phishweb/en/chart_detail/26/.
152. Chau, C.K., et al., *Estimating the total exposure to air pollutants for different population age groups in Hong Kong*. *Environment international*, 2002. **27**(8): p. 617-630.
153. Hkepd, *Consultancy study of indoor air pollution in offices and public places in Hong Kong*. 1997, Hong Kong Government, Environmental Protection Department, Air Services
154. Li, A.T.-Y., et al., *Exposure to particles and gases in a shopping mall: spatial heterogeneity and outdoor infiltration*. *Atmosphere*, 2021. **12**(10): p. 1313.
155. Yang, F., et al., *Assessment of personal integrated exposure to fine particulate matter of urban residents in Hong Kong*. *Journal of the Air & Waste Management Association*, 2019. **69**(1): p. 47-57.
156. Che, W., et al., *Factors affecting variability in gaseous and particle microenvironmental air pollutant concentrations in Hong Kong primary and secondary schools*. *Indoor air*, 2021. **31**(1): p. 170-187.
157. Zeng, L., et al., *Contributions of indoor household activities to inhalation health risks induced by gaseous air pollutants in Hong Kong home*. *Aerosol and Air Quality Research*, 2023. **23**(9): p. 230063.
158. Hui, P., L.T. Wong, and K.W. Mui, *Feasibility study of an express assessment protocol for the indoor air quality of air-conditioned offices*. *Indoor and Built Environment*, 2006. **15**(4): p. 373-378.
159. Department, C.a.S. *Table 110-01002 : Population by Sex and Age*. 2025 [cited 2025 31 August]; Available from: https://www.censtatd.gov.hk/en/web_table.html?id=110-01002.
160. Huijbregts, M.A., et al., *Human-toxicological effect and damage factors of carcinogenic and noncarcinogenic chemicals for life cycle impact assessment*. *Integrated environmental assessment and management*, 2005. **1**(3): p. 181-244.
161. EPA, U., *Exposure factors handbook: 2009 update*. Washington DC: National Center for Environmental Assessment, 2009.
162. Guo, H., et al., *Formaldehyde and volatile organic compounds in Hong Kong homes: concentrations and impact factors*. *Indoor air*, 2009. **19**(3).
163. Chao, C.Y. and G.Y. Chan, *Quantification of indoor VOCs in twenty mechanically ventilated buildings in Hong Kong*. *Atmospheric Environment*, 2001. **35**(34): p. 5895-5913.
164. Duan, X. and 段小丽, *Highlight of Chinese children's exposure factors handbook*. China Environmental Science Press, 2016.
165. Department, C.a.S., *Hong Kong in Figures 2025 Edition*. 2025.
166. Quinet, E., *L'évaluation socioéconomique des investissements publics*. 2014, HAL.
167. Wong, T., et al., *Developing an instrument for assessing the health and economic impacts of air pollution in Hong Kong*. Hong Kong: Environmental Protection Department Hong Kong SAR, 2016.
168. Chan, W.S. and F.W.H. Chan, *On selection of the discount rate for actuarial assessment of damages in personal injury litigation in Hong Kong*. *Law, Probability and Risk*, 2003. **2**(1): p. 15-24.
169. Protection, C.f.H. *Life expectancy at birth, 1971 - 2024*. 2024 [cited 2025 2 September]; Available from: <https://www.chp.gov.hk/en/statistics/data/10/27/111.html>.
170. Gou, Z. and S.s.Y. Lau, *A survey of sick building syndrome: Workplace design elements and*

- perceived indoor environmental quality*. 10th International Conference on Healthy Buildings 2012, 2012. **1**: p. 658-663.
171. Thach, T.-Q., et al., *Prevalence of sick building syndrome and its association with perceived indoor environmental quality in an Asian multi-ethnic working population*. Building and Environment, 2019. **166**: p. 106420.
 172. Wargocki, P., D.P. Wyon, and P.O. Fanger, *Productivity is affected by the air quality in offices*. 2000.
 173. Bureau, C.S. *Appointments to the Civil Service in 2024-25 Financial Year*
(excluding Judges and Judicial Officers, ICAC officers and locally engaged staff working in Hong Kong Economic and Trade Offices outside Hong Kong). 2025 [cited 2025 2 September]; Available from: https://www.csb.gov.hk/english/publications_stat/stat/quarterly/544.html.
