Challenges on Field Monitoring of Indoor Air Quality in China

Steven Sai Hang Ho [1,2], Yu Huang [1,*], Shun-Cheng Lee [3], Junji Cao [1]

[1]Key Lab of Aerosol Chemistry & Physics， Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China

[2]Division of Atmospheric Sciences, Desert Research Institute, Reno, NV, United States

[3]Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

* Corresponding author: Prof. Yu Huang

Key Lab of Aerosol Chemistry & Physics,

Institute of Earth Environment, Chinese Academy of Sciences,

Xi'an 710075, China

Email: huangyu@ieecas.cn

Abstract

Field monitoring is critical in the examination of indoor air quality (IAQ) which offers an integrated assessment of human exposure. A good measurement protocol includes appropriate methodologies and compliance of quality control and quality assurance (QC/QA) procedures. In China, there has been huge economic growth in the past 20 years and living standard for Chinese citizens has been improving with rapid development in urban cities and infrastructures. With these developments, there have been a growth of increasing pollution sources, and indoor air quality (IAQ) has been a major concern to the government and many Chinese citizens with widespread reports of the coherent health impacts. However, the indoor monitoring in China is full of technical challenges. In this paper, we review the difficulties in conducting IAQ assessment in China. Techniques and practical consideration have been proposed accordingly.

Keywords: Indoor air quality; Field monitoring; China; Measurement protocols; Exposure.

Introduction

Indoor monitoring of air compounds (including inorganic and organic) is an ongoing challenge.[1] In addition to penetration from outdoor,[2] these compounds can be directly produced from various indoor sources such as cooking, incense burning, environmental tobacco smoke (ETS) and emissions from household products.[3-5] Epidemiological studies report that many, classified as air toxins, can pose potential short-term or long-team health impacts to humans.[5] With characteristic physical and chemical properties, each of the air compounds has its own dynamic behaviours. Multiple factors can influence indoor air quality (IAQ), including quantities of direct emission sources, effectiveness of ventilation and filtration systems, and potential deposition/re-emission onto/from indoor adhesive surfaces. In some circumstances, chemical reaction can play an important role in transformation of the air compounds with consequential effects on indoor environments.[6-8]

Field monitoring is a direct and effective tool to measure levels and compositions of the air compounds, which is applied for source apportionment, health risk assessment and indoor air pollution management.[9] Owing to sustainable and rapid growth in economy, more indoor and outdoor pollution sources are being produced in China. Meanwhile, the publics are beginning to pay more attention to IAQ in their living areas and workplaces and are expressing concerns regarding the possible health effects. There is a need for a more "joint-up" protocol in China for in-situ monitoring of IAQ. However, there are many challenges that can be encountered in these field studies. Our research team has been conducting IAQ studies since 1990's and accumulated over 20 years of hand-on experiences in this subject. This paper discusses the difficulties and solutions for the field monitoring of IAQ in China.

Indoor sources and guidelines of air compounds

China has the largest population in the world, but the information for the important indoor air compounds is very limited or even missing (except in Hong Kong). Carbon dioxide (CO_2) and carbon monoxide (CO) are the two cases in point. CO_2 is one major combustion product from town gas, kerosene, and wood or coal fuelled appliances when they are in operation.[10] Human respiration is also recognized as a crucial indoor source of CO_2. Both CO_2 and carbon monoxide (CO) can be emitted from fossil fuel burning and cigarette smoke as well. CO_2, therefore, acts as a good indicator to evaluate indoor ventilation efficiency. Typical indoor CO_2 concentrations range between 700 and 2,000 ppmv (approximately 3,657 mg/m^3) but can exceed 3,000 ppmv (5,486 mg/m^3) during the use of unvented appliances.[10,11] Gas stove is known as the major source of indoor NO_2. Ozone (O_3) may be generated indoors by photocopy machines, laser printers, ion-generating air cleaners and brush-type electrical motors such as sewing machines. Fine particulate matter ($PM_{2.5}$) can be produced from the indoor combustion sources.

