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An indoor air quality policy maturity framework: Global exemplars and governance pathways

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ABSTRACT

Household and indoor air pollution are among the leading environmental risk factors for premature death worldwide, yet unlike outdoor air pollution they remain largely unregulated: only 7% of countries have established legal standards for indoor air quality. Indoor air quality (IAQ) remains underdeveloped in national policy frameworks compared to outdoor air quality, in part because responsibility sits across different government ministries with no clear lead. This paper examines the global landscape of IAQ governance, surveying 41 countries or jurisdictions with indoor air quality policies or standards from the International Society of Indoor Air Quality and Climate's Indoor Air Quality Guidelines Database. Synthesized from a review of 159 policy documents across the 41 jurisdictions, the foundational IAQ literature, and public policy literature, we introduce a novel Indoor Air Quality Policy Maturity Framework to identify best practices for legislating and implementing IAQ policy. The Framework defines maturity levels across five core criteria of IAQ governance: coordination, indoor air monitoring, health-based indoor air standards, enforcement, and implementation support. Exemplar jurisdictions were selected for each criterion: Finland for coordination, Belgium for monitoring, Japan for health-based standards, South Korea for enforcement, and the United Arab Emirates for implementation support. These case studies demonstrate diverse policy pathways for achieving maturity across all five criteria of the IAQ Policy Maturity Framework, shaped by governance structures, political feasibility, and implementation capacity. The Framework provides a practical tool for assessing gaps in IAQ governance and guiding governments toward stronger, more comprehensive indoor air policies.

1. Introduction

In 1987, the World Health Organization recognized clean air as a human right, and in 2022, the United Nations recognized the right to a clean, healthy, and sustainable environment [1,2]. However, global policy on air pollution has historically focused on outdoor air pollution. According to the United Nations, only 7% of countries had established legal standards for indoor air quality (IAQ) as of 2021 [3]. A more recent effort by the International Society of Indoor Air Quality and Climate (ISIAQ) details 41 jurisdictions with government guidelines, government regulations, or non-governmental guidelines for managing indoor air pollutants. Only 27 of the 41 jurisdictions in the ISIAQ IAQ Guidelines Database have regulations on indoor air pollutant levels that are established and enforced by a government authority [4].

The right to clean air should extend to indoor environments, where populations in high-income countries spend up to 90% of their time and pollutant concentrations can be two to five times higher than outdoors [5]. Indoor air pollution contributes to respiratory disease (including asthma and lung cancer), heart disease, infectious disease transmission, and cognitive impairment [6–8]. In fact, poor indoor air quality is a leading cause of premature death worldwide, causing an estimated 2.9 million deaths per year [9].

Due to growing recognition of clean indoor air as a human right, international action is gaining momentum, with major initiatives taking place among governments worldwide to improve indoor air quality. The Global Pledge for Healthy Indoor Air, launched at United Nations Headquarters in September 2025, is one such example [10]. The Global Pledge is the first international commitment declaring healthy indoor air as fundamental for protecting health and safeguarding well-being. France and Montenegro are the first two countries to sign, along with the cities of Boston and Melbourne, and they are committing to tangible actions towards healthy indoor air.

However, as governments (nations, states, cities) look to take action on clean indoor air, they often find that there is no unifying framework

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for legislating IAQ. IAQ governance is typically distributed among multiple government agencies spanning health, labor, housing, environment, transportation, energy, and education, impeding effective coordination. In addition, policies developed by government agencies are often not health-based but based on odor, comfort, or energy considerations. Other challenges include a lack of monitoring and enforcement, inconsistent implementation of regulations, and lack of harmonized standards for indoor air pollutants. As a result, governments can take a diverse set of pathways to govern IAQ, reflecting differences in public health priorities, economic capacity, and governance structures.

This paper introduces a novel Indoor Air Quality Policy Maturity Framework that directly addresses these barriers. Informed by country best practices, the Framework outlines the five core components necessary for IAQ governance: (1) coordination, (2) indoor air monitoring, (3) health-based indoor air standards, (4) enforcement, and (5) implementation support.

One jurisdiction was chosen to exemplify each of the five criteria of the IAQ Policy Maturity Framework: Finland for coordination, Belgium for monitoring, Japan for health-based standards, South Korea for enforcement, and the United Arab Emirates for implementation support. The case studies demonstrate that there is not necessarily a one-size-fits-all approach to legislating IAQ, but rather they provide a set of models for establishing IAQ governance across all five criteria.

2. Materials/methods

2.1. Review of indoor air quality policies

The impetus for this analysis was a review of indoor air quality policies across 41 jurisdictions.

The ISIAQ IAQ Guidelines Database was used as a foundation to identify countries with indoor air quality policies. The IAQ Guidelines Database was developed in 2020 as an open database of global IAQ guidelines, regulations, and standards and is periodically updated (last updated in 2025). The database contains indoor air pollutant data from 41 jurisdictions, predominantly jurisdictions in Europe and Asia, including the European Union [11].

