

Article

Development of a Qualitative Questionnaire for Indoor Air Quality Monitoring: A Scoping Review of Subjective Assessments in Studies Using Low-Cost Sensors

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Abstract

Background: Individuals spend most of their time indoors, yet the influence of indoor environmental characteristics on cognitive, emotional, and physical health is often underestimated. Indoor Air Quality (IAQ) plays a critical role in preventing discomfort and health issues such as Sick Building Syndrome (SBS). This study proposes a methodological framework integrating quantitative data from low-cost sensors with qualitative assessments of user perception, enabling a comprehensive evaluation of IAQ and its impacts. **Methods:** To develop a qualitative questionnaire, a Scoping Review was conducted with Scopus, since the aim was to identify questionnaire components from previous studies rather than to synthesize intervention effects, as in a systematic review. Keywords related to IAQ, user perception, wellbeing, and pollutant monitoring in living and working environments were applied. Starting from 281 initial documents, only 35 were selected because they reported relevant surveys or questionnaires within the scope of the analysis. **Results:** Across the 35 included studies on living and working spaces, the most frequently reported questionnaire items were grouped into five thematic domains—demographic factors, health symptoms, user perceptions, building and occupancy conditions, and monitored pollutants—to support the development of the qualitative questionnaire. These five domains supported the development of the proposed qualitative questionnaire but are also readily scalable to living spaces. **Conclusions:** Based on these findings, a team designed a structured questionnaire covering lifestyle, demographics, workplace conditions, perceived air quality, and related symptoms. This tool supports parallel analyses of qualitative and quantitative data. The proposed framework fosters multidimensional interpretation and may inform design, management, and AI-driven approaches for improving IAQ assessment across diverse contexts.

Keywords: indoor air quality; working and living spaces; scoping review; questionnaire; occupant perception; low-cost sensors; indoor environmental quality



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1. Introduction

Nowadays, individuals spend nearly 90% of their time indoors [1], making the quality and comfort of these environments critical to well-being and health. Architects, engineers, and other professionals involved in design, construction, and facility management

therefore hold a key responsibility: ensuring that buildings operate efficiently and do not compromise occupant health, yet awareness of this responsibility varies considerably across the profession. While construction is a continuous process, it must prioritize safety and functionality throughout the entire building lifecycle.

Extensive research demonstrates a strong link between the built environment and physical and mental health. This evidence has led to the concept of Indoor Environmental Quality (IEQ), defined as the overall quality of an enclosed space in relation to occupant well-being and commonly discussed in terms of four dimensions: indoor air quality, thermal comfort, visual comfort, and acoustic comfort [2]. As this review focuses specifically on indoor air quality, the remaining IEQ dimensions are not discussed further.

This paper focuses on IAQ and its role in shaping the health and comfort of those who spend prolonged periods indoors. The topic holds strategic importance, as the European Union has invested extensively in initiatives aimed at improving IAQ. The authors of this paper developed a methodology for an integrated qualitative and quantitative analysis of IAQ in working spaces, supported by a qualitative questionnaire on users' perception and well-being and low-cost sensors for monitoring indoor environmental parameters (carbon dioxide, temperature, relative humidity, volatile organic compounds, etc.) as quantitative data [3]. In particular, the paper describes the development of the qualitative questionnaire related to IAQ based on a scoping review.

1.1. Brief Information About the Monitoring Activity Conducted and Scope of the Paper

Starting from the application of some low-cost sensors in an Italian university campus, a research team developed a methodology aimed at collecting useful data and giving rise to management strategies for guaranteeing healthy working spaces. For this reason, the multidisciplinary team carried out a qualitative analysis of users' perceptions in working settings, using 10 department offices of this university (Politecnico di Milano in Milan, Italy). This analysis aimed at combining qualitative data (a questionnaire filled out by users in the selected offices) with quantitative data, collected directly by the air quality sensors that had been deployed in the investigated indoor environments since September 2023.

The integrated analysis of qualitative and quantitative data allows the correlation of users' perception with technical sensor data [3]. For the quantitative analysis, the team adopted a method that considers the location of the sensors in different types of settings with various solar exposures, ventilation systems, human occupancy, and type of activity, etc., with the aim of testing seasonal trends. The qualitative data, in turn, captures a range of information on the user's perceived comfort and symptoms (headache, fatigue, etc.). The data analysis highlights how the different users' perceptions affect the conditions of the monitored rooms, in particular in crowded rooms (four to six people in a room within 20 to 30 sqm). Adaptive lifestyles, such as living and working with door and window openings, regular air changes, etc., can markedly affect occupants' performance and productivity, as well as the quality of the spaces [4,5].

Therefore, referring to a preliminary analysis on IAQ monitoring with low-cost sensors and the users' perception in the ABC Dept. of the university [3], the authors developed a Scoping Review (SR) aimed at investigating previous research activities by scholars who developed and tested qualitative and quantitative analyses regarding IAQ [3,6]. In particular, the main aim is to determine how the outcomes of the scoping review can inform the development of a questionnaire for evaluating perceived IAQ perception, symptoms, etc., to be compared with the quantitative data coming from low-cost sensors. Although the monitoring activities by colleagues of Politecnico di Milano have already been established for working spaces, the scope of the paper is the development of a questionnaire that can

be used in different contexts (living spaces, healthcare settings, educational spaces, etc.) and with different methodologies, to be shared with the scientific community.

1.2. Knowledge of Indoor Air Quality

IAQ refers to the quality of the air within and around buildings, particularly as it relates to the health and comfort of building occupants, as defined by the United States Environmental Protection Agency (USEPA) [7]. Inadequate IAQ can affect occupants' health and cognitive performance, including the ability to concentrate, and can contribute to increased fatigue and reduced work or study performance [8], and it can also affect the overall quality of living spaces.

A complete evaluation of air quality within a confined space involves two aspects: the range of pollutants present, including physical, chemical, and biological types, and the indoor microclimate, discussed below.

In parallel, the indoor microclimate refers to features of indoor environments such as ventilation, temperature and humidity, etc., which combine with pollutant levels to determine the level of comfort for the occupants [9]. The Italian Ministry of Health defines the microclimate as *“the set of environmental parameters such as temperature, relative humidity and air speed, which condition the heat exchange between the individual and the environment”* [10]. Thermal comfort (the relationship between occupants and the enclosed environment that generates an adequate state of well-being) is therefore closely related to, but conceptually distinct from, indoor air pollution.

Buildings, however, do not completely protect their occupants from air pollution. Enclosed spaces can allow bacteria and molds to grow, and pollutants to accumulate at even higher levels than outdoors. These problems can lead the occupants to feel a variety of symptoms that can then lead to actual illnesses [1]. In particular, Coppola stated that the pathologies that are directly associated with exposure to pollutants in enclosed environments [9] are divided into two major types: Sick Building Syndrome (SBS) and Building-Related Illness (BRI) [11,12].

Having outlined the pathologies that can develop from poorly controlled IAQ, it is necessary to study the most common pollutants and air contaminants associated with these illnesses. Understanding how they work and how they can be controlled can significantly help with SBS and IAQ in general. Hansen states that these pollutants can be divided into two major groups [1]:

- Particles (solids and liquid): Respirable particles as a group (e.g., PM₁₀ and PM_{2.5}, with an aerodynamic diameter of 10 µm or less), tobacco smoke, asbestos fibers, allergens (pollen, fungi, spores, etc.), pathogens contained in other particulate matter (PM), etc.;
- Vapor and gases: Carbon oxides (CO and CO₂), radon gas, formaldehyde (HCHO), benzene, nitrogen oxides (NO and NO₂), other Volatile Organic Compounds (VOCs), and Semi Volatile Organic Compounds (SVOCs), etc.

The scientific community is continuously working to improve indoor environments, given that eliminating exposure to artificial and synthetic substances entirely is not feasible [6]. USEPA identifies three basic strategies for improving IAQ [9]: (1) source control, generally the most cost-effective approach, which eliminates or reduces pollutant emissions at their origin; (2) improved ventilation, particularly through natural means such as window and door openings during activities that generate high pollutant levels (e.g., cooking, painting); and (3) air cleaning/filtration, whose effectiveness depends on device type, positioning, and operating conditions, and which does not replace source control or adequate ventilation. No single strategy guarantees complete protection; combining good practices in everyday life supports a healthier indoor environment.

There is no universal method to guarantee complete control of IAQ, and following these recommendations will not necessarily provide full protection; however, learning and implementing good practices in everyday life can help occupants navigate this complex topic and support a healthier life in enclosed environments.

