Workplace Safety and Health Guidelines

Management of Indoor Air Quality in Air-Conditioned Workplaces

WSHCOUNCIL

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1 Introduction

Indoor air quality (IAQ) is an important subject in our daily life as we spend a substantial amount of our time indoors. Most people spend their working hours in indoor spaces such as offices, factories and other buildings. In Singapore, where the climate is hot and humid, we rely heavily on air conditioning and mechanical ventilation (ACMV) system to provide thermal comfort in sealed indoor environments. The subject of IAQ becomes more pertinent since the potential for indoor air contamination is increased. Sources of contamination can include carpets, rugs, laser printers and photocopiers. The air quality in these tightly sealed environments is hence affected by gases (including volatile organic compounds), particulates, and microbial contaminants such as mould and bacteria.

Poor air quality in indoor air-conditioned workplaces can result in potential health and comfort problems for occupants. Some acute health effects associated with poor IAQ include coughs, headaches and eye irritation or connotatively referred to as sick building syndrome. This can then lead to the consequential decline in work productivity when sickness-absenteeism prevails. Good IAQ is therefore essential to ensure the health and wellbeing of all people in indoor environments such as buildings and offices.

Recognising the need for practical guidance in the management of IAQ in buildings and/or workplaces, this set of guidelines was developed. It will also supplement the Singapore Standard SS 554: 2009, Code of Practice for Indoor air quality for air-conditioned buildings, in the effective establishment and on the-ground implementation of the IAQ Management Programme.

This set of guidelines is primarily aimed at building owners or occupiers of workplace who have direct control over the risks associated with poor IAQ, as well as the responsible person who is appointed as the IAQ Manager (e.g., facility manager) for the premises in which he or she owes a duty of care.

2 Terms and Definitions

For the purpose and context of this publication, the terms used and their definitions are explained in Table 1.

Terms	Definitions
Accredited Laboratory	A laboratory that is operated by the government, statutory board or any private entity which is accredited under the Singapore Accreditation Council's Accreditation Scheme for Laboratories (SAC SINGLAS). For more information, refer to SAC's website at: http://www.sac-accreditation.gov.sg/Resources/sac_documents/Pages/Laboratory_Accreditation.aspx
Airborne Contaminant	An unwanted airborne constituent that can compromise the quality of indoor air.
Competent Person	A person who is qualified by training and experience, has sufficient knowledge of IAQ, and is recognised by cognisant authorities to perform the work to be carried out.
Cognisant Authority	An agency or organisation that is recognised as authoritative and has the expertise to establish guidelines, limit values, or concentration levels for airborne contaminants; or an agency or organisation that has the expertise and jurisdiction to establish and regulate concentration limits for airborne contaminants.
Environmental Tobacco Smoke (ETS)	Mixture of aged and exhaled mainstream and side stream smoke produced from the burning of tobacco substance.
Indoor Air	Air inside a building, including air which is within a room and air which is removed from a room by mechanical means.
Outdoor Air	Ambient air entering the system or opening from outdoors before any air treatment.
Sick Building Syndrome	An excess of work-related irritations of the skin and mucous membranes and other symptoms (including headache and fatigue) reported by occupants in modern office buildings.
Third Party or Professional Assistance	The practice of obtaining assistance or guidance from person(s) outside of the organisation who are experienced or knowledgeable in air quality, when internal knowledge is not sufficient.

Table 1: Terms and definitions.

