6 Indoor air quality parameters and measurement

6.1 IAQ parameters

IAQ is influenced by thermal comfort parameters and airborne contaminants.

Factors that affect thermal comfort include air temperature, mean radiant temperature, relative humidity and air movement. PMV and PPD can be used as thermal comfort indices that integrate these parameters with clothing and activity for the evaluation of the dissatisfaction level of the occupants in the building (see ISO 7730 and ASHRAE Standard 55).

Airborne contaminants include a wide range of gases, vapours and particulates as well as biological organisms generated from building materials, human activities, office equipment, outdoor air and activities outside the building.

Common airborne contaminants and thermal comfort parameters that are general indicators of IAQ are presented in Table 1 as recommended IAQ parameters. Other contaminants that may exist in a particular indoor environment are presented in Table 2 as Target Contaminants triggered by specific sources. These airborne contaminants, if suspected to be present in the indoor environment, should be included for monitoring and mitigation.

The acceptable limits and methods of measurement of these parameters are included in Tables 1 and 2 respectively.

6.2 Indoor air quality audit

6.2.1 IAQ profile

In order to carry out an indoor air quality audit to develop an IAQ profile of a building, a four-step audit protocol, to be conducted by competent personnel, is recommended as follows (see Figure 1):

a) For existing buildings or premises, the frequency of an IAQ audit should minimally adhere to the frequency of risk management as stipulated under the Workplace Safety and Health (Risk Management) Regulations.

b) For newly commissioned or renovated buildings and premises, an IAQ audit should be conducted after fitting out works and before occupancy.

6.2.2 IAQ Audit Step 1 – Walk-through inspection

A walk-through inspection of the premises and the ACMV system should be conducted to identify possible irregularities. A sample checklist for building inspection is provided in Annex G and the following should be obtained:

a) Building plans showing the details of all the floors, and location of the cooling towers and outdoor air inlets to the building;

b) ACMV system layout plans or schematic diagrams; and

c) ACMV system operating schedule and maintenance records.

6.2.3 IAQ Audit Step 2 – Data collection

6.2.3.1 Conducting air sampling

Measurement of IAQ parameters with reference methods should be made on an eight-hour basis as far as practicable. Where it is not practical to make eight-hour continuous measurement, a surrogate measurement should be conducted. An acceptable surrogate measurement should involve at least three time slots of 30 minutes per sampling point.

Where reference methods are not available, indicative methods can be used to estimate the level of a contaminant.

6.2.3.2 Obtaining feedback from occupants

Feedback on the indoor environmental conditions in the building and the operation of the ACMV system should be obtained from the occupants of the respective building or premises that are undergoing the IAQ audit. A sample of a confidential questionnaire which can be administered to obtain information is provided in Annex I. A customised questionnaire tailored to the needs of the situation could also be used.

6.2.4 IAQ Audit Step 3 – Data analysis

The IAQ parameters measured should be analysed by comparing the data with the recommended acceptable limits in Tables 1 and 2. The analysis should include an investigation into the possible causes if the thermal comfort parameter values fall outside recommended ranges, or the airborne contaminant concentrations exceed the acceptable limits. The questionnaire responses solicited should be evaluated through statistical analysis.

The findings should be documented in an IAQ assessment report. A sample report is provided in Annex J.

6.2.5 IAQ Audit Step 4 – Building remedial action

Based on the findings of the IAQ audit, building remedial measures should be formulated, implemented and evaluated so that good indoor air quality can be achieved and maintained.

Table 1 – Recommended IAQ parameters

Parameter	Acceptable limit	Unit	Measurement method / Analytical method[1)]
i. Thermal comfort parameters			
Air temperature[2)]	23 to 25	°C	Air temperature – by hot wire, thermistor or thermometer sling method. *ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices and local thermal comfort criteria*
Relative humidity	< 65 (for buildings designed to SS 553/SS 554) < 70 (for other buildings)	%	By thin film capacitor, hygrometer or thermometer sling method. *ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*

