Scoping Review of Indoor Air Quality indexes: Characterization and Applications

Mohsen *POURKIAEI*[1*], Anne-Claude *ROMAIN*[1]
[1]*Sensing of Atmospheres and Monitoring Laboratory (SAM Lab), University of Liège, Belgium*
Corresponding Author: sm.pourkiaei@uLiège.be
(Bât. BE-014 Surveillance de l'environnement avenue de Longwy 185, 6700 Arlon)

Abstract
Better understanding of indoor air quality (IAQ) and parameters affecting it, can improve the management of indoor environment quality (IEQ), reduce health risks, and enhance the occupant's well-being. The energy divisions, health and economy sectors are highly correlated to the concept of IAQ in terms of air ventilation, public health, and productivity. We performed a worldwide scoping review in accordance with the PRISMA extension (PRISMA-ScR) on IAQ indexes with different definitions and indicators, for various aims and applications (from indoor climate to indoor pollutants; for different indoor environments and ventilation setups). Correspondingly, IAQ-related issues were reviewed, including health effects, energy efficiency, and economic impacts. Information on different IAQ indexes was obtained from 110 studies from 23 countries. The use and type of ventilation systems as well as the duration and location of studies are reviewed. Also, the variability of the studied parameters in the literature were investigated. Finally, a novel detailed scoping classification based on different approaches for IAQ index development is presented for the first time. The "objective" approach, has become prevalent over the "subjective" approach, in design, development, and application of IAQ indexes. In addition, consideration of mechanical and natural ventilation was observed in 57 and 18% of the studies, respectively. This scoping review can aid as a first step, to better understand different expressions of IAQ by mean of an index, and their applications for future research and developments.
Keywords
IAQ, Indoor Air Quality Index, Indicator, Scoping review, OCCuPANt.

1. Introduction

Based on extensive reports in scientific sources the percentage of time in which the people are exposed to indoor environment (residential buildings, working places, vehicles, public transports and public buildings such as schools, hospitals, museums, theaters, libraries etc.) is more than 80% in developed nations, more than 87% in U.S and 85-90% in Europe. These values could certainly be estimated even higher by the emerging COVID-19 pandemic and associated changes in people life-styles such as carrying on lockdowns and teleworking [1-6]. So, it is truly crucial to consider the impacts of indoor air quality (IAQ) on human health and well-being. Study and characterization of IAQ as well as growing interest and practical efforts to provide healthy and comfortable indoor environments, will enhance the occupants' quality of life and productivity [7, 8]. Exposure to indoor air pollution can exceed more than twice of exposure to outdoor air pollution, and it is estimated that a global population of 3 billion are subjected to improper IAQ levels on a daily basis [2]. It has been reported a wide range of illnesses and health issues correlated to low quality of indoor environment. In this regards, short and long-term exposure to poor IAQ can lead to negative impacts on the respiratory and cardiovascular systems, skin irritation, allergic symptoms, cognitive capabilities and productivity, dizziness, headaches, restlessness, asphyxia, coma, cancer and death [9-13].

The main purpose of this scoping review is to globally identify and categorize available IAQ indexes. To meet this goal, a scoping review based on the PRISMA-ScR is performed with the consideration of all IAQ indexes (indices) available in the literature, due to the best knowledge of authors to date [14]. The main purpose of this research is to map different definitions of available IAQ indexes- represented in the context of IAQ and/or IEQ. It is noteworthy to mention that; IAQ (air quality in a building which is breathed in) is a subset of IEQ (conditions inside the building) and their terminologies are explained more in details in sections 3.2.1, 3.2.2 and via Figure 2.

A scoping review of a body of literature can be of particular use when the topic has not yet been extensively reviewed or is of a complex or heterogeneous nature [15, 16].

2. IAQ Background

Here in this part, we aim to explain and describe the "key elements used to conceptualize the review questions (PRISMA-ScR). Afterwards, the questions are presented in section 2.7., and then it has been tried to answer them through the scoping review-study.

2.1. Health

United States Environmental Protection Agency (EPA) has defined the low IAQ as one of the five high priority environmental risks to public health [17,18]. Moreover, official reports of World Health Organization (WHO) approximate great number of premature deaths being linked to poor IAQ [19]. Thera are also some other health problems such as sick building syndrome (SBS), building related illnesses and multiple chemical sensitivities which have been studied in the literature [20]. The poor IAQ levels are not only limited to rural areas, but also to the dynamic and complex housing arrangement and energy regulations in urban areas. A deeper look into the concept of IAQ reveals that in addition to the status of human health and well-being, it can be highly correlated to the building energy consumption, lifecycle costs and economy aspects as well as the raising climate change measures and mitigations [21, 22].

2.2. Energy

Modern comprehensive methods and standards such as Standard NBN EN 16798-1:2019 in which building energy efficiency is integrated with the indoor environmental conditions, are progressively carried out [23, 24, 25]. The new trend of tight sealed dwellings, encourages the architectures and building construction companies to enhance the performance of ventilation units and improve the total energy efficiency, continuously. It is obvious that providing more air exchange rates (AERs) raise the energy use of ventilation utilities and decrease the building energy efficiency, simultaneously. Regarding the contradiction among "energy efficiency improvements" and "implementation of IAQ guidelines", the design, development and optimization of multipurpose approaches for indoor air purification is ever more required. Consequently, the energy consumption necessary to provide an adequate ventilation is related to a number of parameters, including but not limited to IAQ standards, ventilation system types, and occupants' activity. This can lead to a duality of interest among policies that aim providing high levels of IAQ and those motivating the decrease in building energy use. Modern indoor environments should enable reliable solutions for upcoming challenges and needs [26-28].
In this regard, the EU's policy making organization; the amended Energy Performance of Buildings Directive (EPBD, 2018/844), has stated energy performance criteria established by executive administrations of EU members should optimize health, IAQ and comfort measures. In order to support the transition into an energy efficient and decarbonized building stock by 2050, it is essential for EU governments to obtain a new perspective with these key factors [29]:

- Introducing measures of IEQ in long-term renovation approaches,
- Combining IEQ and Energy Performance Certificates (EPCs),
- Developing cost-optimal strategies & evaluating the influential factors of IEQ,
- Certify agreement and quality control actions to support providing acceptable IEQ.

2.3. Economic Point of View

The maintenance of indoor air quality can meaningfully impact the energy consumption of building design and operation stages, considered as indirect impacts on micro-economics. Occupants that are uncomfortable with their indoor environment are expected to take actions in achieving comfort which may have additional cost implications [30, 31]. Another important subject associated with the indoor environment and IAQ is the economic aspect in a direct way. The economy sector has faced an emerging switch to the service and knowledge-based teleworking from indoor office/home areas. This potential has quickly become a reality by the COVID-19 pandemic outbreak in 2020-21 [32, 33]. In addition to the health issues, poor IAQ can negatively affect the economic sector by reduction of work force productivity up to 15%. In fact, the economic cost of air pollution is huge. A pioneer study carried out in the 90's estimated that improved indoor environment can increase the potential productivity in the range of 0.5-5%, which was equivalent to US$12-125 billion per year [34]. The total economic cost of health effects by the integrated ambient PM and household air pollution was estimated to be US$ 1.575 trillion for the WHO European Region in 2010 [35]. Considering the only indoor pollution, recent studies have estimated annual economic costs (mortality, morbidity, and the productivity loss) to be around €20 billion for France in 2014, $37 billion for India in 2019 and (with only health cost consideration) about US$300 million for Morocco in 2017 [35-38].

2.4. Ventilation and IAQ

Many indoor environments rely on mechanical ventilation units with a limited amount of diluted outdoor air, which is likely to cause indoor pollutant accumulation. Based on the ASHRAE standard [39] three approaches entitled as: a) Ventilation Rate, b) IAQ, and/or c) Natural Ventilation, are applicable to satisfy the ventilation criteria. In the ventilation rate procedure (a prescriptive method), the air ventilation rates are defined based on the uses of building, number of residents, and floor area. In the IAQ procedure (a performance-based method), the outdoor air intake rates and other parameters are defined according to pollution sources, Exposure limit values (ELVs), and perceived IAQ admissibility. In the natural ventilation procedure (a prescriptive approach), the outdoor air flows via openings to the indoors, and can be applied in combination with mechanical ventilation systems. Modern designs with high energy saving targets include minimized air leakage, highly sealed construction, that considerably decrease the natural ventilation. High sealed indoor environments also can lead to accumulation of indoor pollutants, derived by inadequate air exchange rates [40, 41]. Also, there is a common conclusion in the literature that ventilation rates lower that 10 $^{l}/_{s.person}$ are related with higher frequencies of SBS symptoms. On the contrary, adequate ventilation rates can enhance productivity [42, 43]. However, the advised minimum levels for the indicators of indoor air are not necessarily always at optimum levels. For instance, the EN 16798-1 presents the absolute minimum value of ventilation equal to 4 $^{Lit}/_{s.person}$, while the scientific researches suggest it should be $6-7$ $^{l}/_{s.person}$ or even higher if additional parameters (e.g., productivity and learning) are considered [44-46].

2.5. IAQ and Sources of Impacts

The IAQ is a complex concept that is influenced by a number of parameters, such as indoor emission and outdoor penetration of pollutants, chemical reactions (secondary pollutants), sorption and desorption phenomena, air exchange rates and ventilation characteristics, indoor and outdoor temperature and relative humidity (RH). According to the literature, effective parameters involved in IAQ can be categorized to different groups and sub-groups on different basis. Some studies have classified these parameters into physical-chemical, organic-inorganic or internal-external and building characteristics. Pollution sources and emission trends vary quickly over different time periods, however in the following, an attempt has been made to provide a holistic schematic of classification of affective parameters on IAQ and their subgroups [6, 27, 47-56]. Figure 1. illustrates the main IAQ determinants with examples.