From the set of 41 jurisdictions, a systematic review of national legislation, government reports, and official government websites was conducted to identify countries and regions with features of a mature policy system. The searches were conducted between July 2025 and May 2026 in English using keywords that combined an indoor air quality term, a policy instrument term, and the jurisdiction name (Table 1). For jurisdictions where the text was not available in English, Google Translate was used to translate the primary text into English, supplemented where needed by peer-reviewed English-language analyses of the legislation.

The review yielded 159 policy documents from 41 jurisdictions that met three criteria: (1) they addressed indoor air quality directly or through a closely related topic (e.g., ventilation requirements, building occupant health, or indoor environmental quality); (2) they were issued by a government body; and (3) they were in force at the time of data collection. The 159 policies captured instruments spanning the spectrum from non-binding recommendations to legally enforceable mandates, including guidelines, government initiatives, standards, building codes, and regulations:

- Guidelines are non-binding recommendations that interested stakeholders can consult and adopt. However, guidelines lack monitoring and enforcement, which can result in inconsistent uptake and application.
- Government initiatives refer to programs that directly seek to improve indoor air quality, such as government-funded or supported indoor air monitoring programs, air purifier deployments, and voluntary building certification schemes.
- Standards are technical specifications promulgated by organizations like ASHRAE, the International Organization for Standardization, or the European Committee for Standardization, but remain voluntary.
- Building codes are legally adopted construction standards that govern the design and operation of a building, usually enforceable through building permitting and inspection systems.
- Regulations are legally enforceable rules that come with a penalty if violated [11].

The policy documents for each jurisdiction were analyzed to capture the responsible government agencies; the pollutants and settings governed; the legal force of each instrument; and mechanisms for monitoring, enforcement, and implementation.

2.2. Indoor air quality policy maturity framework development

Across the collected IAQ policy documents, certain elements emerged as critical for indoor air quality governance: coordination mechanisms for organizing responsibility; requirements for measuring and disclosing indoor air quality; indoor pollutant thresholds; enforcement mechanisms to ensure compliance; and support for implementation. These themes were then validated against the indoor air quality policy literature and the public policy literature to develop the Indoor Air Quality Policy Maturity Framework.

A structured analysis of three foundational policy documents in the indoor air quality literature was conducted: (1) the Model Clean Indoor Air Act (MCIAA) developed by the Johns Hopkins Center for Health Security, (2) the State Guide for Clean Indoor Air developed by the Brown University Pandemic Center, and (3) recommendations on mandating indoor air quality standards in public buildings from Morawska et al [12-14]. These documents were selected because they each provide evidence-based recommendations for indoor air quality governance at the national or subnational levels.

The MCIAA provides a comprehensive legal framework for IAQ governance in the United States, conceptualizing a governance model that is based on coordinated state authority, public transparency, monitoring, complaint and inspection pathways, and administrative implementation capacity [12]. The State Guide for Clean Indoor Air provides a roadmap for state and local leaders in the United States to strengthen indoor air quality through stronger coordination; health-based indoor air quality targets; implementation support; building standards; and sector-specific action across schools, homes, long-term care facilities, and workplaces [13] . The article by Morawska et al. argues that governments should establish mandatory indoor air quality standards for public spaces grounded in health-based pollutant thresholds, routine monitoring, and enforceable regulatory frameworks [14].

In addition, the public policy literature was reviewed to analyze the policy levers that public institutions use to implement change. Two foundational tools in the comparative governance literature are Christopher Hood's NATO framework and Schneider and Ingram's behavioral typology of policy tools [15,16]. A synthesis of these two frameworks yielded five tools that governments often use to advance public policy goals:

Table 1
Keywords Used to Identify Indoor Air Quality Policy Documents.

Indoor air quality terms	"indoor air quality"; "indoor environmental quality"; "indoor climate"; "ventilation"; "energy performance"
Policy terms	"law"; "act"; "regulation"; "decree"; "directive"; "standard"; "policy"; "strategy"; "program"

- Organization tools: Institutional capacity to coordinate, align, and deliver policies across agencies and stakeholders.
- Information tools: Instruments that address information deficits to enable policy actors to make decisions.
- Capacity-building tools: Instruments that provide the means, infrastructure, or technical standards to enable desirable behavior.
- Regulatory tools: Binding rules that compel compliance through state authority.
- Financial tools: Positive payoffs (e.g., financial subsidies, tax credits) or penalties that change behavior by altering the cost-benefit calculus of a policy solution.

Governance elements identified in the three IAQ policy papers, Hood's NATO framework, and Schneider and Ingram's policy typologies yielded five high-level, distinct categories that are essential for indoor air quality governance: (1) coordination, (2) indoor air monitoring, (3) health-based indoor air standards, (4) enforcement, and (5) implementation support (Table 2).

2.3. Maturity levels

Each criterion is characterized across four maturity levels: absent, early, intermediate, and mature. The maturity levels represent a progression in legal force, scope, and institutional ownership. The specific definition for each maturity level differs by criterion and is detailed in Table 2:

- Absent: No indoor air quality obligations, responsibilities, or policies exist for the criterion.
- Early: Initial engagement with indoor air quality, in which indoor air quality is addressed indirectly, voluntarily, or only through a single sector, often through adjacent domains such as workplace safety or sustainability.
- Intermediate: Indoor air quality specific mechanisms and policies start to become formalized through binding requirements or institutional roles but remain limited to a certain number of pollutants, settings, or sectors.