3 Risk Management

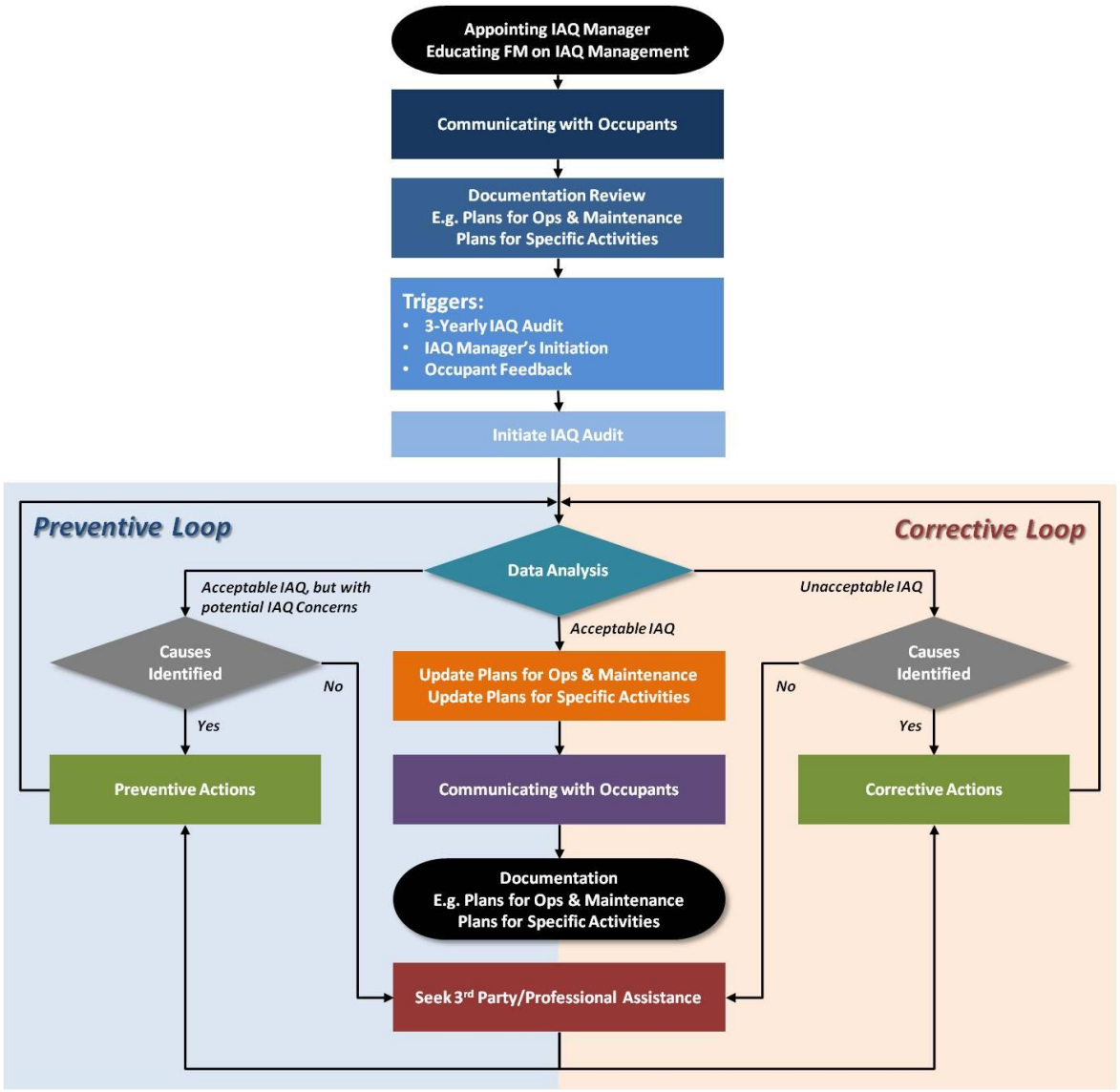
Safety, health and wellbeing should be managed holistically, both at the workplace and of the employees. Under the Workplace Safety and Health (Risk Management) Regulations, organisations are required to conduct risk assessment (RA) to identify, evaluate and control safety and health risks posed to any person who may be affected by the activities in the workplace. RA aims to reduce workplace incidents and improve the overall safety, health and wellbeing of everyone in the workplace.

A proper and thorough RA must be conducted prior to the start of any IAQ management related work and activity. The RA should identify all potential hazards, establish all the risks associated with IAQ management work (e.g., carrying out maintenance work on ACMV system at height), and propose measures to prevent or minimise these risks. Available documents such as building specifications and survey reports should be referred to when conducting RA, so as to ensure a thorough understanding of the area or work for a more effective RA.

Figure 1: Solvent used to remove adhesive on flooring can introduce Volatile Organic Compounds (VOCs) into the air and adjacent units.

For more information on RA, refer to the Workplace Safety and Health (WSH) Council's *Approved Code of Practice for WSH Risk Management*.

4 IAQ Management Framework Flowchart



5 IAQ Management Programme

The IAQ management programme provides a systematic approach to achieving good air quality in indoor work premises such as air-conditioned buildings.

The following sections will provide guidance arranged in a typical sequence of establishing an IAQ management programme in most types of establishments and proceed with more information on how processes and situations are dealt with towards this goal.

5.1 Appoint IAQ Manager

The IAQ Manager is responsible for establishing and managing the overall IAQ management programme within the building or premise. He or she should be sufficiently familiar with the building or premise, and afforded direct access to the building owner or occupier. It is paramount that the IAQ Manager is experienced and competent for the job. Competency can be attained through completing relevant training courses[1].

To assist him or her in the management of IAQ within the building, the IAQ Manager can establish an IAQ team. The members in the team should also preferably demonstrate the relevant competency through appropriate courses.

5.2 Communicate with Occupants

Prior to the commencement of IAQ management activities, all relevant stakeholders such as building owners, tenants and contractors should be made aware of their roles in maintaining acceptable IAQ, and commit to cooperate in the effort. The IAQ Manager should disseminate the relevant information such as policies and terms relating to the maintenance of acceptable IAQ in the building. He or she should also provide regular updates to occupants and tenants on the IAQ of the building.

From time to time, feedback should be obtained from building occupants to ensure that the current operations match the needs and activities of the occupants, and to solicit information on possible IAQ problems (e.g., the existence of health problems that may be related to the indoor environment within the building). The IAQ Manager can obtain feedback from occupants in the form of a questionnaire to collect information from environmental conditions to health issues or complaints.

[1] The "Manage Indoor Air Quality" course module is offered under the WSQ Specialist Diploma in Occupational Hygiene by the relevant training providers. Visit WDA's website at www.wda.gov.sg/content/wdawebsite/L207-AboutWSQ/L301-WSQIndustryFramework-OccupationalHygieneProfessionals.html for more details.