1.3. Aim of This Paper

This work aims to develop a qualitative questionnaire for indoor air quality research. To this end, a scoping review of previous studies combining subjective assessment with objective monitoring was conducted, identifying the questionnaire items and domains most frequently investigated in relation to occupants' perception of indoor air quality. The resulting questionnaire is intended for application in studies that pair subjective data with quantitative environmental measurements.

2. Materials and Methods

Starting from the aims of the analysis to be conducted [3], an SR has been developed with the goal of mapping the current state of the art on previous qualitative IAQ surveys, combined with quantitative analyses supported by high- and/or low-cost sensors [13]. Therefore, the scope of the SR, referring to previous research experiences, is to investigate which types of qualitative information were collected and how researchers correlated this information with quantitative analyses of the IAQ sensors, such as perceived comfort, indoor activities (meetings, cleaning activities, etc.), occupancy conditions (window and door openings, etc.), and health symptoms.

As noted above, this investigation aims to develop a qualitative questionnaire to be applied to different monitoring methodologies for comparing the qualitative and quantitative data for better understanding how the users can use and manage indoor spaces adequately and to become active health promoters for improving their well-being [14].

Scoping Review on Existing Studies Related to IAQ Monitoring and Qualitative Surveys

The analysis started with an SR of the studies on IAQ, conducted using the Scopus database. This was not conducted as a systematic review because the aim was to identify and synthesize questionnaire components reported in previous studies rather than to estimate intervention effects or perform a quantitative synthesis, as would typically be expected in a systematic review. It was undertaken as a methodological phase of a broader study [3]. It aimed to develop a questionnaire that would highlight the common practices applied to the different analyses. This SR followed the PRISMA-ScR reporting guidelines [15].

This SR was guided by the following research question: which questionnaire domains and items are most frequently used to investigate occupants' perceptions in studies combining indoor air quality monitoring with subjective assessment? Therefore, the first step was to look up the most common terms used in similar IAQ-monitoring studies; these keywords informed the search of the Scopus database. The terms were identified from relevant books and articles in this field. The groups of terms were divided as follows: (TITLE-ABS-KEY ("indoor air" OR "IAQ" OR "indoor air quality" OR "indoor air pollution") AND TITLE-ABS-KEY ("survey*" OR "questionnaire*" OR "poll*") AND TITLE-ABS-KEY ("wellbeing*" OR "well-being" OR "psychophysical" OR "psycho-physical" OR "health" OR "perception" OR "wellness") AND TITLE-ABS-KEY ("VOC" OR "Volatile organic compound*" OR "NO₂" OR "NO_x" OR "Nitrogen dioxide" OR "CO₂" OR "Carbon dioxide" OR "CO" OR "Carbon monoxide" OR "PM" OR "Particulate matter*")) AND TITLE-ABS-KEY ("living" OR "working") AND PUBYEAR > 2013 AND PUBYEAR < 2024 AND (LIMIT-TO (OA, "all")) (see Figure 1).

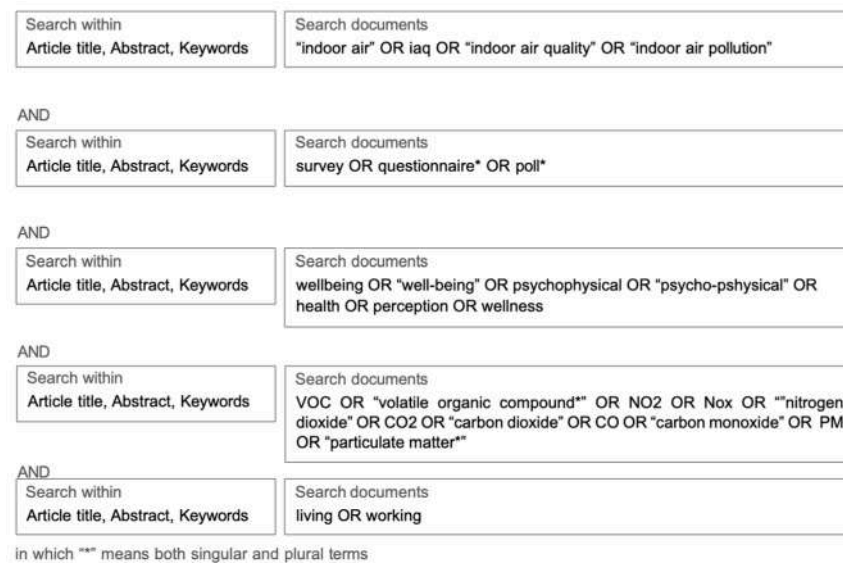


Figure 1. Term selection in query in Scopus.

All these keywords were defined by the research team, and the query on the database was run on 23 October 2023. The search filtered the papers published within the past 10 years before the query (from 2014 to 2023), and it used "open access" as the second filter to make sure the full texts of all retrieved studies were available, with no other filters on the fields or languages. By applying different groups of keywords to the search, considering article titles, abstracts and keywords, a total of 281 documents were found, as Figure 2 shows. A single search was conducted, without repeated searches or database alerts; no update search was performed after the initial search date of 23 October 2023.

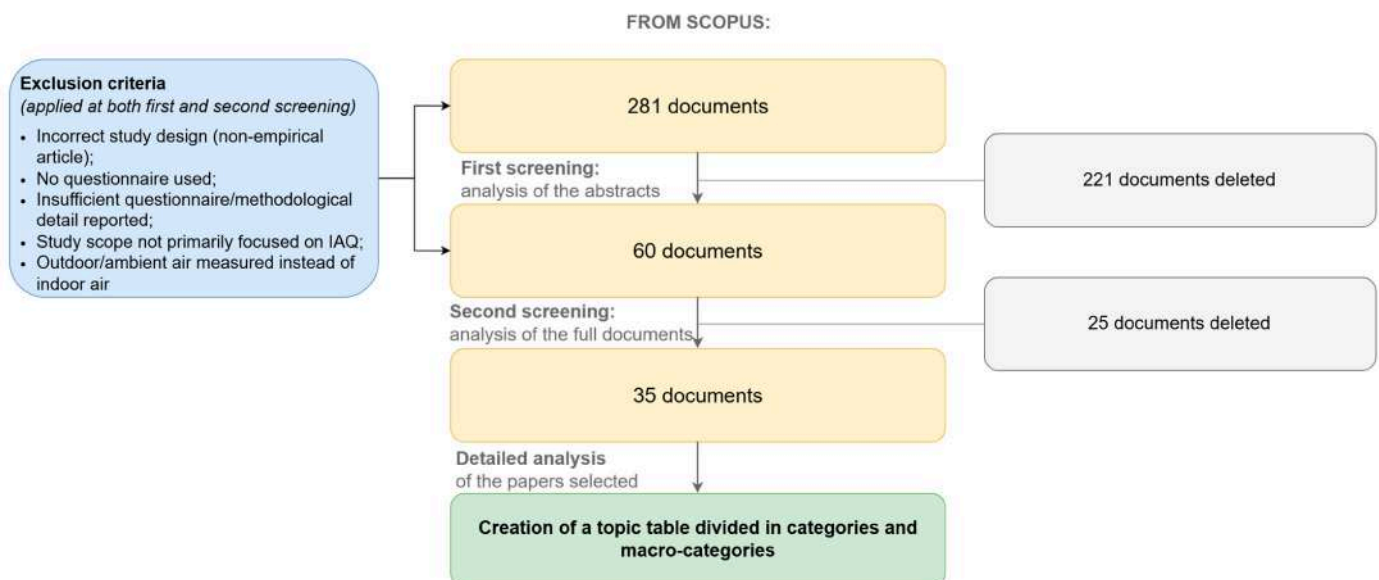


Figure 2. Prisma graph and the exclusion criteria.

The search was restricted to the Scopus database and to open-access publications to ensure full accessibility and reproducibility of the search, screening, and data extraction process. As a single database (Scopus) was searched, no duplicate records were identified across sources. Where the same author group reported the same study population in both a journal article and a conference paper, the journal publication was retained, and the corresponding conference paper was excluded.

No restrictions were applied regarding peer-review status or publication type; conference abstracts, preprints, and other grey literature were eligible for inclusion and were assessed individually based on topic relevance and the availability of sufficiently detailed questionnaire content. Studies were excluded during screening if the questionnaire or survey instrument used was not described in sufficient detail to allow extraction of its content.