 174. Department, C.a.S. *Employment and vacancies statistics for September 2024*. 2024 [cited 2025 2 September]; Available from: <https://www.info.gov.hk/gia/general/202412/20/P2024122000417.htm?fontSize=1>.
 175. Lee, S.-C., et al., *Inter-comparison of air pollutant concentrations in different indoor environments in Hong Kong*. Atmospheric Environment, 2002. **36**(12): p. 1929-1940.
 176. Cheung, P.K. and C.Y. Jim, *Indoor air quality in substandard housing in Hong Kong*. Sustainable cities and society, 2019. **48**: p. 101583.
 177. Huy, L. and S. Lee, *Indoor Air Quality in Residential Homes of Hong Kong*. 2017.
 178. Tong, X., *Predicting Indoor Fine Particulate Matter and Investigating Its Health Effects on Elderly Residents in Hong Kong*. 2020: The Chinese University of Hong Kong (Hong Kong).
 179. Tong, X., et al., *Indoor air pollutant exposure and determinant factors controlling household air quality for elderly people in Hong Kong*. Air Quality, Atmosphere & Health, 2018. **11**: p. 695-704.
 180. Tong, X., et al., *Prediction model for air particulate matter levels in the households of elderly individuals in Hong Kong*. Science of The Total Environment, 2020. **717**: p. 135323.
 181. Wong, J.K.-W., et al., *The effects of the indoor environment of residential care homes on dementia suffers in Hong Kong: A critical incident technique approach*. Building and environment, 2014. **73**: p. 32-39.
 182. Cheung, P.K., C.Y. Jim, and C.T. Siu, *Air quality impacts of open-plan cooking in tiny substandard homes in Hong Kong*. Air Quality, Atmosphere & Health, 2019. **12**(7): p. 865-878.
 183. Dong, X., et al., *Household Air Pollution, Physical Activity, and the Risk of Frailty Among Middle-Aged and Older Adults: A Cohort Study*. Journal of the American Medical Directors Association, 2025. **26**(6): p. 105525.
 184. Bentayeb, M., et al., *Indoor air pollution and respiratory health in the elderly*. Journal of Environmental Science and Health, Part A, 2013. **48**(14): p. 1783-1789.
 185. Madureira, J. and J.P. Teixeira, *Indoor Air Quality in Elderly Care Centers*, in *Handbook of Indoor Air Quality*. 2022, Springer. p. 1961-1985.
 186. Mata, T.M., et al., *Indoor air quality in elderly centers: Pollutants emission and health effects*. Environments, 2022. **9**(7): p. 86.
 187. Koo, L.C., et al., *Carcinogens in the indoor air of Hong Kong homes: levels, sources, and ventilation effects on 7 polynuclear aromatic hydrocarbons*. Environmental technology, 1994.

- 15(5): p. 401-418.
188. Kwok, S.-m., *Analysis on the links between housing and respiratory health of residents in Hong Kong*. 2005.
 189. Lee, S. and M. Chang, *Indoor and outdoor air quality investigation at schools in Hong Kong*. Chemosphere, 2000. **41**(1-2): p. 109-113.
 190. NIEHS. *Lead*. [cited 2025 22 June]; Available from: <https://www.niehs.nih.gov/health/topics/agents/lead>.
 191. Nandasena, S., A.R. Wickremasinghe, and N. Sathiakumar, *Indoor air pollution and respiratory health of children in the developing world*. World journal of clinical pediatrics, 2013. **2**(2): p. 6.
 192. EPA. *The Inside Story: A Guide to Indoor Air Quality*. [cited 2025 22 June]; Available from: <https://www.epa.gov/indoor-air-quality-iaq/inside-story-guide-indoor-air-quality>.
 193. Vardoulakis, S., et al., *Indoor exposure to selected air pollutants in the home environment: a systematic review*. International journal of environmental research and public health, 2020. **17**(23): p. 8972.
 194. Oloo, A., et al., *The Association Between Indoor Air Pollution and Inflammation in Children—A Scoping Review*. Indoor Environments, 2025: p. 100104.
 195. Maung, T.Z., et al., *Indoor air pollution and the health of vulnerable groups: a systematic review focused on particulate matter (PM), volatile organic compounds (VOCs) and their effects on children and people with pre-existing lung disease*. International journal of environmental research and public health, 2022. **19**(14): p. 8752.