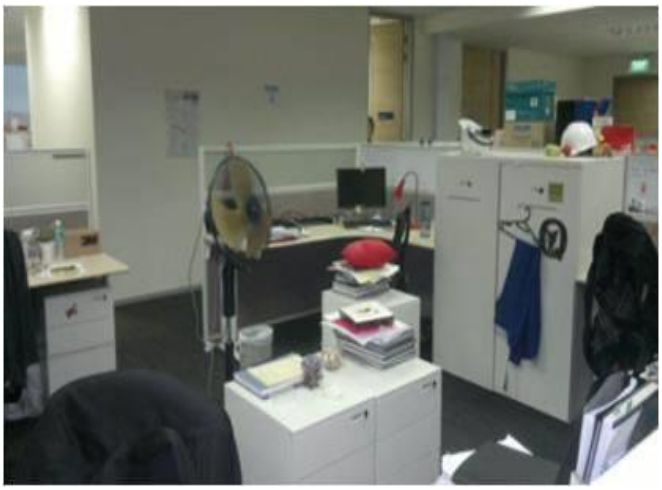


Figure 2: Presence of fan in the office may indicate thermal discomfort.

The IAQ Manager may even explore conducting in-house training for the facility management (FM) personnel to educate them on IAQ management. Such training can equip these personnel with the necessary knowledge to better manage IAQ issues at the workplace besides raising their awareness in this area.

5.3 Review Document

Documentation review is necessary for the diagnosis of potential IAQ problems in the building. This will aid in the formulation and implementation of any remedial action downstream. Documents to be collected for review include existing operations and maintenance records, previous IAQ audit results (including any corrective action taken), building specifications and design, and so on. A sample documentation checklist that identifies a list of useful documents to be gathered for review purposes is given in **Appendix A**.

To identify those relevant documents for review, the responsible person or IAQ Manager should recognise those activities in the air-conditioned environment that can have potential adverse effects on the air quality. Some of these activities include addition and alteration (A&A) works, custodial cleaning and pest control. Each of these activities has the potential to produce indoor air pollutants that may cause acute or chronic health effects.

Figure 3: Renovation fumes from a room being exhausted into the common corridor.

The following table shows the types of pollutants that can be generated from specific activities taking place in the building. Other activities that are specific to the nature of the business or workplace with the potential of releasing air pollutants should be noted accordingly.

Pollutant Type / Activity	Particles	Biological	Chemical	Odour
Renovation Works	✓		✓	✓
A & A Works	✓	✓	✓	✓
Pest Control	✓		✓	✓
Cleaning & Maintenance	✓	✓	✓	✓

Table 2: Characterisation of IAQ pollutants to specific activities.

For those activities recognised, the information and documentation specific to each of them are to be obtained from the parties involved. Such information or documentation can include the methodology of the activities and the materials used.

5.4 Initiate IAQ Audit

It is important to ascertain the objective of an IAQ audit so that the intended outcome could be achieved by carefully planning of the sampling points and parameters to be measured.

5.4.1 Triggers for IAQ Audit

The following are common triggers for initiating an IAQ audit:

- 3-yearly IAQ audit;
- IAQ Manager's initiation to collect data before and after rectification work; and
- Feedback on poor IAQ from occupants.

5.4.2 Preparation

An IAQ audit may be performed by a competent person either from within the organisation or from a third party IAQ consultancy. Before conducting the audit or engaging an IAQ consultant, the IAQ Manager should prepare the following documents:

- Past IAQ report including floor layout plans, ACMV layout plans, past sampling points, and so on to show consistency in sampling location and sampling requirement;
- Records for all preventive and corrective actions performed to show that the effort and effectiveness of any such action(s) taken;
- Records on occupants' feedback including both routine questionnaire and ad-hoc feedback that indicate the occupants' perception on air quality in the building or premise;
- Records for operation and maintenance of the building or premise as changes to ACMV system may influence change in testing requirements; and
- Records for specific activities [e.g., alteration and addition (A&A) works, pest control, cleaning services, other potentially polluting activities] which may influence change in testing requirements.

In addition, a walk-through inspection should be conducted to detect any irregularities which may adversely affect the perceived and/or measured air quality. The irregularities, such as visible mould, water leakages and malfunction of air-conditioning system, should be rectified before the start of the IAQ audit.

Figure 4: Fungal growth on ceiling board.

Figure 5: Water marks on ceiling board may indicate leakage from water pipe.

5.5 Evaluate Findings

From the audit findings, the measured values of the various IAQ parameters or common airborne contaminants (e.g., thermal comfort, chemical, respirable suspended particles and biological) and other contaminants (e.g., PM 2.5, asbestos and volatile organic compounds) are evaluated against the recommended acceptable limits in SS 554: 2009. See Table 1/Table 2 of Singapore Standard SS 554 – "Code of Practice for Indoor Air Quality for Air-conditioned Buildings" for recommended IAQ parameters or target contaminants triggered by specific sources. The IAQ manager should also observe if there are any unusual trends by comparing with past year results, if available.

There are three possible outcomes arising from the evaluation:

(i) Acceptable IAQ

Acceptable IAQ is where a substantial majority (80%) of occupants express no dissatisfaction towards the air in an occupied space. The air is also unlikely to contain known contaminants at concentrations leading to exposures that would pose a significant health risk.

(ii) Acceptable IAQ, but with potential IAQ concern

If results indicate acceptable IAQ but with elevated levels and/or increasing trends or other potential IAQ-related contaminants beyond those found in Table 1/Table 2 of SS 554 [e.g., *Legionella*, hydrogen sulphide (H_2S), odour], preventive actions should be taken.

(iii) Unacceptable IAQ

When the requirements for acceptable IAQ are not met, corrective action should be performed.

5.6 Determine and Implement Course of Action

From the evaluated outcome, the appropriate course of action may be determined. The following table lists some possible actions based on the different outcomes.