Parameter	Acceptable limit	Unit	Measurement method / Analytical method[1)]
	(under peak and common part load conditions)		
Air movement [3)]	< 0.30	m/s	By hot wire method for linear air velocity or Kata thermometer for omni-directional air velocity method. *ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*
ii. Chemical parameters			
Carbon dioxide	700 above outdoor (8 h)	ppm	By real-time non-dispersive infra-red sensor method *ISO 12039: Stationary source emissions - Determination of carbon monoxide, carbon dioxide and oxygen - Performance characteristics and calibration of automated measuring systems;* or *EPA IP-3A: Determination of Carbon Dioxide in Indoor Air Using Non-dispersive Infra-red (NDIR).*
Carbon monoxide	31 (1 h) and 9 (8 h) [4)]	ppm	By real-time electrochemical sensor method *EPA IP-3C: Determination of Carbon Monoxide in Indoor Air Using Electrochemical Oxidation*
Formaldehyde	100 (30 min) 0.08 (30 min)	$\mu g/m^3$ ppm	Reference method: By continuous air sampling with dinitrophenylhydrazone (DNPH) cartridges and analysis by High Performance Liquid Chromatography (HPLC). *ISO 16000-3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air – Active sampling method;* *NIOSH 2016 Formaldehyde;* *EPA IP-6A/6B/6C: Determination of Formaldehyde and Other Aldehydes in Indoor Air Using Solid Sorbent Cartridge/continuous Colourmetric Analyser;* or *EPA method 0100: Sampling for aldehyde and other carbonyl compounds in indoor air or equivalent.* Indicative method for screening.[4)]: By detection tubes or real-time electrochemical sensor method. *ISO 16000-2: Sampling strategy for formaldehyde*
Total volatile organic compounds (TVOC) that are photo-ionisable (10.6 eV) [5)] calibrated to isobutylene equivalent	1000 (8 h)	ppb	Reference method: By continuous air sampling with Tenax tube and subsequent analysis using gas chromatography and mass spectrometry. *ISO 16000-6: Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA*

Parameter	Acceptable limit	Unit	Measurement method / Analytical method[1)]
			sorbent, thermal desorption and gas chromatography using MS or MS-FID; *EPA IP-1B: Determination of volatile organic compounds (VOCs) in ambient or indoor air using solid sorbent tubes;* or *NIOSH Manual of Analytical Methods 2549: Volatile Organic Compounds Screening* Indicative method for screening: By real-time photoionisation detector method.
iii. Particulate matter			
Respirable suspended particles (particles sampled with a median cut-point of 4 µm)	50 (24 h)	µg/m^3	Reference method: By gravimetric analysis, beta-attenuation, tapered element oscillating microbalance (TEOM) or indicative method calibrated to gravimetric method.
PM 2.5	37.5 (24 h)	µg/m^3	*EPA IP-10A/10B: Determination of Respirable Particulate Matters In Indoor Air using size specific impactor/continuous particulate monitor;* or *EN 12341: Standard gravimetric measurement method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter.* Indicative method for screening[6)]: By real-time optical scattering or piezoelectric monitoring method.
iv. Biological parameters[7,8)]			
Total viable bacterial count	1000	cfu/m^3	By single-stage airborne microbial-viable impactor method with performance equivalent to Anderson (N6) or equipment with flow rate of 28.3 L/min (1 ft^3/min) for 4 minutes, or equal volume of air. Bacteria is cultured by Tryptone Soya Agar (TSA) media and incubated for 48 hours at 35 ^{0}C. The samples on the culture plate should yield between 30 and 300 colonies for best results. *NIOSH 0800: Bioaerosol Sampling-Indoor Air* When a single species dominating from the culture plate, speciation should be done

NOTES –

1) For laboratories using measurement/analytical methods that are not listed in Table 1 and 2, the accuracy of such methods shall be demonstrated and documented in the IAQ audit report.

2) Where radiant heat is of concern, it is more relevant to consider the operative temperature. Operative temperature is the average of the air temperature (weighted by the convective heat transfer coefficient) and the mean radiant temperature (weighted by the linearised radiant heat transfer coefficient for the occupant). For occupants engaged in near sedentary physical activity (with metabolic rates between 1 and 1.3 met), not in direct sunlight, and not exposed to air velocities greater than 0.20 m/s, the relationship can be approximated with acceptable accuracy as follows:

Operative temperature, $T_o = \frac{T_a + T_r}{2}$

where:

T_a = air temperature in ^{0}C

T_r = mean radiant temperature in ^{0}C (see also ISO 7726 'Ergonomics of the thermal environment - Instruments for measuring physical quantities')

Mean radiant temperature for a fully clothed subject, $T_r = T_g + 2.44 \times V^{0.5}(T_g - T_a)$

T_g = globe temperature in ^{0}C

T_a = air temperature in ^{0}C

V = air speed in m/s

3) Air speed and air temperature can be controlled to improve thermal comfort. Low air speed can be compensated by reducing air temperature; and relatively high air temperature can be compensated by increasing air speed.