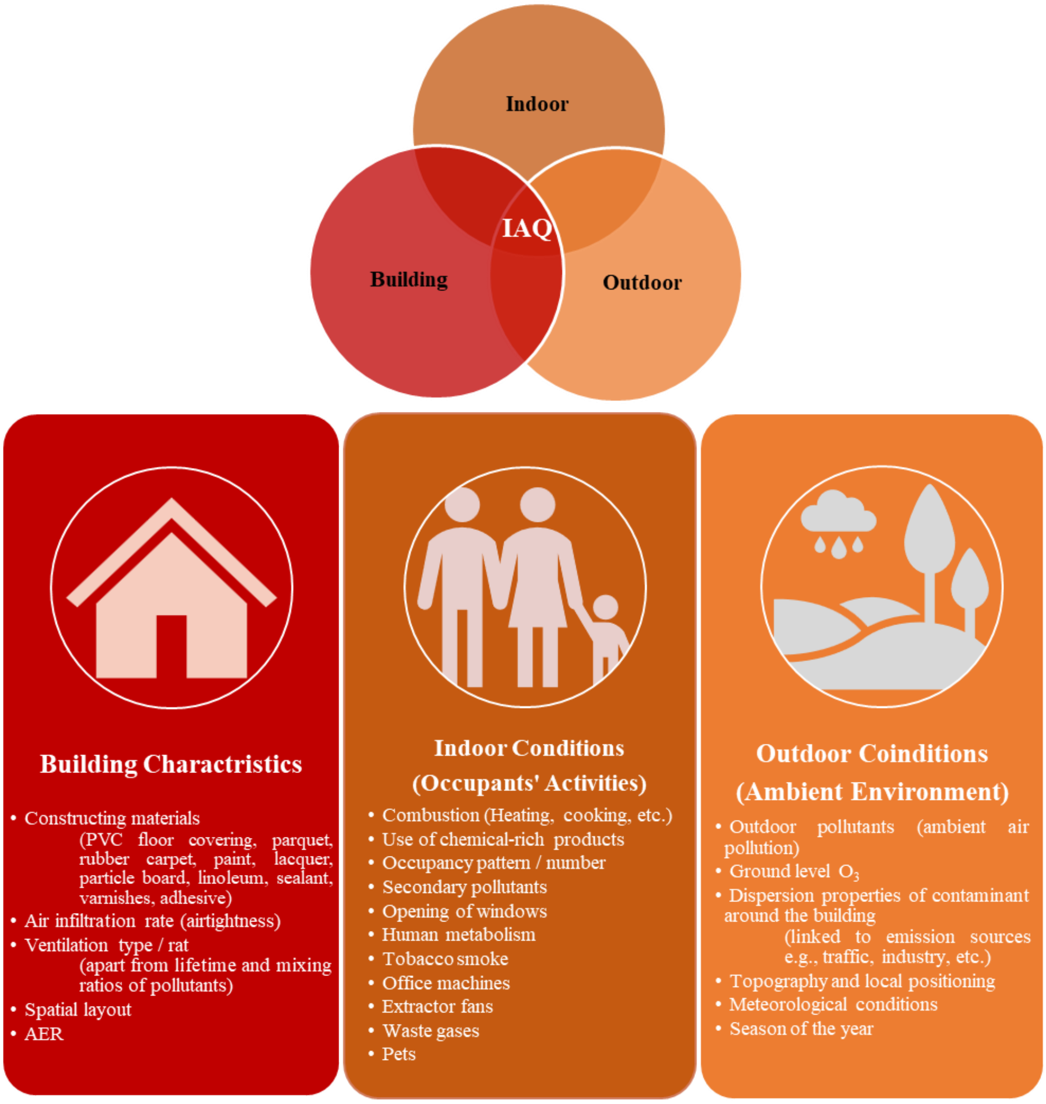


Figure 1. Main IAQ determinants with examples.

It is noteworthy to mention that outdoor sources of pollutions are more well-known and the measures to control them are more developed. With higher attention of policymakers to "energy transition" concept, the "carbon neutrality" context, and "net-zero emission" targets, the outdoor air pollution regulations and policies are being developed and implemented faster than those of indoor environments. Also, inhabitant's behavior and variation of life styles as a consequence of climate change can impact the indoor pollutant concentration as well [57]. Hence, the effects of indoor pollution sources on IAQ may attract more attention. Reducing indoor contaminants by controlling the emission origins is only applicable when the sources are well-recognized, though new substances are continuously identified and categorized as harmful to health. So, prevention or reduction of indoor contaminant emissions are usually limited (mainly low-emissivity materials), technically impractical, and not cost efficient [58-61]. In this regard the role of ventilation seems to be critical in the control and maintenance of good IAQ.

2.6. IAQ Complexity

The absence of explicit and detailed legal directives on the IAQ is mostly due to the variability, diversity and difficulty in gathering consistent analytical data for all involved factors/sources in a single pool. IAQ as a complex concept is more like to a broad spectrum of factors rather than a solitary measurement element. Likewise, there are different architecture and design variables associated with it (Figure 1). Additionally, aforementioned (section 2.2.) contradictory energy target settings among numerous parameters adds to the complexity, interlinks and versatility of IAQ, in spatial and temporal scales. To address this issue, IAQ indexes seems to be essential for explaining, categorizing and improving the quality of indoor air by processing user-friendly and extensive scoring (ranking) of IAQ levels in indoor environments. Although various IAQ indexes have been developed globally in recent years, their different relevance to IAQ level assessment has not been fully explored. A comprehensive and fast realization of IAQ by an index, will simplify the design of effective measurement, qualification and maintenance protocols in terms of control. Choosing an evaluation measure for this aim is a critical challenge as there are numerous of indexes in the scientific literature, but the distinction among health risk-based and comfort-based indexes is unclear [62].

2.7. Research Questions

In order to organize this review, a number of research questions (RQs) were defined:
RQ1: What are the different types of IAQ indexes?
RQ2: Which parameters (IAQ indicators) are employed within the literature?
RQ3: Where can specialized IAQ indexes be applied?
RQ4: What are the different design and development methods of IAQ indexes?
RQ5: What are the standard and ELV bases applied in IAQ indexes development?
By the RQ1 and RQ2, it is possible to classify different types of IAQ indexes and the employed indicators. RQ3 enables information regarding the site location and different indoor implementations. RQ4 aims the different structure and methodologies regarding the design and development of IAQ indexes. And RQ5 provides insights to the available guidelines used in IAQ domain and their threshold basis.

3. Review Methods

3.1. Research Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [63] framework applies four major tasks including identification, screening, eligibility, and inclusion. A scoping review provides a mapping process that can identify relevant areas for further enquiry in an area where there is only emerging evidence to provide clarification for key concepts and gaps. The application of the PRISMA framework allows for a transparent, logical approach that exhibits how articles were classified as included. A traditional literature review seldom provides this logical approach for the reader [14, 64]. To find most appropriate studies of any kind, an advanced deep search by Google Scholar was carried out.

3.2 Terminology

Different combination of keywords was applied to capture various literature with application of IAQ indexes and related application with indoor built environment, health and well-being, productivity, energy efficiency and HVAC systems. Table 1 presents the search terminology of current review.

Table 1. Terminology used to search the sources in the current review study.

Indoor environment and Building	Index	IAQ
Indoor environment	Index	Indoor environmental quality
Residential, dwellings, domestic, homes, houses,	Indexes	Perceived Indoor air quality
Green buildings, ZEB, NZEB	Indices	Indoor air quality
Offices, work Places	Indicator	Perceived IAQ
Museums, galleries	Rank	Indoor air
Historical heritage	Score	IAQI
Library	Scale	IAQ
Malls, stores	Range	
Subways, metro stations	Level	

3.2.1. Indoor Environmental Quality (IEQ)

IEQ is a keyword which generally explains the measurement of indoor environmental properties concerning air quality and visual, thermal and acoustic comfort [65]. There are several leading organizations with different purposes and origins that have provided definitions for IEQ, such as: ASHRAE (American not-for-profit organization), REHVA (European non-profit association), NIOSH (American federal government) and GSA (American governmental agency). All these definitions are common in considering the IAQ as one of the major sub-components of the IEQ (figure 2); with direct effects on health, well-being, comfort and work performance [66-68].

Figure 2. IEQ schematic definition (ASHRAE) and IAQ as one of its subcomponents.

3.2.2. Indoor Air Quality (IAQ)

According on the definition proposed by EPA, the IAQ is stated as “the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.” It is mentioned that a better perception and control of IAQ, enable the risk mitigation of indoor health issues. By another definition presented by ASHRAE Technical Committee (TC) 1.6, IAQ refers to the “attributes of the respirable air inside a building (indoor climate), including gaseous composition, humidity, temperature, and contaminants.” [69, 70].

3.2.3. Indoor Air Pollution (IAP)

Based on the definition proposed by British Lung Foundation (BLF), the IAP can be expressed as dust, dirt or gases in the indoor environment which can negatively affect inhabitants’ health via aspiration. IAP includes but not limited to gases (e.g., VOCs, and inorganic compounds), PMs, and biological elements [55, 71].

IAQ is an expression of air quality within buildings, and has a very strong impact on the quality of life. The common elements for assessment of IAQ are IAP, thermal conditions (T, RH, airflow), and ventilation characteristics.

3.2.4. IAQ Standards

Current IAQ standards and guidelines try to provide the advised concentration levels, indoor climate parameter values, and proper air ventilation requirements. Guidelines provide a scientific basis for legally enforceable standards. Advised pollutant concentration levels are labeled under different terms: Exposure target value (ETV), Exposure limit values (ELV), Threshold limit value (TLV), Lowest concentration of interest (LCI), Toxicity reference value (TRV), and Occupational exposure limit (OEL). In the following the definition of some common terms used in the context of air pollutant concentrations are presented.