Acceptable IAQ	• Communicate findings to building occupants.
Acceptable IAQ, but with potential IAQ concern	• Develop a preventive action plan. • Communicate findings to building occupants. • Seek third party or professional advice, where necessary.
Unacceptable IAQ	• Develop a corrective action plan. • Update any improvement made to existing plans, for example, as-built ACMV layout, pest control schedule, maintenance schedule, new maintenance or housekeeping procedures. • Establish a communication channel for timely updates and feedback on the updated plans to all stakeholders (including FM team, contractors, tenants, building owner, building management). • Seek third party or professional advice, where necessary or when the causes cannot be identified.

Table 3: Evaluation outcomes and possible courses of action.

After determining the course of action, whether corrective or preventive, proceed to implement the shortlisted measure(s) that is/are appropriate for the premise. The following may be considered before implementing the measures:

- Always select an energy efficient measure;
- Availability for space;
- Inter-reactivity between current installation and new measures;
- Potential generation of secondary by-products which could be harmful to occupants; and
- Sustainability of the effectiveness of the new measures.

Annex B provides some suggested actions for certain IAQ problems.

5.7 Perform and Update Documentation

The effectiveness of each action taken should be reviewed to ensure the effective intervention. This may include but not limited to the comparison with historical data, evaluation of different stages of actions taken, and so on.

All the relevant information and records to develop and/or support the IAQ management programme should be documented. Documentation enables the correct execution of the various elements or steps in the proper management of IAQ which will lead to the achievement of the objective of the programme. The maintenance of documents also serves as evidence of results achieved or activities performed.

The IAQ audit final report is one document that must be kept. It should contain details which can include, but not limited to:

- documentation review;
- observations from walk-through inspection;
- measurement methodology used;
- IAQ parameters monitoring results;
- existing and potential IAQ problems or areas;
- remedial or preventive actions or measures; and
- communications with building occupants.

Feedback received (verbal and written) on IAQ issues should also be properly documented. Feedback on poor IAQ that warrant further investigation should be followed up with. **Annex C** provides some procedures that could be established for responding to IAQ complaints.

Appendix A – Sample Documentation Checklist

DOCUMENTATION CHECKLIST*

Workplace Name: _____

Workplace No: _____ Date:_____

Type	**Document Ref.** **Name & Contact No. (if any)**	**Yes**	**No**
Specifications and Design			
Ducting floor plans			
Original or new ACMV: Equipment and specifications list			
Equipment settings			
Testing and balancing			
Commissioning reports			
ACMV components' operation and maintenance schedules			
Facilities Operation and Maintenance			
Tenancy list and activities			
Housekeeping schedules			
Routine cleaning activities or services			
Pest control activities or services			
Register of Safety Data Sheets (SDS)			
Records			
Questionnaires			
Feedbacks and complaints			
IAQ investigation reports [(1)]			
Sketch plan[(2)]			

(1) Reports should include communication records and remedial actions for IAQ-related incidents.

(2) Sketch plan should show the possible locations where IAQ problems are present that require close monitoring, further investigation and/or corrective action.

* This checklist is not exhaustive. Users should customise the checklist to suit their needs to ensure a comprehensive documentation review.

Appendix B – Suggested Actions for IAQ Problems

IAQ Problem	Potential Sources or Causes	Suggested Actions or Plans
Thermal comfort problem (air or radiant temperature, RH, air velocity)	Too much or too little air movement. Inadequate thermal zoning or control. Sun-lit window. Excessive heat sources (e.g., server, equipment, printer cluster). Inadequate dehumidifying performance of cooling coils. Raising indoor set-point temperature without compensatory humidity control. Short-circuiting of supply air to the return grill. Personalised intervention that interfere with the design intention (opening of window or tampering of the supply diffuser) when the indoor space is too cold.	Reduce or increase air movement. Improve localised air movement. Air balancing.
High Relative Humidity (RH)	Flooding or water leaking or poor construction joints. Condensation due to adjacent air-conditioned and non-air conditioned space. Loss in integrity of insulating materials on chilled water pipes or punctured vapour barrier. Excessive and prolonged cooking activities. Inadequate dehumidifying performance of cooling coils. Raising indoor set-point temperature without compensatory humidity control.	Identify source of moisture and rectify it. 1) Structure integrity: Ensure integrity of water-proofing layer in the respective structure(s); 2) Activity of occupants: Avoid opening of windows while air-conditioning system is being switched on. 3) ACMV system: Ensure adequate cooling and dehumidifying performance as per design. Type of filter media to use—water resistance glass fibre paper media. Avoid using filter with high loft glass fibre fleece media and synthetic media. The high loft media commonly used in pockets filter and deep pleat box filter. Its performance is doubtful due to constant fibre shedding throughout its service life. The loss of filtering element reduces it efficiency. The media absorbs moisture in the air, when dampened, it is conducive for bacteria growth and the media tear easily.