Two authors (A.L., Y.Y.) independently screened all identified records for eligibility. Any discrepancies between the two reviewers were resolved by a third author (M.G.), whose judgment determined the final eligibility decision for the affected records. Formal interrater agreement statistics (e.g., Cohen's κ) were not calculated for the screening stage; this is acknowledged as a limitation in Section 5.

During the first screening, all the records ($n = 281$) were screened on the basis of article titles, abstracts, and keywords. Documents were retained or discarded according to the inclusion and exclusion criteria summarized in Table 1. As Figure 2 shows, after the first screening, 60 documents remained.

Table 1. Inclusion and exclusion criteria applied during the screening process.

Inclusion Criteria	Exclusion Criteria
Study used a questionnaire and/or survey as a method to investigate occupants' perceptions	Did not mention the use of a questionnaire and/or did not apply a survey as a method
Primary focus on indoor air quality (IAQ)	Focused on thermal parameters or other topics not primarily related to IAQ
Questionnaire/survey applied and reported as an actual method (not merely mentioned)	Mentioned a survey in the abstract but did not apply it as a method
Occupant-perception focus	Related to IAQ but addressed medical/clinical aspects or animal studies, not occupant perception
Questionnaire/survey instrument described in sufficient detail to allow extraction of its content	Questionnaire/survey instrument not described in sufficient detail to allow extraction of its content
No restriction on peer-review status or publication type (grey literature eligible, assessed individually)	—
Journal article version retained when the same study population was reported in both a journal and a conference paper	Corresponding conference paper excluded when the same study population was already reported in a journal article (duplicate study population)

During the second screening, all articles that passed the first phase were retrieved and read in full, with particular attention to the methodologies applied by international scholars in studies that used questionnaires and analyzed survey data. During this phase, 25 works were excluded according to the same criteria detailed in Table 1; examples of excluded content included studies related to cooking fuel use and body function, and analyses of indoor environments and Sick Building Syndrome that did not address IAQ. Therefore, as Figure 2 shows, after the second screening, 35 documents remained.

Given the heterogeneity of methods and outcome measures across the included studies, network or cluster analyses were not considered appropriate within the scope of this scoping review; percentage-based frequency reporting and summary statistics were used instead to synthesize the extracted data.

A meta-analysis was not performed, given the substantial heterogeneity in study designs, questionnaire structures, monitored environmental parameters, and outcome reporting formats across the included studies.

3. Results

Starting from the selection of the 35 documents, the team created an Excel worksheet, with the support of Gaetano Settimo (GS) and Stefano Capolongo (SC), co-authors of this paper, who acted as experts on the topic. Here, the team collected all the topics and/or questions, subdivided into general demographic information, health and symptoms, personal perception, building and occupancy conditions and studied pollutants, addressed in all the surveys analyzed.

Among the studies identified in the SR, and considering the aims and scope of the proposed methodology, the research team observed, in particular, the following studies:

- The study by Alomirah and Moda in which an online questionnaire survey was conducted, focusing on sensory perceptions of indoor environments, workplace control, and psychosocial responses affecting productivity, and, at the same time, air quality monitoring was carried out, measuring airborne microflora, TVOCs (Total Volatile Organic Compounds), CO₂ (Carbon Dioxide), CO (Carbon Monoxide), temperature, and relative humidity in each environmental unit [16];
- Another study by Gabriel et al., in which a questionnaire on IAQ was conducted and, in the second phase, a monitoring activity was applied to test indoor air conditions and pollutant levels in households (e.g., VOCs, aldehydes, PM) [17];
- The study by Justo Alonso et al., in which participants were asked to keep an activity log, and in parallel, IAQ measurements (formaldehyde and TVOCs, as well as CO₂, humidity, and temperature) were carried out in both winter and summer [18].
- The study by Latib et al., in which a questionnaire-based survey was conducted to assess public perceptions of IAQ in living spaces and monitoring activities, assessing parameters such as temperature, relative humidity, air velocity, PM₁₀, CO₂, NO₂ (Nitrogen Dioxide), TVOCs, and formaldehyde [19].

Geographically, the 35 included studies were conducted across five continents, though the evidence base is concentrated in Europe and Asia, as detailed in Table 2.

The publication years of the included studies ranged from 2014 to 2023, with the number of studies published annually generally increasing over this period, as shown in Figure 3.

As Table 3 shows, a column was dedicated to each paper, and all investigated topics were recorded. The table uses color coding to highlight the questions most frequently asked across the included questionnaire- or survey-based studies.

Extracted questionnaire items were classified into thematic domains through team consensus: following data extraction, the three authors (Y.Y., A.L., M.G.) jointly reviewed the extracted items and agreed on their grouping into domains through discussion. This was a consensus-based grouping process rather than a formal independent double-coding procedure followed by a structured thematic or content analysis.

In the following paragraphs, the team summarizes the useful insights and common issues that emerged from the analysis.

Table 2. Geographic distribution of the studies included in the Scoping review (n = 35).

Region	Country (n)	References
Europe (n = 16)	Portugal (3)	[17,20,21]
	UK (3)	[16,22,23]
	Greece (2)	[24,25]
	Finland (2)	[26,27]
	Italy (1)	[28]
	Norway (1)	[18]
	Slovenia (1)	[29]
	Spain (1)	[30]
	Sweden (1)	[31]
	Multi-country ¹ (1)	[32]
Asia (n = 12)	China (6)	[33–38]
	Malaysia (3)	[19,39,40]
	Indonesia (1)	[41]
	Pakistan (1)	[42]
	Thailand (1)	[43]
North America (n = 5)	USA (4)	[44–47]
	Canada (1)	[48]
Africa (n = 1)	South Africa (1)	[49]
Oceania (n = 1)	Australia (1)	[50]

¹ Bentayeb et al. (2015) [32]: nursing-home study spanning 7 European countries, counted once under Europe.

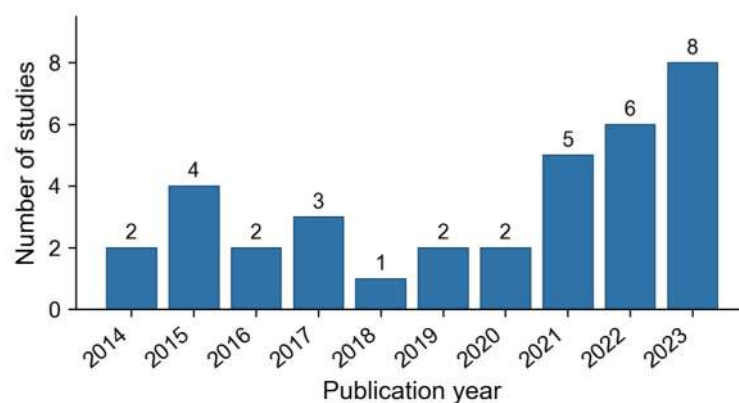
**Figure 3.** Number of studies per year included in this Scoping review (n = 35).

Table 3. Outcomes of the Scoping review with survey question topics ranked by counts.

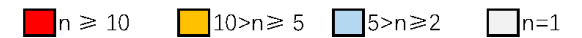
[illegible]

Table 3. Cont.

Classification		Key words	Afroz et al., 2023 [48]	Alomirah and Meda, 2020 [16]	Bentayeb et al., 2015 [32]	Chan et al., 2020 [33]	Chi et al., 2016 [34]	Cibella et al., 2015 [28]	Colbeck et al., 2018 [42]	Des Santos et al., 2020 [20]	Fernández-Agüera et al., 2023 [30]	Frey et al., 2014 [44]	Gabriel et al., 2021 [17]	Gibbey et al., 2023 [50]	Gupta and Howard, 2019 [22]	Handika et al., 2023 [41]	Justo Alonso et al., 2022 [18]	Kaji et al., 2014 [45]	Kapwata et al., 2018 [49]	Kkepeis et al., 2017 [46]	Latif et al., 2023 [19]	Lavtizar et al., 2023 [29]	Lee M. et al., 2021 [35]	Lim F. et al., 2015 [39]	Lu et al., 2022 [36]	Mendes et al., 2016 [21]	Morgan et al., 2016 [23]	Nezis et al., 2022 [24]	Niu et al., 2022 [37]	Pekkonen et al., 2015 [26]	Ricklund et al., 2023 [31]	Roh et al., 2021 [47]	Sakellaris et al., 2023 [25]	Salvaraji et al., 2022 [40]	Surawattanasakul et al., 2022 [43]	Trkkonen et al., 2017 [27]	Wu et al., 2021 [38]	total = 35				
general demographic information	Lifestyle and exposure	non/ex/current-smoker																																						16		
		Pets keeping																																						4		
		use of cleaning products																																						4		
		smoking environment																																						3		
		flowering plants keeping																																						2		
		non-flowering plants keeping																																						2		
		alcohol consumption																																						2		
smoking influence to person																																							1			
Health and Symptoms	Presence of any kind of diseases (to be rearranged)	Asthma																																						7		
		Allergic rhinitis																																							3	
		Sinusitis																																							2	
		Allergy																																							2	
		Allergic/atopic rash																																						1		
		Allergic ophthalmitis																																							1	
		emphysema																																						1		
		Skin diseases																																							1	
	General symptoms	COPD																																							1	
		Headache																																							7	
		concentration difficulties																																							4	
		fatigue																																							4	
		dizziness																																							3	
		lethargy/Drowsiness																																							3	
		Nausea																																							3	
		unusual tiredness																																							3	
		any general symptoms																																							2	
		flu-like symptoms																																							2	
		office-related symptoms																																							1	
		fever																																							1	
		Irritation of ears																																							1	
		Irritation of nose																																							1	
		Irritation of scalp																																							1	
		muscle pain																																							1	
		rhinitis																																							1	
	Savere Headache																																							1		
	Hoarseness																																							1		
	vomiting																																							1		
	respiratory	dry throat																																								7
		runny nose																																								6
		wheezing																																								6
		nasal obstruction or blockage																																								5
		shortness of breath																																								

