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INDOOR AIR QUALITY MANAGEMENT FOR BUILDINGS

Organised by:

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Indoor Air Quality Management for Buildings

Day 1 (24 Aug 2015)			
No	**Time**	**Lesson**	**Lecturer**
1.0	**9.00am – 10.30am**	**An overview of Indoor Air Quality & Green Mark requirement for IAQ** • Indoor Air Quality Fundamentals • Impacts of IAQ on productivity & health • Green Mark requirements for good IAQ in New and Existing Buildings • SS 554 – Guideline for acceptable IAQ	BCA – GM Dept Mr Lee Jang Young/ Dr Ng Kok Wee
2.0	**10.30am – 11.00am**	**Tea Break**	
3.0	**11.00am – 12.00pm**	**IAQ Parameters and Measurements for buildings** • Types of IAQ Parameters: - Thermal Comfort parameters - Chemical parameters - Biological parameters	Prof Tham Kwok Wai
	12.00pm – 1.00pm	**Lunch**	
3.0	**1.00pm – 3.00pm**	**IAQ Parameters and Measurements for buildings (cont)** • Measurement and Verification requirements for IAQ	Prof Tham Kwok Wai
	3.00pm – 3.30pm	**IAQ consideration in design, construction, renovation and commissioning works for building** • Design & construction for IAQ	Prof Tham Kwok Wai
	3.30pm - 4.00pm	**Tea Break**	
4.0	**4.00pm – 5.00pm**	**IAQ consideration in design, construction, renovation and commissioning works for building (cont)** • Renovation & commissioning works for IAQ (new and existing buildings) • Maintenance for good IAQ • Identification of Problems related to IAQ (Sick Building Syndrome)	Prof Tham Kwok Wai
Day 2 (25 Aug 2015)			
5.0	**9.00am – 10.30am**	**IAQ Audit for Buildings** • IAQ audit methodology • IAQ audit procedures	Prof Tham Kwok Wai
	10.45am – 11.00	**Tea Break**	
6.0	**11.00am – 12.00am**	**Air-Conditioning & Mechanical Ventilation (ACMV) for Good IAQ** • Inspection of ACMV System - Air quality	Dr Ang Keng Been

		- Air flow - Temperature & humidity level	
	12.00pm – 1.00pm	**Lunch**	
7.0	**1.00pm – 2.00pm**	**Air-Conditioning & Mechanical Ventilation (ACMV) for Good IAQ** • ACMV operation and maintenance • Ventilation and Filtration systems in ACMV • Causes of poor IAQ in Tropical Climate • Energy efficient methods of control • Relative Humidity to improve IAQ	Dr Ang Keng Been
8.0	**2.00pm – 3.30pm**	**Measurement and Instrumentation (Practice session) and Hand-on Session** • Pollutant Standard Index (PSI) • Volatile Organic Compound (VOCs) • Carbon (CO), Carbon Dioxide (CO_2) • Temperature & humidity Bacterial, yeast and mould demonstration	Dr Ang Keng Been
	3.30pm – 4.00pm	**Tea Break**	
9.0	**4.00pm – 5.00pm**	**Case Studies on Indoor Air Quality**	Dr Ang Keng Been
10.0	**5.00pm – 5.30pm**	**Assessment**	BCAA

Update: 08/05/2015

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GREEN MARK REQUIREMENTS FOR INDOOR AIR QUALITY – AN OVERVIEW

DR NG KOK WEE (BCA GMND)
MR. LEE JANG YOUNG (BCA GMEB)



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Scope of Presentation

1. BCA Green Mark (GM) Schemes
2. Impacts of IEQ on Productivity and Health
3. Principles of good IEQ and IAQ
4. Current Guidelines for Acceptable IAQ
5. Proposed GM v.5 Requirements for IAQ
6. Q & A



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Singapore BCA Green Mark Scheme

- A green building rating system to evaluate building for its environmental impact and performance

- Launched in Jan 2005 – a rating system for the tropics

BCA GREEN MARK



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The Green Building Masterplan

BCA GREEN MARK

1st GREEN BUILDING MASTERPLAN

2nd GREEN BUILDING MASTERPLAN

3rd GREEN BUILDING MASTERPLAN

2005	2006 - 2007	2009	2014
Intro of GM Scheme	New Bldg.	Existing Bldg.	Tenants / Occupants



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Singapore BCA Green Mark Scheme

Launched in Jan 2005 – a rating system for the tropics

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5 Key Assessment Criteria

1. ENERGY EFFICIENCY
2. WATER EFFICIENCY
3. ENVIRONMENTAL PROTECTION
4. INDOOR ENV. QUALITY
5. OTHER GREEN FEATURES

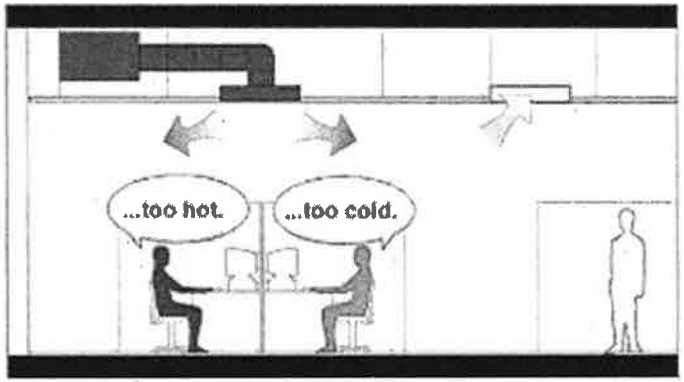
1. **Big Emphasis on Energy Efficiency**
2. **Customized for Tropics**
3. **Post Completion Building Performance Evaluation**

Green Mark	Try Again	Certified	Gold	Gold Plus	Platinum
Score	0 – 49	50 – 74	75 – 84	85 – 89	90 – 100
Estimated Energy Savings		10% to 15%	15% to 25%	25% to 30%	> 30%



Impacts of IEQ: The link between Green Buildings, Productivity & Health

- The primary function of a building is to increase occupant satisfaction, reduce environmental impacts and improve productivity levels
- Small improvements in IEQ have been shown repeatedly to increase occupant productivity levels and yield big benefits
- To achieve 1 – 1.5% higher productivity levels by greening the Indoor Air Quality (IAQ)





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IAQ Impacts on Health and Productivity

- Studies show the IAQ of green buildings improved worker productivity, health and well-being
- Reduced sick leave and staff turnover translate to better organizational outcomes to businesses
- Attract better tenants and command higher rents





Health, Wellbeing & Productivity: Flow chart

The physical office environment

The office environment is made of up several factors, which can be measured or evaluated in numerous ways.

Indoor air quality & ventilation
- Pollutants, including VOCs
- CO_2
- Aroma
- Ventilation rate or fresh air
- Moisture content

Thermal comfort
- Indoor air temperature
- Mean radiant temperature
- Air velocity
- Relative humidity
- Clothing
- Activity

Lighting & Daylighting
- Quantity
- Quality
- Glare
- Daylight
- Task type

Noise & acoustics
- Background noise
- Privacy & interference
- Vibration

Interior layout & active design
- Workstation density
- Task based spaces & ergonomics
- Breakout spaces and social features
- Active design

Biophilia & views
- Connections to nature
- Views outside

Look & feel
- Design character & brand ethos, including colour, shape, texture & art
- Cultural, gender & age sensitive design

Location & access to amenities
- Access to amenities
- Transport
- Quality of public realm

Occupant health outcomes

The physical office factors influence the health of occupiers (health outcome) which can be measured or evaluated.

Health
- Headaches
- Eye strain/damage
- Skin irritation
- Infections
- Fatigue
- Seasonal Affective Disorder
- Asthma & breathing disorders
- Stress & depression
- Other physical complaints, e.g. back ache
- Other serious disorders, including cardio-vascular etc.

Occupant wellbeing and perception outcomes

Health is an important element of wellbeing, but an occupant's sense of wellbeing is also comprised of their perception of numerous factors, including how productive they think they are:
- Perceived physical health
- Perceived psychological health
- Perceived productivity
- Perceived office environment
- Perceived organisational culture

Organisational or financial outcomes

The office environment can have a direct impact on occupant productivity, in which health and wellbeing is often a compounding factor. This 'outcome' for the organisation can be measured or evaluated in the following ways (not exhaustive), all of which have financial implications for the employer.

Productivity
- Absenteeism
- Presenteeism
- Staff turnover/retention
- Revenue
- Medical costs
- Medical complaints
- Physical complaints
- Task efficiency & deadlines met



Ultimate aims

Maximised Return on Investment (financial evaluation based on life cycle costing – capital & operational) for all strategies designed to benefit occupants and improve productivity:

- Lower employment cost per employee, including reduced absence costs
- Higher staff retention and reduced costs of staff turnover
- Greater ease of high quality recruitment, lowering recruitment costs and adding value
- Greater productivity of staff on core tasks, e.g. deadlines met, sales made etc.
- Optimised green building ratings resulting in higher value/lower risk/ improved reputation
- Reduced occupant complaints via 'Help Desk' and other similar feedback systems, leading to reduced costs
- Increased company revenue

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What adversely impacts IAQ?

- **Gases:**
  - Formaldehyde, VOCs, CO_2, Ozone etc.
- **Biologicals:**
  - Bacteria, Moulds, viruses etc.
- **Airborne Particles:**
  - 95+% smaller than 0.5 microns

Ultrafine Particles (UFPs) are the most dangerous…

" high pulmonary deposition efficiency…UFPs' surfaces can carry large amounts of absorbed toxic air pollutants (oxidant gases, organic compounds, transition metals" (Oberdörster 2001)



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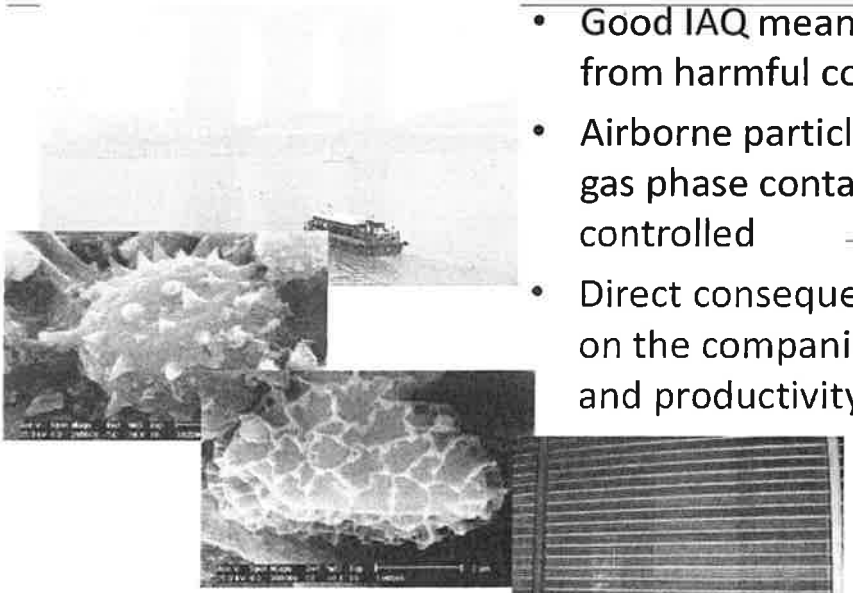
Healthy Indoor Air

- Good IAQ means that the air is free from harmful contaminants
- Airborne particles, biologicals, and gas phase contaminants must be controlled
- Direct consequences from poor IAQ on the companies' operating costs and productivity levels







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Principles for good IEQ and IAQ



Good Indoor Air Quality

Ventilation	*Filtration*	*Source Control*	*Humidity Control*
Dilute indoor air with sufficient outdoor air	Remove particulates and bio aerosols	Minimise the generation of pollutants within the indoor space	Reduce the risk of fungi & bacteria growth



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SS 554: Competency of IAQ Audit

- Indoor air quality auditing and air sampling should be conducted by a **competent person**
  - attended and met the requirements of an indoor air quality course conducted by a training provider recognised by cognizant authorities
- Samples that require laboratory analysis
  - 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** should ensure that the instruments used are properly calibrated and records of calibration are maintained.