Table 2
Indoor Air Quality Policy Maturity Framework.

Criterion	Definition	Policy Lever	Maturity Levels
Coordination	Institutional infrastructure through which governments organize responsibility for IAQ.	Organization tools	**Absent:** No ministry, agency, or institution has an explicit mandate, responsibility, or coordinating role for IAQ. **Early:** At least one ministry, agency, or institution has responsibility for IAQ-related issues, but governance remains largely sector specific and fragmented. **Intermediate:** Multiple government bodies are formally engaged in IAQ governance through defined roles, collaborative mechanisms, or national policy frameworks. **Mature:** IAQ governance is embedded within a national framework with clear leadership, accountability, and cross-sector coordination mechanisms.
Indoor Air Monitoring	Measurement and disclosure of IAQ performance through pollutant testing; heating, ventilation, and air conditioning (HVAC) audits; or formal risk analyses. Monitoring may be continuous or periodic.	Information tools	**Absent:** No legal requirements for IAQ monitoring and no public disclosure mechanisms. **Early:** Monitoring is required only when a risk is identified or a complaint is made, with or without requirements for public disclosure. **Intermediate:** Monitoring is only required in a limited number of public settings (e.g., schools, workplaces, hospitals), and may be continuous or periodic. **Mature:** Continuous monitoring of CO_2 and/or $PM_{2.5}$ in most or all public spaces along with public disclosure and labelling or certification.
Health-based Indoor Air Standards	Existence of legally recognized indoor air pollutant thresholds based on health risk. Health-based standards mean that there is an explicit linkage to health protection, including through coverage of both infectious and non-infectious risks.	Capacity-building tools	**Absent:** No identified indoor air quality limits, ventilation requirements, or infection control standards. **Early:** Indoor air quality is addressed through non-binding guidelines related to comfort, energy performance, building design, or occupational safety, but is not explicitly framed around health protection. **Intermediate:** Health-based IAQ standards or guidelines exist but remain voluntary or are only legally applicable to a limited number of pollutants, sectors, or settings. **Mature:** Legally binding, health-based IAQ standards across multiple pollutants and settings.
Enforcement	Legal authority and mechanisms available to ensure compliance with IAQ obligations. Enforcement mechanisms include inspections, complaint-based investigations, civil/criminal penalties, and corrective orders.	Regulatory tools	**Absent:** No legal authority or enforcement mechanisms exist to ensure compliance with IAQ obligations. **Early:** IAQ enforcement is addressed indirectly through general building, housing, or occupational safety systems, but no IAQ-specific enforcement mechanisms exist. **Intermediate:** IAQ-specific enforcement mechanisms exist but are limited to specific pollutants, sectors, or settings. **Mature:** IAQ-specific enforcement mechanisms exist across multiple sectors, settings, and pollutants.
Implementation Support	Institutional, financial, and technical mechanisms that enable IAQ policies to be implemented. Six core implementation elements include national strategies or action plans; technical guidance; workforce development; building code integration; financial or programmatic support; and pilot projects.	Financial tools / capacity-building tools	**Absent:** No implementation support identified **Early:** Implementation support is limited to 1–2 of the core implementation elements. **Intermediate:** A partial implementation pathway exists with 3–4 of the core implementation elements present. **Mature:** A structured implementation pathway exists that translates IAQ policy to deployment at scale, with 5 or more of the core implementation elements present.

- Mature: The criterion is fully institutionalized and applied comprehensively across pollutants, settings, sectors, and responsible institutions.

The maturity levels were adapted from adjacent scales, indexes, and evaluation tools in the tobacco control, health security, and international health literature, including the Tobacco Control Scale, the Global Health Security Index, and the Joint External Evaluation Tool [17-19].

2.4. Case selection

Using the 159 collected policy documents, the 41 jurisdictions were then assessed against the maturity levels in Table 2 for each of the five criteria. Jurisdictions were considered as potential case studies on the basis of maturity for a specific criterion rather than overall strength across all five criteria. When more than one jurisdiction achieved the mature level, the case studies presented in this paper were selected for diversity of geography, governance structure, and policy pathway.

3. Results

Based on the literature review, Finland, Belgium, Japan, South Korea, and the United Arab Emirates were selected as comprehensive case studies illustrating mature policy actions for one of the five criteria (Fig. 1).

3.1. Finland: a blueprint for strengthening coordination

In the Indoor Air Quality Policy Maturity Framework, Finland serves as the exemplar of coordination, highlighting how cross-sectoral collaboration and long-term programmatic planning can reduce fragmentation within indoor air governance.

IAQ is a broad and cross-cutting topic, with government agencies across health, energy, environment, education, housing, and labor all sharing responsibility. Divided responsibilities between national and subnational governance bodies add a further layer of complexity. The fragmented nature of indoor air governance means that often no single agency is responsible for IAQ outcomes, leading to the complete lack of country action or inconsistent implementation and enforcement [13]. To address this challenge, some countries have established coordination mechanisms for indoor air governance.