Table 3. Cont.

Classification		Key words	Afroz et al., 2023 [48]	Alomirah and Mada, 2020 [16]	Bentayeb et al., 2015 [32]	Chan et al., 2020 [33]	Chi et al., 2016 [34]	Cibella et al., 2015 [28]	Colbeck et al., 2018 [42]	Dos Santos et al., 2020 [20]	Fernández-Agüera et al., 2023 [30]	Frey et al., 2014 [44]	Gabriel et al., 2021 [17]	Gilbey et al., 2023 [50]	Gupta and Howard, 2019 [22]	Handika et al., 2023 [41]	Justo Alonso et al., 2022 [18]	Kaji et al., 2014 [45]	Kapwata et al., 2018 [49]	Klepeis et al., 2017 [46]	Latib et al., 2023 [19]	Lavtizar et al., 2023 [29]	Lee M. et al., 2021 [35]	Lim F. et al., 2015 [39]	Lu et al., 2022 [46]	Mendes et al., 2016 [21]	Morgan et al., 2016 [23]	Nezis et al., 2022 [24]	Niu et al., 2022 [37]	Pekkonen et al., 2015 [26]	Ricklund et al., 2023 [31]	Roh et al., 2021 [47]	Sakellaris et al., 2023 [25]	Salvaroji et al., 2022 [40]	Surawattanasakul et al., 2022 [43]	Tirkkonen et al., 2017 [27]	Wu et al., 2021 [38]	total = 35		
Health and Symptoms	respiratory	chronic bronchitis																																					1	
		respiratory infections																																					1	
		respiratory irritation																																					1	
		sputum																																					1	
		Sinus congestion																																					1	
	Heart symptoms	sneezing																																						1
		tachycardia																																					3	
		irregular heartbeats																																					3	
	Mucosal symptoms	bradycardia																																						2
		cough																																					10	
		irritation of eyes																																					8	
		nasal catarrh																																					2	
	skin symptoms.	swollen eyelid																																					2	
		irritation of skin																																					5	
		Dry Skin																																					3	
		rash																																					3	
Other	Erythema																																						1	
	Eczema																																					1		
	itches																																					1		
	comorbidities																																					1		
personal perception	Satisfaction Survey	Air temperature																																						9
		Indoor air quality																																					7	
		relative humidity																																					5	
		odor																																					5	
		Light																																					3	
		Acoustic																																					3	
		smoke																																					3	
		Overall environment																																					2	
		Outdoor air quality																																					1	
		indoor air velocity																																						

Table 3. Cont.

Classification		Key words	Afroz et al., 2023 [48]	Alomirah and Moda, 2020 [16]	Bentayeb et al., 2015 [32]	Chan et al., 2020 [33]	Chi et al., 2016 [34]	Cibella et al., 2015 [28]	Colbeck et al., 2018 [42]	Des Santos et al., 2020 [20]	Fernández-Agüera et al., 2023 [30]	Frey et al., 2014 [44]	Gabriel et al., 2021 [17]	Gibbey et al., 2023 [50]	Gupta and Howard, 2019 [22]	Handika et al., 2023 [41]	Justo Alonso et al., 2022 [18]	Kaji et al., 2014 [45]	Kapwata et al., 2018 [49]	Klepis et al., 2017 [46]	Latib et al., 2023 [19]	Lavtizar et al., 2023 [29]	Lee M. et al., 2021 [35]	Lim F.etal., 2015 [39]	Lu et al., 2022 [36]	Mendes et al., 2016 [21]	Morgan et al., 2016 [23]	Nezis et al., 2022 [24]	Niu et al., 2022 [37]	Pekkonen et al., 2015 [36]	Ricklund et al., 2023 [31]	Roh et al., 2021 [47]	Sakellaris et al., 2023 [25]	Salvaraji et al., 2022 [40]	Surawattanasakul et al., 2022 [43]	Trkkonen et al., 2017 [27]	Wu et al., 2021 [38]	total = 35			
building and occupancy conditions	Space occupancy	duration of natural ventilation																																					8		
		internal equipment/ furniture																																						7	
		N. of People																																						6	
		Schedule of activities																																						4	
		Indoor Activities																																						2	
	Building Information	indoor greenery																																							1
		Ownership of house																																						1	
		year of construction																																						4	
		type of construction																																						3	
		furnishings/coverings																																						3	
		potential source of pollutant																																						3	
		floor count																																						2	
		building materials																																						2	
	Cooking	N. of exterior door																																							1
		distance to road																																						1	
		surrounding road type																																						1	
		fuel type																																						3	
	Building Management	Stove type																																							2
		cleaning activities																																						3	
		allow to smoke																																						1	
	Building Condition	documented complaints																																							1
		Lawn Chemical																																						1	
		visible mold																																						7	
		water damage																																						3	
		renovation in recent																																						3	
	Ventilation type	odor																																							2
		Condensation in winter																																						1	
		type of ventilation system																																						9	
		ventilation through window																																						4	
		air purifier																																						1	
		exhaust fan in the kitchen																												</											

Table 3. *Cont.*[illegible]

Table 4. Brief summary of the results obtained by the SR, with emphasis on the most characteristic aspects of the methodology.

Topic	What Was Investigated	Emerging Issues by the SR
General demographic information	• Demographic information • Occupational information • Lifestyle and exposure	• Age • Gender • Self-perceived health status • Educational level • Profession • Non/ex/current smoker etc.
Health and symptoms	• Presence of any pre-existing diseases • General symptoms • Respiratory symptoms • Mucosal symptoms • Skin symptoms	• Asthma • Headache • Dry throat • Runny nose • Cough • Irritation of eyes/nose/skin etc.
Personal perception	• Satisfaction survey	• Indoor temperature • Air quality • Relative humidity • Odor
Building and occupancy conditions	• Space characteristics • Space occupancy • Building conditions • Ventilation types • Heating and cooling system	• Room function • Room exposure • Number of people • Visible mold/damage • Duration of natural ventilation • Type of HVAC system
Included Parameters	• Microclimate • Chemical pollutants	• Temperature • Relative humidity • CO₂ • PM • tVOCs • Formaldehyde etc.

3.1. General Demographic Information

As Table 2 shows, regarding the general demographic information, many surveys asked participants about their age ($n = 22$, 62.9%), gender ($n = 20$, 57.1%), educational level ($n = 10$, 28.6%), disease history ($n = 8$, 22.9%), self-perceived health status ($n = 6$, 17.1%), and weight ($n = 5$, 14.3%). Many other demographic variables were also included in one to four studies, such as family member, social context, etc., which may be relevant for research targeting specific populations or social contexts, such as secondhand smoke and pregnant women by Morgan et al. [23] or building tenure status and IAQ by Pekkonen et al. [26]. In addition, Mendes et al. investigated exposure to potential risk factors [21].

Regarding occupational information, the most common question concerned respondents' profession ($n = 11$, 31.4%), followed by several less frequent items, namely working hours per week, work task type, years of experience, task schedule, means of commute, and full- or part-time status, each reported in two to four studies (5.7 to 11.4%).