*For more information, please refer to information published on website: http://www.sac-accreditation.gov.sg/index.asp.

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Site Navigation : Accredited Organisations Search > Accredited Calibration and Testing Laboratories

Accredited Calibration and Testing Laboratories

Field of Testing: Environmental

Category of Test: Indoor Air Quality

To search for accredited laboratories, you will have to first select the **field of testing** then choose the relevant **category of test**. The page will automatically reload to display accredited laboratory that match the specified criteria.

List of accredited laboratories that falls under the current selection

FIELD OF TESTING: ENVIRONMENTAL
CATEGORY: INDOOR AIR QUALITY

Laboratory	Cert Num
ALS Technichem (S) Pte Ltd	LA-2000-0178-F
CPG Laboratories Pte Ltd	LA-2010-0474-F
IAQ Consultants Pte Ltd	LA-2007-0377-F
Setsco Services Pte Ltd-Biological & Chemical Technology Div (BCTD)	LA-2000-0181-F
Singapore Test Services Pte Ltd	LA-1999-0166-F
TÜV SüD PSB Pte Ltd -Environmental Monitoring (Pt 2/2)	LA-2007-0381-F



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Minimum Ventilation Rates stated in SS553

Type of building/ Occupancy	Minimum outdoor air supply			
	l/s per m² floor area	m³ /h per m² floor area	l/s per person	Air class
Restaurants	3.4	12.2	5.1	2
(i) Dance halls	7.0	25.0	10.5	1
Gym	3.8	13.6	13.2	2
Offices	0.6	2.0	5.5	1
(ii) Shops, supermarkets and department stores	1.1	3.8	5.5	1 or 2
Theatres and cinemas seating area	2.0	7.3	3.0	1
Lobbies and corridors	0.3	1.1	3.3	1
Concourses	1.1	4.0	3.3	1
(iii) Hotel guest rooms	15.0 l/s per room	54.0 m³ /h per room	5.5	1
(iv) Classrooms				
Primary school children and above	2.8	10.0	4.2	1
Childcare centres	2.8	10.0	8.4	1

SS 553 Table 1 – Outdoor air supply requirement for comfort air-conditioning



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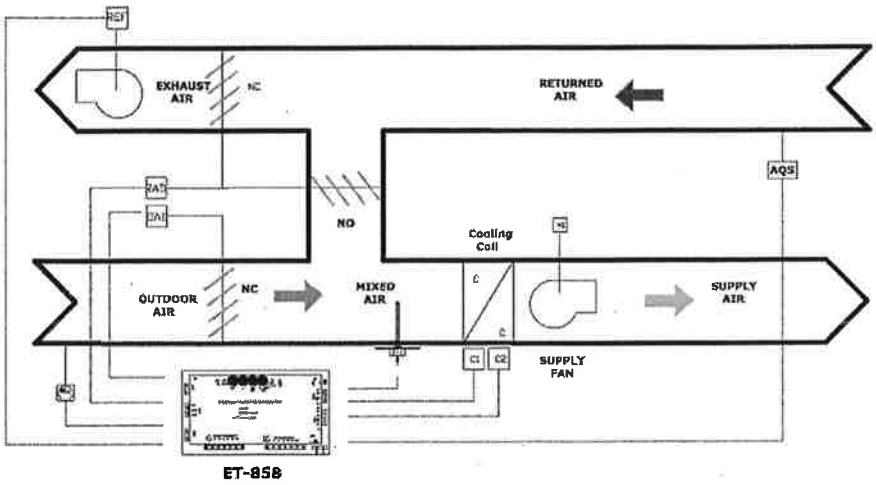
Local exhaust & Air purging

- Air purging system to replace contaminated indoor air with outdoor fresh air (weekend build-up, renovation works etc.)





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GM : Indoor Air Quality Management

Provisions for acceptable IAQ under normal operations:

- Filtration media & Differential pressure monitoring equipment in AHUs:
  - Reference: SS554: Clause 4.3.4.5 and its Annex E
- Implement effective IAQ Management plan:
  - Ensure ventilation systems are clean and free of residuals left over from construction activities
  - Internal surface conditions tests for environmental control systems to be included
  - Reference: SS554: Clause 4.6 & Annex F



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SS 554: Air Filtration

Filter Classification	ASHRAE 52.2-1999 MERV 14 / EN 779:2012 Class F8				
Rated Airflow	3400 CMH				
Filter Type	Pocket Filter	Rigid Cell Filter		Compact Filter	Panel Filter
	6 to 10 pockets	Deep pleat media pack		mini-pleat media pack	Mini-Pleat
Operating Face Velocity	<2.5 m/s	<2.5 m/s	<2.5 m/s	>2.5 m/s	<2.5 m/s
Media Type	High Loft Glass fibre		Glass fibre Paper		
Pleats Spacer	Span stitch	Pleat Stabiliser	Corrugated aluminium foil	Thread or Hot-melt beads	
Filter Service Life consideration					
Media Area (approximate based on the stated dimension)	3.0 – 9.0 m^2	5-6 m^2	10-12 m^2	18-20 m^2	10-12 m^2
	610 x 610 (depth: 457 – 610)	610 x 610 x 305			610 x 610 x 100
Service Life duration	Short		Moderate	Long	Moderate
Energy Consumption consideration					
Initial Press Drop at filter face velocity (approx.)	100 – 150 Pa	160-180 Pa	130-165 Pa	<90 Pa	170 Pa
Energy consumption	Low/Moderate	High	Moderate	Low	Moderate



Source: SS 554

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Air filter classification and possible applications

ASHRAE 52.2 MERV	EN779/EN1822 Class	Possible applications
1	G1	Remove coarse dust
2	G2	
3		
4		
5	G3	
6		
7	G4	
8		
9		Remove coarse dust that cause plugging to the cooling coil
10	F5	
11	F6	
12		
13	F7	
14	F8	Reduce indoor contaminants and provide better protection for AHU and cleaner ductwork
15	F9	High removal rate against sub-micron particle size. Improve IAQ and provide good protection for cooling coil and reducing frequency or eliminating duct cleaning
16	H10	



Source: SS 554

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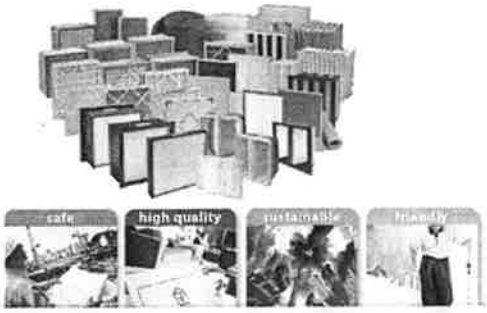
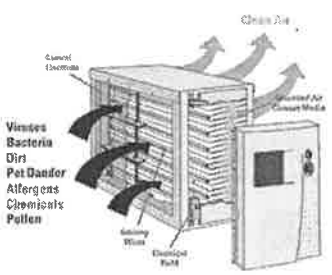
SS 553: Air Filtration

Note:

- Under normal outdoor air conditions, MERV 6 or better is recommended for all AHUs
- When outdoor pollution level is in unhealthy range (in accordance to MOH's guidelines), MERV 14 or better to be provided for all AHUs







Source: SS 553

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Emission Source Control

Selection of building and furnishing materials:

- Building and furnishing materials may be sources of indoor air contaminants
- Limit the use of high-emitting building and furnishing materials
- Materials with lower emission rates should be selected provided that they meet all relevant statutory requirements, e.g. fire resisting properties etc.

Indoor Air Pollutants	Application of GM Point(s)
Use of certified low VOC paints	Extent of Coverage: 90% of applicable internal walls
Use of environmentally friendly adhesives & finishes	Extent of Coverage: 90% of applicable areas

***Local labelling schemes for low emission flooring products and control of VOC emissions from coating**



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Emission Source Control

- Indoor Air Pollutants:
  - Use of low VOC paints certified by approved local certification bodies
  - Use of Environmental friendly adhesives certified by approved local certification bodies
- Setting of sustainable and environmental-friendly procurement and purchasing policy

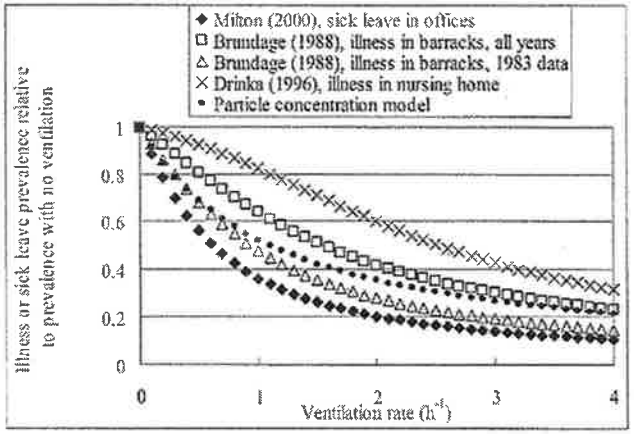
Green Label Singapore

Singapore Green Building Product SGBC



GMOI v.1.1: IAQ-related Requirements

- Sustainable Office Design
- Sustainable Material Selection
- Post Occupancy Evaluation
- IAQ performance
- Indoor Air Pollutants



Predicted trends in illness of sick leave versus ventilation rate (source : Fisk et. al. 2003)

Building	Indoor air quality	Acoustics	Lighting
• Exterior design & construction • Location • Accessability • Interior design & layout • Materials • Space & density • Ergonomics • Private/ public space • Level of control • Workstations	• HVAC • Indoor air pollutants • Thermal comfort and ventilation • Air temperature, RH • Air speed and ventilation rates	• Noise in open areas • Noise at workstations • Building and mechanical noise	• LUX • Daylight • Glare

Factors affecting indoor environment



Humidity Control

Bacteria

- Sources:
  - the mouth, nose, nasopharynx and skin
  - damp interior surfaces in indoor environment e.g. surfaces of HVAC system components
- *Legionella:*
  - man-made water systems such as cooling towers and water fountains, Jacuzzis, spa pools or in equipment capable of generating aerosols such as mist fans, showerheads.

Mould

- Sources:
  - originate from outdoors
  - Persistently damp indoor environments
- *Allergic Reactions:*
  - Flu-like symptoms
  - skin rash may occur
  - aggravate asthma conditions



Source: SS554

Humidity Control

Possible locations for hidden mould growth:

- walls behind furniture
- porous thermal or
- acoustic liners inside ductwork,
- condensate drain pans inside AHU
- roof material above ceiling tiles

Other locations:

- dry walls covered with vinyl wallpaper, wood panelling
- Carpets which serve as vapour barriers and trap moisture underneath their surfaces.