The importance of IAQ has often been underestimated in China. The local features of indoor sources (e.g., in-house fuels and materials), environments (e.g., building structures and designs) and life styles (e.g., behaviours and activities) are greatly different from those in the other countries. Indoor levels of the air compounds also have close relationships between the volume of indoor spaces, quantity of sources, air removal or/and exchange rates, and the corresponding concentration outdoors. Actual human exposures are often hard to be quantified. This is largely because both behaviour and activity pattern of an individual can strongly affect their levels of exposure. The results from the Total Exposure Assessment Methodology (TEAM) studies undertaken by the U.S. Environmental Protection Agency (U.S.EPA) in the 1980s consistently showed that personal exposures to many indoor pollutants can markedly exceed than those anticipated from the concentrations in ambient air. This phenomenon has been known as the "personal cloud effect".

Our team has reported the variations in indoor VOCs composition between China and other regions.

The levels are mostly elevated by a variety of sources, including utilization of consumer household products (e.g., cleaning agents and air fresheners), Environmental Tobacco Smoke (ETS), emissions from paints, varnishes, solvents, adhesives, furnishing, clothing and building materials, and incense burning,[3, 4, 12] which are sometimes higher than those found in outdoor air.[13] Primary indoor sources of formaldehyde, a carcinogen to human, include building materials such as particle-board, medium-density fibreboard, plywood, resins, adhesives, and carpeting.[14,15] Formaldehyde is also used in the manufacture of urea formaldehyde foam insulation (UFFI) which is injected into wall cavities to supplement the insulation in existing buildings.[16] In-building radon levels could be highly relate to its abundance in the soil surrounding the structure and number of entry points (e.g., foundation joints, cracks in floors and walls, drains and piping, electrical penetrations, and cellars with earth floors) that allow the gas to infiltrate from outdoors.[16] Microorganism is an important biological pollution to indoor environment.[17] A diversity of fungi and bacteria are found indoors, and their survivals are associated with the presence of organic matter (e.g., wall coatings, woods, and foodstuffs). The penetration from outdoor is one of the major sources for fungi and bacteria, particularly in summer and autumn. Humid environment favours the fungal growth. Hence the microorganisms are always located in apartments with damp conditions, especially those containing structural faults, at basements or under floor crawl spaces.

The integrity of quality control/quality assurance (QC/QA) for the materials and products made in China is always a concern for the consumers. Any poor quality matters can contribute to the indoor air pollutions. Therefore it is absolutely vital to conduct the IAQ investigations in China.

Guidelines or criteria for common indoor air compounds have been established by health organizations or governments (Table 1). Most time-integrated exposure limits are defined for long-term (i.e., 8 h average or even longer) but only few are for short-term. In comparison, the environmental protection agency in China has a better foresight to inform the publics of the "peak values" by defining more short-term exposure limits for the air compounds. This is a good start since the restriction can be more effectively reflect the risk levels to the residents and workers.

Challenges on Micro-scale Indoor Monitoring in China

A lack of hand-on experience is a big barrier to conduct an intensive indoor monitoring in China. Many researchers applied inappropriate methodologies, and few even completely follow the procedures reported in other countries' study, without any consideration of on-site parameters. The key for a successful field study is to establish an explicit objective for the monitoring. The scheme should be divided into three important stages, including (1) preparation, (2) sampling, and (3) post-sampling. In the preparation stage, it is important to collect all necessary background information and conduct walkthrough inspection to proposed sites.[9] Questionnaires should be designed to collect the useful information about the locations. Through the visits, the number of sites and locations, sampling frequencies and methodologies should be outlined. Preliminary tests must be run and accurate calibrations of all sampling equipment and analytical devices must be initialized under the QC/QA instructions. The selection of sampling point is fairly critical in micro-scale indoor monitoring. Outdoor monitoring usually requires the equipment to be placed close to fresh air intake from any air handling unit (AHU) in the study area. However, in indoor monitoring, the distances between ground, walls, ventilation systems, potential sources and sampling devices are admirably specified, subjected to the purposes of the assessment. During the sampling stage, the operators must strictly follow all well-defined procedures and schedules to collect real time data or offline samples. The samplers should be set-up in a breathing zone (from 0.5 to 1.5 m height) and placed 0.5 m away from the walls. All parameters on field (i.e., relative humidity, ventilation speed, air exchange rate, and temperature) must be recorded and documented. Field blanks and collocated samples have to be collected. The real time data must be reserved while the offline samples must be stored and transported properly. In the post-sampling stage, sample and data analyses must be conducted through QC/QA inspections. These include calculations of accuracy, precision and uncertainty for the data sets. The data interpretation must be done by any professional.