Finland's action on IAQ is organized through the Indoor Air and Health Programme 2018–2028, which serves as a coordinating platform led by the Finnish Institute for Health and Welfare. The Finnish Indoor Air and Health Programme is being implemented in phases, with the second phase currently underway:

- Phase 1 (2018–2022): Implemented actions across four areas to inform the public through evidence-based tools and guidance; improve how indoor air problems in buildings are managed; support people with indoor air-related symptoms and illnesses, including through new rehabilitation clinics; and train healthcare professionals, occupational health specialists, employees, and indoor environment experts.
- Midterm Evaluation (2023): Found measurable reductions in indoor-air health complaints, improved public knowledge, and greater satisfaction with municipalities' indoor air actions.
- Phase 2 (2023–2028): Focuses on ensuring that the large number of guidelines and training materials produced in phase 1 will be integrated by municipalities, healthcare systems, and the private sector. A final evaluation will be conducted in 2028 [20,21].

The program, while led by the Finnish Institute for Health and Welfare, was designed in consultation with over 25 state agencies and civil society organizations. In addition, program functions are implemented by multiple Finnish ministries, municipal governments, research institutions, and private sector partners. For example, the program steering group includes representatives from 15 Finnish ministries and NGOs, the expert group draws on a range of healthcare professionals, and the program secretariat includes representatives from 8 different ministries and organizations [21]. The Finnish Indoor Air and Health Programme serves as a best practice for coordinating across stakeholders with responsibilities for various aspects of the IAQ ecosystem. This coordination has achieved measurable improvements in indoor air-related symptoms and health worry [20].

3.1.1. Belgium: a model for monitoring and transparency

Belgium provides one of the best examples of how IAQ monitoring can be translated into public transparency and accountability. Belgium's Law of 6 November 2022, "Improvement of Indoor Air Quality in Closed Spaces Accessible to the Public," establishes CO_2 monitoring in all public spaces and a certification and labelling scheme [22]. The central feature of the law is positioning IAQ as a right-to-know issue, empowering the public with information that can catalyze action to improve IAQ. The law prioritizes CO_2 monitoring. CO_2 levels rise when a space is crowded or poorly ventilated because people exhale CO_2 as they breathe, making it a useful proxy for occupant-emitted contaminants and pathogens, as well as a means of assessing the ventilation rate. Importantly, CO_2 can be measured accurately by inexpensive, readily available monitors and its concentration can be used to model risk of pathogen transmission [14].

Belgium has traditionally recognized indoor air quality as a workplace health issue, dating back to the Act of 4 August 1996, but the Law of 6 November 2022 marks a fundamental shift. IAQ shifted from an occupational health issue to a public health obligation, with the law applying to roughly 2 million enclosed spaces accessible to the public. The law establishes four overarching pillars, with pillars 2 and 3 directly applicable to monitoring and transparency:

1. Defines good **IAQ reference levels** (Level A and Level B) that are indicative and not mandatory. The law does not obligate those responsible for public spaces to provide clean indoor air but establishes guidelines for IAQ to be assessed. Level A defines a CO_2 concentration below 900 parts per million (ppm) and Level B below 1200 ppm.
2. Encourages those responsible for indoor environments to **seek to improve air quality**, specifically calling out CO_2 monitoring. Other provisions include conducting an indoor air pollution risk analysis and implementing an action plan to achieve good IAQ. These provisions will become mandatory on January 1, 2027.
3. Establishes a **certification and labelling scheme** for buildings. Each public space must prominently display a label, awarded by the Federal Public Service Health, Food Chain Safety, and Environment, informing the public that IAQ is being measured and controlled in that space. These provisions will become mandatory on January 1, 2038.
4. Creates an **Indoor Air Quality Platform** as a permanent advisory body bringing together scientists, public authorities, and industry representatives. The platform provides guidance, recommends updates to reference levels, and ensures that policy evolves with new evidence and technology [22].

Importantly, the law creates a phased approach to implementation, giving stakeholders time to comply. Since October 1, 2024, operators of publicly accessible spaces may apply the law on a voluntary basis, but pillar 2 becomes mandatory on January 1, 2027, and pillar 3 by January 1, 2038 [22]. Ultimately, Belgium creates a unique system for public transparency through widespread indoor air quality monitoring and its certification and labelling scheme.