Source: SS554

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GM IAQ Requirements

To conduct an IAQ audit once in 3 years

To comply with Code of Practice (Singapore SS554: 2009) for 'Indoor Air Quality for Air-conditioned in buildings or NEA's Guidelines for Good Indoor Air Quality in Office Premises

To comply with Outdoor air supply requirements for Mechanical Ventilation as stipulated in SS553: 2009

CO_2 monitoring to ensure delivery of sufficient/ minimum outside air requirements



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Current Guidelines for Acceptable IAQ

SS553 (2009) - Code of practice for air-conditioning and mechanical ventilation in buildings

SS554 (2009) – Code of practice for Indoor air quality for air- conditioned buildings

NEA Guidelines for good indoor air quality in office premises (1996)



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IAQ Guidelines based on SS 554

- Acceptable IAQ:
  - Air in an occupied space toward which a substantial majority (80 %) of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk.
- Acceptable Perceived IAQ:
  - Air in an occupied space toward which a substantial majority (80 %) of occupants express no dissatisfaction on the basis of odour and sensory irritation. Acceptable perceived IAQ is necessary but not sufficient to meet the acceptable IAQ.



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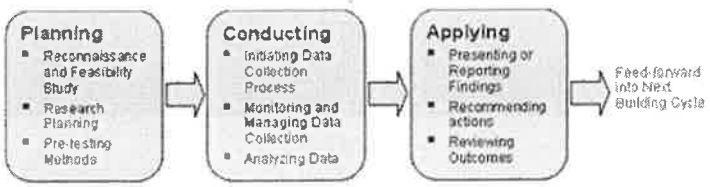
Closing the Loop: IAQ Management

- Appoint IAQ Manager
- Develop IAQ Profile of Building(s)
- Develop and implement plans for facilities operation and maintenance
- Communicate with occupants about their roles in maintaining acceptable IAQ
- Establish procedures for responding to IAQ complaints
- Maintenance of ACMV systems





Source: SS553, 554 & NEA "Guidelines for Good IAQ in Office Premises 1996"

Proposed GREEN MARK 2015 (NRB V5.0)

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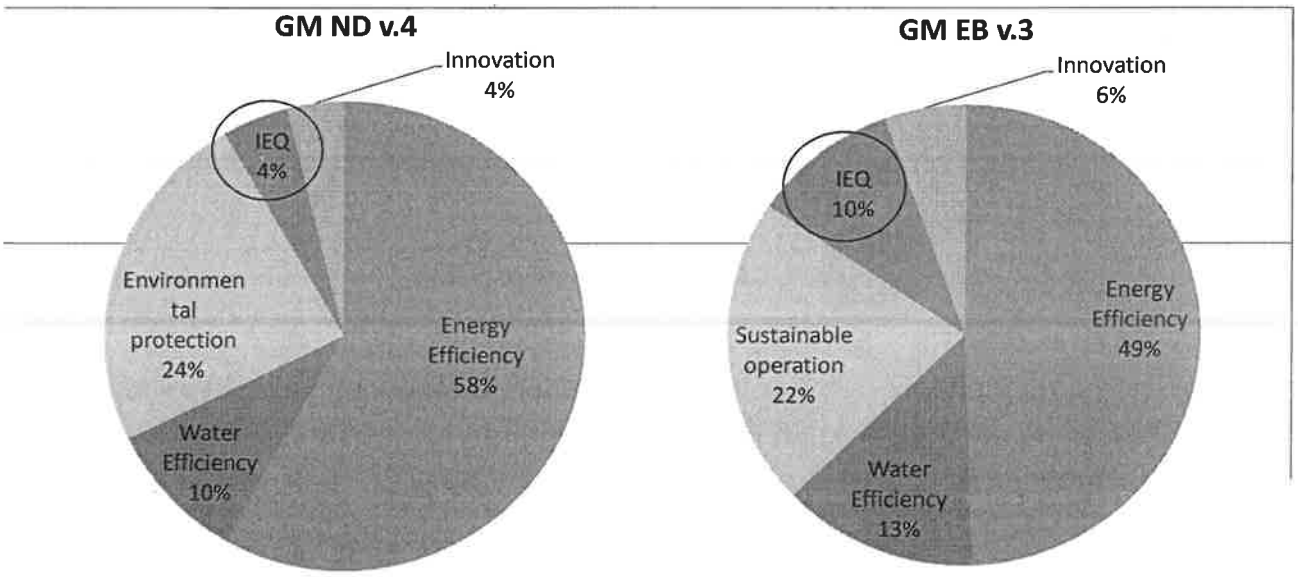
Current Green Mark IEQ Assessment Criteria





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Upcoming Green Mark NRB v.5

- **Enhancements to Indoor Health**
  - IAQ
  - Thermal Comfort
  - Day lighting & Lighting levels
  - Noise
- Design for Convenience

Smart and Healthy Buildings

BCA GREEN MARK



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IEQ – Version 4.1 and Version 5

Current IEQ criteria (V.4.1)	Proposed IEQ criteria (V. 5)
1. Thermal Comfort	1. Thermal Comfort
2. Noise Level	2. Sound Performance
3. Indoor Air Pollutants - Low VOC paints - Adhesive with Green Labels	3. Visual Performance
4. IAQ Management - MERV 13 filters - IAQ management plan	4. Indoor Air Quality (IAQ) - IAQ audit and Post Occupancy Evaluation (POE) - IAQ monitoring and display - Ventilation Rates (VR) monitoring and Demand Control Ventilation - Filtration (MERV 14 filters) - Low VOC paint, low emitting materials - Local exhaust & Air purging systems - Ultraviolet Germicidal Irradiation (UVGI) system - Dedicated Outdoor Air System
5. High Frequency Ballasts	



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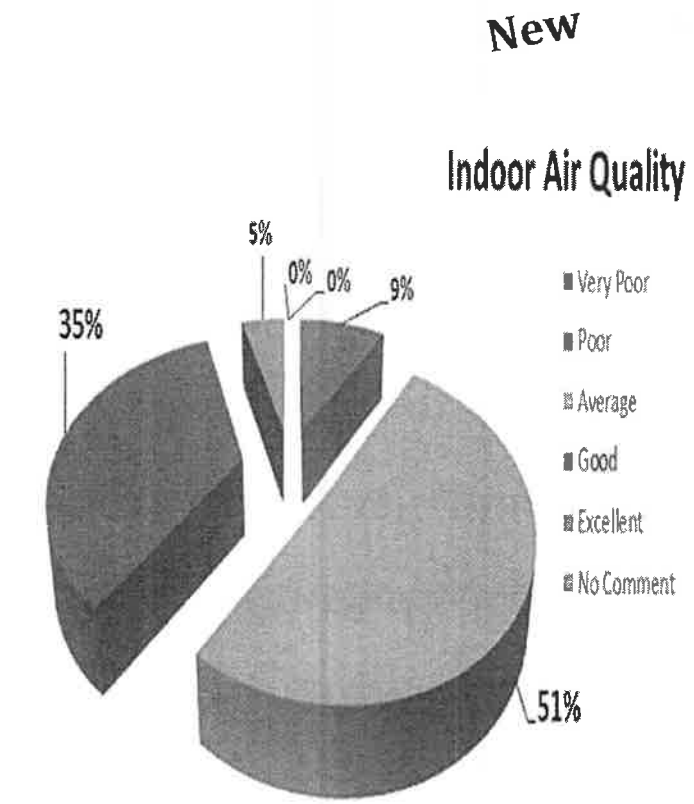
IEQ – IAQ audit and POE

IAQ audit and Post Occupancy Evaluation (POE) within one year after occupancy – prerequisite for all





IAQ parameters	NEA's IAQ guidelines for office premises (1996)	SS554: 2009
Temperature	22.5 – 25.5 °C (db temp)	24-26 °C (Opr temp)
Relative Humidity	≤ 70%	≤ 65% for new ≤ 70% for EB
Air Movement	≤ 0.25 m/s	0.1 - 0.3 m/s
Carbon Dioxide	1000 ppm	700 + outdoor ppm
Carbon Monoxide	9 ppm	9 ppm
Formaldehyde	0.1 ppm	0.1 ppm
TVOC	3 ppm	3 ppm
Ozone	0.05 ppm	0.1 ppm (table 2)
Particulate Matter (PM4)	150 µg/m3	50 µg/m3
Particulate Matter (PM2.5)	NA	35 µg/m3 (table 2)
Total Bacteria Count	500 cfu/m3	500 cfu/m3
Total Mould Count	500 cfu/m3	500 cfu/m3

IEQ – IAQ monitoring

IAQ monitoring and display

a) Room display / Centralised display to monitor temp and RH

b) Permanent monitoring of indoor air contaminants **New**







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IEQ – Ventilation

Ventilation Rates

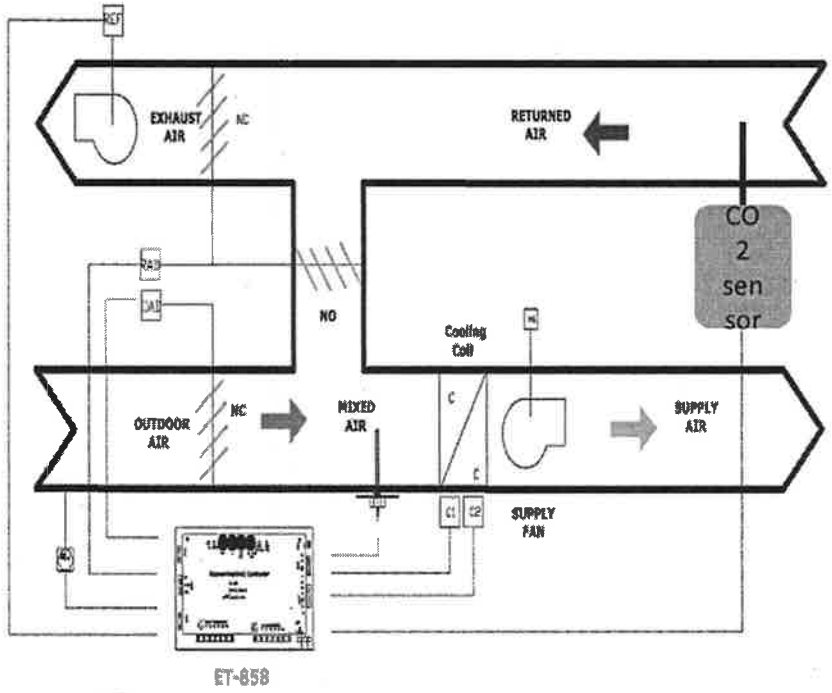
a) Ventilation rates to meet the requirement of SS553 – Prerequisite for all