Regarding lifestyle and exposure, which can strongly affect health status and/or users' perceptions, several surveys examined whether users were never, former, or current smokers ($n = 16$, 45.7%), while pet keeping, use of cleaning products, exposure to smoking environments, the presence of flowering or non-flowering plants, and alcohol consumption were each addressed less frequently (two to four studies, 5.7 to 11.4%).

In conclusion, the team observed that in the analysis by Sakellaris et al., there were specific psychological factors (work-related stress and model of affect as one indicator) and possible recent personal events, positive or negative ones, both of which can affect the data analysis [25], as detailed in Table 3.

Demographic characteristics such as age and sex are commonly included because they are known to influence thermal sensation, symptom reporting, and susceptibility to indoor pollutants, allowing IAQ assessments to account for population heterogeneity.

3.2. Health and Symptoms

Regarding health and symptoms, several studies investigated different issues related to users' health status, as summarized in Table 3. Although the previous section is related to the general demographic information, several questions were about disease history and self-perceived health status; a separate section was devoted to more detailed information about the presence of pre-existing conditions. In this section, several scholars analyzed asthma ($n = 7$, 20.0%), with allergic rhinitis, sinusitis, and allergy each reported less frequently (two to three studies, 5.7 to 8.6%). In addition, among the studies, the team observed that Chi et al. and Mendes et al. investigated possible Chronic Obstructive Pulmonary Disease (COPD) [21,34], and Surawattanasakul et al. investigated skin diseases, information useful for better understanding possible influences on data collection [43].

Among the general symptoms, several scholars investigated headache-related issues ($n = 7$, 20.0%), while concentration difficulties, fatigue, dizziness, lethargy or drowsiness, nausea, unusual tiredness, and flu-like symptoms were each reported less frequently (two to four studies, 5.7 to 11.4%). A few other authors also examined general symptoms ($n = 2$), including Justo Alonso et al. [18] and Lim et al. [39]; Tirkkonen et al. [27] reported rhinitis; and Lim et al. reported office-related symptoms [39].

Turning to respiratory symptoms, the research team observed a high frequency of dry throat ($n = 7$, 20.0%), runny nose ($n = 6$, 17.1%), wheezing ($n = 6$), and nasal obstruction or blockage ($n = 5$, 14.3%), while shortness of breath, sore throat, chest tightness, and phlegm/mucus were each reported less frequently (two to three studies, 5.7 to 8.6%). Among the studies, Tirkkonen et al. also investigated respiratory infections [27], and Nezis et al. focused on respiratory irritations [24].

Among the other healthcare issues, heart symptoms were investigated by a few scholars, namely tachycardia, irregular heartbeats, and bradycardia, each in two to three studies (5.7 to 8.6%). The most frequently investigated mucosal symptoms were cough ($n = 10$, 28.6%) and irritation of eyes ($n = 8$, 22.9%), while among skin symptoms, skin irritation was most common ($n = 5$, 14.3%), with dry skin and rash each reported less often ($n = 3$, 8.6%).

In addition, Mendes et al. also investigated the presence of possible comorbidities with the survey [21].

3.3. Personal Perception

As summarized in Table 4, many papers focused on users' satisfaction with the indoor environments in which they live or work. In particular, several scholars investigated the air temperature ($n = 9$, 25.7%), the perception of IAQ ($n = 7$, 20.0%) and relative humidity ($n = 5$, 14.3%), and the possible presence of odors ($n = 5$, 14.3%), while lighting

comfort, acoustic comfort, presence of smoke, and overall environmental quality were each addressed less frequently (two to three studies, 5.7 to 8.6%). In addition, a few authors also evaluated indoor air velocity [37], the presence of dust [40], and the room's size [16].

In addition, the team observed that Latib et al. investigated users' awareness and knowledge of IAQ, which was mentioned just once among all the included research but is important for the occupants' daily lives [19].

These subjective measures often act as an early indicator of deteriorating indoor conditions, complementing objective sensor data by capturing aspects of occupant experience that instruments alone cannot measure.

3.4. Building and Occupancy Conditions

Occupant activities directly influence pollutant generation (e.g., cooking, cleaning) and ventilation behavior (e.g., window opening), making it necessary to record these activities for interpreting variations in measured IAQ parameters that cannot be explained by environmental monitoring alone.

As several experts on IAQ highlighted, the characteristics of indoor spaces and their suitability for the activities carried out are important. For this reason, the research team investigated the role of building design and its management (building and occupancy conditions), as Table 3 shows.

Regarding the space characteristics, several scholars investigated room function ($n = 6$, 17.1%) and building location ($n = 5$, 14.3%), while total building area, number of occupants, number of rooms, room volume, and number of windows were each reported less frequently (two to four studies, 5.7 to 11.4%). Among the studies, Lavtižar et al. also analyzed the area of openable windows [29].

Regarding space occupancy, the scholars focused in particular on the duration of natural ventilation through window openings ($n = 8$, 22.9%), internal equipment and furniture ($n = 7$, 20.0%), and the mean number of people in the room ($n = 6$, 17.1%). In addition, a few asked for information about the schedule of activities carried out ($n = 6$, 17.1%), whereas Sakellaris et al. focused on the presence of indoor greenery [25].

Among the issues, several surveys requested information about the building (building information), with a particular focus on year of construction, type of construction, types of furnishings and coverings, potential sources of pollutants, floor count, and building materials, each reported in two to four studies (5.7 to 11.4%). In addition to these, more specific questions addressed the number of exterior doors and the distance to the road by Klepeis et al. [46] and the surrounding road type by Lavtižar et al. [29].

In relation to its management (building management), a few surveys investigated cleaning activities ($n = 3$, 8.6%), and others verified the presence of documented complaints and permission to smoke [25] and the use of lawn chemicals [47]. In terms of the building condition, many authors investigated the presence of visible mold ($n = 7$, 20.0%), while recent renovation, presence of odors, and water damage were each reported less often (two to three studies, 5.7 to 8.6%). In addition, Pekkonen et al. also considered the presence of condensation in winter [26].

Another issue that strongly affects indoor spaces is the natural and mechanical ventilation system (ventilation type and heating and cooling). The team observed that several colleagues investigated the types of ventilation systems ($n = 9$, 25.7%), while ventilation through windows, heating system, cooling system, and fuel type were each reported less frequently (two to four studies, 5.7 to 11.4%); only Klepeis et al. analyzed the presence of air purifiers [46], and only Sakellaris et al. investigated the presence of control systems [25].

In addition, although the review focuses on IAQ, few analyses on IEQ were considered in the screening phase. In any case, it was observed that the survey by Sakellaris et al.

also considered acoustic issues, such as the existence of acoustical insulation, indoor noise sources, and outdoor noise sources, as well as lighting conditions, such as contrast of window frames, control of main lights and shading devices [25].

3.5. Brief Summary of Key Issues Asked in the Survey in the Literature

Across the 35 included studies, the number of the five thematic domains addressed per study ranged from one to five (mean = 3.5, median = 3); general demographic information and included pollutants were each reported in 33 studies (94.3%), followed by building and occupancy conditions (71.4%), health and symptoms (48.6%), and personal perception (37.1%). The number of distinct pollutants monitored per study ranged from zero to 10 (mean = 4.2, median = 4).

By the end of the SR, all summarized results were considered (in relation to the scope of the analysis) to develop a qualitative questionnaire, revealing which questions were most worth investigating. In particular, Table 4 highlights the topics most closely related to the team's methodology [3].

3.6. Included Pollutants

In addition to the questionnaire items, this review also recorded building types, pollutant types, monitoring methods, and other approaches applied across the included studies. Although the review's methodology was shaped largely by the type of active sensors adopted, it also identified the pollutant categories investigated in the included protocols (Table 4).

Regarding microclimatic parameters, most studies monitored temperature ($n = 23$), relative humidity ($n = 22$), and, less frequently, air velocity ($n = 4$); one study by Lavtižar et al. exclusively analyzed air pressure [29].

Among chemical and physical pollutants, CO_2 ($n = 15$) and $\text{PM}_{2.5}$ ($n = 12$) were the most frequently monitored in both working and living spaces. Particulate matter was further broken down by fraction: PM_{10} ($n = 6$), $\text{PM}_{2.5}$ ($n = 12$), PM_1 ($n = 2$), unspecified PM ($n = 5$), and PM_4 in a single study by Kapwata et al. [45]. Volatile organic compounds were also commonly investigated, with tVOC ($n = 9$), VOC ($n = 2$), and formaldehyde ($n = 5$, three in residential and two in healthcare settings) as the most reported, alongside one study on aldehydes in dwellings by Sakellaris et al. [25]. Less frequently monitored gases included NO_2 ($n = 8$), SO_2 ($n = 2$), and O_3 ($n = 4$).