3.1.2. Japan: Health-based Standards Across Building Types

Health-based indoor air quality standards have been published by several reputable sources, including the World Health Organization,

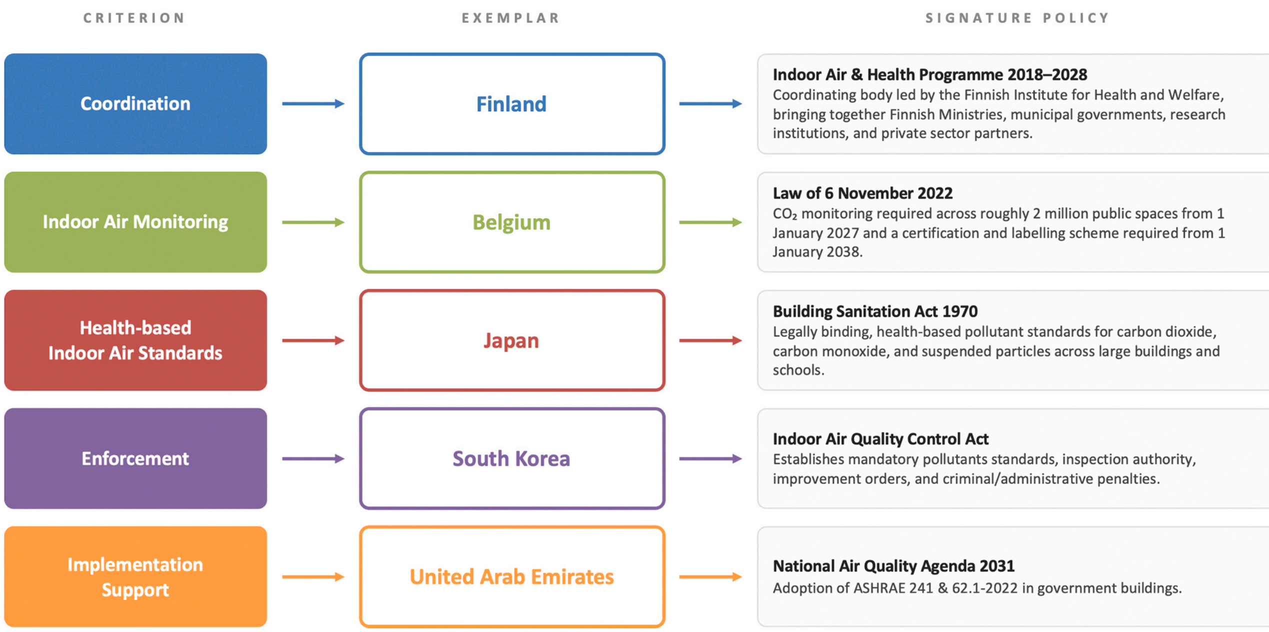

Fig. 1. Country Exemplars by Indoor Air Quality Policy Maturity Criterion.

Global Open Air Quality Standards, and Morawska et al [14,23,24]. Japan exemplifies how such health-based frameworks, grounded in occupant health protection, can be translated into legal requirements that extend to both non-infectious and infectious risks.

Japan's main legislative framework for indoor air quality is grounded in the Act on Ensuring a Hygienic Environment in Buildings (1970), commonly referred to as the Building Sanitation Act. The Act applies to "specific buildings" with a total floor area of 3000 square meters or more, and to schools of 8000 square meters or more. "Specific buildings" include offices, entertainment venues, stores, libraries, and museums [25].

An enforcement order under the Building Sanitation Act describes regulations for suspended dust, CO, CO_2, temperature, relative humidity, airflow, and formaldehyde concentration for specific buildings with air conditioning equipment (Table 3). The enforcement order also states that measures must be taken to prevent indoor air from being contaminated by pathogens in spaces with air conditioning equipment installed [26].

Importantly, the pollutant thresholds are paired with requirements for building operators to conduct regular indoor air environmental measurements to ensure compliance with the pollutant thresholds. Building owners are required to appoint a Building Environmental Sanitation Management Technician, who is responsible for the building's indoor air quality [25].

The Ministry of Health, Labour and Welfare (MHLW) also established the Committee on Indoor Air Pollution (CIAP) in the 1990s in response to the emergence of "Sick Building Syndrome." Between 1997 and 2002, MHLW established indoor air quality guidelines for 13 chemicals, based on the scientific consensus of CIAP, to prevent adverse health effects in humans. Guidelines have been established for chemicals including formaldehyde, toluene, and xylene [27]. In addition, the Building Standards Law was amended in 2003 to incorporate countermeasures against sick building syndrome. The amended law banned certain chemicals in buildings, restricted the use of formaldehyde, and mandated continuous 24-hour mechanical ventilation providing at least 0.5 air changes per hour in dwellings [28]. The CIAP was relaunched in 2012 and continues to establish new or updated guidelines, providing a valuable mechanism for reviewing emerging scientific evidence [29].

Japan offers a model for mandating health-based indoor air quality standards, combining the Building Sanitation Act's pollutant thresholds, the CIAP's chemical guidelines to prevent adverse health effects, and enforcement provisions that address pathogen contamination indoors.

3.1.3. South Korea: a regulatory approach for enforcement

In 1996, South Korea became the first country in Asia to enact a standalone IAQ law:

- Indoor Air Quality Control Act (2024): First established as the "Air Quality Control in Underground Location Act" by the Ministry of Environment in 1996, updated to the "Indoor Air Quality Control in Public Use Facilities, etc. Act" in 2004, and most recently updated and renamed the "Indoor Air Quality Control Act" in 2024 [30].