Definitions:

- ELV are satisfactory pollutant levels in specified period of time that can also be employed as a benchmark to show whether IAQ is getting better or worse.
- An exceedance is a time interval when pollutant levels are greater than ELVs. As ELVs may be defined in respect to various averaging times, the number of exceedance days are used for a better comparison.
- An objective is the target date on which exceedances of an ELV must not be more than a certain number [72].
- A toxicity reference value (TRV) is a toxicological indicator to qualify or quantify a risk to human health by exposure [73].
- Occupational exposure limits (OELs) are directing values of chemical substances in the workplace air for assurance the health in regard with exposure [74]
- LCIs are the maximum accepted levels of pollutants limiting emissions from construction products before being utilized by end-users [75].

Hereafter, we use the "ELV" as most common term applied to describe the value limit of pollutants in references. The ELVs are defined by lower and upper concentration limits or by divided intervals (breakpoint concentrations) based on corresponding health risks. Also, it should be noted that the break point concentrations' themselves, are determined by official surveys, and health impact studies and experiments. Since, different ELV references advise different time intervals and concentration values for their measured target parameters, determining a specified measurement protocol is essential, as well. Yet, limited existing IAQ standards and guidelines, are not all the same in terms of variety of pollutants and parameters, content presentation structure, the targeted indoor space applications, and the geographical region. Moreover, several countries have developed guidelines and regulations related to the IAQ at their own national level (by the health or building sectors/organizations), while most countries are without any specific code. It should be noted that the ELV of indoor pollutants, is the most essential parameter extracted from IAQ standards and guidelines, that can be used in the design, development, and calculation of a typical IAQ index. Lack of such parameter, is the primary motivation of series of studies based on IAQ sensory assessment and survey of occupants (will be discussed in the following; Section 4.2.1)

WHO updated the Global Air Quality Guidelines (AQGs) in 2021, after 16 years [76]. Regarding the indoor air, WHO has presented the first IAQ guidelines and exposure thresholds (advisory), which have been since widely employed by other regulatory sections worldwide [9]. Also, standard NBN EN 16798-1:2019 (provided by technical committee of CEN: European Committee for Standardization) presents required indoor environmental input factors for design and assessment of energy performance of buildings, addressing the IAQ, as well as the thermal environment, lighting and acoustics. There are several remarkable studies in the literate which have partially/fully studied available air pollution guidelines and standards [47, 77-83].

3.3. Eligibility Criteria

The key criteria for the inclusion in this scoping review were scholarly literature, including but not limited to peer-reviewed journal papers, academic books, and conference papers, which were published in English, in the past two decades (2000–2021). The primary focus was on review researches of IAQ and IEQ, with addressing the challenges and IAQ indexes. After that, original single studies with presentation of various index definitions, indicators, and configurations were taken into account. Considering the former extensive research on the topic of IEQ, this review is specifically determined to extract and evaluate the studies including IAQ indexes and their application. Our inclusion criteria did not pose restrictions for region of study, sample size, time period, and methodology. Table 2. represents the reference inclusion and exclusion criteria for the current study.

Also, for 5 repeated indexes in the literature that were firstly introduced before year 2000, the primary studies were considered, as well.

Table 2. Inclusion and exclusion criteria for the present study.

Exclusion Basis	Inclusion Basis
× Studies with no details about the target index × Researches in non-English languages × Secondary studies × Duplicated results	✓ Studies with clear refer to IAQ “index” ✓ Studies with IAQ index description ✓ Studies that are published after 2000

3.4. Data Abstraction

The search of the online databases by Google Scholar, resulted in 202 correlated references that have been stored on Zotero (Zotero is an open-source reference management software to manage the bibliographic data). Forty-four review papers and 158 original studies with correlated content to IEQ and IAQ index application were categorized. Six non-English language references were removed. We excluded 42 study after reading the content as they did not meet the inclusion criteria for this study. 92 papers were classified as duplicate index application and research method. From the 62 remained papers, a comprehensive assessment was carried out in full text. After matching the content with the inclusion criteria, 8 articles were excluded further. In summary, we retained 54 papers for our scoping review, 22 presenting IAQ indexes exclusively and 32 present the indexes within the domain of IEQ. Figure 2 presents the schematic diagram and corresponding statistics of the applied PRISMA scoping framework in the present study. Figure 4 presents the worldwide distribution of the references for the current study. Moreover, Figure 5 presents the temporal distribution of the references since 2000.

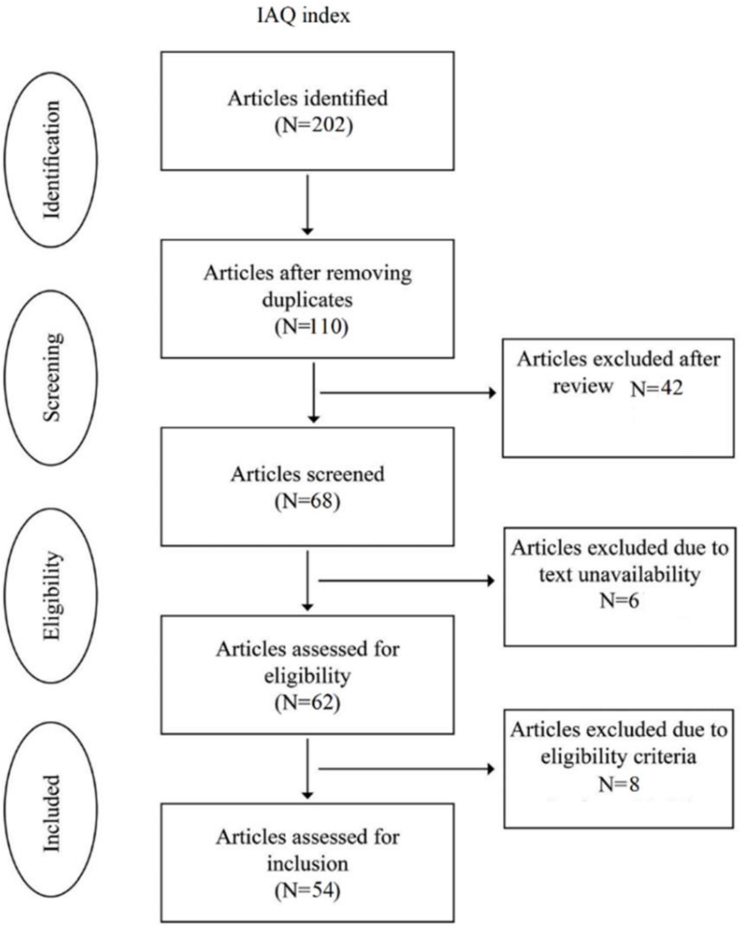


Figure 3. Schematic diagram and the corresponding statistics of the PRISMA framework.

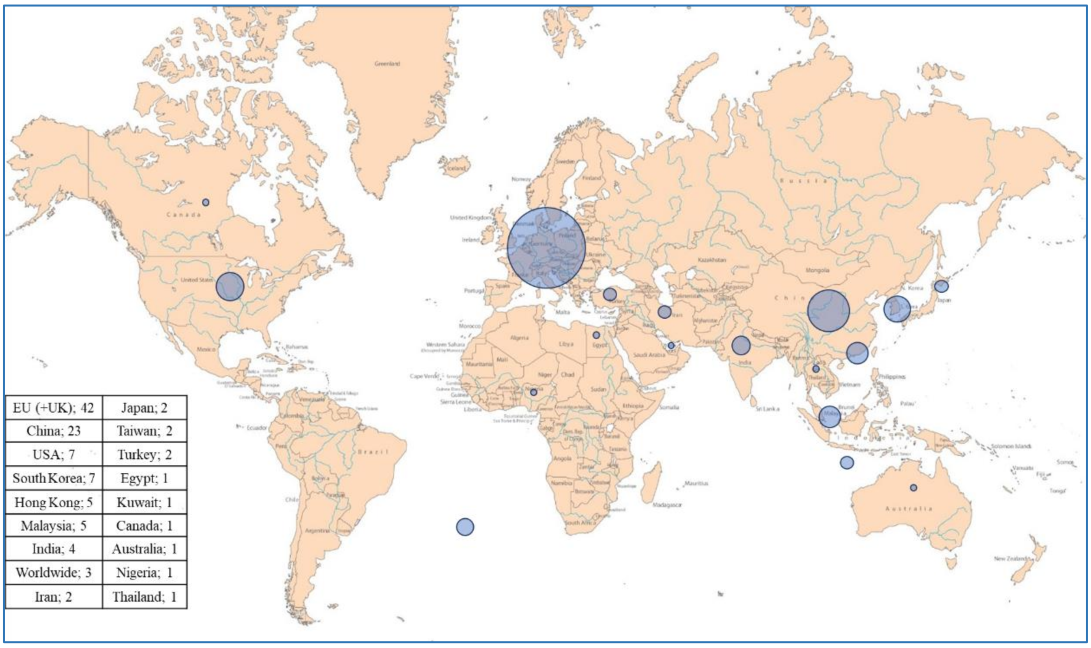


Figure 4. Worldwide distribution of the references for the present scoping study.

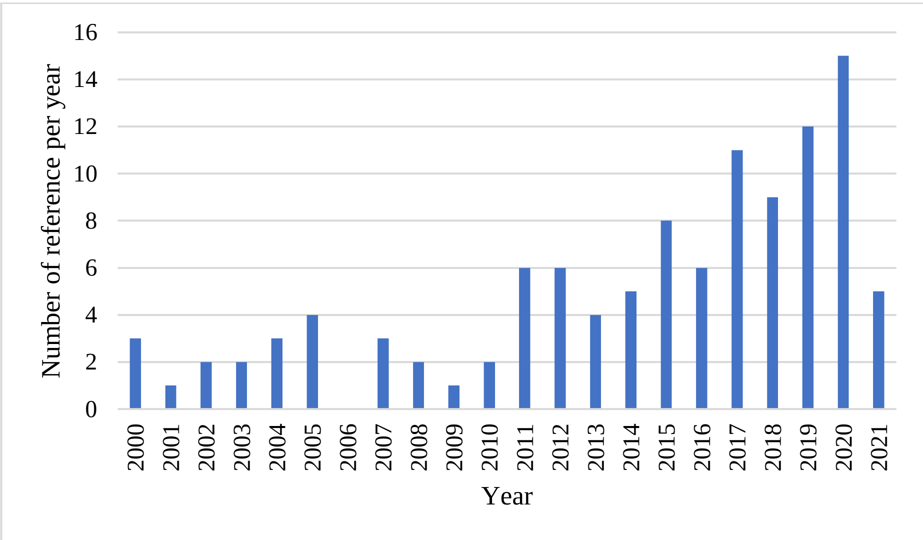


Figure 5. Temporal distribution in the references-screening stage, of the present scoping study since 2000.