		Synthetic media depends on electrostatic charge to remove particles performs well initially but lost it effectiveness when the electrostatic on the media is drained due to usage and earthed. Air distribution components and joints in return plenums and supply and exhaust ducts must be sufficiently airtight to prevent suction that otherwise pulls humid outdoor air into the building and/or leakage that allows cold supply air to chill surfaces inside humid building cavities. Mould and microbial growth accelerate when the indoor dew point stays high while surfaces are intermittently chilled by cooling systems.
Carbon dioxide level exceeded limit	Over-crowding. Insufficient outdoor air intake (ventilation) and/or air distribution. Presence of combustion activities.	Ensure CO_2 levels are within SS554 limit. Explore strategies to reduce CO_2 levels (e.g., increase ventilation, check air distribution, for instance, by identifying dead space and combustion sources or other CO_2 sources).
Carbon monoxide exceeded limit	Incomplete combustion from indoor cooking activities (e.g., personalised stoves using charcoal and gas, etc.). Infiltration from adjacent areas and activities [e.g., vehicular exhaust, environmental tobacco smoke (ETS)].	Explore strategies to exhaust CO to outdoors [e.g., proper selection and operation of local exhaust ventilation (LEV)]. Explore strategies to prevent CO from entering (e.g., adequate air pressurisation; install air curtains). Contact concerned parties (when the source is from the adjacent properties or areas) to resolve CO issue.

High formaldehyde and VOC content in the air	New furnishings and building materials (e.g., wooden furniture, ceiling and partition boards, carpeting, vinyl flooring, fabric or synthetic materials in rugs and upholstery etc.). Paints, lacquers, adhesives and glues. Cleaning and pest control chemicals. Chemical-based air fresheners or scenting. Infiltration from adjacent areas and activities (e.g., petrol stations, pedicures, manicures or hair salons, etc.). Inadequate ventilation or means to remove the build-up of chemicals.	Specify formaldehyde-free and low-VOC emission materials in your contract. References may be made to the following: - Green Label endorsed product list by SEC (www.sec.org.sg/awards/greenlabel/buygreen); and - Singapore Green Building Council (SGBC) Material Labelling System (www.sgbc.sg/green-certifications/online_catalogue/). Manage the use of cleaning or pest control chemicals. Manage the use of air fresheners. Appropriate ventilation or exhaust strategies should be considered to manage indoor activities that generate excessive chemical pollutants. Proper selection and operation of air cleaning technologies (gas phase filtration) should be considered as the last resort.
High particulate level (PM10, RSP, PM2.5)	Infiltration (e.g., outdoor air, vehicular exhaust, diesel vehicle, haze). Inadequate filtration (e.g., haze[2], poor installation of filter). Construction work. Indoor air chemistry (e.g., secondary products from ozone reaction with cleaning agents, air fresheners, indoor emission from fabrics and furniture). Indoor activities (printer, photocopiers, vacuuming, cooking, smoking, misting machine, other combustion activities). Renovation work. Air distribution through carpeted floor tiles.	Identify the source of particulate matter and rectify it. Ensure appropriate rating of the air filter (refer to SS554).Ensure no unintentional by-pass (leaks) of the air filter and all joints are sealed. Maintain air filter according to manufacturer's recommendations, for example, use the filter within its airflow capacity and replace it when it has reached the final pressure drop or the system allowed for optimum performance. Ensure that no infiltration of renovation fume and duct into the occupied areas. Explore additional preventive measures for extraordinary external causes such as haze and adjacent sites under construction or demolition (e.g., install efficient filter at the outdoor air intake

[2] The main air pollutant in the event of haze is particulate matter (PM). Appendix D discusses some measures that can be taken to manage PM levels in air-conditioned buildings.

		duct).AHU existing filter installation is 2-stage filtration systems that normally would have sufficient fan static for higher grade fine dust filters such as MERV 15/EN779-F9. This filter has a higher safety factor to overcome higher PM concentration. If existing AHU filter are of low efficiency coarse dust filter and upgrading is not possible, install a Filter Fan Unit (FFU) to draw in the required outdoor air volume to the ACMV system. This is to avoid the filter pressure drop overstretching the AHU limited fan static. Alternatively, if upgrading is possible and to avoid replacing the AHU fan; increase the existing filtering area to accommodate more high efficiency filters. The number of filters required is based on the filter operating airflow determine by its initial pressure drop similar or lower than the existing low efficiency filter. Pre-filter is not necessary.

		The FFU or AHU should be equipped with 2-stage filtration of MERV 10 & 15 / EN779 - M6 & F9 filters to handle the high inflow of coarse and fine particles. A good filter combination that has both economic benefit and better IAQ. Select filters with glass fibre paper media, high air flow capacity and low initial pressure drop. Both filters should have large media area for longer service life. To minimise indoor fine dust pollution, the following could be explored: Outdoor air: Use high efficiency filter with booster fan to overcome filter pressure drop or. Pre-cool MAU (Make- up Air Unit) or AHU: Install MERV 13/EN779-F7 at the pre-cool MAU to protect the cooling coil and as pre-filter to the downstream higher grade filter MERV 15/EN779-F9 to be installed in the AHU. Select filters with glass fibre paper media, high air flow capacity with low pressure drop. Both filters should have large media area for longer service life. For Electronic Air Cleaner (EAC) Users: The device is not an air filter per se and it is vulnerable to breakdown that would not be noticeable until the next servicing. This could affect indoor air quality and the cooling coil. Therefore, its performance is not guaranteed. It is necessary to conduct daily testing to ensure every unit of installation is functional. EAC is velocity sensitive and its peak efficiency happens when the unit is clean and deteriorates when the collecting plates get dirty. It is recommended that the occupier installs low pressure drop filter of MERV 15/ Class F9 after the EAC as the primary or backup filtration.