New

b) Permanent outdoor air flow measurement and monitoring system

c) Demand control ventilation



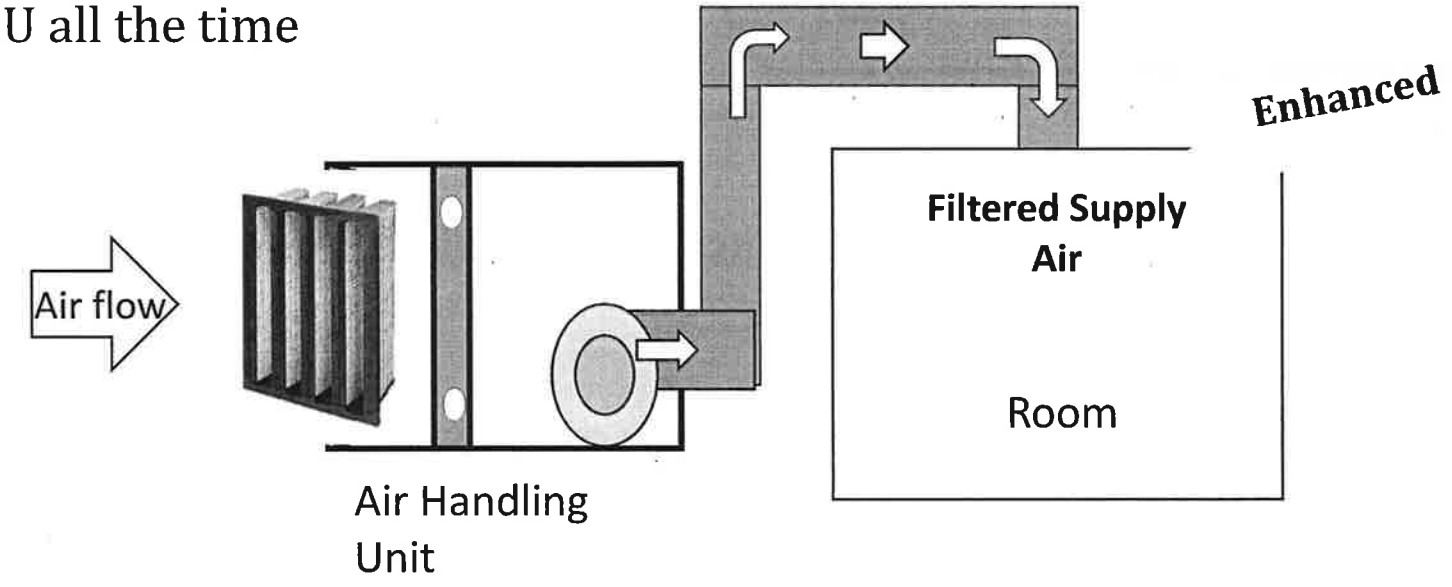


IEQ – Filtration

Filtration for haze resilience

a) Outdoor air filters to meet the requirement of SS553 – Prerequisite for all

b) Enhanced filtration for Platinum and Gold Plus: Use of MERV 14 filters for PAHU all the time



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IEQ – Source control

Enhanced

Low Emitting Materials

a) Use of low VOC paint – Prerequisite for all

b) Use of certified green building products for low chemical emissions



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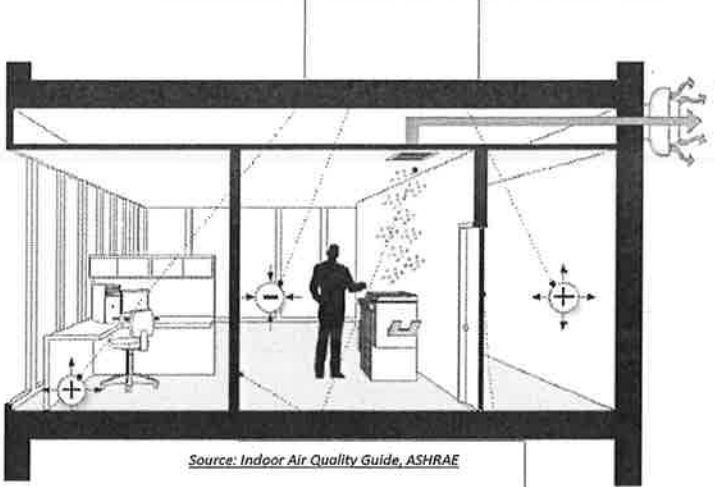
IEQ – Source control

Local exhaust & Air purging systems

a) Local exhaust system to extract contaminants from point sources

New

b) Air purging system to replace contaminated indoor air with outdoor fresh air



Source: Indoor Air Quality Guide, ASHRAE



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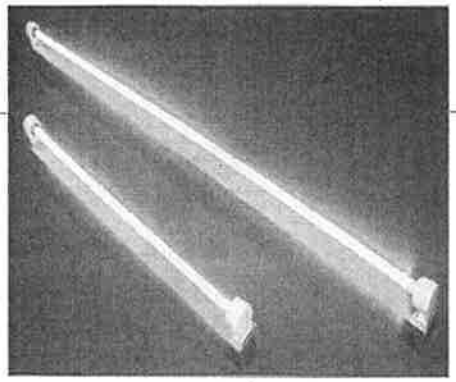
IEQ – Enhancement

Ultraviolet Germicidal Irradiation (UVGI) system New

- UVGI system to remove germs and bacteria in the indoor air (UV wavelength of 254nm)





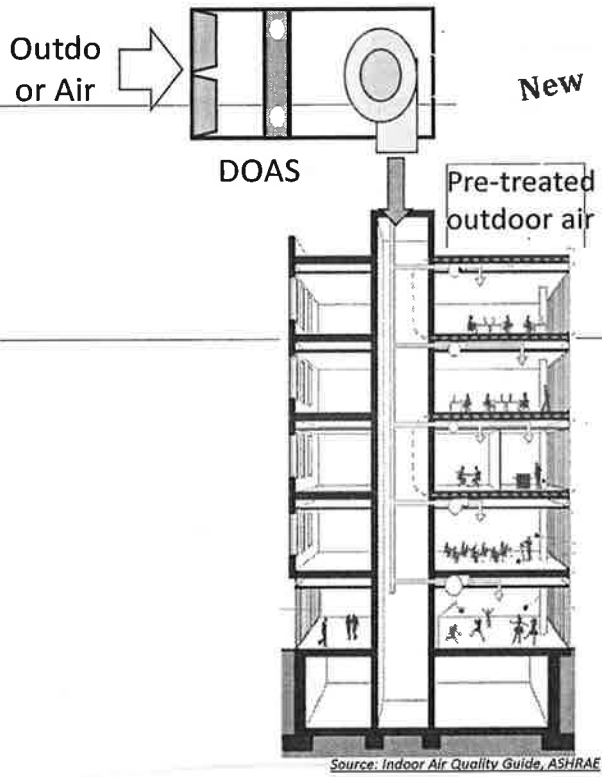


Building and Construction Authority

IEQ – Enhancement

Dedicated Outdoor Air System (DOAS) New

- Effective way of treating outdoor air to achieve thermal comfort and to minimise microbial growth
- Centralised outdoor air filter for haze protection
- Combined with heat recovery system to save cooling energy



Source: Indoor Air Quality Guide, ASHRAE



Building and Construction Authority

IEQ – Summary

Proposed IEQ criteria (V. 5)
1. Thermal Comfort
2. Sound Performance
3. Visual Performance
4. Indoor Air Quality (IAQ) - IAQ audit and Post Occupancy Evaluation (POE) - IAQ monitoring and display - Ventilation Rates (VR) monitoring and Demand Control Ventilation - Filtration (MERV 14 filters) - Low VOC paint, low emitting materials - Local exhaust & Air purging systems - Ultraviolet Germicidal Irradiation (UVGI) system - Dedicated Outdoor Air System



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Mr Aloysius Aw
Tel: +65 6325 5981
Email: aloysius_aw@bca.gov.sg

- ✓ **Green Mark Version 5**
- ✓ **10th Anniversary of Green Mark**
- ✓ **Latest update of BCA Green Mark Schemes**
- ✓ **Updates from the Asia-Pacific region on Sustainable Developments**
- ✓ **Green Building Trends, Technologies & Strategies**
- ✓ **Converge with 10,000 delegates from over 40 countries**
- ✓ **Co-located with Sustainable Laboratories Conference**
- ✓ **Green Tours**
- ✓ **Held alongside the annual BEX ASIA 2015**
  (exhibition of green construction and building products and services)

Organised by Building and Construction Authority
Strategic Partners Reed Exhibitions
Co-Located Event BEX Asia

Building and Construction Authority

2015 IGBC IEQ Workshop

Topic: Does Green Buildings Makes a Difference?

- ✓ The evidence of GM scheme towards enhancing IEQ, productivity and healthy
- ✓ Benchmarking IEQ in the existing GM Platinum certified buildings with reference to buildings w/o GM certification

Performance of IEQ & productivity

GM Platinum vs. Non-GM buildings



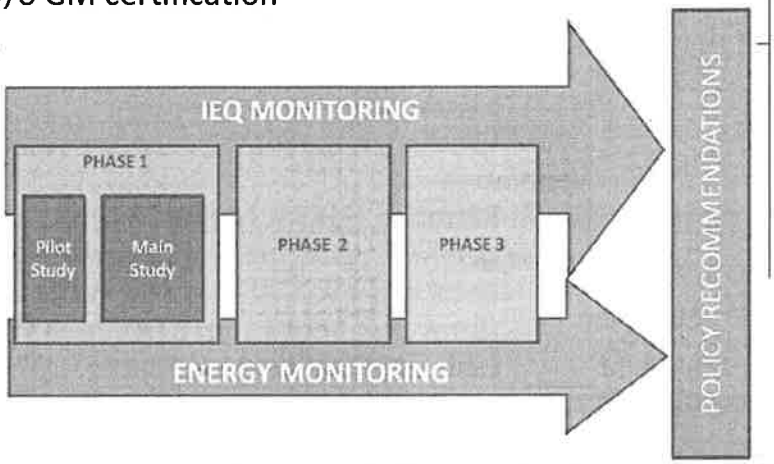

Figure 1. The concept of the proposed work

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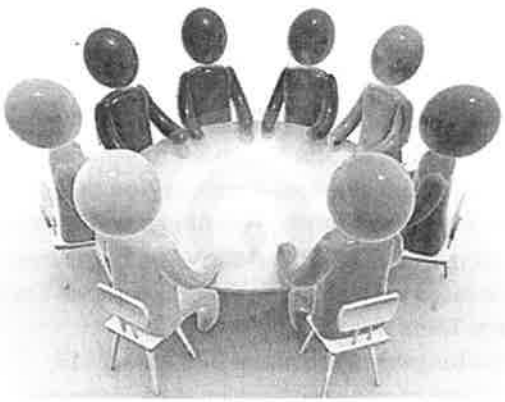
Thank You!!





IAQ Parameters and Measurements for Buildings

Tham Kwok Wai

National University of Singapore

IAQ in Perspective



Person's Daily Consumption

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What is IAQ ?