South Korea is a leading example of establishing IAQ enforcement through legislation combining mandatory pollutant standards for regulated facilities, government inspection authority, improvement orders requiring corrective action, and administrative and criminal penalties for noncompliance (Box 1).

Table 3
Japan's Standards for Air Environments in Specific Building Types.

Pollutant	Threshold Value	Monitoring Requirement
Suspended particles	$\leq$ 0.15 mg/m^3	Measured once every two months or more frequently
CO	$<$ 6 ppm	
CO_2	$<$ 1000 ppm	
Temperature	18 ℃ - 28 ℃	
Relative humidity	40% - 70%	
Air flow	$<$ 0.5 m/s	
Formaldehyde	$<$ 0.1 mg/m^3	Measured when newly built, repaired, or renovated

Within the Policy Maturity Framework, South Korea exemplifies a mature enforcement system, combining indoor air pollutant thresholds, monitoring, and tiered compliance mechanisms.

3.1.4. United Arab Emirates: leading the way through implementation

The United Arab Emirates (UAE) exemplifies how indoor air quality policy can be operationalized through a national strategy, technical guidance, building code integration, government funding, and pilot projects, even in the absence of an overarching IAQ law. The UAE has taken practical steps to improve IAQ, including the adoption of ASHRAE standards in government buildings across the UAE. ASHRAE is a professional association of HVAC engineers that publishes standards relevant to indoor air quality and ventilation systems.

This effort, launched in 2023, was informed by the UAE's National Air Quality Agenda 2031, developed by the Ministry of Climate Change and Environment, as well as by Cabinet Resolution No. (86) of 2023 [31, 32]. The National Air Quality Agenda 2031 outlines four key focus areas for the effective monitoring, management, and mitigation of air pollution: outdoor air quality, indoor air quality, ambient odor, and ambient noise. It also outlines three key IAQ programs across monitoring, management, and mitigation [31].

In 2023, the Ministry of Energy and Infrastructure (MoEI) announced the adoption of the latest ASHRAE technical specifications for government buildings. In 2024, the MoEI completed a pilot project implementing ASHRAE Standards 62.1–2022 and 241–2023 at the Daba Fujairah Court [33]:

- ASHRAE 62.1–2022 sets minimum ventilation requirements to ensure IAQ is acceptable to human occupants and to minimize adverse health effects in commercial, institutional, and high-rise residential buildings [34].
- ASHRAE 241–2023 establishes minimum ventilation requirements to control infectious aerosols and reduce the risk of disease transmission, especially during periods of elevated infection risk [35].

The pilot project's primary objective was to demonstrate that indoor air quality can be improved while simultaneously reducing energy consumption through an integrated design and operational approach. Key interventions included:

- Optimizing outdoor air ventilation rates using the Indoor Air Quality Procedure under ASHRAE Standard 62.1.
- Continuous monitoring of CO_2, $PM_{2.5}$, and other key IAQ indicators to verify acceptable indoor air quality and optimize ventilation operation.
- Upgrading air filtration to improve removal of fine particulate matter.
- Optimizing HVAC system operation, including fresh air control, scheduling, and system balancing to reduce energy consumption.
- Improving building operation and maintenance practices.

Together, these measures produced significant improvements in IAQ and an approximately 35% reduction in HVAC-related energy consumption, demonstrating that healthy indoor air and energy efficiency can be achieved simultaneously through performance-based ventilation strategies. Following the success of the pilot, the MoEI is implementing the same methodology and technologies across several new government projects [33].

Within the Framework, these efforts make the UAE a mature exemplar of implementation support, fulfilling five of the six core implementation elements: national strategy, technical guidance, building code integration, government funding, and pilot projects.

4. Discussion

The Indoor Air Quality Policy Maturity Framework is the first comprehensive tool to assess and benchmark indoor air quality governance across jurisdictions. It outlines five key criteria essential to a holistic indoor air quality governance system: coordination, indoor air monitoring, health-based indoor air standards, enforcement, and implementation support. The Framework can be used by policymakers, governments, and researchers to identify gaps, prioritize resources, and evaluate indoor air quality governance over time. The Framework is also designed on the basis that measuring countries' capacities and gaps will motivate governments, donors, and the private sector to work together to improve indoor air quality governance.

However, comprehensive policy architecture does not necessarily translate into measurable improvements in indoor air quality, reduced indoor pollutant exposure, or better health outcomes. Only widespread

Box 1
Key Provisions of South Korea's Indoor Air Quality Control Act.

Settings: Public-use facilities (e.g., transit centers, underground shopping centers, museums, libraries), facilities serving sensitive populations (e.g., childcare centers, medical facilities), and newly constructed multi-family housing.

Standards (two tiers):

- Maintenance standards: Mandatory limits for general public facilities and facilities serving sensitive populations, including PM_{10}, $PM_{2.5,}$ CO_2, formaldehyde, total airborne bacteria, and CO.
- Recommended standards: Voluntary targets for additional pollutants (e.g., radon, ozone, asbestos).

Monitoring: Annual monitoring of pollutants under mandatory standards and semi-annual monitoring of other sources. Results retained for 10 years.