Selection of proper monitoring technique is another challenge. Typical indoor monitoring techniques include real-time measurement (online) and time-integrated sampling (offline). Table 2 summarizes the feasible methodologies that can be applied in the micro-scale indoor monitoring. They can be further classified as continuous and intermittent monitoring subjected to sampling time effectiveness, and as passive and active techniques based on the driving force principles. Passive sampling technique has some merits for micro-scale field monitoring: (1) small in size and light weight, (2) unobtrusive and more readily acceptable to study participants, (3) comparatively easier to be operated and no AC power required (e.g., battery or external electrical power), and (4) cost-effective. However, the diffusive rate for a passive method is generally low, and hence a long sampling time (e.g., >24 hr) is required and only integrated measurements can be conducted.[18] Moreover, variations in ventilation, indoor air pollution sources and activities can greatly affect the concentrations and compositions of the target compounds and their stabilities in a function of time. These multiple factors must be considered while a measurement protocol is chosen with appropriate detection range and sensitivity. Real time monitoring equipment and active samplers offer collections of data and samples, respectively, in short-time intervals; however, they are usually costly and bulky. Besides, space is always limited for the micro-scale indoor monitoring and thus meticulous equipment are needed. Unfortunately, many local factories manufacture the products that require little capital and low technology. In addition to sensitive and steady (i.e., low flow rate) monitors must be required, the reliability and stability for the local equipment are doubt. Import of guaranteed devices and accessories from international vendors is possible. However, rather than high shipping cost, this is time- and labour-consuming due to complicate custom regulations and tax-related problems in China.

Representativeness, reliability and stability of the sampling locations are also concerns in China. In the micro-scale monitoring, multiple locations must be selected as representatives of the site. This must require a degree of consistency for the sites. At many sites, there could be a variety of ethnicities, communities and cultures in the Chinese society. Different degrees of variations in minor to major features (e.g., materials, behaviour and activities) can cause difficulties in the classifications of the sampling locations. Besides, poor and unsatisfactory indoor conditions can greatly affect the steady indoor monitoring in buildings of an economically-developing country.

Apart from those scientific issues, the researchers could often meet difficulties to access the target locations. It is very common in China that the residents, owners or building/work supervisors would strongly refuse or disagree or oppose to conduct the indoor monitoring in their apartments and workspaces due to insufficient knowledge and communication. Valuable data are thus lost. Public education is an important factor to assist the environmentalists who are seeking to acquire information to improve the IAQ for the building in question. The scientists should also keep up-to-date with the advance technology in the monitoring and analysis of IAQ.

Conclusions

There is a need to conduct IAQ researches through on-field monitoring in China. It is critical to have a good planning before the study starts. This includes clear definition of the purposes and objectives, collection of background information and walkthrough inspection. All of the procedures must be followed by the QA/QC instructions. Passive samplers are usually small, light, and simple to operate in the micro-scale field environments but their performances can be varied by environmental factors in addition to a long sampling duration is required. The cost, size and quality of the equipment and measuring devices must be considered. Precise selection and proper classification of representative monitoring sites are also important. Public education and promotion can assist the environmentalists to conduct more significant IAQ researches. Conclusively appropriate methodologies and advanced technology must be applied to meet the goals of the studies.

Acknowledgements

This study was supported by the Research Grant (1-ZV9R) of the Hong Kong Polytechnic University, Research Grants Council of Hong Kong (PolyU 152083/14E), and was also partially supported by National Science Foundation of China (41401567). Yu Huang has been supported by the "Hundred Talent Program" of the Chinese Academy of Sciences.

Declaration

Authors' contribution: Huang Y, Lee SC and Cao JJ conceived and designed the study. Ho SSH conducted the data analysis and wrote the manuscript, and all the authors provided comments and feedback on the manuscript.