 196. Abdel-Salam, M.M., *Assessment of children's exposure to air pollutants in urban residences during the Covid-19 pandemic*. Frontiers in Environmental Science, 2022. **10**: p. 1050623.
 197. Cheung, P.K. and C.Y. Jim, *Impacts of air conditioning on air quality in tiny homes in Hong Kong*. Science of the Total Environment, 2019. **684**: p. 434-444.
 198. Wong, G.W., et al., *Factors associated with difference in prevalence of asthma in children from three cities in China: multicentre epidemiological survey*. Bmj, 2004. **329**(7464): p. 486.
 199. Wan, M.P., C. Chao, and C. Wu. *Indoor generated ultrafine particles in Hong Kong homes*. in *ISEE Conference Abstracts 25*. 2013.
 200. Zhou, Y., et al., *Airborne Bacteria in Outdoor Air and Air of Mechanically Ventilated Buildings at City Scale in Hong Kong across Seasons*. Environmental Science & Technology, 2020. **54**(19): p. 11732-11743.
 201. Hui, P.-S., K.-W. Mui, and L.-T. Wong, *Influence of indoor air quality (IAQ) objectives on air-conditioned offices in Hong Kong*. Environmental Monitoring and Assessment, 2008. **144**: p. 315-322.
 202. Liao, S., J. Bacon-Shone, and Y.S. Kim, *Factors influencing indoor air quality in Hong Kong: measurements in offices and shops*. Environmental Technology, 1991. **12**(9): p. 737-745.
 203. Yao, X.H., et al., *A review of Legionella transmission risk in built environments: sources, regulations, sampling, and detection*. Frontiers in Public Health, 2024. **12**: p. 1415157.
 204. Liao, G., et al., *Higher bisphenol analogues exposure levels in e-waste workers and their associations with DNA oxidative damage in Hong Kong*. Environmental Research, 2025. **275**: p. 121415.
 205. Wong, T.W., et al., *Respiratory health and lung function in Chinese restaurant kitchen workers*. Occupational and environmental Medicine, 2011. **68**(10): p. 746-752.

206. NIEHS. *Flame Retardants*. 2016 [cited 2025 23 June]; Available from: https://sites.nicholas.duke.edu/stapletonlab/files/2020/12/NIH-Factsheet-flame_retardants_508.pdf.
207. Kim, S., et al., *Characterization of air freshener emission: the potential health effects*. The Journal of toxicological sciences, 2015. **40**(5): p. 535-550.
208. CHP. *Number of Deaths by Leading Causes of Death by Sex by Age in 2023*. 2024 [cited 2025 17 June]; Available from: <https://www.chp.gov.hk/en/statistics/data/10/27/340.html>.
209. Sun, J., et al., *A bibliometric analysis of the impacts of air pollution on children*. International journal of environmental research and public health, 2020. **17**(4): p. 1277.
210. Buka, I., S. Koranteng, and A.R. Osornio-Vargas, *The effects of air pollution on the health of children*. Paediatrics & child health, 2006. **11**(8): p. 513-516.
211. Dondi, A., et al., *Outdoor air pollution and childhood respiratory disease: the role of oxidative stress*. International journal of molecular sciences, 2023. **24**(5): p. 4345.
212. Lee, S., W. Wong, and Y. Lau, *Association between air pollution and asthma admission among children in Hong Kong*. Clinical & Experimental Allergy, 2006. **36**(9): p. 1138-1146.
213. Bureau, H. *Regulatory Regime on Basic Housing Units*. 2024 [cited 2025 16 June]; Available from: https://www.hb.gov.hk/eng/policy/housing/policy/tenancy_control/pdf/BHU%20consultation%20document_eng.pdf.
214. Saxena, K., *Association Between Maternal Prenatal Exposure to Household Air Pollution and Child Respiratory Health: A Systematic Review and Meta-analysis*. The Yale Journal of Biology and Medicine, 2024. **97**(1): p. 29.
215. Deierlein, A.L., et al., *Personal care and household cleaning product use among pregnant women and new mothers during the COVID-19 pandemic*. International journal of environmental research and public health, 2022. **19**(9): p. 5645.
216. Trifunovski, A., et al., *Analysis of Women's Knowledge, Health Risk Perceptions, Beliefs and Avoidance Behaviour in Relation to Endocrine-Disrupting Chemicals in Personal Care and Household Products*. Toxics, 2025. **13**(5): p. 414.