Inspection authority: Officials may request monitoring reports or enter regulated spaces to collect pollutant data. Results may be publicly disclosed when standards are exceeded.

Corrective action: Authorities may issue improvement orders requiring facility owners to upgrade or replace air purifiers or ventilation equipment within a set timeframe.

Penalties:

- Administrative fines up to 20 million won (~US$13,200)
- Criminal liability up to 1 year imprisonment or a fine up to 10 million won (~US$6600) for failure to comply with an improvement order
- Corporate liability for violations in the course of business

indoor air quality monitoring systems would provide direct evidence of these outcomes. For example, South Korea's monitoring requirements for regulated facilities enabled it to track reduced indoor pollutant exposure following policy changes, with decreases in $PM_{2.5}$ and CO_2 concentrations between 2019 and 2022 in public-use facilities [36]. In the absence of widespread indoor air quality monitoring across jurisdictions, the Framework serves as a useful guidepost for policymakers on the five foundational elements necessary for improving indoor air quality.

The case studies presented in this paper are meant to show decision-makers what countries have accomplished and what is possible. They showcase diverse policy pathways for achieving maturity across all five criteria of the Framework, shaped by existing legal frameworks, political feasibility, and resource constraints.

Finland's model of programmatic coordination with the Indoor Air and Health Programme drew on other successful population-based health programs, including the Finnish Asthma Programme and the Finnish Allergy Programme. Finland has made substantial efforts to improve indoor air quality over the past three decades, with a focus on moisture damage and mold in buildings. Among the public, health concerns related to indoor air quality and building-related complaints are common, and public knowledge of indoor air quality often differs from the scientific evidence. As a result, Finland designed an indoor air quality program to address public misconceptions, reduce indoor air quality-related symptoms, and decrease health worry. Uniquely, Finland brought together a wide-array of government ministries to successfully coordinate on this topic.

Belgium's transparency model enhances knowledge about indoor air quality in public spaces, without mandating that spaces meet certain indoor air conditions. The CO_2 reference levels are not legally enforceable but serve as useful benchmarks for assessing indoor air quality, a model that balances public health with political feasibility. Belgium is also employing a phased regulatory approach that allows time for market adoption, workforce development, and adaptation by building owners and facility managers.

Similarly, the United Arab Emirates is taking a more flexible approach to indoor air quality governance by integrating health and indoor air quality into building policy, in lieu of comprehensive legislation. The UAE is also aligning indoor air quality with broader sustainability goals, showing that indoor air quality improvements can provide benefits for both energy efficiency and health outcomes. The UAE's pilot projects identify effective interventions and demonstrate impact that can inform scalable regulation and funding.

Japan and South Korea have some of the most comprehensive indoor air quality governance in the world, grounded in pollutant limits and enforceable legislation. Both countries have a long history of regulating indoor air quality, with South Korea being the first country in Asia to have an IAQ-specific law. South Korea is also demonstrably successful in achieving acceptable indoor air quality levels, given its widespread monitoring requirements, with monitors across transit centers, daycare centers, and shopping malls. The two countries demonstrate the importance of institutionalizing binding pollutant thresholds to ensure widespread compliance and prevent health inequities.

The case studies also demonstrate that the five criteria of the Framework are mutually dependent rather than distinct categories. For example, health-based standards alone will not produce measurable improvements in indoor air quality without monitoring systems to assess performance, enforcement mechanisms to compel compliance, and implementation support to enable action. Japan and South Korea illustrate this interdependence most clearly, pairing binding pollutant limits with monitoring, enforcement, and institutional authority. Meanwhile, Belgium and the United Arab Emirates show that political and financial constraints might require a phased implementation approach or pilot projects demonstrating impact before maturity can be achieved across other criteria of the Framework. Finland's coordination model functions as an enabling condition for the other four criteria, since siloed efforts can compromise their consistent application (Table 4).

No exemplar jurisdiction is mature across all five criteria, showing the usefulness of the Framework to identify gaps, even in countries that are leading the way on indoor air quality governance. Finland has an opportunity to implement a routine nationwide indoor air quality monitoring program. Belgium and the United Arab Emirates lack legally enforceable IAQ standards, which may limit the long-term effectiveness of their policies. Finally, countries that rely on regulatory-heavy models, such as Japan and South Korea, need to consider equitable application of IAQ standards among non-statutory facilities and low-resource settings that may lack the capacity to comply [39].

5. Limitations and future work

The analysis has several limitations. First, the Framework is skewed towards high-income countries, and its applicability may be limited in low-resource settings, where governments are mostly focused on the clean fuel transition, given that solid fuel cooking is a major contributor to poor indoor air quality [9]. Since all five exemplar jurisdictions are high-income countries, the direct transfer of lessons learned to low-resource settings may be unrealistic. However, governance elements described in the Framework are meant to be broadly applicable across governance and economic systems. The tiered nature of the Framework can support low-resource settings as they move from the "absent" to "early" maturity level, or from "early" to "intermediate."