Regarding biological factors, a smaller number of studies investigated bacteria ($n = 4$) and fungi ($n = 3$), predominantly in healthcare settings, along with individual studies on mold [16], dust mites [39], and dampness in dwellings [48].

3.7. Additional Methodological Characteristics of Included Studies

In the reviewed papers, most studies analyzed their survey data in parallel with the monitoring results. Among their supportive measurement methods, monitoring with active sensors ($n = 25$) was the predominant approach to quantitative data collection, followed by use of passive samplers ($n = 8$) and data retrieved from local weather stations ($n = 2$). Depending on target pollutants, some of the works had to use multiple measurement methods at the same time, such as the works by Salvaraji et al. [40] and Surawattanasakul et al. [43], due to the limitations of active sensors.

As for the building types, residential buildings ($n = 20$) and office buildings ($n = 7$) were the most investigated spaces, followed by healthcare facilities ($n = 4$) and education facilities ($n = 3$). There is one additional study on an occupational disease in a barber shop.

In addition to the measurement and questionnaire, the study by Wu et al. also used a productivity test to evaluate users' behavior in the environment with designed IAQ levels, testing participants across four domains, including logical thinking, perception, understanding and memory, and visual attention [38].

Among the reviewed items, the productivity test domain (e.g., logical thinking, perception, memory) was reported in only one of the 35 included studies, indicating markedly lower adoption compared with the other five domains and suggesting it may be a lower priority for inclusion in future questionnaire iterations. Regarding predictive relevance, questionnaire-derived variables have already shown value in a related study, where several were retained among the predictors selected for a machine learning model of occupant symptom risk [51]; a systematic item-level correlation or regression analysis against measured environmental parameters was beyond the scope of the present scoping review and is identified in the Limitations in Section 5.2 as a priority for future validation work.

4. Discussion

According to the questions and their keywords summarized from the literature in Table 3, especially those questions with high frequency marked in colors, the most relevant IAQ-related issues concern occupants' demographic information, perceptions and comfort, health condition and symptoms, as well as the occupancy conditions of their rooms.

After making selections and adaptations based on the needs of the target space or building type, the questions from different categories can be organized into suitable questionnaires. Adaptations are essential because factors like occupants' social status and schedules, potential air pollutants, and existing health conditions vary significantly across different types of spaces. Moreover, the selected questions should be closely aligned with the research objectives. For example, research on cooking activities in kitchens should focus on kitchen-related activities, while studies on offices should tailor questions to the specific activities that take place in office settings. Using overly general questions can sometimes lead to ambiguous or misleading responses.

In addition, both the order and the total number of questions are important. When a questionnaire contains a large amount of information, it is better to place the most important questions at the beginning to ensure that respondents answer them seriously and to prevent loss of patience. At the same time, the questions should be stated clearly, as vague wording can easily confuse respondents and reduce their willingness to engage. Questions supported by easy-to-read diagrams or figures can also help respondents provide more accurate responses.

Unlike established, psychometrically validated instruments such as OFFICAIR [52] or the MM040/Indoor Air Questionnaire [53], which are administered periodically to assess overall satisfaction and symptom prevalence across large occupant samples, the proposed questionnaire was specifically designed for hourly-resolution use alongside continuous low-cost sensor monitoring, allowing direct temporal comparison between subjective perception and measured environmental parameters within the same day. This design choice trades the statistical robustness and validated scoring of established instruments for finer temporal granularity, at the cost of the formal psychometric validation that OFFICAIR and MM040 already possess, as acknowledged in the Section 5.2.

4.1. Definition of the Questionnaire

Based on the list of questions identified in the SR, a questionnaire was generated in parallel with the IAQ monitoring activities for a research topic in working spaces (in particular for departmental offices of the university) to collect qualitative data. The qualitative data consisted of the most frequent and selected survey questions, adapted from the results of the scoping review. The questionnaire was developed from the outcomes of the SR, and in particular, it was structured in the following sections, as Figure 4 shows:

- The questionnaire starts with questions about user lifestyle and demographic information, such as age range, sex, and health conditions (specifically, whether they have any

pre-existing health condition that could alter their perception and whether they had flu or fever in the days prior to the analysis). These items are strategically important for better understanding general information about the user and whether a specific health status should be considered, which can influence the user's perception and feelings;

- It continues with questions about the environment and the user's perception, asking the user if the room is comfortable, whether windows are left open at the end of the day, if there are any plants in the room, etc. This information is useful for identifying possible features of the space to be considered, as well as capturing the user's perception to be considered, etc.;
- This is followed by a table covering working hours from 8 a.m. to 8 p.m., with different questions related to activities undertaken in the room (3A), the user's perception about the environment and possible symptoms (3B), and ventilation-related issues (3C). This information is useful for better understanding the activities carried out, possible symptoms caused by environmental conditions, and the natural and artificial ventilation patterns during the day to better understand and interpret the quantitative data (i.e., CO₂ reduction due to window opening, possible influence of cleaning products, possible overcrowding of space, etc.);
- In the last section, the user can provide feedback on their experience, including comments or other perceptions and feelings. The questionnaire is interactive and a means of communication between the users and the research team, ensuring respondents' anonymity;
- In conclusion, to better support the data analysis and identify any errors in the information reported by the user, during the application of the monitoring activity [3], the team added a final box that asks how the user completed the questionnaire: every hour or at the end of the working day.

The selection of individual items for the final questionnaire was based primarily on the frequency with which each item was reported across the included studies, discussed and agreed upon by the authors through consensus; this process was informed by expert judgment from the two co-authors with domain expertise in indoor air quality and public health, who provided methodological oversight throughout. No independent external review of the proposed questionnaire was conducted prior to its field application; the questionnaire has, however, subsequently been used in two peer-reviewed publications by the author team, in which reviewer comments on the instrument were successfully addressed [51,54].

No item that was described in sufficient detail in an included study was excluded from the final questionnaire on the basis of its content; the only items not retained were those for which a study reported investigating a given topic (e.g., a specific symptom) without disclosing the exact survey wording used, making it impossible to extract the item text.

The inclusion of transient health conditions such as flu or fever, alongside pre-existing health conditions, reflects their potential to temporarily affect symptom reporting and perceived comfort during the monitoring period; other health characteristics were not considered, as the questionnaire focuses on transient factors likely to influence occupants' perception within the study timeframe.

An hourly recording interval was selected for questionnaire usability, allowing respondents to reasonably recall their activity and window-opening patterns without the burden of finer time resolutions, such as minute-by-minute reporting.

1 Personal and health informations of the user

2 Environmental conditions

4 Extra information and suggestions

5 Method of compilation

3A Activities in the room

3B User's wellbeing and perception

3C Adaptive behaviour towards the air ventilation

QUALITATIVE SURVEY

Age range: 20–30 ☐ 30–40 ☐ 40–50 ☐ 50–60 ☐ 60–70 ☐ 70–80 ☐ Sex:

Do you have any medical condition that could alter your perception of odors, temperature, humidity, etc.?

Did you have a fever or the flu in the last days?

Do you find this room comfortable?

At the end of the day, were the windows left open? YES ☐ NO ☐

Are there any plants in the room? If yes, how many of them?

The following table refers to the day the questionnaire is given, compile it as you prefer: during the day or at the end of it. A team of researchers will come tomorrow to collect the questionnaires, thank you for your contribution!

ps. Where you find symbols or initials (instead of a blank space) please cross the option/s more appropriate. You can cross more than one option.

	Activity done (cross the symbol, if none of these activities was done, leave it blank)	N. of people in the room, including you (write a number)	Symptoms (if you feel any of these symptoms, write the corresponding letter as the list below reports)	Temperature perception (cross the appropriate option)	Air ventilation (cross one or more options)	Shading system (cross if they were lowered, even just half)	Functioning of the Heating and Cooling system (please select if the system was on or off)	Others (if you have any other suggestions, write them below with another number)
08:00 — 09:00	  			TC C N H TH	   		ON OFF	
09:00 — 10:00	  			TC C N H TH	   		ON OFF	
10:00 — 11:00	  			TC C N H TH	   		ON OFF	
11:00 — 12:00	  			TC C N H TH	   		ON OFF	
12:00 — 13:00	  			TC C N H TH	   		ON OFF	
13:00 — 14:00	  			TC C N H TH	   		ON OFF	
14:00 — 15:00	  			TC C N H TH	   		ON OFF	
15:00 — 16:00	  			TC C N H TH	   		ON OFF	
16:00 — 17:00	  			TC C N H TH	   		ON OFF	
17:00 — 18:00	  			TC C N H TH	   		ON OFF	
18:00 — 19:00	  			TC C N H TH	   		ON OFF	
19:00 — 20:00	  			TC C N H TH	   		ON OFF	

Are there any more informations or feedbacks that you think you weren't able to include in the answers of this questionnaire?