Acceptable indoor air quality

"Air in an occupied space toward which a substantial majority of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk" ISO

"Air in which there are no known contaminants at harmful concentrations as determined by the public health authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" ENV, 1996

"Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities, and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" ASHRAE 62:2001

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IAQ Guidelines based on SS 554

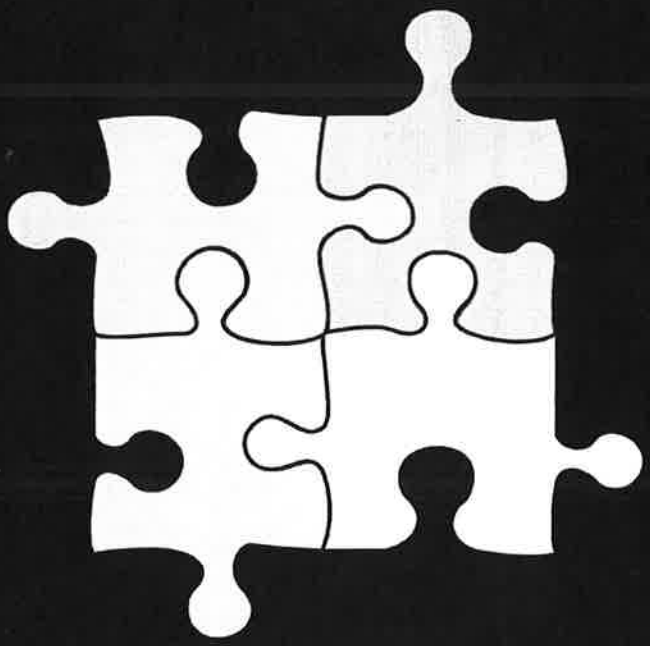
- Acceptable IAQ:
  - Air in an occupied space toward which a substantial majority (80 %) of occupants express no dissatisfaction and in which there are not likely to be known contaminants at concentrations leading to exposures that pose a significant health risk.
- Acceptable Perceived IAQ:
  - Air in an occupied space toward which a substantial majority (80 %) of occupants express no dissatisfaction on the basis of odour and sensory irritation. Acceptable perceived IAQ is necessary but not sufficient to meet the acceptable IAQ.



What is IAQ ?

PHYSICAL

BIOLOGICAL



CHEMICAL

ENVIRON
MENTAL

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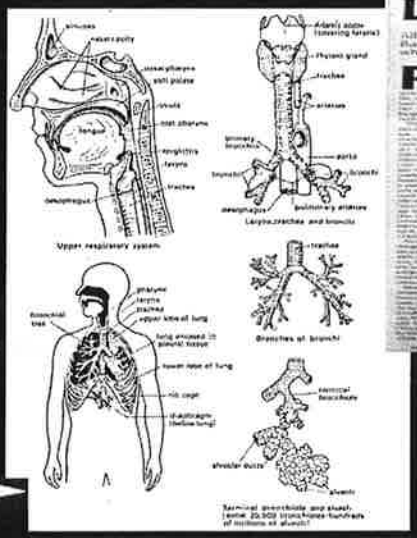
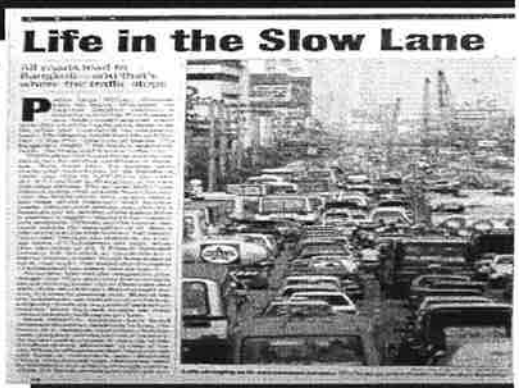
What is IAQ ? - PHYSICAL













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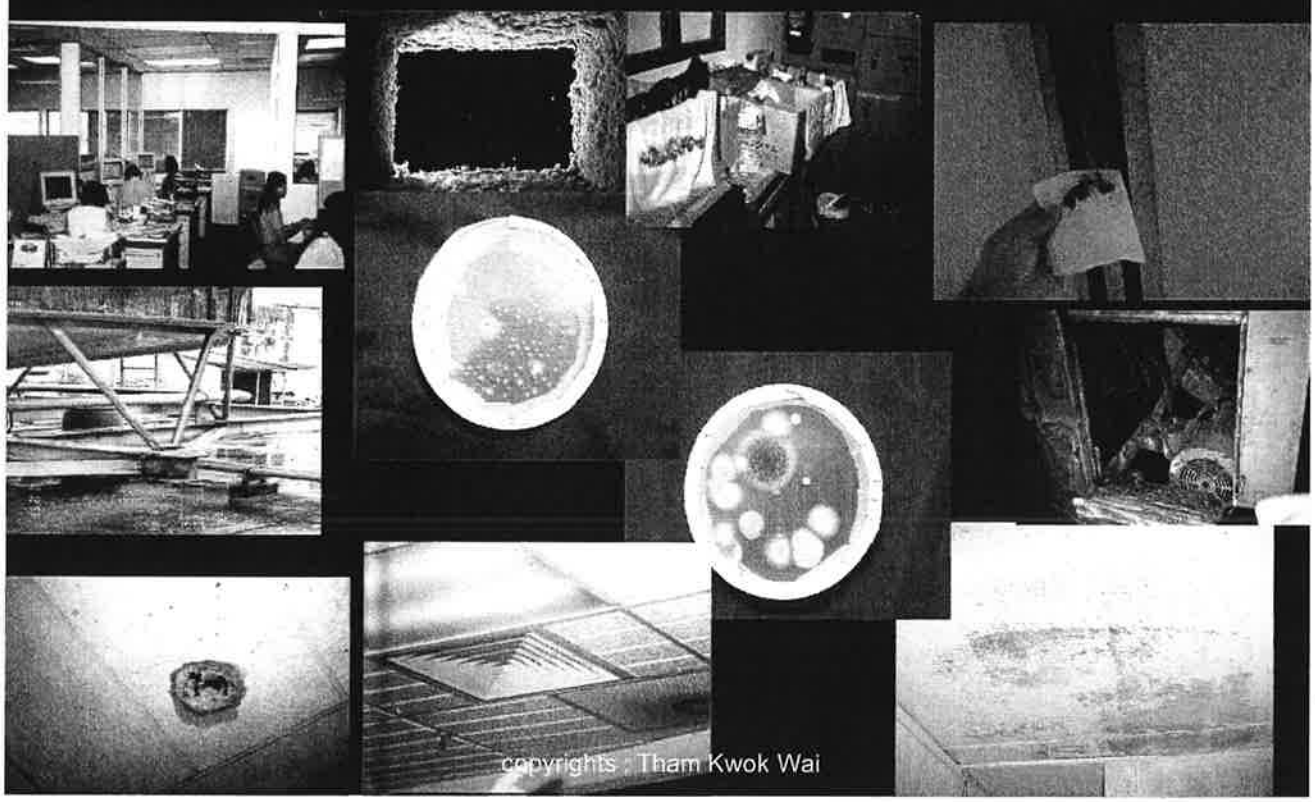
What is IAQ ? - BIOLOGICAL



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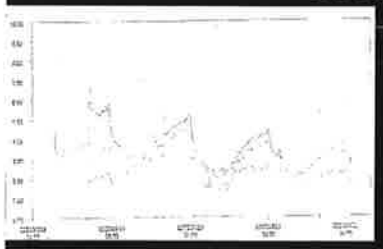
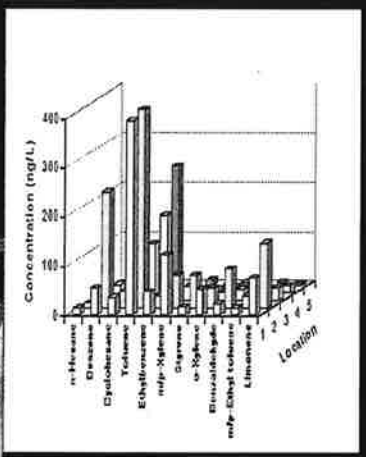
What is IAQ ? - CHEMICAL





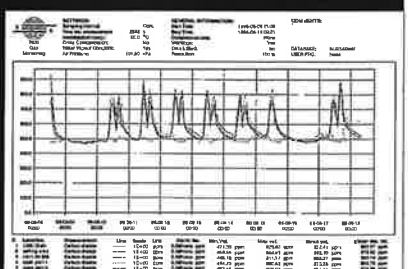












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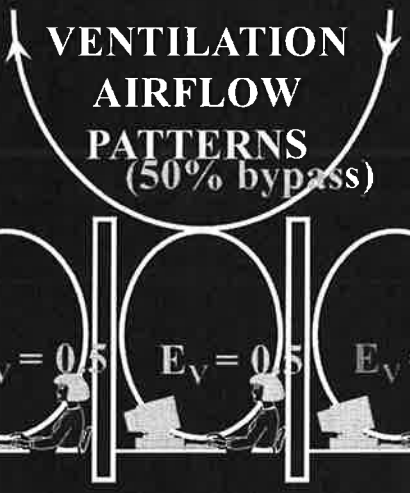
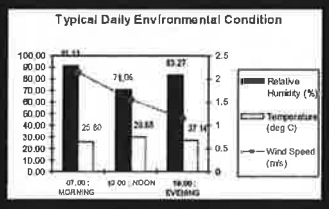
What is IAQ ? - ENVIRONMENTAL

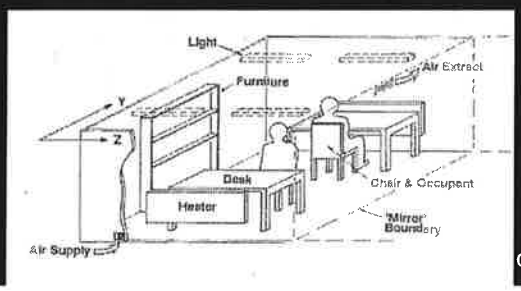












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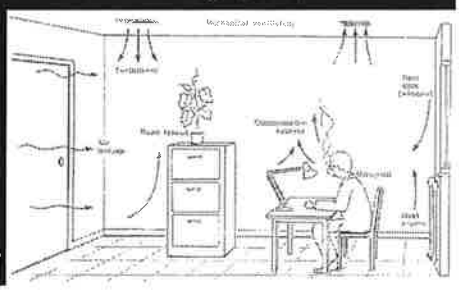

Challenges in the indoor environment

- External pollution
- Energy conservation
- Inadequate design of air-conditioning systems (capacity, filtration)
- Ventilation effectiveness
- Synthetic materials in furnishings, volatile chemicals and Indoor chemistry
- Spread of indoor contaminants and infectious agents
- Renovation activities (ageing building stock)
- Lack of monitoring
  - fear of adverse implications
  - no reward for good IAQ
  - lack of awareness
  - lack of resources and expertise
  - unwilling to provide for adequate budget
- Social factors
  - not prone to complain
  - docile and tolerant
  - no precedent in successful litigation/arbitration nor mediation
  - lack of knowledge/awareness
- building operation & maintenance
- Occupant densities and activities
- Public awareness & tolerance