Conflict of interest: The authors declare no competing financial interests.

References

1. Lee WC, Wolfson JM, Catalano PJ, Rudnick SN and Koutrakis P. Size-resolved Deposition rates for ultrafine and submicron particles in a residential housing unit. *Environmental Science & Technology* 2014; 48: 10282−10290.
2. MacNeill M, Kearney J, Wallace L, Gibson M, Heroux ME, Kuchta J, Guernsey JR and Wheeler AJ. Quantifying the contribution of ambient and indoor-generated fine particles to indoor air in residential environments. *Indoor Air* 2014; 24: 362-375.
3. Lee SC and Wang B. Characteristics of emissions of air pollutants from burning of incense in a large environmental chamber. *Atmospheric Environment* 2004; 38: 941-951.
4. Lee SC and Wang B. Characteristics of emissions of air pollutants from mosquito coils and candles burning in a large environmental chamber. *Atmospheric Environment* 2006; 40: 2128-2138.

5. Zhang JJ and Smith KR. Household air pollution from coal and biomass fuels in China: Measurements, health impacts, and interventions. *Environmental Health Perspectives* 2007; 115: 848-855.

6. Weschler CJ and Shields HC. Indoor ozone/terpene reactions as a source of indoor particles. *Atmospheric Environment* 1999; 33: 2301-2312.

7. Wainman T, Zhang JF, Weschler CJ and Lioy PJ. Ozone and limonene in indoor air: A source of submicron particle exposure. *Environmental Health Perspectives* 2000; 108: 1139-1145.

8. Guo ZS and Hubbard HF. Chemical reactions in indoor sources. I*ndoor Built Environment* 2015; 24: 725-728.

9. Yu CWF and Kim JT. Building pathology, investigation of sick buildings – VOC emissions. *Indoor Built Environment* 2010; 19:30-39.

10. Bertoni G, Ciuchini C and Tappa R. Measurement of long-term average carbon dioxide concentrations using passive diffusion sampling. *Atmospheric Environment* 2004; 38: 1625-1630.

11. Lee SC and Chang M. Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere* 2000; 41: 109-113.

12. Halios CH, Assimakopoulos VD, Helmis CG and Flocas HA. Investigating cigarette-smoke indoor pollution in a controlled environment. *Science of the Total Environment* 2005; 337: 183-190.

13. Weisel CP, Alimokhtari S and Sanders PF. Indoor air VOC concentrations in suburban and rural New Jersey. *Environmental Science & Technology* 2008; 42: 8231-8238.

14. Salthammer T, Mentese S and Marutzky R. Formaldehyde in the indoor environment. *Chemical Reviews* 2010; 110: 2536-2572.

15. Yu CWF and Kim JT. Long-term impact of formaldehyde and VOC emissions from wood-based products on indoor environments; and issues with recycled products. *Indoor Built Environment* 2012; 21: 137-149.

16. Kim JT and Yu CWF. Hazardous materials in buildings. *Indoor Built Environment* 2014; 23: 44-61.

17. Singh J, Yu CWF and Kim JT. Building pathology, investigation of sick buildings – toxic moulds. *Indoor Built Environment* 2010; 19: 40-47.

18. Yu CH, Morandi MT and Weisel CP. Passive dosimeters for nitrogen dioxide in personal/indoor air sampling: a review. *Journal of Exposure Science and Environmental Epidemiology* 2008; 18:

441-451.

19. Bhangar S, Mullen, NA, Hering SV, Kreisberg NM and Nazaroff WW. Ultrafine particle concentrations and exposures in seven residences in northern California. *Indoor Air* 2011; 21: 132-144.

20. Plaisance H, Piechocki-Minguy A, Garcia-Fouque S and Galloo JC. Influence of meteorological factors on the NO_2 measurements by passive diffusion tube. *Atmospheric Environment* 2004; 38: 573-580.

21. Ogawa. NO, NO_2, NO_X and SO_2 sampling protocol using the Ogawa sampler. Pompano Beach, FL: Ogawa & Co., 2006.

22. Bhangar S, Huffman JA, Nazaroff WW. Size-resolved fluorescent biological aerosol particle concentrations and occupant emissions in a university classroom. *Indoor Air* 2014; 24: 604–617.