How did you compile?
☐ Every hour
☐ At the end of the day

Legend

Activity

 Working at the desk
 Meeting / Revisions / Workshop
 Maintenance (for example cleaning activities)

Possible symptoms

a) Cough
b) Difficulty concentrating
c) Dizziness
d) Drowsiness / Lethargy
e) Dry skin
f) Dry / Sore throat
g) Fatigue
h) Fever
i) Headache
j) Severe Headache
k) Hoarseness
l) Irregular heartbeat
m) Irritation of ears
n) Irritation of eyes
o) Irritation of scalp
p) Irritation of skin
q) Irritation of nose
r) Muscle pain
s) Nausea
t) Rhinitis
u) Runny nose
v) Shortness of breath
w) Sneezing
x) Unusual tiredness
y) Vomiting

Temperature perception

TC) Too Cold
C) Cold
N) Neutral
H) Hot
TH) Too Hot

Air ventilation

 Open door
 Open window, turn
 Open window, tilt (vasistas) or sliding
 No ventilation

Others

1) Dust
2) High humidity
3) Odor
4) Odor of smoke
5) Odor of smog

Figure 4. Contents of the questionnaire related to working spaces.

Currently, Figure 4 shows the questionnaire defined for the analysis of IAQ monitoring with low-cost sensors and the users' perception inside working spaces [3], but it may be adaptable to living spaces following appropriate validation, for example by expanding the time slots and modifying the activities considered [55].

Moreover, to ensure an adequate comparison between the qualitative and quantitative data, in the top-right corner, the team added two boxes: the first is for recording the device code—each questionnaire is marked with the code of the sensor in its room, this code is not public information and this ensures the privacy of the users; and the second box is for the date. Both boxes are completed by the team before distributing the questionnaires.

4.2. Paper or Online Survey: How to Collect the Qualitative Data?

Referring to the methodology developed by the authors [3], the team considered at the outset how the questionnaire should be administered: online or on paper. To this end, the team evaluated the advantages and disadvantages of each format: the online format seemed easier to complete, and data collection was simplified for the graphs, but an email containing a link to an online questionnaire could also be more easily forgotten than a paper copy.

A printed questionnaire, by contrast, would be harder to forget, and the team would retain control over the questionnaire's layout, although it would also make data collection more difficult, with the risk of losing sheets or introducing transcription errors. It would also require printing a large amount of paper and would therefore be a less sustainable choice.

Meanwhile, some questions, particularly those on occupancy conditions such as presence schedules and window operation, proved difficult to fit into the fixed templates of the online questionnaire tools that were tested. In this respect, the printed questionnaire allowed more flexibility in designing those questions.

Lastly, the paper questionnaire also made it easier to protect users' privacy, a matter of considerable importance for the team since responses could not be traced back to the respondents.

On balance, both formats had advantages and disadvantages, but the final choice to use a physical paper questionnaire was driven by the fact that no online format could reproduce the layout the team wanted to develop. Indeed, by developing the questionnaire from scratch, the team was able to create it as a large table (Figure 4), in which the different answers could be easily read, collected, and compared with one another at a given hour of the day. The online survey tools available at the time offered layouts that were barely editable, making it impossible to develop a more engaging and interactive questionnaire.

In addition, this solution also proved the most suitable, since for the application of the methodology, the Ethics Committee confirmed that the paper format was the most consistent way to maintain pseudonymization of participants' data.

However, the authors do not rule out that the questionnaire could also be administered through digital systems, in accordance with ethical requirements, allowing for better data collection and organization, especially when the number of users or monitoring days is large. This would otherwise require transcribing a very large number of questionnaires, as in the studies by Alomirah and Moda [16] and Latib et al. [19], and by other scholars included in the SR.

4.3. Integration and Interpretation of Qualitative and Quantitative Data

All the issues discussed here have also led to the creation of graphs that are uncommon in the scientific literature, with the specific aim of merging quantitative data from the sensors with qualitative data. The diagram shown in Figure 5 is intended to demonstrate

an example of the solution identified by the authors for interpreting the data and identifying possible actions to implement.

As can be seen from the graph, the qualitative data represented in red and the quantitative data in blue are easily readable, and this also makes it possible to highlight the possible causes of positive or negative values. These data are related to the number of users present, the CO₂ levels, the type of activity (for example, the activity performed), and the tVOC, as well as the issue of door openings, turns, and/or the temperature perceived by users.

The qualitative data, referring to Figure 5, are as follows:

- Section A1 shows the temperature perception of each participant, in which all users recorded their perceptions of the room each hour;
- Section A2 represents the sum of all the symptoms that were noted in a specific hour by all the users;
- Section A3 shows the issues related to air ventilation, in which the types of window and door openings are defined on the basis of users' answers, as explained in the legend;
- Section A4 shows the hours in which the shading systems were used, even just partially (among the building hygiene strategies, the role of shading systems can reduce the solar exposure and, as a consequence, the high temperatures inside the indoor spaces);
- Section A5 defines the possible operation of the heating/cooling systems, in relation to the season;
- Section A6 shows the activities carried out, i.e., desk work, meetings, or maintenance;
- Section A7 represents the occupancy, i.e., number of people in the room.

Among the quantitative issues, referring to Figure 5, the data are shown in the following way:

- Section B1 shows the outdoor temperature levels that can be provided by outdoor sensors or by the local weather station;
- Section B2 represents the indoor temperature and humidity levels, in which B2a refers to the temperature levels and B2b shows humidity levels measured by the sensors;
- Section B3 shows the ideal temperature comfort range, referring to the national or local guidelines [56];
- Section B4 represents the CO₂ levels, in which B4a refers to the acceptable CO₂ range [57], and B4b shows the CO₂ values provided by the sensors;
- Section B5 defines the VOC levels measured by the sensors.

As the figure shows, at the bottom of the graph, there are two boxes arranged as follows:

- The symptoms listed in Section A2 are explained;
- Some comments and considerations by the users are listed, and they are useful for identifying possible overlaps between the qualitative and quantitative data.

Referring to the previous descriptions, the order of graphs is a suggestion by the authors of this paper. The proposed visualization facilitates temporal comparison between subjective perceptions and environmental measurements, supporting the identification of critical issues and the definition of actions for occupants and facility managers.

The methodology developed by the authors [3] considered quantitative data collected over the entire day (24 h) and qualitative data collected during the working hours spent by users in the monitored spaces.

This discrepancy allows observers to assess environmental conditions before and after work activities, as well as anomalies associated with ventilation systems, space characteristics, management, and cleaning activities.

A) Qualitative data

A1

Temperature perception: every participant noted his/her feelings inside the room each hour.

A2

The sum of all the symptoms that were noted in a specific hour.

A3

Air ventilation: the single blue column represents the window being open, the double column represents the window being fully open. It is added to the single brown column which represents the door being open.

A4

The grey area shows the hours when the shading system was used, even just partially.

A5

The light red / light blue columns show if the heating / cooling system was on or off.

A6

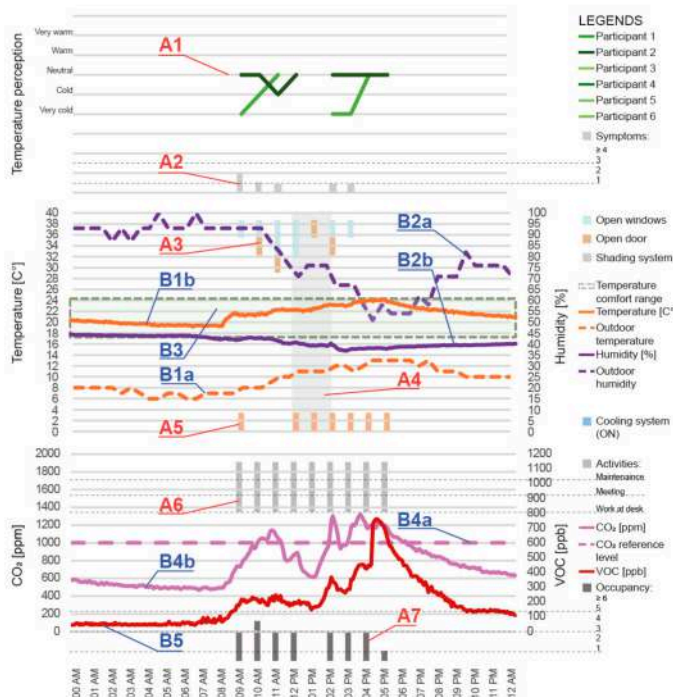
Activities: it shows if in the room were being done either work at the desk, meeting or maintenance.