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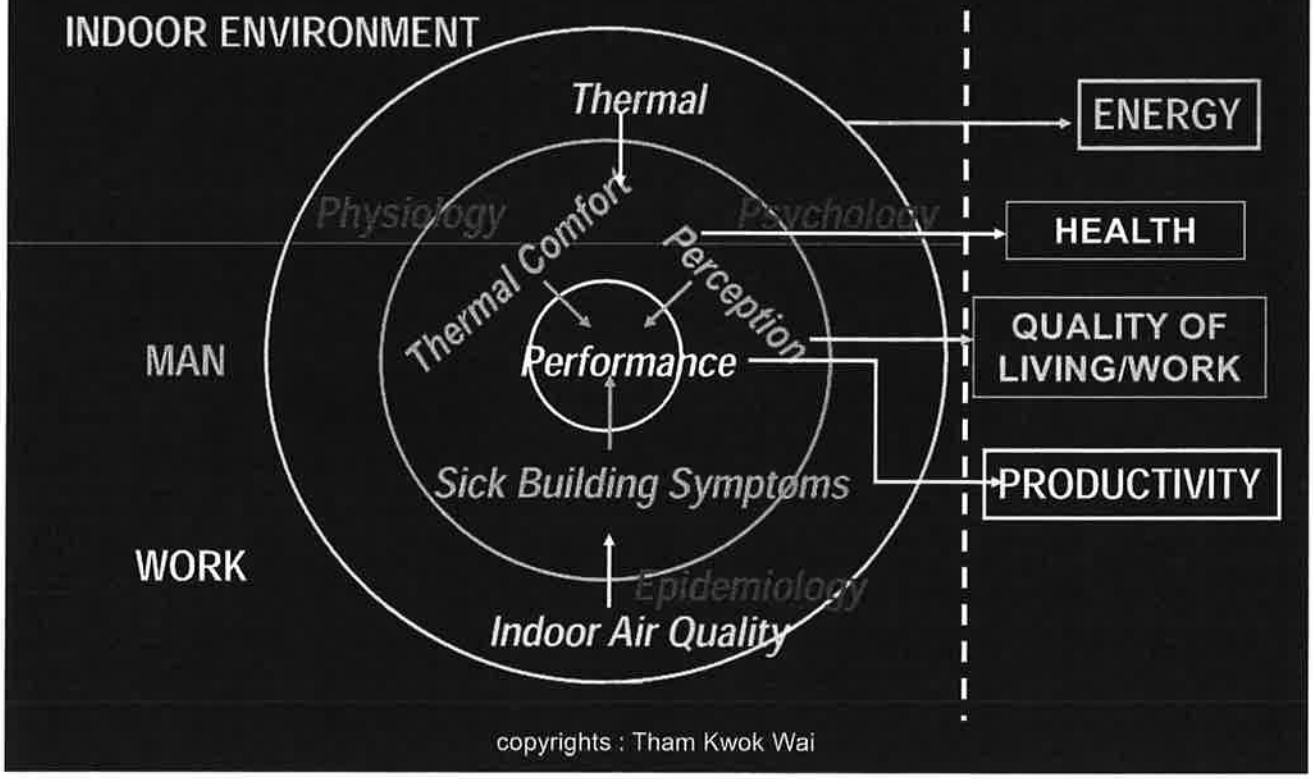
Why IAQ ?



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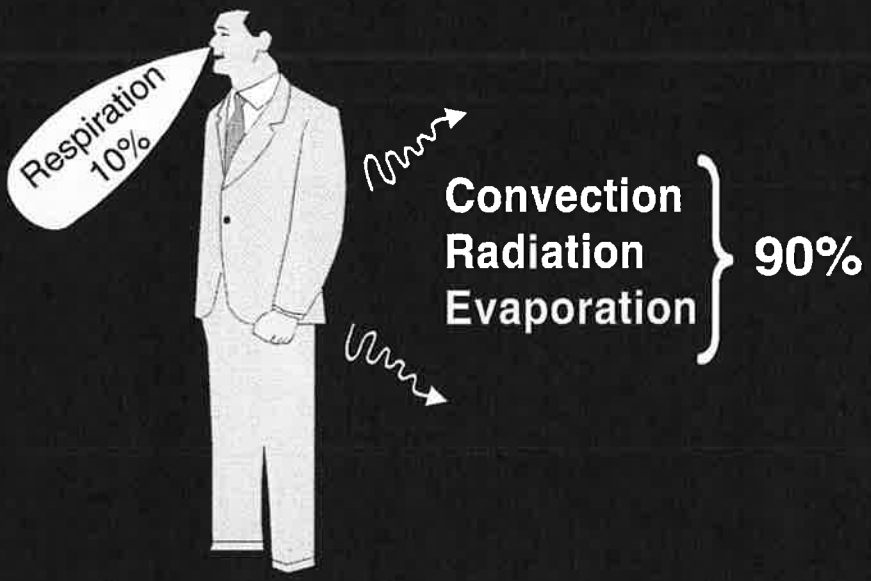
Thermal Comfort Parameters

Thermal balance



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Thermal balance

warmth or cold -comfort/discomfort sensed by skin

skin temp. range between 31^0 C and 34^0 C (averaged for the whole body surface) is the thermal comfort region

thermal balance = Met - Evp ± Cnd ± Cnv ± Rad
= 0

Met = metabolism (basal or muscular)
Evp = evaporation (of moisture and sweat)
Cnd = conduction (with surfaces in contact)
Cnv = convection (with the surrounding air)
Rad = radiation (with opposing surfaces/objects)
thermal imbalance leads to thermoregulatory mechanisms

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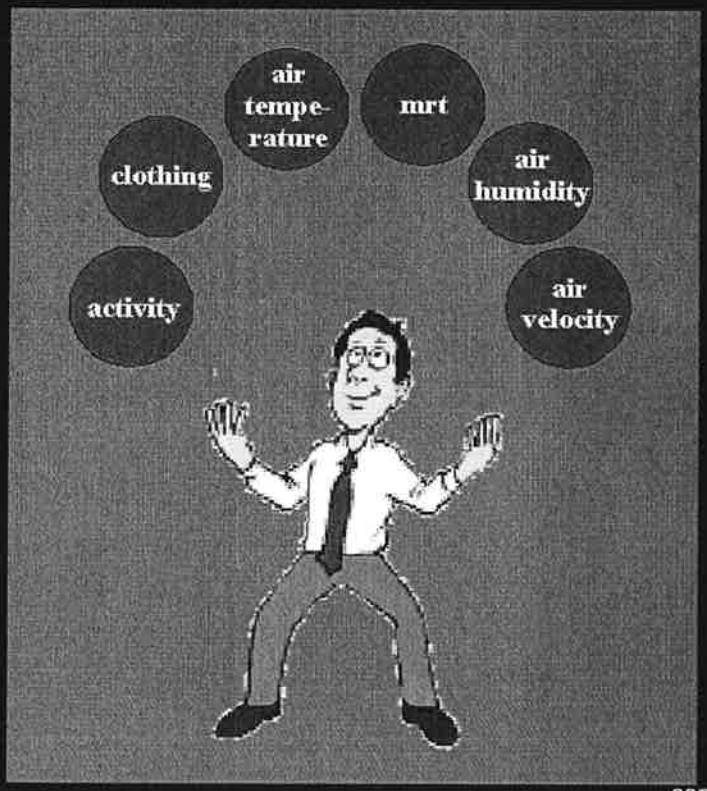
Thermal balance



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Thermoregulatory Control Mechanisms

Physiological → **Body's actions**

Behavioural responses → **Man's actions**

Warm Env
Heat gain > Heat loss
Body Warming
-Vasodilation
- Sweating
-Hyperthermia

Cold Env
Heat loss > Heat gain
Body cooling
-Vasoconstriction
- Shivering
-Hyporthermia

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Thermal Comfort

Absence of irritation/discomfort due to heat or cold

A state of pleasantness

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Factors affecting Thermal Comfort (PHYSICAL FACTORS)

- Temperature t_a
- Radiation
- Humidity
- Air velocity V

+ → Operative Temperature to

$$t_o = (t_a + t_r) / 2$$

$$t_r = t_g + 2.44 \times V^{0.5} (t_g - t_a)$$

t_g is the globe temperature in ^0C
t_a is the air temperature in ^0C
V is the air speed in m/s

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t_r is the radiant temperature

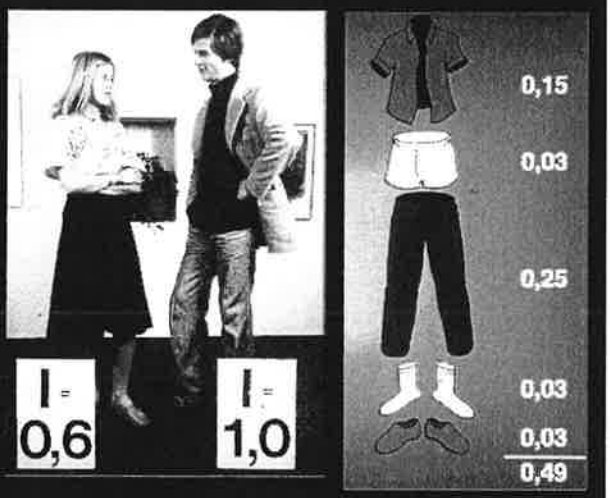
Factors affecting Thermal Comfort (Personal)

Metabolic rate (activity)



RECLINING	0.8 met
SEDENTARY	1.0 met
SEDENTARY WORK	1.2 met
STANDING WORK	1.5 met
WALKING 5 km/h	3.0 met

Clothing



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Factors affecting Thermal Comfort (SUBJECTIVE FACTORS)

- Acclimatisation
- Age and sex
- Body shape
- Subcutaneous fat
- State of health
- Food and drinks
- Skin colour

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SS 554 : 2009

Thermal Comfort parameters

	SS CP 554 (2009)
Operative temperature	24-26 °C
RH	• <65% (new building) • <70% (existing building during peak & common part-load conditions)
Air velocity	0.10-0.30 m/s

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Thermal Comfort Index

Too many parameters

Simplicity

Thermal comfort analysis

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Fanger's equation of comfort

Met rate, Clothing
Air temp, Humidity, MRT, Air Vel

Measure for thermal sensation

PMV Model of thermal comfort

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7-point psycho-social ASHRAE Scale

-	3	Cold
-	2	Cool
-	1	Slightly cool
	0	neutral
+	1	Slightly warm
+	2	Warm
+	3	Hot

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Thermal sensation Index

Comfort equation

Thermal sensation
Subjective response

Predicted Mean Vote PMV)

Comfort equation inherent in PMV

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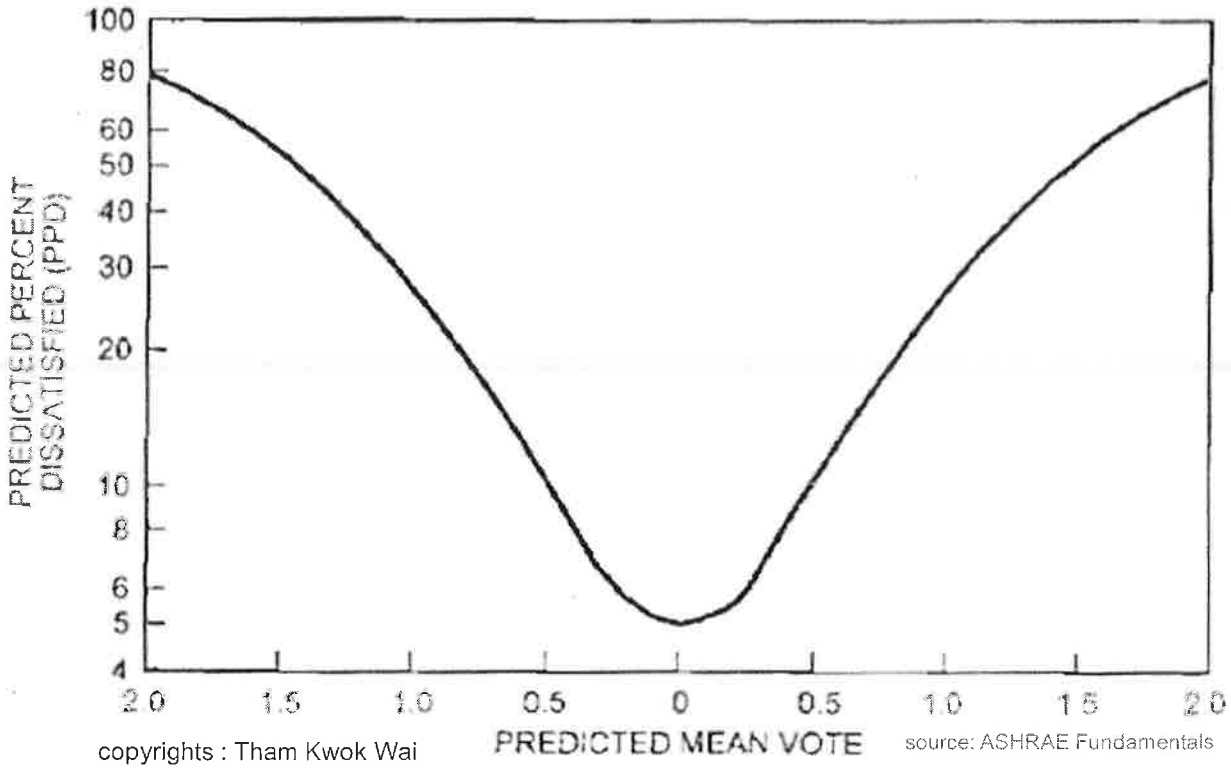
PMV vs PPD