4. Findings and Discussions

4.1. IAQ Target-oriented Projects

By exploring the studies and scientific papers of past twenty years in online databases, it was revealed that a number of prominent nation and global-wide projects regarding the IAQ were conducted [84, 85]. These projects aimed the investigation of IAQ in various indoor environments in different themes of health, energy, socio-economy and risk management. Table 3 presents these projects and their specifications. Figure 6 show the distribution of different IAQ evaluation parameters (IAQ indicators), at the screening stage among 110 references. Also, regarding the ventilation systems in IAQ index studies, it was revealed that 18, 57, and 35% of the references were corresponding to natural ventilation, mechanical ventilation, and unexplored ventilation state, respectively.

Table 3. Prominent nation and global-wide defined projects with the focus on the IAQ.

Year	Name	Region	Description
1992	Joule Program	EU	Audit project to optimize indoor air quality and energy consumption in office buildings.
1994	BASE	USA	Building Assessment Survey and Evaluation Study.
1995	INGA	Germany	Indoor and genetic factors in asthma and allergy.
1999	NHEXAS	USA	National Human Exposure Assessment Survey.
2001	Airless	EU	Optimize indoor air quality and energy consumption of HVAC-systems
2002	PEOPLE	EU	Population Exposure to Air Pollutants in Europe.
2002	INDEX	EU	The Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in EU.
2002	Hope	EU	Health Optimization Protocol for Energy-efficient Buildings.
2003	MACBETH	EU	Monitoring of Atmospheric Concentration of Benzene in European Towns and Homes.
2003	AIRMEX	EU	European Indoor Air Monitoring and Exposure Assessment.
2003	IAIAQ	EU	Promoting actions for healthy indoor air.
2004	SINPHONIE	EU	Schools Indoor Pollution and Health: Observatory Network in Europe.
2004	ENVIE	EU	Co-ordination Action on Indoor Air Quality and Health Effects.
2006	BUMA	EU	Prioritization of Building Materials as Indoor Pollution Sources.
2008	CLEAR-UP	EU	Exploring a comfortable and healthy indoor environment based on resource efficient technologies.
2008	HITEA	EU	Health effects of indoor pollutants: integrating microbial, Toxicological and Epidemiological Approaches.
2010	OFFICAIR	EU	Framework towards an integrated approach in evaluating the health risk from indoor air pollution, in modern office buildings.
2010	EPHECT	EU	Emission, Exposure patterns and health effects, of consumer products in the EU.
2012	HelthVent	EU	Ventilation guidelines for Europe, existing buildings, building codes, ventilation standards and ventilation in Europe.
2014	EPA 83575001	USA	Combining Measurements and Models to Predict the Impacts of Climate Change and Weatherization on Indoor Air Quality and Chronic Health Effects in U.S. Residences.
2017	ALDREN	EU	ALliance for Deep RENovation in buildings (TAIL: Thermal environment, Acoustic environment, Indoor air quality and Lighting).
2019	GerES	Germany	Analyze indoor air composition, determine reference values, Investigate the possible reasons for high pollutant concentrations and find new indoor pollutants.
2019	OCCuPANt	Belgium	Impacts of climate change on the indoor environmental and energy performance of buildings in Belgium during summer.
2020	Level(s)	EU	An approach to assess and report on the sustainability performance of buildings, throughout the full life cycle of buildings.
2020	EXPOLIS	Portugal	develop an air quality exposure sensing system, composed by a network of sensor nodes, and deploy it on public transportation (buses) to obtain the real-time air pollution distribution in urban areas.

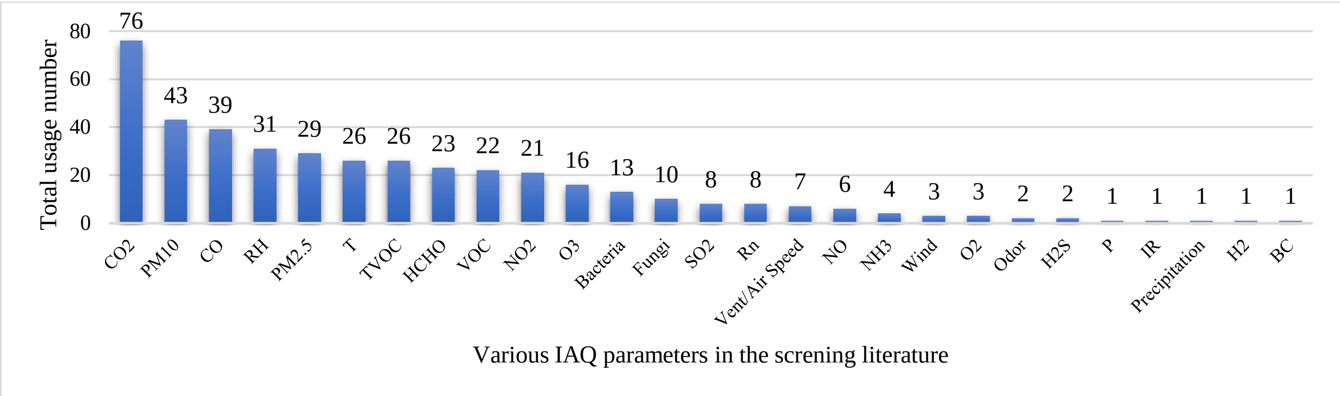


Figure 6. Distribution of different IAQ indicators among 110 studies in the screening stage of index scoping review. (BC, IR, Rn, TVOC and P, stand for Black-Carbon, Solar irradiance, Radon, Total VOC and Pressure, respectively.)

4.2. IAQ Indexes

Due to the inherent complexity of IAQ, normally it is not possible to express it by a single end result, however lots of efforts have put to boil it down in the form of an IAQ index. IAQ indexes have been proposed in the literature with different labels (e.g., indicator, index, scale, rank), solely in the context of IAQ or incorporated into the IEQ concept. Absence of a universal standard approach in order to uniformly index IAQ, probably leads to further confusion of the topic and makes it practically challenging for future research framework development, as well as the inter-study comparison. The dynamics of IAQ is observed in the entire literature as scientists try to deliver their own detailed comprehension of what forms/establishes IAQ.

4.2.1. IAQ Index Scoping (Classification)

The leading objective of this paper is to create a comprehensive scoping overview of different IAQ with different applications, for the first time. This collection and classification can also be helpful for those who focus on the quality of indoor air in different fields, such as BEMS (Building Energy Management Systems) specialists, HVAC designers, architects, indoor air monitoring device producers, indoor air purifier producers, healthcare professionals, as well as all other involved scientists and engineers.

There are couple of classification perspectives in the literature on IAQ indexes. Though, researchers unanimously agree that IAQ indexes can be structured based on both subjective and objective principals. The subjective assessment of IAQ examines the perceived feeling of occupants whether dissatisfaction or comfort, while the objective evaluation of IAQ deals with the concentration measurement of pollutants and (health risk-based) ELVs.

Two main approaches for establishing/designing IAQ indexes are the ***survey*** approach (also known as: qualitative, or comfort-based method) for subjective indexes; and the ***measurement*** approach (also known as: quantitative, or health risk method) for objective ones. We name the survey approach-based indexes "**S series**", and the measurement approach-based indexes "**M series**". The survey approach (subjective indexes) can question and assess the perceived dissatisfaction, perceived IAQ, perception of indoor comfort, building characteristics and well-being of a group of individuals in an indoor environment. According to the type of use of the interior space of a building, as well as the considered parameters in an IAQ index, the designed questionnaires can be diverse.

On the other hand, by the evolution and progress of low-cost sensors (LCSs) for monitoring IAP and indoor climate, as well as the scientific trend in the field of IAQ, the measurement approach (objective indexes) has been widely employed for the IAQ index development [86].

The measurement approach is based on ELVs. In this approach the index is addressed whether directly as a suggested concentration range, itself (M4), or as a score (rank/ratio) derived after proposed health risk assessment (M1, M2, M3). In the score (rank/ratio) method, the comparison between measured pollutants and their corresponding ELVs according to a selected standard or guideline, plays the key role.

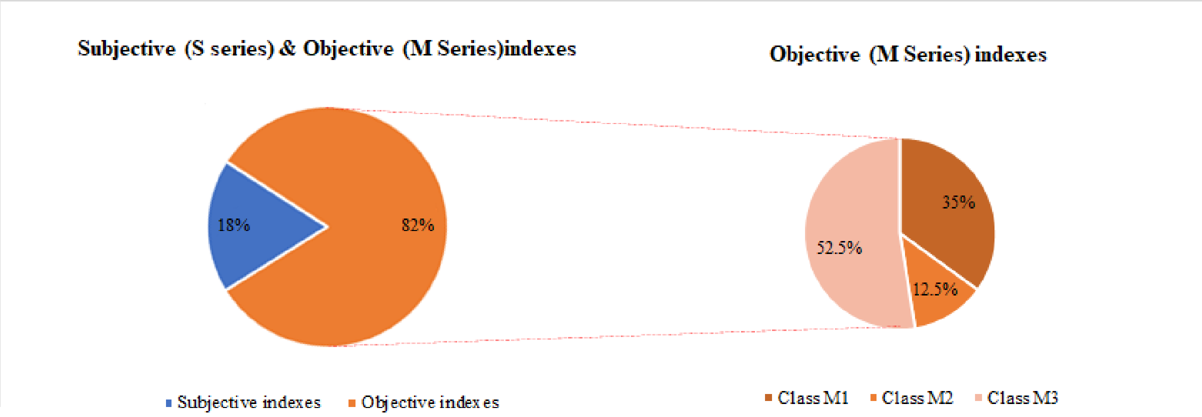
There are several ways to apply the score (rank/ratio) method:

i) M1: Another way is to involve all measuring pollutants in the formation of IAQ index by a summation/averaging function.

ii) M2: One another way is to select the pollutant with the maximum relative value regarding its reference ELV among all contaminants, and represent its corresponding score as the index result.

iii) M3: The basic method is to choose a single IAQ indicator (parameter/contaminant) as an index representative. Also, a normalization procedure can be carried out if needed.