4) The duration associated with the recommended level of each parameter refers to the exposure period, and not the sampling period. If a surrogate measurement is to be used, refer to the lowest recommended level.

5) Indicative method may not be as accurate as reference method, but can be deployed as a method for screening.

6) When TVOC > 1000 ppb or when smell is perceived or when ventilation rate is less than the recommended rate by SS 553, remediation work should be carried out to reduce the TVOC level. Identifying the individual VOC species could be performed to target pollutant sources (Annex C) for more effective remediation work.

7) The indicative method for PM has an inherent source of error due to the characteristic differences between the calibration and test dust. The value obtained using this method is only indicative of the general cleanliness of the premise. If the accuracy of the PM level is crucial, the reference method should be used.

8) Micro-organisms are ubiquitous in indoor environment and do not necessarily constitute a health hazard. The concentration at which each microorganism becomes a threat to health is unknown and may vary greatly with each individual. Culture-based methods are suitable for detection of culturable agents and allow species identification. However, it is widely agreed that only a small fraction (0.1 to 10 %) of the total microbial flora in an indoor environment is currently culturable (White DC, 1983). Total viable bacterial count is only a measure of the sanitary conditions of the premises and may not correlate with the presence of any specific pathogen. Total Viable Mould Count has been excluded because it does not reflect the extent of fungal contamination. Culture method detects mainly spores, concentration of which fluctuates with sporulation cycles of the fungus. Moreover, mould allergens and toxins, which are contaminants of concern, are produced by hyphae fungal fragments and mycelial growth (WHO, 2009), which are not quantified by culture methods. ASHRAE Position Document on Limiting Indoor Mould and Dampness in Buildings (2012) recommends that the presence of visible water damage or stains, visible mould, and/or odours from microbial growth — alone or in combination — is a warning and calls for necessary action to remediate the source of the water accumulation or mould infestation.

9) IThe presence of visible water damage or stains, visible mould, and/or odours from microbial growth, alone or in combination is a warning (ASHRAE, 2013) and an investigation process should be initiated. The investigation should involve the use of culture and molecular method (but not limited to these 2 methods), so as to be able to establish any epidemiological link.

Table 2 – Target contaminants triggered by specific sources[1)]

Parameter	Acceptable limit	Unit	Measurement method / Analytical method
Nitrogen dioxide	40 (8 h)	$\mu g/m^3$	By real-time chemiluminescence, diffusion tube passive samplers, chemical detector tubes method. *ISO 16000-15: Sampling strategy for nitrogen dioxide (NO_2); NIOSH Methods 6014: Nitric oxide and nitrogen dioxide;* or *EPA IP-5A/5B/5C: Determination of Nitrogen Dioxide in Indoor Air using continuous chemiluminescence monitor/diffusion tubes/ passive sampling device*
Ozone[2)]	0.05 (8 h)	ppm	By real-time chemiluminescence, gas-sensitive semi-conductor, chemical detector tubes method *ISO 10313: Ambient air - Determination of the mass concentration of ozone - Chemiluminescence method*
Radon	100 (8 h)	Bq/m^3	By an electronic radon monitor equivalent method which complies with the device performance test described in the USEPA National Radon Proficiency Program Handbook (EPA, 402-R-95-013, Jul 1996) *ISO11665: Measurement of radioactivity in the environment – Air: radon-222 Part 6: Spot measurement method of the activity concentration*
Asbestos	0.01 (8 h)	fibre / cc	By phase contrast microscopy method followed by Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM) method for identification of fibre.[3)] *Phase contrast microscopy* *ISO 8672: Determination of the number concentration of airborne inorganic fibres by phase contrast optical microscopy -- Membrane filter method; or* *NIOSH Methods 7400: Asbestos and other fibres by phase contrast optical microscopy* *SEM* *ISO 14966: Ambient air - Determination of numerical concentration of inorganic fibrous particles - Scanning electron microscopy method* *TEM* *ISO 10312: Ambient air - Determination of asbestos fibres - Direct transfer transmission electron microscopy method*
Nicotine	< 0.01 (8 h)	$\mu g/m^3$	By air sampling using XAD-4 tubes and subsequent analysis using gas chromatography with nitrogen selective detection method. *NIOSH Methods 2551: Nicotine method Using XAD-4 Sorbent Tube; or* *ASTM D5075: Standard Test Method for Nicotine and 3-Ethenylpyridine in Indoor Air*
Semi volatile and volatile organic compounds (VOC)	Permissible exposure limit (PEL) of toxic substances	ppm	By continuous air sampling with Tenax tube and subsequent analysis using gas chromatography and mass spectrometry. *ISO 16000-6: Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID;* *EPA IP-1B: Determination of volatile organic compounds (VOCs) in ambient or indoor air using solid sorbent tubes;* or *NIOSH Manual of Analytical Methods 2549: Volatile Organic Compounds Screening*