23. Garnett MH and Hartley IP. A passive sampling method for radiocarbon analysis of atmospheric CO_2 using molecular sieve. *Atmospheric Environment* 2010; 44: 877-883.

24. Bertoni G, Ciuchini C and Tappa R. Measurement of long-term average carbon dioxide concentrations using passive diffusion sampling. *Atmospheric Environment* 2004; 38: 1625-1630.

25. ISO 4224:2000. Ambient air - determination of carbon monoxide - non-dispersive infrared spectrometry method. International Organization for Standardization (ISO), Geneva, 2000.

26. Valerio F, Pala M, Lazzarotto A and Balducci D. Preliminary evaluation, using passive tubes, of carbon monoxide concentrations in outdoor and indoor air at street level shops in Genoa (Italy). *Atmospheric Environment* 1997; 31: 2871-2876.

27. Alm S, Mukala K, Tiittanen P and Jantunen MJ. Personal carbon monoxide exposures of preschool children in Helsinki, Finland - comparison to ambient air concentrations. *Atmospheric Environment* 2001; 35: 6259-6266.

28. Blondeau P, Iordache V, Poupard O, Genin D and Allard F. Relationship between outdoor and indoor air quality in eight French schools. *Indoor Air* 2005; 15: 2-12.

29. Helaleh MIH, Ngudiwaluyo S, Korenaga T and Tanaka K. Development of passive sampler technique for ozone monitoring. Estimation of indoor and outdoor ozone concentration. *Talanta* 2002; 58: 649-659.

30. Liu LJS, Olson MP, Allen GA, Koutrakis P, Mcdonnell WF and Gerrity TR. Evaluation of the Harvard Ozone Passive Sampler on Human Subjects Indoors. *Environmental Science & Technology*

1994; 28: 915-923.

31. US EPA Compendium method TO-11A: Determination of formaldehyde in ambient air using adsorbent cartridge followed by high performance liquid chromatography (HPLC) [Active Sampling Methodology]. Washington: U.S. Environmental Protection Agency (U.S.EPA), 1999.

32. Iyiegbuniwe EA. Assessment of LEED indoor environmental quality parameters at a new church building In South-central Kentucky. *Energy Engineering* 2013; 110: 6-19.

33. Park JS and Ikeda K. Variations of formaldehyde and VOC levels during 3 years in new and older homes. *Indoor Air* 2006; 16: 129-135.

34. Yim B and Jung E. Badge-type diffusive sampler using 3-methy-l-2-benzothiazolinone hydrazone for measuring formaldehyde in indoor air. *Analytical Sciences* 2006; 22: 993-997.

35. Koziel JA, Noah J and Pawliszyn J. Field sampling and determination of formaldehyde in indoor air with solid-phase microextraction and on-fiber derivatization. *Environmental Science & Technology* 2001; 35: 1481-1486.

36. Nirlo EL, Crain N, Corsi RL and Siegel JA. Volatile organic compounds in fourteen U.S. retail stores. *Indoor Air* 2014; 24: 484-494.

37. Meininghaus R, Salthammer T and Knöppel H. Interaction of volatile organic compounds with indoor materials—a small-scale screening method. *Atmospheric Environment* 1999; 33: 2395-2401.

38. Schripp T, Etienne S, Fauck C, Fuhrmann F, Märk L and Salthammer T. Application of proton-transfer-reaction-mass-spectrometry for indoor air quality research. *Indoor Air* 2014; 24: 178-189.

39. Mullen NA, Russell ML, Lunden MM and Singer BC. Investigation of formaldehyde and acetaldehyde sampling rate and ozone interference for passive deployment of Waters Sep-Pak XPoSure samplers. *Atmospheric Environment* 2013; 80: 184-189.

40. Chai M, Arthur CL, Pawliszyn J, Belardi RP and Pratt KF. Determination of volatile chlorinated hydrocarbons in air and water with solid-phase microextraction. *Analyst* 1993; 118: 1501-1505.