A7

Occupancy: number of people in the room.

ROOM: XX
DATE: XX

Average number of users: XX
Ventilation: XX



Symptoms:	Comments:

C1
List of all the symptoms noted by the users, referring to section A2.

C2
List of comments and considerations. Here the team list all the useful considerations that they can deduct from the overlap of the qualitative and quantitative data.

C3

Hours of the monitoring day
• Qualitative data 08 AM - 08 PM
• Quantitative data 00 AM - 12 AM

* This hours range is the maximum range in which users could be found in the rooms

B) Quantitative data

B1a

Outdoor temperature levels: data provided by the local weather station.

B1b

Indoor temperature levels: data provided by the sensors.

B2a

Outdoor humidity levels: data provided by the local weather station.

B2b

Indoor humidity levels: data provided by the sensors.

B3

The light green area shows the ideal temperature comfort range.

B4a

CO₂ reference level: acceptable CO₂ range as reference. *
(Settimo et al., 2023)

B4b

CO₂ levels: data provided by the sensors.

B5

VOC levels: data provided by the sensors.

Figure 5. How to create the graph that merges qualitative data (on the left from A1 to A7) and quantitative data (on the right from B1 to B8). The reference level for CO₂ is from Settimo et al., 2023 [57].

4.4. Validation of the Questionnaire

The proposed questionnaire items were derived through team consensus among the author team following the screening of the included studies, based on the thematic domains identified in this scoping review; the search and screening methodology was guided by two co-authors with domain expertise in indoor air quality and public health. Ethical approval for its use was granted by the Ethics Committee of Politecnico di Milano (No. 31/2024, 31 May 2024).

For its validation, the questionnaire was subsequently applied in two independent studies by the authors, one related to the working spaces [6] and another to living spaces [51,54].

At first, a related, smaller-scale pilot application of the questionnaire was conducted across approximately ten shared office spaces as part of a research project at Politecnico di Milano [6]. Together, these applications provided preliminary criterion-related evidence that questionnaire responses relate meaningfully to independently measured environmental conditions and reported outcomes, using this office-based field dataset of about 35 participants [6].

Regarding the living spaces, using the residential field dataset of about 75 respondents, in a cross-sectional analysis of sick-building-syndrome-related symptoms, specific symptom clusters corresponded to concurrent exceedances of measured CO₂, PM_{2.5}, temperature and relative humidity thresholds [54]. In a subsequent study, the same questionnaire responses were used alongside sensor data as predictor variables in machine learning models developed to predict individual symptom risk; several questionnaire-derived variables were retained among the predictors selected for the final models [51].

Taken together, these applications support the practical applicability of the questionnaire, although formal psychometric evaluation of the instrument, including content validity, construct validity, and test-retest reliability, has not yet been conducted and is identified in the Section 5.2 as a priority for future work.

4.5. Prioritization of Questionnaire Items for Future Applications

Item priority within the questionnaire is not fixed but depends on the specific aim of the IAQ investigation. A study focused on respiratory health, for instance, would treat personal disease history as core alongside basic demographics, whereas a thermal-comfort study might treat the same item as optional.

Three priority tiers can nonetheless be distinguished:

- **Core items** required regardless of research focus: Basic demographic information (age, gender, and, where relevant, occupation) and detailed occupant-presence information (occupancy time, duration, and frequency). IAQ measurements are difficult to interpret without knowing who was present and for how long, particularly in spaces shared by multiple occupants.
- **Recommended items** applicable to most studies but adjustable to the research context: Occupational status and health condition, including symptom reporting; subjective perception of overall comfort, thermal sensation, humidity, and air quality; ventilation frequency and mode; and indoor activities and their frequency, tailored to the function of the monitored space.
- **Optional items** included only when required by the specific building type or research objective: Space-specific descriptors, such as the presence of plants, and open-ended comments.

The level of detail required for occupancy items should also be adapted to the monitoring duration: a single-day campaign requires only a one-day schedule, whereas longer campaigns call for items on frequency and typical daily patterns instead. Applying this

tiered structure allows the questionnaire to be adapted to the specific aim of each study while preserving a consistent core across applications.

5. Conclusions

5.1. Conclusions and Findings

This scoping review addressed the research question of which questionnaire domains and items are most frequently used to investigate occupants' perceptions in studies combining indoor air quality monitoring with subjective assessment. Analysis of the 35 included studies identified five thematic domains: general demographic information, health and symptoms, personal perception, building and occupancy conditions, and included pollutants. Demographic information and pollutant-related items were the most frequently reported. These domains formed the basis for developing a qualitative questionnaire designed for parallel use with low-cost sensor monitoring, together with an integrated visualization framework (Figure 5) that merges quantitative sensor data with qualitative occupant perceptions to support the identification of critical issues and the definition of actions for occupants and facility managers.

The proposed approach couples an evidence-based questionnaire with hourly-resolution sensor data. This provides a replicable method for combining subjective and objective indoor air quality assessment. The questionnaire has not yet undergone formal psychometric validation, as discussed in Section 5.2; future work should prioritize this validation, as outlined in Section 5.3. Beyond validation, the approach could be extended to building types beyond the office and dormitory settings examined here, such as residential, educational, and healthcare facilities, potentially supported by AI-driven approaches for multidimensional data analysis and building management.

5.2. Limitations

Several limitations of this review should be acknowledged. The development of the questionnaire itself relied on team consensus among the authors rather than a formal, structured consensus methodology such as a Delphi process; this is identified as a priority for future refinement of the instrument.

The proposed questionnaire has not undergone formal psychometric validation. Preliminary criterion-related evidence exists from its application in two subsequent studies linking questionnaire responses to independently measured environmental and symptom data [51,54]. Symptom items were treated as independent indicators throughout these analyses rather than combined into composite subscale scores; internal consistency statistics (e.g., Cronbach's α) are therefore not reported, as they are not informative for a checklist of etiologically distinct symptoms not designed to form a unidimensional scale. Construct validity (e.g., via factor analysis) and test-retest reliability of the instrument have not yet been formally assessed and are identified as priorities for future validation work.

Formal inter-rater agreement statistics (e.g., Cohen's κ) were not calculated for the screening stage; agreement was instead supported by a full independent re-screening of all records by a third author. Following standard scoping review methodology, no formal quality appraisal of the included studies was conducted, as scoping reviews prioritize breadth of evidence mapping over in-depth methodological quality assessment.

The search was restricted to a single database (Scopus) and to open-access publications, which may have excluded relevant studies indexed elsewhere or published in subscription-based journals, potentially introducing selection bias; grey literature (e.g., theses, conference proceedings, institutional reports) was not included for the same reason. Future scoping reviews on this topic should adopt a more systematic, multi-database search strategy, for example combining Scopus with other bibliographic databases such as PubMed or Web of

Science and including subscription-based sources, to reduce this potential bias and broaden the evidence base.

Finally, given the heterogeneity of study designs, questionnaire structures, and outcome measures across the included studies, the statistical synthesis was primarily descriptive (percentage- and frequency-based); network or cluster analyses were not considered appropriate within the scope of this scoping review (Section 2).

5.3. Future Research Steps

Future work should prioritize formal psychometric validation of the instrument, including assessment of internal consistency and test–retest reliability, and construct validity testing, for example via factor analysis. Preliminary criterion-related evidence already exists: questionnaire-derived variables were retained among the predictors selected in a machine learning model developed to predict occupant symptom risk in a related study [51]. Future studies should extend this evidence through formal criterion validity assessment against independently measured environmental and health outcome data, across larger and more diverse samples.

Beyond validation, practical extensions of the instrument should be explored, including: (1) pilot implementation of the questionnaire in real monitoring campaigns; (2) development of a digital or electronic version to facilitate data collection; (3) translation and cross-cultural adaptation for multilingual use; and (4) application and adaptation across a wider range of building categories, such as residential, educational, and healthcare settings, beyond the office and dormitory contexts examined in the present review.

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