Total bacterial count exceeded limit	High human traffic. Insufficient outdoor air intake (ventilation) and/or air distribution. Presence of moisture and biological matter (e.g., food, drinks and poor waste management). Presence of dampness [e.g., on building materials and upholstery; stagnant water in air-conditioning and mechanical ventilation (ACMV) components; leakages and seepages; wrong use of humidifier].	Ensure that TBC levels are within SS554 limit. Promptly look out for and identify water sources in order to rectify the dampness issue (e.g., fix leakages; remove source of dampness; replace wet or water damaged materials) Proper selection and operation of air cleaning technologies should be considered. Refer to **Appendix B-1** for the available air cleaning technologies.
Mould growth	Refer to sources and causes for high RH (see above). Presence of organic nutrients or food. Interstitial condensation. Water-retaining materials. Poorly ventilated and dark spot. Poorly maintained AHU (e.g., by pass of the air filter or condensate pan or coils). Basement waterproofing layer and source of moisture. Waterproof wall paper and leaky pipes to reduce risk of hidden mould.	Refer to Suggested Action for High RH. Besides ensuring Total Fungal Counts (TFC) within SS554 levels, ensure no visible mould and musty or earthy fungal smell. Undertake effective remediation. Discard the porous materials. Disinfect the non-porous materials (e.g., air-conditioning duct). Implement preventive measure (e.g., Ultra-violet Germicidal irradiation (UVGI) at the AHU).
Ozone	Emitted from ozone generating equipment (e.g., generator, ozone producing ioniser, photocopier, etc.). Infiltration of ozone from outdoor air (e.g., during haze period).	Choose non-ozone emitting products or processes, control the source by isolation and/or local exhaust from occupied areas. Proper selection and operation of air cleaning technologies should be considered.
Asbestos	Ceiling boards, partitions or wall panels or fire walls containing asbestos in buildings built before 1990.	Ensure no puncturing of the insulation material and compiled with asbestos level within SS554 limits. Contract an accredited laboratory to conduct the air sampling after the remediation measures have been completed. The room should be dry and surfaces and furniture of the room should be swept to re-suspend any remaining asbestos while air sampling is being conducted. See SS554 Table 2 for permissible limit for asbestos.

		For more information on asbestos management and removal, see WSH Council's *WSH Guidelines on Management and Removal of Asbestos*.
Environmental tobacco smoke (ETS)	Infiltration from adjacent areas and activities (e.g., from designated smoking zones, smoking outside the designated areas such as staircases, toilets, linked bridges, etc.).	Explore separate ventilation from non-smoking areas and ensure a negative pressure in designated smoking zones at all times. Proper selection and operation of air cleaning technologies should be considered.
Legionella bacteria	Aerosol generating equipment (e.g., water fountains or features, spas, mist fans, shower heads, hot water storage tanks, cooling towers, humidifiers or dehumidifiers, etc.)	Ensure compliance with Environmental Public Health (Cooling Towers and Water Fountains) Regulations 2001, and SS556: 2010 Code of Practice for the Design and management of aquatic facilities. Note: "Water fountain" means any water feature located in a publicly accessible area which is capable of generating water aerosol and having a capacity exceeding 0.25m^3, measured to the overflow level of its pool. It does not include any water feature located in any reservoir maintained by the Public Utilities Board. Cooling towers and water fountains in use.

Appendix B-1 – Notes on Air Cleaning Technologies

Technology	Typical Application(s)				Mode of Action	Notes
	Particulate	**Chemical**	**Biological**	**Odours**		Proper selection, installation and maintenance required for proper function
<u>Filters</u>						
Standard media and HEPA (High Efficiency Particulate Arresting)	*		*		Captures particles by sieving, inertial impaction, interception, molecular forces.	Selection based on matching particle removal efficiencies to equipment or purpose. Filters with higher particulate-capturing efficiencies generally require more power to push or pull air through them at a given rate. Filter installations should be checked for leaks through damaged media or the presence of gaps between filters to ensure that all the air passes through the filters. Monitoring changes in pressure drop across are useful in indicating replacement.
Carbon filter	*	*		*	Activated carbon affixed onto a media filter adsorbs hydrocarbon-based gas-phase contaminants.	Better carbon filters typically have higher adsorption surface areas per filter which translate to higher adsorptive capacities. Carbon filters require periodic replacement as the number of available adsorption sites on the activated carbon particles decreases with a corresponding fall in effectiveness.
Electret filter	*				Capture particles by sieving and molecular forces.	Normally used as an add-on to standard media filters. Particle capture efficiency dependent on material and construction of electret filter as well as proper fitting to prevent bypass.
Treated filters or filter treatment	*		*		Action depends on properties of chemicals applied.	Normally used as an add-on to standard media filters. Selection dependent on purpose. May off-gas chemicals depending on treatment.*

Electrostatic air cleaner or filter	*				Ionisation and capture.	Effectiveness dependent on constant operation and use with pre and aft filters. May release dry particulates during on-off power cycles and ionise air to create ozone.
Air washing	*	*			Capture or dissolution in liquid solution.	Effectiveness dependent on airflow rate through the water and solubility in or affinity of contaminants for water. Requires regular changes of water. May increase relative humidity and off-gas chemicals.*
Incineration		*			Oxidation by high temperature when air passes through heated cores.	Effectiveness dependent on the rate of air passing through the device. May raise temperature in rooms.
Photo catalytic oxidation		*	*	*	Oxidation by photo catalysis.	Effectiveness dependent on application and availability of light at required wavelength(s) for activation. May produce secondary by-product chemicals.*
UV Light irradiation			*		Breaking of DNA bonds or mutation.	UV light irradiation at 254nm at specific intensity and duration damages genetic material in cells.
Ozone		*	*	*	Gaseous-phase oxidation by interaction with the triatomic oxygen (O3) known as ozone.	Ozone levels should not exceed prescribed limits and may require monitoring for safe application. High concentrations of ozone may produce secondary by-product chemicals in an applied environment.*
Polarised charge ionisation	*	*		*	Charge transfer and gaseous-phase oxidation.	(See Ozone.)
Non-polarised charge ionisation		*	*	*	Gaseous-phase oxidation.	(See Ozone.)
*May accumulate in applied environment and require monitoring.						