Table 1. Summary of Exposure Guidelines/Criteria for Important Air Compounds in Offices and Public Places

Criteria / Parameters	USA	Canada	UK	Finland	Japan	Korea	Singapore	Hong Kong[n]	China
Carbon Dioxide (mg/m^3)	1440 (averaging time not mentioned) [a]	1530 (8-hr)[c]	--	2160 (8-hr) [g]	--	I: 1800 (8-hr) [j] II: 1800 (1-hr) [l]	1800 (8- hr) [l] 1260 above outdoor (8-hr) [m]	Excellent Class: <1440 Good Class: <1800	1800 (24-hr)[h]
Carbon Monoxide ($\mu g/m^3$)	--	10000 (8-hr) [c]	11000 (8-hr) [f]	10000 (8-hr) [g]	--	I: 11000(8-hr) [j] II: 29000 (1-hr) [k]	10000 (8-hr) [l,m]	Excellent Class: < 2000 Good Class: <10000	10000 (1-hr) [h]
Ozone ($\mu g/m^3$)	--	--	--	--			100 (8-hr) [l]	Excellent Class: <50 Good Class: <120	160 (1-hr) [h]
Nitrogen dioxide ($\mu g/m^3$)	--	560 (24-hr) [d]	280 (1-hr) [f]	200 (1-hr) [g]	--	--	--	Excellent Class: <40 Good Class: <150	450 (1-hr) [h]
Formaldehyde ($\mu g/m^3$)	--	120 (1- hr) [c]	120 (30 min) [d]	50 (8-hr) [g]	160 (30 min) [i]	200 (8-hr) [j,k]	200 (8-hr) [l, m]	Excellent Class: <30 Good Class:<100	100 (1-hr) [h]
PM_{10} ($\mu g/m^3$)	--	150 (24-hr) [c]	--	50 (24-hr) [g]	--	150 (8-hr) [j, k]	150 (max) [l] 50 (8-hr) [m]	Excellent Class: <20 Good Class: <180	150 (24-hr) [h]
$PM_{2.5}$ ($\mu g/m^3$)	--	--	--	--	--	--	--	--	--
Total VOC ($\mu g/m^3$)	--	5000 [d] (24-hr)	--	--	400 (30-min) [i]	--	6900 (max) [l, m]	Excellent Class: <200 Good Class: <600	600 (8-hr) [h]
Radon (Bq/m^3)	--	150 (1-yr) [d]	200 (1-yr) [e]	200 (annually) [g]	--	--	--	Excellent Class: <150 Good Class: <200	400 (1-yr) [h]
Airborne Bacteria (cfu/m^3)	--	--	--	--	--	--	500 (max) [l, m]	Excellent Class: <500 Good Class: <1,000	2500 (depends on instrument used) [h]
Fungi cfu/m^3	200 [b]	150 cfu/m^3 (3 of more species reflective of outdoor flora; 50 cfu $/m^3$ (only one specie other than *cladosporium* or *alternaria*); Up to 500 cfu $/m^3$ (summer if the species is primarily *Cladosporium* or other tree/leaf fungi) [d]	--	--	--	--	500 (max) [l], Up to 500 cfu/m^3 is acceptable[n] (if the species present are primarily *Cladosporium*)	--	--

Note: (a) US EPA (1996), Facilities Manual: Architecture, Engineering, and Planning Guidelines. Maximum Indoor Air Concentrations; (b) US Public Health Services recommend this value for fungal bio-aerosols; (c) Health Canada 1993, revised in 1995; (d) Alberta IAQ Guideline; (e) Health Canada, 2006; (f) Department of Health's Committee on Medical Effects of Air Pollutants (COMEAP) 2004; (g) Indoor Climate and Ventilation of Buildings Regulations and Guidelines 2003, Ministry of the Environment, Finland; (h) General Administration of Quality supervision, Inspection and Quarantine, Ministry of Health, State Environmental Protection Administration of China 2002; (i) Ministry of Health, Labour and Welfare, Japan; (j) Ministry of Labour, Korea I: Offices; (k) Ministry of Environment, Korea II: Public Using Facilities; (l) Guidelines for Good IAQ in Office Premises. Ministry of the Environment, 1996; (m) Singapore Standard SS 554: 2009 "Code of Practice for Indoor Air Quality in Air-conditioned Buildings"; (n) Guidance Notes for the Management of IAQ Management, EPD 2003 (Note: the numerical values are 8-hr averages)