Figure 7.a illustrates the distribution of IAQ indexes based on subjective (**Survey** / "**S series**") and objective (**Measurement** / "**M series**"), and Figure 7.b depicts the distribution of M series, separately.



a) b)

Figure 7. a) Distribution of IAQ indexes reviewed in this study based on survey/measurement (subjective/objective) classification, and b) the distribution of M series indexes.

Likewise, further averaging operation (e.g., arithmetic, logarithmic, weighted etc.) may be applied to provide an image of the mean IAQ state. Figure 8 illustrates the Scoping/Mapping diagram of IAQ indexes. Table 4, as the heart of this scoping review; presents the reviewed IAQ indexes, their corresponding scoping class, employed IAQ indicators (parameters), and available index applications (experiments' details).

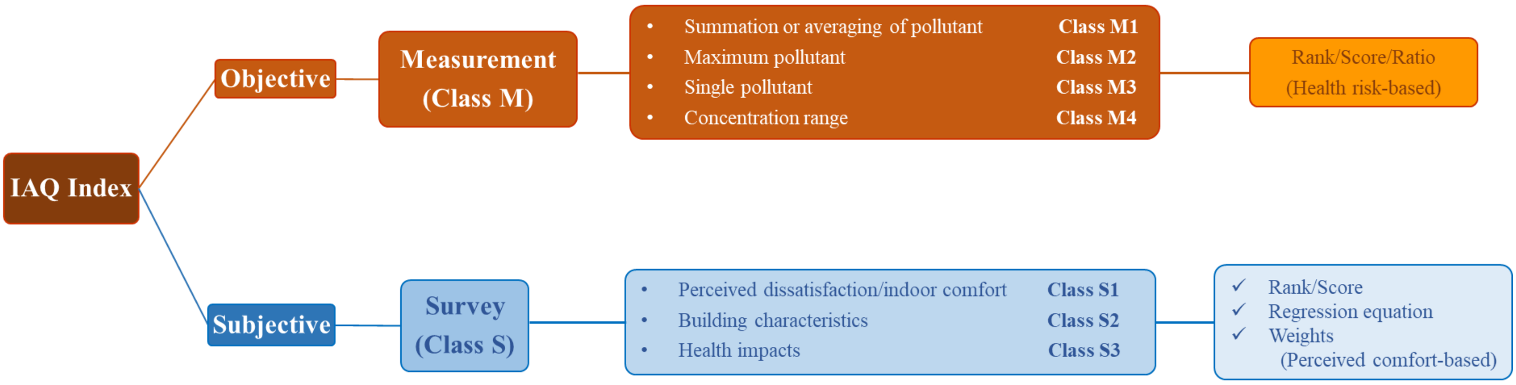


Figure 8. Scoping/Mapping diagram of IAQ indexes.

4.2.2. IAQ Index Applications

Generally, IAQ indexes make available information about the health effects of their target parameters, and how to avoid those effects. Despite the existing air quality indexes, absence of a universal metric which quantitatively defines the IAQ, is an important challenge against a) common standard IAQ management system, and b) the integration of energy and IAQ strategies in indoor environment management (with respect to HVAC applications). Such an index enables the analysis and comparison of different methods to reach high "IAQ-Energy performance". In order to characterize the "IAQ index applications" more in details in this section; we express their different purposes, indicators, time frames, and localized applications, separately.

IAQ index purposes:

IAQ indexes are tools for communicating the state of indoor air contaminants. They can easily be linked to user-friendly color-coded categories to provide statements for each sub-class. Each category represents different levels of the health-risk. Subsequently, the information about population groups at high-risk (patients with respiratory and cardiovascular disease, elderlies and infants) whom may be affected, and the guidelines to reduce exposure to indoor pollution would be easier to access and follow. The IAQ index can be employed as the basis for IAQ forecasts and online IAQ monitoring, as well.

IAQ index parameters (indicators):

As it was earlier presented in Figure 6, different IAQ indexes cover wide variety of indoor air quality indicators, commonly including indoor pollutants (chemical, physical, biological) and indoor climate parameters.

IAQ index time frames (time range):

The time range of an IAQ index depends on the averaging time of its components. Generally, the averaging time is determined by following the chosen/developed exposure guideline (standard), or it is defined based on the end-user needs (instantaneous, daily, etc.).

IAQ index localized applications:

Generally, IAQ indexes are designed/developed for specific indoor applications, such as residential dwellings (Flat, apartment, studio, etc.), institutional buildings (medical, educational or administrative use), commercial offices, subways, malls and shopping centers, heritage and sensitive objects preservation (museums, galleries), etc.
Although, a typical IAQ index could have been applied to different indoor environments, it will most probably fail to satisfy all users, since each category of inhabitants require their own personalized deliverables based on their indoor environment type.
For instance, with respect to the “key Table 4” it is realized that:

- applied IAQ indexes for highly occupied interior spaces (like classrooms in schools), focus more on CO_2 levels (as an accredited ventilation indicator [87]) and PM concentrations,
- applied IAQ indexes for residential indoor environments, focus more on indoor climate, as well as the CO, CO_2, PM and O_3 concentrations;
- and applied IAQ indexes for health care and treatment centers (hospitals, and medical centers), focus more on the indoor biological pollution levels.

On the other hand, some other indexes are utilized for exclusive applications, making them specific in their implementation or research field. Among those, the “Radon index” aiming the radioactive Rn gas, and the “DALY index” common in the field of health impact assessment, are best two examples. While some IAQ indexes are case specific, others would tend to simplify the evaluation strategy with aim of generalization. Still, more time is needed for a universal IAQ index that everyone agrees on, due to following challenges:

1. Wide range of different indoor environments with varied applications and inhabitant groups,
2. Lack of unity in IEQ and IAQ policymaker/responsible organizations (worldwide),
3. Involvement of multidisciplinary filed of expertise and diverse interests in the domain of IAQ: Energy sector, Health sector, Building sector (plan design, HVAC), etc.

One practical solution to overcome these challenges would be further cooperation among different stakeholders of IAQ/IEQ domain, to define “general cohesive IAQ guidelines” for different interior spaces, based on (at least) two crucial criteria of: a) type of building use, and b) building geographical and regional specifications.

4.3. Study Limitation

In the organization of a scoping-review study, issues with research samples and selection, and lack of previous research studies on the topic, were key limitations. Besides, lack of a universal IAQ assessment approach or standard was an additional constraint. Recently, the ongoing project IAE EBC annex 86 [140] is aimed to create a unified general assessment approach to support the development, rating and implementation of innovative and highly energy efficient IAQ management strategies.

Table 4. Scoping table of IAQ index studies.