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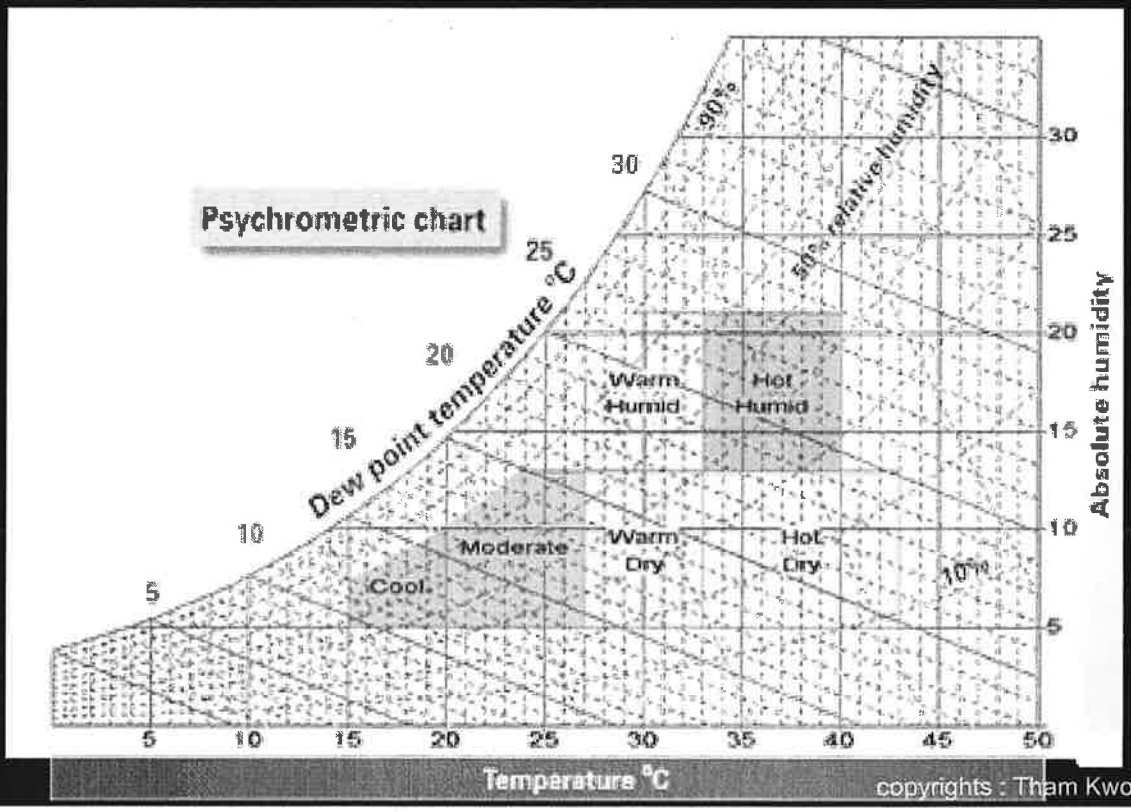
source: ASHRAE Fundamentals

Psychrometrics



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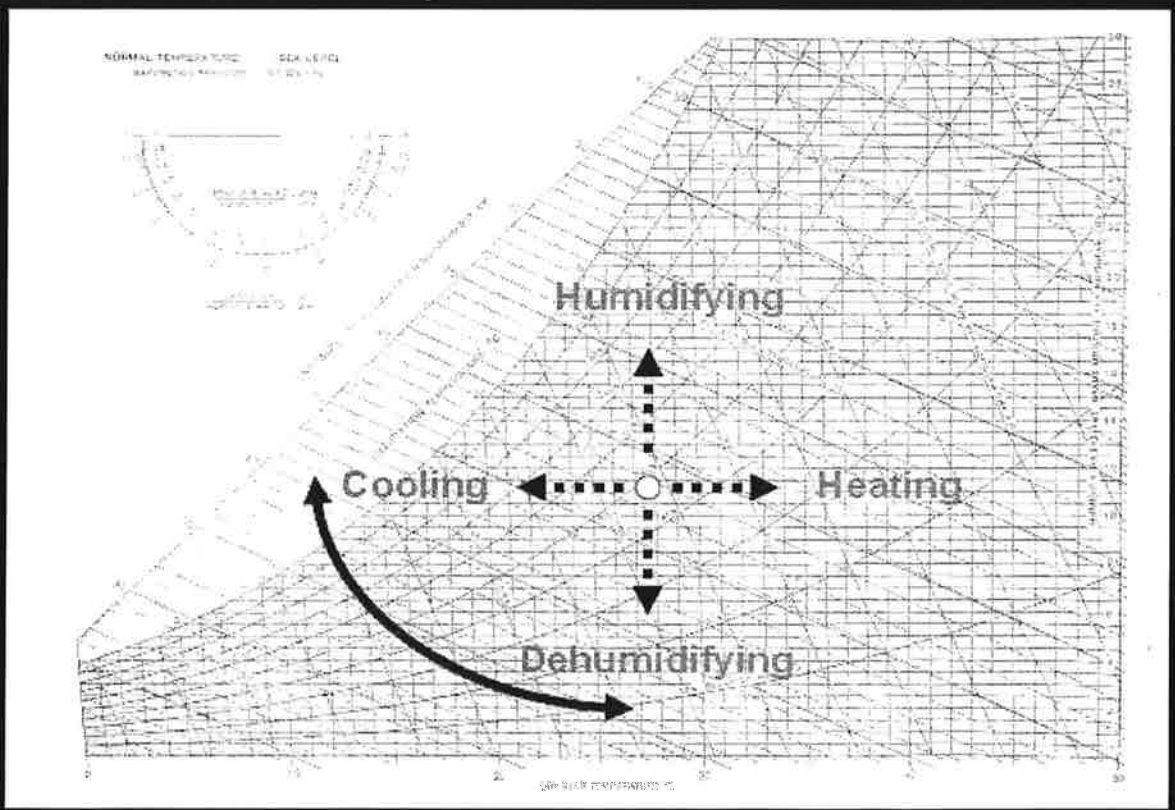
Basic Psychrometric Processes



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Some causes of thermal comfort problems

- Setpoint too low (cold)
- Air movement too low
- Inadequate matching of air-conditioning systems (capacity) with
  - Renovation
  - tenancy
  - load (activity) changes
- Poor air distribution
  - warm versus cold zones
  - Still versus drafty zones
- Inability of ACMV system to respond to diversity of loads
  - CAV – same supply air temperature from AHU
  - VAV - may not meet ventilation needs
- Inadequate maintenance

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Chemical Parameters

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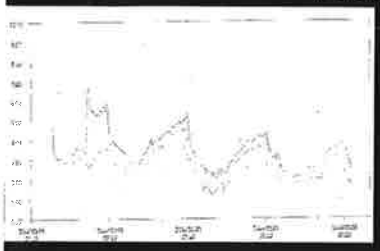
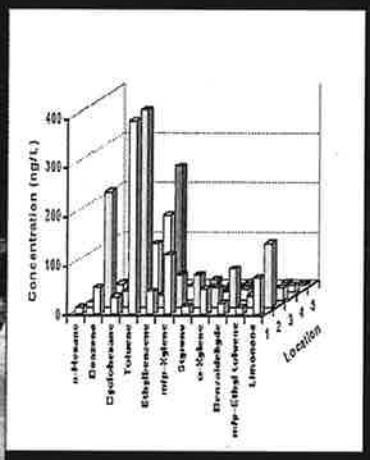
What is IAQ ? - CHEMICAL





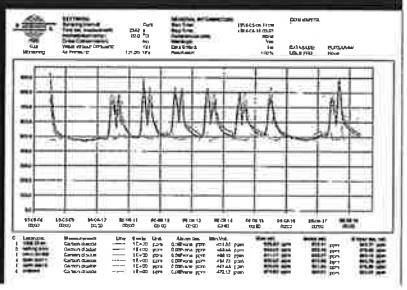












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SS 554 : 2009

Chemical parameters

	SS CP 554 (2009)
CO_2	700 above ambient
TVOC	3000 ppb
CO	9 ppm
HCHO	0.1 ppm/ 120 $\mu g/m^3$

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Some causes of chemical related problems

- Outdoor sources
  - Traffic
  - Industrial or other pollution sources
- Emissions from non green materials
  - Paints
  - Carpets
  - Fabric
  - furniture
- Polluting activities / equipment
  - Photocopiers / printers
  - Paper and stationery
- Poor air distribution
  - Inadequate ventilation in some spaces
  - Cross contamination from zones with higher pollution load
- Inadequate containment
  - No isolation of sources
  - No localised pollution removal

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Biological Parameters

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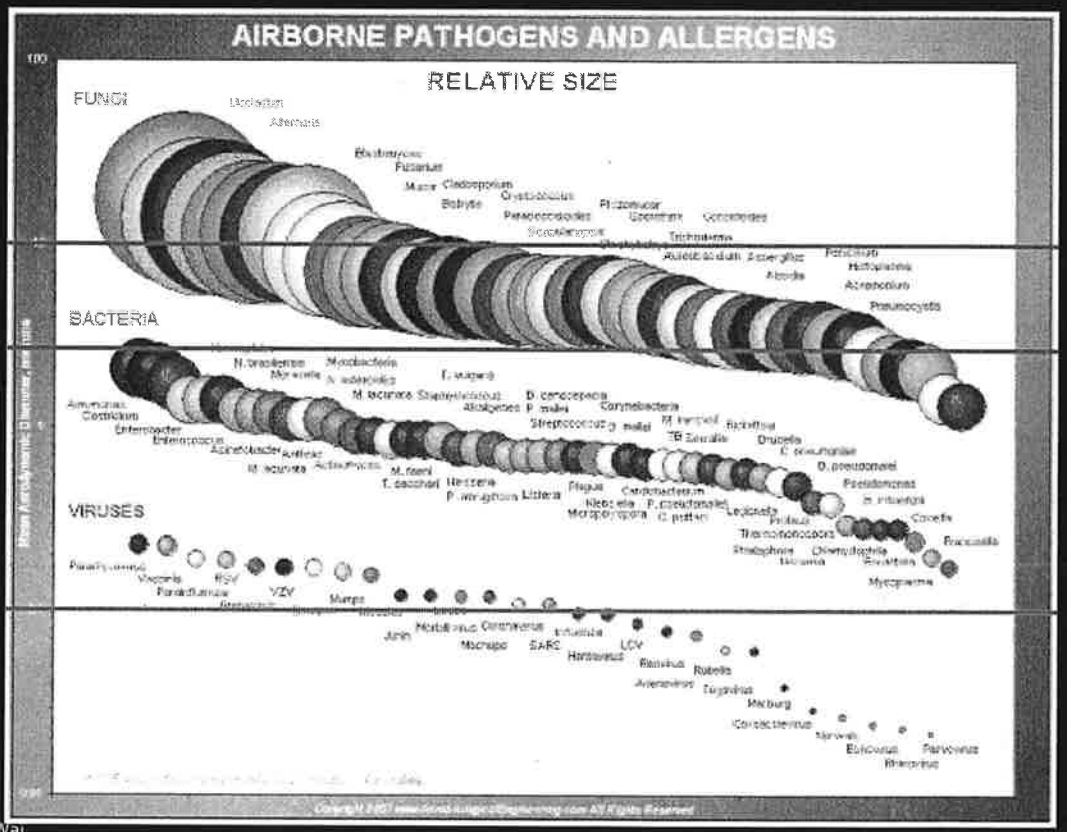
Relative size of biological particles