NOTES –

1) The listed contaminants may not be commonly found in a typical indoor space, but should be monitored in a situation when a potential source is suspected. When any suspected IAQ concern cannot be traced to IAQ issues, other factors such as ergonomic (e.g. lighting, noise) and work stressors covered in SS 514 `Code of Practice for Office Ergonomics' may be considered.

2) It is important to ensure that indoor ozone concentration levels are not elevated at all times, even if it is generally within the permissible exposure level (PEL). Recent research findings suggest that elevated ozone levels in the indoor environment (e.g. ozone from outdoor air or ozone generating equipment) can trigger indoor chemistry involving ozone and VOC, resulting in oxidation products that can be associated with poor perceived air quality, irritation and health impacts.

3) Phase contrast microscopy is the accepted method for measuring the asbestos-in-air concentration. However, the method, which does not discriminate fibres of different composition, could lead to false positives due to other fibres (e.g. fibre glass, gypsum, etc.). For confirmation of presence of asbestos, electron microscopy methods, such as Transmission Electron Microscope or Scanning Electron Microscope, should be used in conjunction. .

Additional Note - For background information on the airborne contaminants, mould remediation, prevention of mould in dwellings and clean-up methods, refer to Annex C.

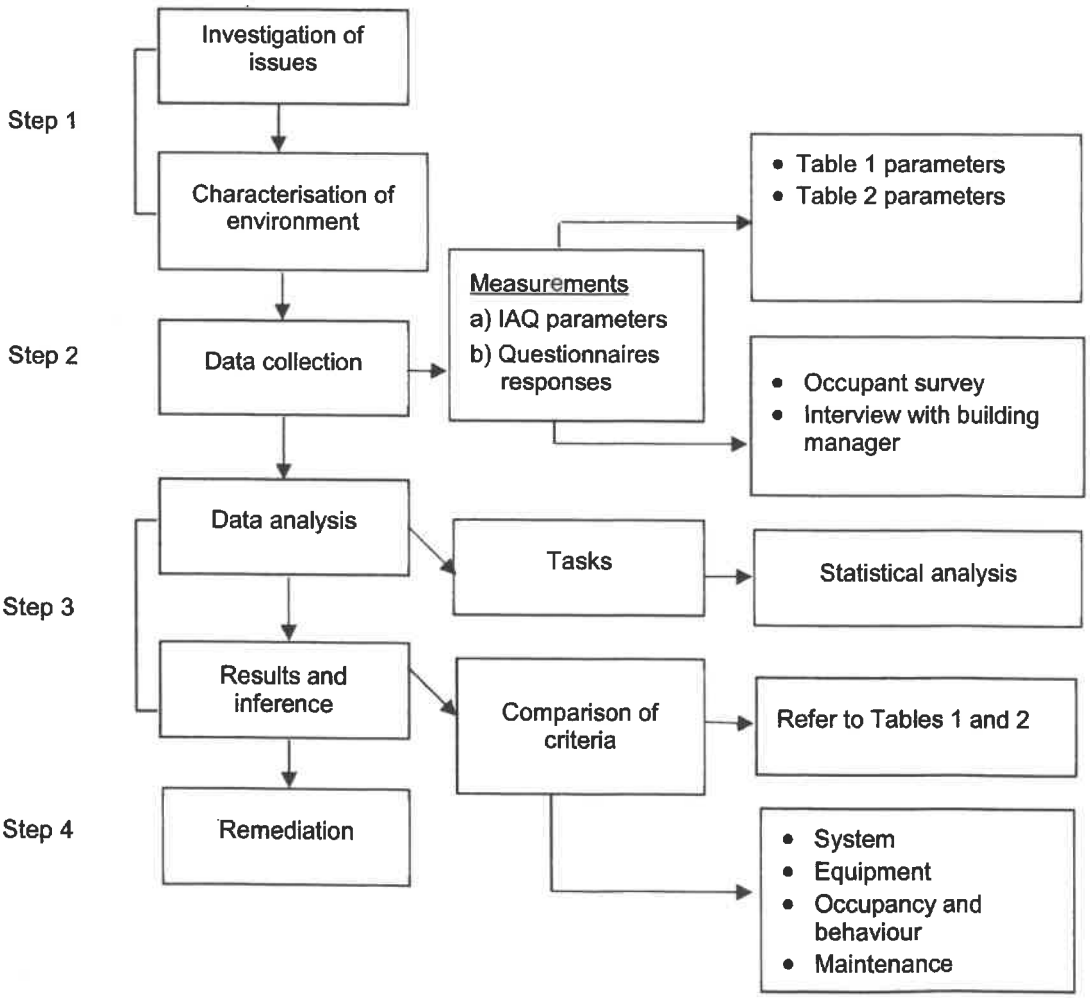

Figure 1 – Indoor air quality audit methodology

6.3 Measurement of indoor air quality

6.3.1 Outdoor sampling points

Outdoor measurements should be performed whenever indoor measurements are performed.

At least one sampling point should be located at or near the outdoor air intake, if possible. Otherwise, an alternate sampling location that would represent the conditions of outdoor air intake should be taken.

6.3.2 Indoor sampling points

6.3.2.1 Number of sampling points

In order to determine the number of indoor sampling points, the following should be considered:

a) Number of floors in the building;

b) Floor area of each floor/premises and ventilation types; and

c) Indoor generated pollutants that could exfiltrate to surrounding premises.

6.3.2.2 Number of floors in the building

For a multi-storey building, the percentage of floors to be randomly sampled is indicated in Table 3.

Table 3 – Sampling requirements for a multi-storey building

Number of occupied floors in a building	Percentage of randomly selected floors to be sampled (%)*