Author, Year	Index	IAQ indicators* (Parameters)	Index application (Experiments' details)	Index Class
(Fanger 1988a&b, Piasecki & Kostyrko 2020) [88-90]	The perceived air quality is measured in decipol (dp), One dp is the perceived air quality (PAQ) in a space with a sensory load of one olf (one standard person) ventilated by 10 L/s. Percentage of dissatisfied: $PD = 395 \exp(-3.25C^{-0.25})$ for $C \leq 31.3$ dp, PD = 100% for $C > 31.3$ dp	VOCs, CO_2	Non-industrial buildings (e.g., offices, schools or dwellings), and outdoors	S1
(Dounis et al. 1996) [91]	CO_2 concentration	CO_2	IAQ of naturally ventilated buildings - An office on the second floor of a three-storey building at the National Observatory of Athens	M3
(Cohas 1996, Abadie et al. 2016) [92, 93]	$I_{BILGA} = \begin{cases} \max\left(\frac{E - VRL}{VRI - VRL}\right), if\ E > VRL \\ \max\left(\frac{E - VRL}{VRL}\right), if\ E \leq VRL \end{cases}$ E: average concentration, VRL: ELV, VRI: important risk value of a pollutant.	Any	Residential premises	M2
(Gadeau 1996, Abadie et al. 2016) [93, 94]	$I_{CLIM2000} = \frac{1}{4}\left(\frac{[CO]}{30} + \frac{[CO_2]}{4500} + \frac{[NO_2]}{0.4} + \frac{[HCHO]}{0.06}\right)$	CO, CO_2, NO_2, HCHO concentrations are expressed in (mg/m^3)	Assessment of ventilation strategies	M1
(Castanet 1998, Abadie et al. 2016) [93, 95]	$I_{LHPV} = \frac{[CO]}{5} + \frac{[CO_2]}{100} + \frac{[DTB]}{1000}$	DTB total airborne bacteria concentration (cfu/m^3), CO, CO_2,	Assessment of ventilation strategies	M1
(Shi & Tao 2000) [96]	Air Quality caused Percentage Dissatisfied index: $QPD = \exp(5.98 - \sqrt[4]{\frac{112}{C}})$, C=decipol	CO (mgm^{-3}), CO_2 (%), Bacteria number($1m^{-3}$)	5 hotels in Shanghai	S1
(Jokl 2000) [97]	$L_{odour(CO_2)} = 90 \log \frac{\rho_{iCO_2}}{485}, \Delta\rho_{CO_2} = 167350\ (\ln(PD) - 5.98)^{-4}$ $L_{odour(TVOC)} = 50 \log \frac{\rho_{iTVOC}}{50}, \Delta\rho_{TVOC} = 46000\ (\ln(PD) - 5.98)^{-4} - 10$	CO_2, TVOC	Presenting a decibel scale for CO2, TVOC. Various buildings: library, office building, offices, town hall, schools, homes and apartments	S1+S2
(Chiang et al. 2002) [98]	S= Evaluated score corresponding to the field-measured value (20,40,80,100 ELV), If $\exists i, S_{si} < 60, then\ S_x = \min(S_{xi}), else\ S_x = \frac{1}{n}\sum_{i=1}^{n} S_{xi}$. $I_{IEI_{IAQ}} = \begin{cases} \frac{1}{p}\sum_{i=1}^{p} Grade_i\ if\ all\ Grade\ i\ \geq\ 60\ (good\ IAQ) \\ min\ (Grade\ i)\ ifnot \end{cases}$	CO_2, CO, CH_2O, PM_{10}, TVOC	Set of references as the benchmarks for determining the scores. Measurements in 2 apartments	M1+M2
(Sofuoğlu & Moschandreas 2003) [99]	Indoor Air Pollution Index: $IAPI = \frac{1}{I}\sum_{i=1}^{I}\frac{1}{J}\sum_{j=1}^{J}\frac{1}{K}\sum_{k=1}^{K} 10[1 - \frac{C_{i,j,k}^{max} - C_{i,j,k}^{obs}}{C_{i,j,k}^{max} - C_{i,j,k}^{min}} (\frac{C_{i,j,k}^{dmc} - C_{i,j,k}^{obs}}{C_{i,j,k}^{dmc}})]$, The *i*, *j*, and *k* are labels for the number of pollutant variables in different 3 levels. C^{obs} is the measured concentration in the subject building, C^{max} is the maximum measured concentration, C^{min} is the minimum measured concentration, C^{dmc} is the demarcation concentration.	Fungi, bacteria, PM_{10}, $PM_{2.5}$, CO, Radon, TVOC, HCHO	The experimental data of (BASE) study [100, 101]: 13 residential buildings	M1
(Moschandreas & Sofuoglu 2004) [102]	$Indoor\ Discomfort\ Index\ IDI = \frac{1}{L}\sum_{i=1}^{L} 10 \frac{\lvert CA_{i,opt} - CA_{i,obs}\rvert}{CA_{i,ucl} - CA_{i,lcl}}$, for T, RH, L=2 C is the pollutant concentration, *opt* stands for optimum comfort agent value, *ucl* stands for upper comfort level, *lcl* stands for lower comfort level IEI = (IAPI + IDI)/2, (IAPI; [99])	TVOC, HCHO, CO2, CO, PM2.5, PM10, Fungi, Bacteria, T, RH	(BASE) study [100, 101]: 13 buildings	M1
(Fabian et al. 2005) [103]	Indoor/Outdoor ratio of total airborne particle numbers	Airborne bacteria and fungi, PM, VOC	8 single story flood-damaged houses and one non-flooded house	M3
(Cariou et al. 2005) [104]	GAPI ($Global\ Airborne\ Pollutant\ Indicator$) $= \sum_i W_i C_i$, (mean pollution)$GAPI_n = \sum_{t=1}^{n} \frac{GAPI_t}{n}$ $W_i = \sqrt[2]{X_i Y_i}; X_i = \frac{V_i}{V_{ref}}, V_i$ is the volume of molecule *i*,	VOCs	Controlling air toxicity, determining the level of pollution in the controlled	M1

	$Y_i = \frac{\sigma_i}{\sigma_{ref}}$, σ_i is the sticking coefficient of molecule *i (ref= smallest)*		environment. Experiments: glass fiber fab, and vegetable packaging plant. France	
(Wong et al. 2007) [105]	‘‘IAQ index θ’’ $\theta = \frac{1}{N}\sum_{j=1}^{N} \Phi_j^*$; $\Phi = \frac{\Phi_j - \Phi_{j,o}}{\Phi_{j,e} - \Phi_{j,o}}$ The average fractional dose to certain exposure limits of the representative pollutants *j* among all air pollutants. Φ_j^* is the fractional dose of a representative pollutant *j*, Φ_j is the average level of *j* assessed over an exposure time period, $\Phi_{j,o}$ is the background pollutant concentration of outdoor air, $\Phi_{j,e}$ is the exposure limits.	ABC (airborne bacteria count), Rn, CO, RH, PM10, CO_2, TVOC, O_3, T, V, NO_2, CH_2O	422 air-conditioned offices in Hong Kong	M1
(Kim et al. 2007) [106]	Contribution Ratio of Pollutant Sources (CRPS) $CRPS1(x,n) = C_w(x,n)/\lvert C_{w,n} \rvert$ S1 > 0: Pollutant generation ratio from floor [mg/s], S2 > 0: Pollutant generation ratio from human (mg/s), S3 < 0: Pollutant absorptive ratio by adsorptive material (mg/s) $C_w(x,n)$: Concentration at position ‘x’ due to the generation of a pollutant from pollutant source ‘n’ (mg/m^3), $C_{w,n}$: Perfect mixing concentration when pollutant source ‘n’ is the only pollutant source (mg/m^3) $$C(x) = \sum_n CPRS1(x,n) \times C_{w,n} = \sum_n CPRS1(x,n) \times \frac{q_n}{Q_s}$$ $C(x)$: Concentration caused by all pollutant sources at position ‘x’ in the room (mg/m^3), q_n: Pollutant flux of source ‘n’ (mg/s), Q_s: Air volume of ventilation system (m^3/s) $$CRPS2(x,n) = \frac{C_w(x,n)}{C_t}$$ C_t: Perfect mixing concentration of pollutants generated/adsorbed from all pollutant sources (mg/m^3), $CRPS3(x,n) = \frac{C_w(x,n)}{C_x} = \frac{C_w(x,n)}{\sum_m C_w(x,m)}$, C_x is the same as $C(x)$	Air pollutants (Particles that have buoyancy are inadmissible in the scheme)	The contribution ratio distribution of each pollutant in the room air-conditioned by the displacement ventilation system was analyzed using CFD.	M3
(Wang et al. 2008) [107]	IAIQ $Q = \frac{(P_i - P_o)}{Q_i - Q_o} \times (C - Q_o) + P_o$ (for each pollutant) Implementation of AQI, developed by EPA [108], for indoor purposes. Q is the IAQI value of indoor air pollutant, C is the on-site concentration of indoor air pollutant, Q_i is greater than or equal to the on-site boundary value of air pollutant concentration corresponded with IAQI value, Qo is smaller than or equal to on-site boundary value of air pollutant concentration corresponded with IAQI value, Pi is greater than or equal to boundary value of IAQI value corresponded with on-site air pollutant concentration, Po is smaller than or equal to boundary value of IAQI value corresponded with on-site air pollutant concentration.	HCHO, CO, CO_2, NO_2, SO_2, PM_{10}, $PM_{2.5}$, bacteria, fungi, TVOC, O_3	30 IAQI results for various building types in Taipei Metropolitan Area: 5 hospitals 7 kindergartens 3 exhibition halls 3 shopping malls 2 hotels 8 office buildings 2 libraries	M2
(Zheng et al. 2011) [109]	Health Performance Evaluation (HPE) model of IAQ: The health effect score for IAQ: $Q = \sum_{i=1}^{n} M_{EC_i} W_{EC_i}$, EC_ievaluation category, M_{EC_i} the score of the evaluation category, W_{EC_i} the weight for each category $M_{EC_i} = \sum_{i=1}^{n} M_{EF_i} W_{EF_i}$, EF_i the evaluation factor, M_{EF_i} the score assigned to measured pollutant concentration, W_{EF_i} the weight calculated for each pollutant $k_i = \frac{100}{\ln \frac{Max\, S_i}{S_{oi}}}$, $p_i = k_i ln \frac{S_i}{S_{oi}}$; *k* constant factor, S_i measured concentration of a pollutant, p_i evaluation score: [0–100]	CO, CO_2, NO_2, SO_2, TSP, VOCs, Formaldehyde, Aldehyde, Virus, Fungus (Inorganic, organic, bio)	Emphasis on apartment buildings	S3
(Ribéron et al. 2011) [110]	Air stuffiness index (ICONE) = $\left(\frac{2.5}{\log(2)}\right)\log(1 + f_1 + f_2)$ $f_1 = {n_1}/{n_0 + n_1 + n_2}$ proportion of CO_2 values between 1000 and 1700 ppm $f_2 = {n_2}/{n_0 + n_1 + n_2}$ proportion of CO_2 values above 1700 ppm n_0 Between 0 and 1700 ppm, n_1 Between 1000 and 1700 ppm, n_2 Greater than 1700 ppm	CO_2	7 nursery and 10 elementary schools, France	M3
(Logue et al. 2012) [111]	$DALY_{disease} = YLL_{disease} + YLD_{disease}$	$PM_{2.5}$, acrolein, formaldehyde, secondhand tobacco smoke, and radon	Quantify and compare health impacts from IAP. For residents in U.S. households.	S3