217. Hui, P., K.W. Mui, and L.T. Wong, *Recent trends in indoor air quality in air-conditioned office buildings in Hong Kong: a systematic review*. Architectural Science Review, 2006. **49**(4): p. 367-371.
218. Hui, P., L.T. Wong, and K.W. Mui. *Indoor air quality benchmarks of 'Grade A' offices in Hong Kong*. in *Proceedings of The 1st International Conference on Building Energy and Environment (COBEE)*. 2008.
219. Lau, W.K.Y., et al., *Human health risk assessment based on trace metals in suspended air particulates, surface dust, and floor dust from e-waste recycling workshops in Hong Kong, China*. Environmental Science and Pollution Research, 2014. **21**: p. 3813-3825.
220. EPD, *Guidance Notes for the Management of Indoor Air Quality in Schools*. 2022.
221. JEITA, *VOC Emission Rate Specification for Personal Computers and Tablet Devices (Ver. 1)*. 2014.
222. Cho, S., et al., *Study on characteristics of particulate matter resuspension in school classroom through experiments using a simulation chamber: influence of humidity*. International Journal of Environmental Research and Public Health, 2021. **18**(6): p. 2856.
223. CDC, U.S. *Radon and Your Health*. 2024 [cited 2025 23 June]; Available from:

- <https://www.cdc.gov/radon/about/index.html>.
224. EPD, *Guidance Notes for the Management of Indoor Air Quality in Elderly Homes*. 2022.
 225. Gheitasian, P., et al., *Evaluation of bacterial bioaerosol diversity and density in the indoor air of elderly care facilities*. Environmental Health Engineering And Management Journal, 2025. **12**: p. 1-7.
 226. Zemouri, C., et al., *A scoping review on bio-aerosols in healthcare and the dental environment*. PloS one, 2017. **12**(5): p. e0178007.
 227. BOARD, C.A.R. *Hazardous Ozone-Generating Air Purifiers*. [cited 2025 24 June]; Available from: <https://ww2.arb.ca.gov/our-work/programs/air-cleaners-ozone-products/hazardous-ozone-generating-air-purifiers>.
 228. M.Sc., J.J. *Questions Abound on the Safety of Humidifiers*. 2020 [cited 2025 24 June]; Available from: <https://www.mcgill.ca/oss/article/critical-thinking-health/questions-abound-safety-humidifiers>.
 229. Rosati, J.A., K.A. Krebs, and X. Liu, *Emissions from cooking microwave popcorn*. Critical reviews in food science and nutrition, 2007. **47**(8): p. 701-709.
 230. Surawattanasakul, V., et al., *Respiratory symptoms and skin sick building syndrome among office workers at University Hospital, Chiang Mai, Thailand: associations with indoor air quality, AIRMED project*. International journal of environmental research and public health, 2022. **19**(17): p. 10850.
 231. Parveen, N., S. Chowdhury, and S. Goel, *Environmental impacts of the widespread use of chlorine-based disinfectants during the COVID-19 pandemic*. Environmental Science and Pollution Research, 2022. **29**(57): p. 85742-85760.
 232. Leung, M. and A.H. Chan, *Control and management of hospital indoor air quality*. Med Sci Monit, 2006. **12**(3): p. 23.
 233. Tsai, R.J., et al., *Precautionary practices of respiratory therapists and other health-care practitioners who administer aerosolized medications*. Respiratory care, 2015. **60**(10): p. 1409-1417.
 234. OSHA. *Hospitals : Laboratory - Toluene, Xylene, or Acrylamide Exposure*. [cited 2025 24 June]; Available from: <https://www.osha.gov/etools/hospitals/laboratory/toluene-xylene-acrylamide-exposure>.
 235. Jiemwutthisak, P., et al., *Air monitoring to control the intake of airborne radioiodine-131 contaminants by nuclear medicine workers*. 2012.
 236. Health, D.o. *Health Facts of Hong Kong*. 2024 [cited 2025 30 June]; Available from: https://www.dh.gov.hk/english/statistics/statistics_hs/files/2024.pdf.
 237. Hub, C.O.R. *Overview of Cancer Statistics in Hong Kong*. [cited 2025 30 June]; Available from: https://www.cancer.gov.hk/en/hong_kong_cancer/overview_of_cancer_statistics_in_hong_kong.html.