Appendix C – Investigation Procedures for Responding to IAQ Complaints

Investigation Step	Procedures
Interview the person/s providing feedback	Items to consider for the interview: - description of the feedback; - number of affected person; - affected location; and - symptoms.
Establish preliminary risk assessment based on the feedback	Risk assessment involves the process of evaluating the probability of occurrence of the identified hazard, the consequence of injury or illness arising from exposure to the hazard and determining the appropriate risk control.
Initiate the appropriate follow-up action	- Interview any other affected persons. - Initial walk-through inspection. - To undertake risk assessment (RA) to manage the risks associated with the identified hazards.
Walk-through inspection	Look out for the following tell-tale signs: - Odour: Musty odour, dampness, chemical odour, kitchen exhaust odour, and so on. - Visual: Dusty diffusers, water mark, sweating of walls, wall paper peeling off, mouldy surfaces, collapsed pre-filters, clogged condensate pan , presence of excessive units of fans, and so on. - Sound: Rushing or rumbling sound of air movement, rattling or vibration sounds from fans and other moving parts. - Feel: Air too cold, too warm, too damp, too dry, too stuffy or too drafty, and so on. Inspect the affected area: - Obtain ACMV layout plan. - Is the affected area located at the end of the supply? - Inspect the AHU for by-pass of air filter, clogged condensate coil, blocked outdoor air intake, and so on. - Open up the ceiling to check for irregularities? Look for twisted flexible duct, leakiness of building envelop, infiltration, and so on.
IAQ audit	Monitor the air for IAQ parameters and check for any deviation from the recommended limits. Collate feedback from occupants, for example, specific time of occurrence, affected area, common symptoms, and symptoms relieved upon leaving the premises.
Data analysis	Identify the discrepancies. For example, parameters exceeding limits, data gathered from feedback, and so on. Evaluate the feedback from occupants to zoom in the possible affected areas and potential causes.
Building remediation	Best available options for the building remediation. Evaluate the effectiveness, for example, conduct IAQ check after rectification work.

Appendix D – Managing Particulate Matter Levels in Air-Conditioned Built Environment during Haze

Periodic trans-boundary haze due to forest fires in the region can affect the air quality in Singapore. Singapore is not affected by the haze throughout the year. Any exposure is short-term in nature and such exposure may vary from year to year. Particulate matter (PM) has been identified as the main air pollutant in such haze episodes.

Almost all air-conditioned buildings have some form of outdoor air intake mechanism for ventilation purposes. In the event of haze, the outdoor air should be filtered prior to being distributed in the building. Closing the air intake mechanism is not recommended as indoor air quality will be compromised, as there is insufficient dilution of air indoors. The following discusses measures can be taken to reduce the level of indoor PM in air-conditioned buildings.

Measures to reduce level of indoor PM in air-conditioned building

Use high efficiency filters
Installation of filters to treat outdoor air intake or/and return air at ventilation systems (such as air handling units and fan coil units). Filter performance should comply with SS554 – Code of Practice for Indoor Air Quality for Air-Conditioned Buildings.

Ensure good practices on quality control of work and maintenance
Proper installation of filters and regular checks on ductwork to ensure no bypass and filtration is working optimally.

Use high efficiency filters

Air-conditioned buildings are typically equipped with filters at ventilation systems (such as air handling units and fan coil units) to remove particles from outdoor air. To effectively remove fine particles (PM2.5) from outdoor air taken into the building, the ventilation systems should be fitted with particle filters that perform in compliance with SS554 – Code of Practice for Indoor Air Quality for Air-Conditioned Buildings. A typical air filter installation in an air handling unit is illustrated below.