Table 2. Current Methodologies Suggested for Indoor Monitoring of Air Compounds

		Measuring device/Method	Sampling duration	Working concentration	Detection limit	Analysis principle	References
NO_2	Active	NO monitor/NO_2 Converter	Real-time	0-2,000 ppbv	N.R.	Chemiluminescence	[19]
		APNA - 360	Real-time	0-10 ppmv	10 ppbv	Oxidation catalyst + Chemiluminescence	[12]
	Passive	Palmes tube (Gradkos sampler)	2–4 weeks	1.0–10,000 ppbv	0.4 ppbv for 2 weeks	-	[20]
		Ogawa sampler	Over 24 h	0-25 ppmv	2.3 ppbv for 24 h	-	[21]
CO_2	Active	LI-820 CO_2 analyzer	Real-time	0-20,000 ppmv	N.R.	Non-dispersive infrared	[19,22]
		Q-Trak indoor air quality detector	Real-time	0-5,000 ppmv	1 ppmv	Non-dispersive infrared	[11]
		CO_2 Analyzer 2810	Real-time	0-10,000 ppmv	N.R.	Non-dispersive infrared	[12]
	Passive	Passive diffusion sampler	1-6 weeks	0-500 ppmv	1 ppmv	-	[23]
		Type 13X zeolite molecular sieve	42-294 days	N.R.	N.R.	-	[24]
CO	Active	Q-Trak indoor air quality detector	Real-time	0-500 ppmv	0.1 ppmv	Non-dispersive infrared	[19]
		GXH3011 CO analyzer	Real-time	0-200 ppmv	0.1 ppmv	Non-dispersive infrared	[25]
	Passive	Passive diffusion tubes	8 h	N.R.	0.87 ppmv	Colorimetry	[26]
		Personal CO exposure monitor	8 h	0–50 ppmv	0.25 ppmv	Electrochemical	[27]
O_3	Active	Model 202 O_3 analyzer	Real-time	1.5 ppbv -100 ppmv	3.0 ppbv	UV absorption	[19]
		O_3 42M analyzer	Real-time	0-10 ppmv	N.R.	UV absorption	[28]
	Passive	Passive sampling badges	0-14 h	N.R.	0.1 ppbv	Ion chromatography	[29]
		Harvard ozone passive sampler	7-8 h	0-140 ppbv	0.6 ppbv	-	[30]
HCHO	Active	DNPH-coated solid cartridge	10 min- 8 h	N.R.	0.28 μg/m^3	High performance liquid chromatography	[31]
		Optical meter	Real-time	20 ppbv-1 ppmv	20 ppbv	Photoelectric photometry	[32]
	Passive	Diffusive DNPH cartridge	24 h	0.5-800 mg/m^3	3–11 μg/m^3	High performance liquid chromatography	[33]
		Badge-type diffusive MBTH sampler	Long time	N.R.	9.7 ppbv for 24 h	Spectrophotometer	[34]
		SPME	10 min-8 h	0-100 ppbv	1ppbv	SPME-GC/FID[a]	[35]
VOC	Active	Canister	4 h	Multiple measurements	0.5 ppbv	GC/MS[b]	[36]
		Tenax Tube	<2 L in volume	No background pollution	5 ng/m^3	Thermal Desorption-GC/FID	[37]
		Online monitoring by PTR-MS	Real-time	Mobile, sensitive, robust	50 pptv	Proton transfer reaction – mass spectrometry	[38]
	Passive	Activated Carbon	2 h at 50 ml/min	High concentration only, low accuracy	0.2 μg/m^3	Thermal Desorption-GC/FID	[39]
		SPME	30 s - 15 min	Energy free, short exposure time	2 μg/m^3	SPME-GC/MS	[40]

Note: [a] Solid phase microextraction (SPME)-Gas chromatography/flame ionization detection (GC/FID); [b] Gas chromatography/mass spectrometry (GC/MS)