< 5	80 % of floors*
5 - 10	70 % of floors*
11 - 20	60 % of floors*
21 - 30	12 floors or 50 % of floors*, whichever higher
31 - 40	15 floors or 40 % of floors*, whichever higher
41 - 50	16 floors or 35 % of floors*, whichever higher
> 50	18 floors or 30 % of floors*, whichever higher

NOTE – * Round up to whole number.
The recommended or required sample size will ensure with 90 % confidence that at least one floor from the 10 % floors with the highest IAQ levels is included or contained in the sample.

6.3.2.3 Floor area of each floor/premises

For each selected floor/premises, at least one sample should be taken from each separated area serviced by a separate air handling unit (AHU).

For each selected floor/premises served by fan coil unit (FCU) or any air-conditioning or air distribution system, the number of sampling points is determined by the floor area.

The number of sampling points required is indicated in Table 4.

Table 4 – Sampling requirements for indoor environment

Area of floor (m^2)	Minimum number of sampling points
Below 3000	1 point for every 500 m^2
3000 - 5,000	6, with 1 additional point for every 1000 m^2
5,000 - 10,000	8, with 1 additional point for every 1250 m^2
10,000 - <15,000	12, with 1 additional point for every 1500 m^2
Above 15,000	15, with 1 additional point for every 2000 m^2

6.3.2.4 Additional points

For investigative purposes (e.g. exfiltration/infiltration of pollutants), additional sampling points could be assigned at relevant locations.

6.3.3 Sample position

Samples should be collected from an area with the highest occupant density or area with potential IAQ issues.

The sampling point or sampling probe should be located between 75 and 120 cm from the floor at the centre of the room or an occupied zone, and as close as possible to the breathing zone of the building occupants.

7 Competency of IAQ personnel

Indoor air quality auditing and air sampling should be conducted by a competent person who has attended and met the requirements of an indoor air quality course conducted by a training provider that is recognised by the cognizant authorities.

Samples that require laboratory analysis should be analysed by a laboratory accredited for procedures related to the analysis of indoor air quality parameters under the Singapore Laboratory Accreditation Scheme (SINGLAS) administered by the Singapore Accreditation Council (SAC).

The competent person shall ensure that the instruments used are properly calibrated and records of calibration are maintained.