(Boulanger et al. 2012) [112]	$I_{QAI} = \sum_{P=1}^{Np} \frac{C_p}{C_{lim,p}}$	- CO_2 alone, as a marker of confinement linked to occupation, - NO_2, SO_2 (housing) and O_3 (offices) linked to the activity of the occupants, - CO and 7 VOCs (HCHO, Acetaldehyde, Ethylbenzene, Styrene, Toluene, o-Xylene, Acetone) related to materials, activities and behavior, - $PM_{2.5}$ and PM_{10} related in particular to activities.	Different zones of a dwelling, office, classroom, etc.	M1
(Sarbu & Sebarchievici 2013) [113]	The olfactory pollution degree of a room: $C_i = C_p + 10\frac{G}{L_p}$ C_i is the indoor air quality, in decipol (dp), C_p is the outdoor air quality in dp, G is the contaminant concentration of the room air in olf, L_p is the outside airflow rate, in l/s. $S=kC\beta$ S is odorant intensity (magnitude); C is the odorant concentration in ppm, β is the exponent (0.2–0.7) of psychophysical function, k is the constant characteristic of material. (Fanger)PPD = 395 exp $(-3.66L_p^{0.36})$, for $L_p \geq 0.332$ l/s, PPD = 100, for $L_p < 0.332$ l/s	CO_2, odor	Natural ventilated classroom	S1
(Pereira et al. 2014) [114]	PD (%) = 395 exp $(-15.15 * C_{CO_2}^{-0.25})$	T, RH, CO_2, average clothing insulation value (clo)	2 classrooms, for 2 weeks from the end of April until mid-May	S1
(Zhou & Wang 2014) [115]	Decibel concept index (DB index) $\sum L = L_{odour(CO_2)} + L_{odour(TVOC)} + L_{odour(HCHO)}$ $L_{odourCO2} = 90 \text{ Log } \frac{C_{CO2}}{485}$, $L_{odourTVOC} = 50 \text{ Log } \frac{C_{TVOC}}{50}$, $L_{odourHCHO} = 67 \text{ Log } \frac{C_{HCHO}}{50}$	Main: CO_2, TVOC T, RH, P, CO, CO2, O_3, HCHO, PM_{10}, VOC	4 Office Buildings Nov 2010 to Sep2011 in Lingui	S1
(Balocco et al. 2014) [116]	Air change efficiency (ACE) = $\frac{V_{TV}/\dot{V}_{vent}}{\tau_{z_j}} \times 100$, V_{TV} is the total volume of the room, $\dot{V}_{vent}$ is the mass flow rate of incoming ventilating air, τ_{z_j} is the average value of "*mean age of air"* in different zones, Local Air Change Efficiency (LACE) = $\frac{V_{TV}/\dot{V}_{vent}}{\tau} \times 100$, τ is the is the *mean age of air*, Ventilation Effectiveness (VE) = $\frac{C_E - C_S}{C_{z_j} - C_S}$, C_E is the concentration of contaminants at the exhaust point, C_{z_j} is the and the mean value of contaminant concentration within a specific zone, C_S is the contaminant concentration at the air inlet Contaminant Removal Effectiveness (CRE) = $\frac{C_E}{C_{z_j}}$.	CO_2, PM	2 days 8:00-14:00 orthopaedic Operating Theatre of the University Hospital of Parma (Italy)	M3
(Heidarinejad et al. 2015) [117]	Mean local age of air $A_j(\tau)$: The average lifetime of the air at a particular location in the room relative to the time when it first entered the room: $A_j(\tau) = \frac{C_j(\tau)}{\int_0^\infty C_j(\tau)d\tau}$, C is the concentration, and τ is the time [118].	Mean local age of air	Numerical simulations of a 42.7m^3 room, with an under-floor air distribution	M3
(Mainka & Zajusz-Zubek 2015) [119]	$PMIAQ_{index} = \frac{PM\ concentration}{WHO\ guidelines}$ CO_2 IAQ_{index} = 1 + "IDA4 contribution" "IDA4 contribution": Increase of relative CO_2 concentration (ΔCO_2, ppm) >1000ppm Total $IAQ_{index} = \frac{\sum IAQ_{index}}{n}$	PM_1, $PM_{2.5}$, PM_{10} and TSP (Total Suspended Particulate)	8 classrooms 9 Dec 2013-14 March 2014 4 day per week, 7:30 – 15:30 Poland	M1
(Li et al. 2016) [120]	$PMV_{IAQ} = \text{Max}(PMV_{CO2}, PMV_{RSP}, PMV_{HCHO})$ $PMV_{CO2} = 3.183 \text{ Log } \frac{X_{CO2}}{485}$, $PMV_{HCHO} = 2 \text{ Log } \frac{X_{HCHO}}{0.01}$, $PMV_{PM10} = 2.096 \text{ Log } \frac{X_{PM10}}{0.02}$	CO_2, HCHO, PM_{10}	Field controlled survey of 91 office occupants (subjects) was carried out in a real office building, China, April-May 2014	S1
(Wang et al. 2016) [121]	$0 < NC - TZ = C_t = \frac{C_s - C_a}{C_s - \bar{C}} < 1$ C_s is the contaminant concentration at the source (kg/m^3), C_a is the mean contaminant concentration in the target zone (kg/m^3), and C is the mean contaminant concentration of the whole room (kg/m^3). The range of C_a is C to C_s.	Any contaminant	Industrial buildings, experimental data from Ojima (2002)	M3
(Javid et al. 2016) [122]	Fuzzy-Based Indoor Air Quality Index (FIAQI)	$PM_{2.5}$, O_3, SO_2, PM_{10}, CO, NO2, Formaldehyde, Nicotine, Xylene, BαP,	Virtually generated data for the indoor environments	S3

	The labeling of the final FIAQI values and the concentration breakpoints used for classifying each pollutant were done, on the basis of the USEPA AQI methodology.	Benzene, Toluene, Fungi, Bacteria, Endotoxin, BTEX group		
(Leyva, et al. 2016) [123]	The IAQ-index (range) based on existing standards (Thomson and ASHRAE), and is visualized using color codes.	T, RH	A Chapel located in Antwerp (Belgium). Jan 1- Dec 31 2012 every 15 minutes 35136 data points	M4
(Rojas, et al. 2016) [124]	$Integral\ evaluation\ method I_i = \frac{\int_0^T (C_i(t) - ELV_{lower})dt}{ELV_{upper} - ELV_{lower}}$ Where $C_i(t)$ is the concentration of pollutant *i*, ELV_{lower} and ELV_{upper} are the lower and upper exposure limit values, *t* is the time and *T* is the occupancy period.	CO_2, TVOC and RH	A typical Austrian residential living is modeled in CONTAM	M3
(Koufi et al. 2017) [125]	$I_{IAQ} = \frac{\bar{C} - C_{out}}{C_{Th} - C_{out}}$ Average concentration in the interior ($\bar{C}$), the concentration of extracted air (C_{out}), the concentration "threshold" (C_{Th}).	CO_2	CFD simulation of a ventilated room.	M3
(Salamone et al. 2017) [126]	Indoor–outdoor difference in CO_2 concentration	CO_2, external temperature, solar radiation (8 a.m.- 9 p.m.), wind speed, rain	Two weeks, a 42m^2 office, Italy	M3
(Sidhu et al. 2017) [127]	$PM_{2.5}$ exposure index: $E_i = \sum_i^I \frac{C_i t_{ki}}{C_g t_a}$ C_i $PM_{2.5}$ concentration in micro-environnement *k*, t_{ki} aggregate time that person *k* spends in microenvironment *i*, I different microenvironments, C_g $PM_{2.5}$ guideline value (25 µg/m^3), t_a is the aggregate time (24 h).	$PM_{2.5}$, CO, T, RH	60 Rural kitchens	M3
(Piasecki et al. 2017) [128]	IAQ_{index} = (100 - $PD_{IAQ(CO2)}$); $PD_{IAQ(CO2)}$=395 . exp (-15.15 $C_{CO2}^{-0.25}$), $PD_{IAQ(CO2)}$ = 407 . exp (-15.05 $C_{CO2}^{-0.25}$) $IAQ_{(OI)index}$ = (100 - $PD_{IAQ(OI)}$); $PD_{IAQ(OI)} = \frac{1}{1+\frac{1}{\exp(2.14\,.OI-3.81)}}$, OI: Odour Intensity When the indoor environment is hot and humid (value of air enthalpy *h*>55 kJ/kg), an IEQ sub-component of $IAQ_{(h)index}$ is introduced in addition to the sub-component $IAQ_{(CO2)index}$. $IAQ_{(h)index}$ = (100- $PD_{IAQ(h)}$), $PD_{IAQ(h)} = \frac{100}{1+\exp(-3.58+0.18(30-t_a)+0.14(42.5-0.01p_v))}$, Where t_a is the air temperature within the tested range from 20 to 29°C and p_v is the partial pressure of water vapour within the tested range from 1000 to 3000 Pa.	Odour, RH, CO_2	The OFFICAIR Study' (2016) 167 office buildings Oct 2011 - May 2012.	S1
(Gugliermetti & Astiaso Garcia 2018) [129]	$Air\ Quality\ Index\ (AQI)$=$(1 - \frac{\sum_{i=0}^N \alpha_i \times C_{gas}}{N}) \times 100$, $\alpha_i = \frac{C_{i,limit}}{C_{max}}$ Where $C_{i,limit}$ is the regulatory limit concentration for the *i*th substance, C_{max} is the higher regulatory limit concentration among the analyzed gases, α_i is the weight coefficient for the *i*th substance.	H_2S, CO	Cylindrical test chamber	M1
(Chen et al. 2018) [130]	DALY index and the $PWE_{p,y,h,f} = \frac{1}{P_{p,y}} \sum_j (EXP_{j,f,h}. P_{p,y,j})$ Population-weighted annual mean exposure to $PM_{2.5}$ (PWE): Where $P_{p,y,j}$ is the size of subpopulation *j* in the province (or county) *p* and year *y*. $EXP_{j,f,h} = \sum_k (t_{j,k,h}. c_{f,k,h})$ $EXP_{j,f,h}$ is the daily exposure of subpopulation *j* using fuel *f* for heating or non-heating season, $t_{j,k,h}$ is the proportion of time a subpopulation *j* spent in microenvironment *k* in a heating or non-heating season (*h*), $c_{f,k,h}$ is the area concentration of $PM_{2.5}$ in microenvironment *k* in a heating or non-heating season *h* in a household using fuel type *f*.	$PM_{2.5}$	A meta-analysis of 27 field measurement studies in rural China.	M3
(Guyot et al. 2018) [131]	(Dutch standard NEN 8088) Cumulative CO_2 exposure index requirement per person $LKI_{1200} = \sum_{t=0}^T \left(\frac{C_{CO2>1200}(t) - 1200}{1000}\right).t < 30\ kppmh$ Where C CO2 > 1200 (t) is the absolute concentration at which an occupant is exposed at *t* time-step, if it is higher than 1200 ppm, or 800 ppm above the outdoor concentration. $\acute{E}_{950} = \sum_{t=0}^{T} (C_{CO2>950}(t) - 950) * t$	CO_2	Review of 38 studies	M3
(Zhang et al. 2019) [132]	$P_i = \frac{C_i}{S}$ Where P_i was the pollution index for the *i*th source location, C_i is the value of pollutant concentration for the *i*th source location, and S is the standard for indoor air quality.	HCHO, $PM_{2.5}$	2 CFD models (Chen model: up-inlet and down-outlet, & Posner model: up-inlet and up-outlet)	M3