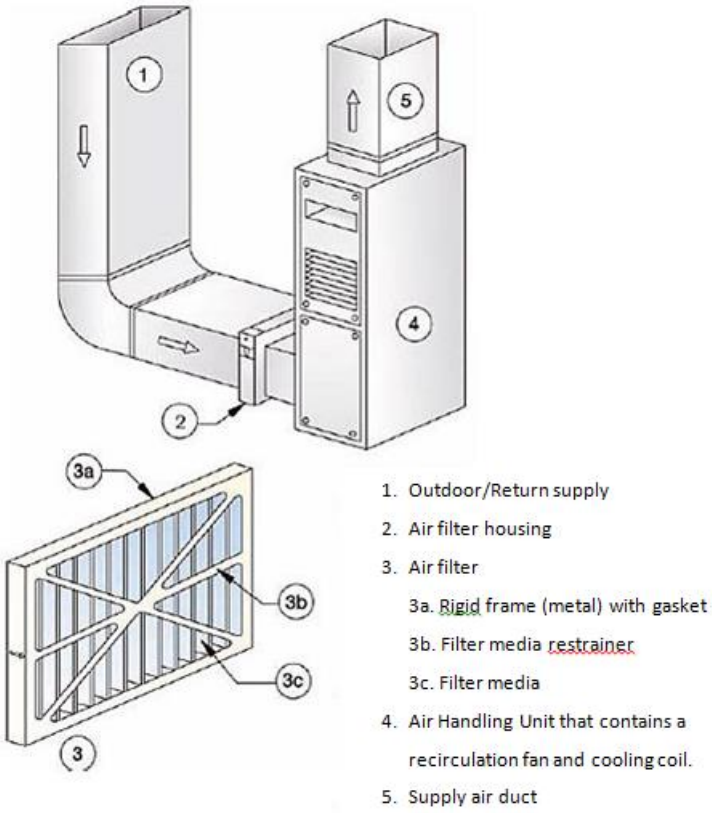


Figure D1: A typical air filter installation in an Air Handling Unit. Adapted and modified from EPA 402-F-09-002 Residential Air Cleaners, 2009.

The removal efficiency of the installed filtration system should be verified on site to ensure that fine particles are removed effectively. Generally, the efficiency of filters that fundamentally rely on electrostatic charge to remove particles is difficult to assess.

Building management can consider the use of a gas-phase filter in conjunction with the particle filters. Note that the use of gas-phase filters together with the particle filters may require additional energy to overcome any increase in pressure drop across the filtration system. Building management should therefore verify whether the existing systems need to be modified or upgraded.

Good practices on quality control of work and maintenance

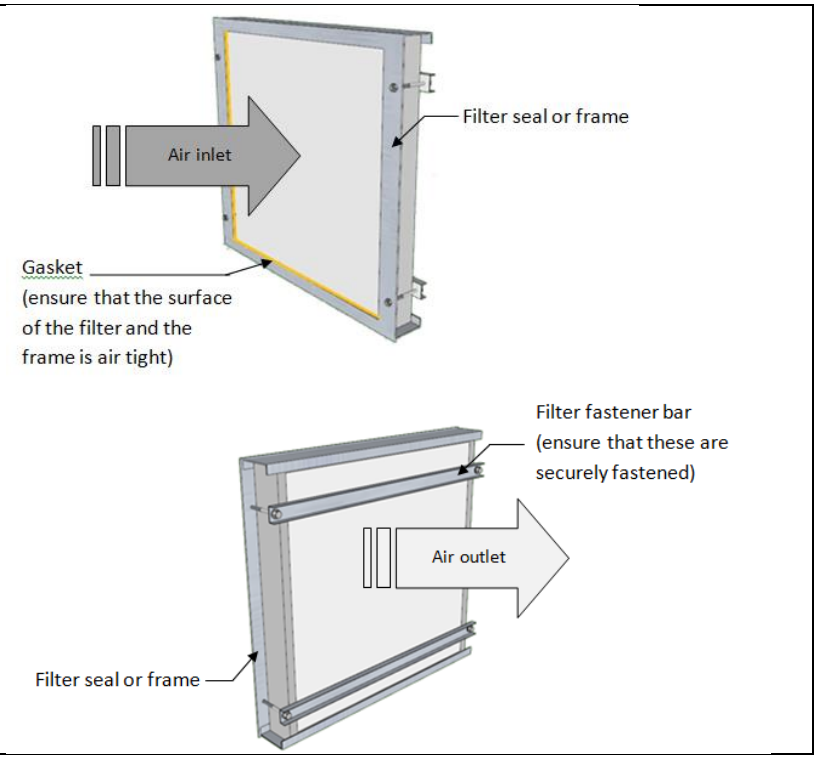
In general, building management should ensure that their building is well-maintained for good indoor air quality. During haze episodes, the following are three areas that building management can consider reviewing:

- A positive pressure created by outdoor air intake through the ventilation system could minimise infiltration through building envelopes, such as door gaps, window gaps or other building gaps. However, if the pressure is insufficient to prevent infiltration through these gaps, filters (in compliance with SS554) may be needed in the air handling unit to treat the return air, to maintain a

clean indoor environment. In addition, air curtains may be used to prevent infiltration of pollutants from opened doors.

- The appropriate filters should be properly fitted onto the ventilation system so as to ensure the integrity of the filters and that there is no bypass when the system is switched on. The figures below illustrates (i) bypass due to the ill-fit of a filter; and (ii) proper installation of air filter onto the filtration system.

(i) Ventilation systems with inappropriate filters (e.g., washable filters) or filters that are not properly fitted allow active infiltration of pollutants into the building.	
(ii) An illustration of proper installation of air filter	 **Gasket**: a mechanical seal which fills the space between two or more surfaces, to ensure sides of filter are air-tight and no bypass, when the filtration system is switched on. Cardboard **filter frames** may distort and results in air by-pass. Metallic metal frames may be used to maintain the shape and seal of the filter.



- A maintenance schedule should be implemented to regularly check and ensure that the ventilation systems and their ducting are not damaged, so as to be operational during haze. A compromised ducting, such as the one shown below, could lead to a bypass of the installed filter.

Figure D2: Damaged outdoor air intake ducts may allow PM to bypass the filtration system and infiltrate the building.

Further Information

Singapore Standard SS 554: 2009 Code of Practice for Indoor air quality for air-conditioned buildings

Singapore Standard SS 553: 2009 Code of Practice for Air-conditioning and mechanical ventilation in buildings

WSH Council Approved Code of Practice on Workplace Safety and Health (WSH) Risk Management

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