Second, the reliance on publicly available official documents discovered through English keywords may underrepresent jurisdictions whose policies are not available publicly or discoverable in the language searched. Third, the ISIAQ IAQ Guidelines Database, while the best available resource, does not fully capture IAQ policies across all jurisdictions and is skewed towards Europe and Asia. In addition, the database captures policies only at the national and supranational levels, which may overlook innovation at the subnational level. Finally, exemplar jurisdictions were chosen and assigned maturity levels by a single reviewer rather than multiple reviewers.

Future work can test the Framework across a broader set of countries to demonstrate its robustness, reproducibility, and practical utility beyond the selected exemplar jurisdictions. The Framework can be tested across all 41 jurisdictions in the ISIAQ IAQ Guidelines Database and other jurisdictions with IAQ policies. The applicability of the Framework to low-resource jurisdictions, and the need to adapt it for these settings, should be examined. In addition, future work can assess whether technological advancements (e.g., IoT-enabled systems, artificial intelligence, low-cost sensors) should be integrated into the Framework as an indicator of policy maturity. Finally, future work can examine whether policy maturity is associated with measured indoor air quality improvements and health outcomes through an analysis of monitoring data and outcome evidence.

6. Conclusions

The Indoor Air Quality Policy Maturity Framework synthesizes the five essential criteria of indoor air governance, identified through a structured review of 159 policy documents across 41 jurisdictions. Coordination, monitoring, health-based standards, enforcement, and implementation support are all crucial for a comprehensive indoor air governance system. The five case studies exemplify mature policy actions for each of the five criteria: Finland for coordination, Belgium for indoor air monitoring, Japan for health-based indoor air standards, South Korea for enforcement, and the United Arab Emirates for

Table 4
Comparison of Exemplar Jurisdictions across the Indoor Air Quality Policy Maturity Framework. Cell shading indicates the assessed maturity level for each criterion, progressing from absent (gray) to early (yellow) and intermediate (light green) to mature (dark green). [37,38]

	Finland: Indoor Air and Health Programme [20, 21, 38]	**Belgium: Law of 6 November 2022** [22]	**Japan: Building Sanitation Act** [25-29]	**South Korea: Indoor Air Quality Control Act** [31, 37, 39]	**United Arab Emirates: National Air Quality Agenda 2031** [32-34]
Coordination	Dedicated indoor air quality coordination platform	Indoor Air Quality Platform for collaboration among industry, scientists, and authorities, but government responsibility remains fragmented	Ministry of Health, Labour and Welfare leads, but responsibility remains fragmented	The Ministry of Environment leads, but responsibility remains fragmented	Divided responsibilities among various ministries, but the National Air Quality Agenda 2031 assigns roles
Indoor Air Monitoring	National Surveys on Indoor Air (2018, 2022) tracking symptom prevalence and perceived indoor air quality	CO_2 monitoring across 2 million public spaces becomes mandatory 1 January 2027	CO, CO_2, and suspended particles measured once every two months	Annual monitoring of PM, CO_2, CO, formaldehyde, and total bacteria count	Evaluation of pilot project performance in government buildings
Indoor Air Standards	CO_2: <1,150 ppm above outdoor PM_{10}: 50 µg/m³, 24-hour average $PM_{2.5}$: 25 µg/m³, 24-hour average (Regulation)	CO_2 reference levels: Level A <900 ppm; Level B <1,200 ppm (Reference levels)	Suspended particles: ≤0.15 mg/m³ CO: <6 ppm CO_2: <1,000 ppm (Regulation)	Fine dust (PM_{10}): ≤100 µg/m³ Ultrafine dust ($PM_{2.5}$): ≤40 µg/m³ Total airborne bacteria: ≤800 CFU/ m³ CO_2: <1,000 ppm CO: ≤10 ppm (Regulation)	Ventilation rates and infectious aerosol control standards as per ASHRAE 62.1 and 241 (Government program)
Enforcement	Municipal health protection authorities carry out enforcement with additional oversight from regional and occupational health organizations	FPS Public Health Inspectors monitor and implement the law. The number of inspectors is limited	Fines or imprisonment for non-compliance	Inspections, public disclosure, improvement orders, administrative fines, criminal penalties	None (adoption mandated administratively for government buildings)
Implementation support	Public outreach campaign, guidelines for moisture damage, establishment of rehabilitation clinics, workforce training, educational materials	National strategy, technical guidance, workforce development, digital app	Technical guidance, licensed building health managers, continuous guideline review	National strategy, Indoor Environmental Management Centers (research and education centers), public education	National strategy, technical guidance, building code integration, government funding, and pilot projects

implementation support.

The case studies also demonstrate that governments can advance healthy indoor air through multiple policy pathways, shaped by their governance structures, political context, and implementation capacity. Importantly, progress does not need to begin with a comprehensive regulatory framework. Governments can start with voluntary guidance, pilot projects, or sector-specific interventions, and gradually move toward achieving maturity across all five criteria of the Framework.

The Framework provides a practical tool for identifying gaps in IAQ governance and guiding governments toward stronger, more comprehensive indoor air policies. It also offers a foundation for future comparative analysis across countries and regions, including efforts to assess policy maturity.

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Declaration of Competing Interest

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

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