	$P=\sqrt{\frac{(P_{mean})^2+P_{max}^2}{2}}$			
(Cony Renaud-Salis et al. 2019) [133]	$I_{URL-IAQ}=\max\left(\frac{10(C_{ind,i}-IAGV_{LT,i}}{IAGV_{ST,i}-IAGV_{LT,i}}\right)$	formaldehyde, acetaldehyde, acrolein, benzene, trichloroethylene, toluene, tetrachloroethylene, styrene, o-xylene, PM_{10}, $PM_{2.5}$, CO	OQAI (French Indoor Air Quality Observatory) dataset of 567 housings	M2
(Piasecki & Kostyrko 2020) [90]	$\sum IAQ_{index}=\sum WP_i\,.\,(IAQP_i)_{index}$, $\Delta c_j=c_j-c_{ref}$, $W_{P,j}=\frac{\Delta c_j}{\sum_j 1\ldots 7\Delta c_{j\ldots 7}}$ Δc_j is a concentration difference between the measured air concentration of pollutant c_j, and the recommended reference concentration c_{ref}. $\sum IAQ_{quality}$ = (CO_2, TVOC, HCHO) $\sum IAQ_{comfort}$ = ($VOC_{odorous}$, CO_2, TVOC, HCHO, h) $\sum IAQ_{comfort/health}$ = ($VOC_{odorous}$, $VOC_{non\text{-}odorous}$, CO_2, TVOC, HCHO, h, $PM_{2.5}$, PM_{10}, O_3, NO_2)	$VOC_{odorous}$, $VOC_{non\text{-}odorous}$, CO_2, TVOC, HCHO, h, $PM_{2.5}$, PM_{10}, O_3, NO_2	Concentration tests in representative groups of UK, Danish and Polish building tests.	M1 S1
(Ha et al. 2020) [134]	IAQI= EPA-USA (breakpoints higher and less than C_p) Enhanced Indoor Air Quality Index EIAQI: (W_h×h) + (W_{IAQI}×IAQI) Where W_h and W_{IAQI} are respectively the humidex and IAQI weighting factors ranging from -2 to 3, h is the humidex. Humidex: $h=T+\frac{5}{9}+(6.112\times 10^{7.5\times\frac{T}{273.7+T}}\times\frac{RH}{100}-10)$	CO, CO_2, H_2, NH_3, C_2H_6O, H_2S, C_7H_8, O_2, RH	An office building	M3
(Florică et al. 2020) [135]	Radon Potential: $RP=\frac{\sqrt[3]{Radon\ Concentration\ in\ Soil}-1}{-\log(Soil\ Permeability)-10}$ If RP<10, then RI (Radon Index) is *low*, if 10 ≤RP<35, then RI is *medium*, if 35≤RP, the RI is *high*.	Radon, CO_2, RH, T, VOC	100 houses 2×6 months campaign	M3
(Zhang et al. 2021) [136]	$I=\sqrt{I_{max}\times I_{av}}=\sqrt{max\left[\frac{C_1}{S_1},\frac{C_2}{S_2},\ldots\frac{C_k}{S_k}\right]*\left[\frac{1}{k}\sum_{i=1}^{k}\frac{C_i}{S_i}\right]}$, S_i standard concentration limit, C_i measured pollutant concentration value	Formaldehyde, PM_{10}, CO_2, TVOC, CO	9 Underground shopping malls, electronic cities, snack cities (each 3) in in Xi'an December 10 to 25,2013, June 15 to 27, 2014	M3
(Wargocki et al. 2021) [83]	Interim rating = $\frac{\sum_1^k R_k*O_k}{n}$, *R*= 1, 2, 3, 4 O_k is the number of measurements for the specific quality level *k*, *n* is the total number of observations, [1, 1.4] = I, [1.5, 2.4] = II, [2.5, 3.4] = III, [3.5, 4] = IV For the IEQ => the worst color is selected	Ventilation rate, RH, CO_2, benzene, formaldehyde, $PM_{2.5}$, Rn, visible mold	April 2019 and March 2020 6 offices 5 hotels	M1
(Sun et al. 2022) [137]	3 indexes were employed to develop a new indicator for di(2-ethylhexyl) phthalate (recommended value) 1.a. $I=\sqrt{(\max\frac{C_i}{C_{oi}})(\frac{1}{n}\sum\frac{C_i}{C_{oi}})}$ (index approach) 1.b. $I=\sum_{i=1}^{n}w_i\frac{C_i}{C_{oi}}$ (weighted index) 2. $L=k\log\frac{n}{n_0}$ (Grey relation approach (Weber-Fechner Law/ Decibel)) 3. $w_i=\frac{(\prod_{j=1}^{n}b_{ij})^{\frac{1}{n}}}{\sum_{i=1}^{n}(\prod_{j=1}^{n}b_{ij})_i^{\frac{1}{n}}}$ (Weight coefficient)	CO_2, $PM_{2.5}$, PM_{10}, formaldehyde, airborne fungi, and TVOC	Field measurements in 454 residential buildings in Shanghai, April 2013 to May 2014.	1.a. M2 1.b. M1 2. M3 3. S1
(Kakoulli et al. 2022) [138]	l_i = result of AQI (developed by EPA (Plaia & Ruggieri 2011)) for contaminant *n* $L=\lVert l\rVert_p=(\sum_{i=1}^{n}\lvert l_i\rvert^p)^{1/p}$, $p=2$ RESET Air Index $I=\begin{cases}L\le 100, & \frac{100-L}{L}\\ L>100, & 0\end{cases}$, *I* is displayed as a percent, [139].	CO_2, $PM_{2.5}$, and TVOC	indoor environments	M1

*** This column presents all the IAQ indicators studied in each reference, and not necessarily all of them are used in the definition of corresponding indexes.**

5. Conclusion

This work is based on the scoping and classification of IAQ indexes. The analysis of the 110 articles gathered via a structured scoping review (PRISMA-ScR) focusing on IAQ indexes, their definitions and applications, showed that there is a global rising research interest in this area. 45 indexes found in the literature were categorized in respect to subjective and objective basis, as well as the calculation process and their localized application. Also, a comparison was made based on the publish year and region of index studies, as well as the utilized parameters, and their available application details. Considering the fact that, only a partial group of indoor pollutants can be commonly measured (technical limitation in measuring all indoor pollutants); and following the logic that is not possible to subjectivize all indoor pollutions with occupants' perceived comfort (human biological limit in sensing/linking pollution episodes by his/her cognition or perception); objective indexes have almost overtaken subjective ones at the present time. However, a global agreement has not yet achieved on which index is the best to apply.

This scoping review has examined the variations of IAQ indexes documented in a broad range of laboratory and field studies. In general, the reviewed studies demonstrate that poor IAQ is associated with increased health risks and decreased productivity and well-being. Inconsistency and uncertainties have been detected in IAQ index application, mainly due to:

1. Different evaluation methods of health risks and well-being,
2. Different ELV of the investigated IAQ parameters in research plans,
3. Ignored complex or arbitrator elements. (Other parameters associated with IAQ, building, and occupants could potentially contribute as well as contaminant concentration levels, temperature and RH.)
4. And most important, lack of a comprehensive unique worldwide standard/guideline for IAQ and ELVs for different indoor environments.

Monitoring the IAQ provides useful information regarding changing trends of IAP and indoor climate. These evidences can help future management for improved indoor environments. Analyzing temporal evolutions of the IAQ index is an essential prerequisite to detect trends of IAQ versus other influential elements. This can also help to draw a clear detailed image of high health-risk/discomfort episodes, in order to detect poor/bad IAQ in a more intensive way. Practically, a well-planned IAQ index plays a double role of: a) a decision-making support tool for adaptation of the indoor environment to maintain certain preservation conditions despite pollution peaks, and b) an efficiency measure for assessment of mitigation plans. However, there are a number of challenges regarding practical IAQ studies such as absence of appropriate utilities and equipment, integrated data network, and a unified control management unit. Moreover, the need for a simple, user-friendly and intensive expression of IAQ levels, always seems to be crucial. By applying a correct index, this need can be answered in a targeted manner. Using such an index, one can take best decision according to the instructions and advices by guidelines for mitigation and adaptation. Among various classified IAQ indexes in this review, 18% were subjective and 82% were objective indexes. The M3 type index (objective index based on single pollutant) is the most employed index type in the studies to date.

Making a comprehensive assessment of the interactive impact of factors such as contaminant concentration levels, temperature and RH, in indoor environments is limited. Whether and how these parameters will contribute to overall IAQ sensation remains unknown. The CO_2 and PM_{10} are the two most commonly used parameters for IAQ assessment, however, the IEQ including thermal, lighting, acoustic, and an *integrated IAQ*, should be the subject of future research. It is important to identify the most influential factors that affect IAQ inside a building. Also, gender, age, health conditions, and other related factors may have an impact on the perceived IAQ.

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Conflict of interest

The authors declare no conflict of interest.

Authors contribution

Mohsen Pourkiaei contributed to conceptuality, study framework, collecting data, literature analysis, validation, original draft and editing. Anne-Claude Romain involved in conceptualization, resources, supervision, project administration, review and editing.

Academic Links

Mohsen Pourkiaei https://scholar.google.com/citations?user=0KW5Tu4AAAAJ&hl=en
Anne-Claude Romain https://orcid.org/0000-0002-7371-9580
https://www.researchgate.net/profile/A-Romain

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