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SS 554 : 2009

Biological parameters

	SS CP 554 (2009)
Total Viable Bacteria Count	500 cfu / m^3
Total Viable Mould Count	Up to 500 cfu / m^3 If species is primarily Cladosporium

Cladosporium	**Cladosporium is an outdoor mould and usually found in leafy plants. Cladosporium cladosporioides and Cladosporium herbarum are phylloplane species that occur in outdoor air at high level. In an indoor environment, Cladosporium spp. occur as secondary wall colonisers, appearing after the primary ones such as Penicillium and Aspergillus spp. Cladosporium is very common in wet building materials.**
Penicillium	**The species of Penicillium are commonly found outdoors and widespread indoors. Many Penicillium species cause damage to damp building materials, including the toxigenic species Penicillium aurantiogriseum which is commonly found in house dust.**
Aspergillus	**Species of Aspergillus are common in warmer climates. These species grow on a vast array of organic materials. Aspergillus versicolor is commonly present on building materials. Aspergillus fumigatus is pathogenic and one of the main causes of the invasive disease, aspergillosis.**

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Some causes of Biological related problems

- Human density not matched with sufficient ventilation
- Outdoor sources
  - Fungi
  - Food exhaust
  - Cooling towers (Legionnaires Disease)
- Inadequate Maintenance / cleaning
  - Accumulation on filters
  - Office cleanliness
- Occupant activities
  - Food
  - Waste
- Dampness
  - Inadequate humidity control (elevated humidity levels support biological growth)
  - Condensation
  - Water leakage
  - Façade leakage (infiltration)
  - ponding

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Dust Parameters

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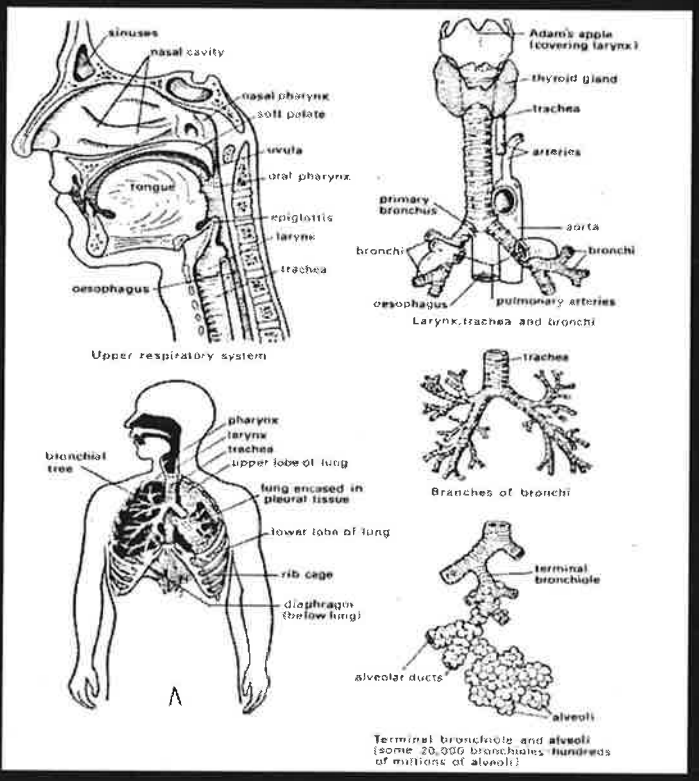
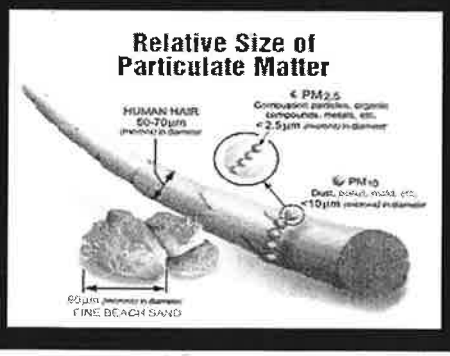
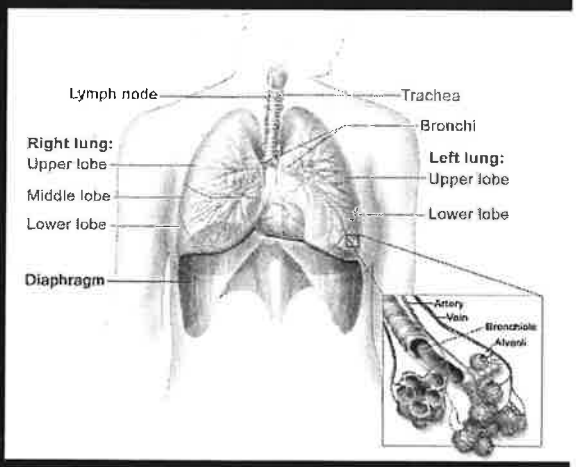
Exposure to Particles







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SS 554 : 2009

Dust parameters

	SS CP 554 (2009)
Respirable Suspended Particles	50 µg / m^3

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Some causes of Dust related problems

- Human density and activities
  - Human circulation and bringing in dust from outside
  - Office activities – photocopying, stationery, etc..
- Outdoor sources
  - Traffic combustion products
  - External dust
- Inadequate Filtration
  - Inadequate MERV rating
  - Gaps in filter installation
- Maintenance / cleaning
  - Accumulation on filters
  - Office cleanliness
- Indoor sources
  - Carpets and fabric
  - Storage and management of paper-based products

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THANK YOU

IAQ Parameters - Measurements and Verification

Tham Kwok Wai

National University of Singapore

Building and Construction Authority

Spot Measurements

- Total Bacteria, Yeasts & Molds
- Temperature, Relative Humidity, Air Movement
- Various Chemical Contaminant Profiles
- Particulate Profiles - especially PM10 Particulate levels / Respirable Suspended Particulates
- Total time taken :30 minutes per location





molds



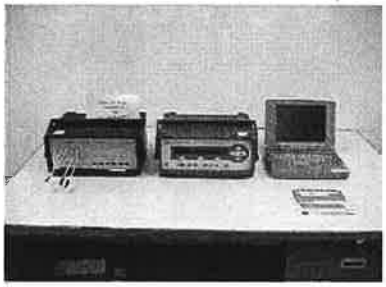


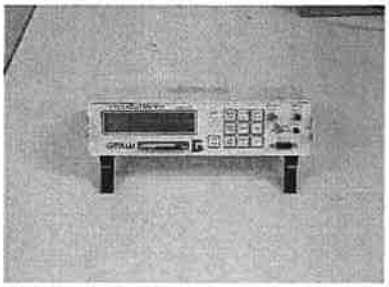


We shape a safe, high quality, sustainable and [illegible] built environment.

Continuous Monitoring

- Chemical Contaminant Profiles(5 - 7 days)
- Ventilation Characteristics (Air Exchange Rates) (1 evening)
- Particulate Profiles (2 days per location)









Thermal Comfort Parameters

Thermal Comfort parameters

	SS CP 554 (2009)
Operative temperature	Air temperature – thermistor Globe thermometer
RH	Thin film capacitor Hygrometer Sling thermometer or equivalent
Air velocity	Hot wire – linear flow Kata thermometer – omni-directional

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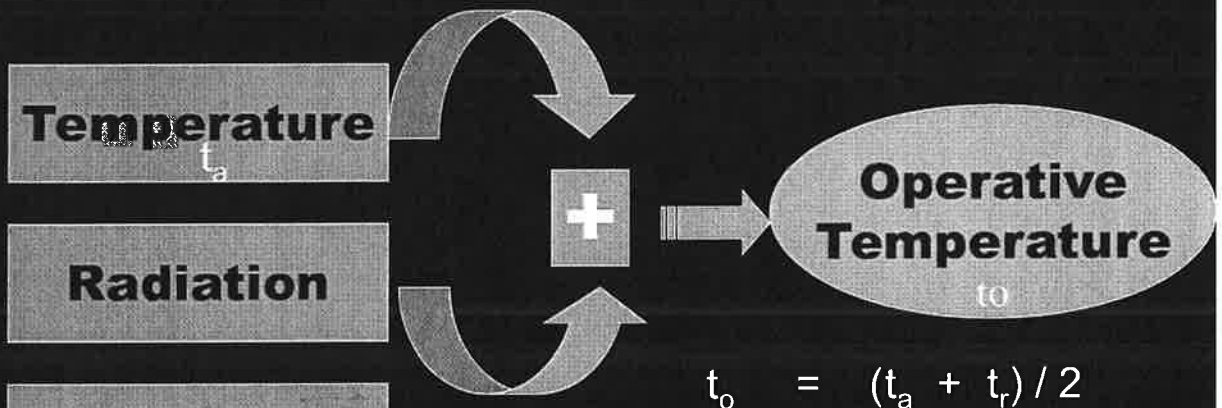
Factors affecting Thermal Comfort (PHYSICAL FACTORS)



$$t_o = (t_a + t_r) / 2$$

$$t_r = t_g + 2.44 \times V^{0.5} (t_g - t_a)$$

t_g is the globe temperature in ^{0}C
t_a is the air temperature in ^{0}C
V is the air speed in m/s

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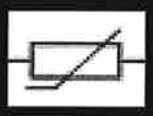
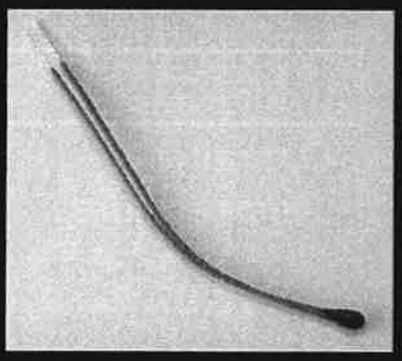
Thermistor

- Essentially a resistor
- Resistance dependent on temperature
- Symbol :





Negative temperature coefficient (NTC) thermistor, bead type, insulated wires

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Globe Thermometer and Operative Temperature

- Mean Radiant temperature measured by globe thermometer
- Thermometer sensor placed in centre of black globe
- Globe exchanges radiant heat with the environment
- Influenced by surfaces that the globe "sees"
- Adjustment made for air velocity



$$t_o = (t_a + t_r) / 2$$

$$t_r = t_g + 2.44 \times V^{0.5} (t_g - t_a)$$

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Air Velocity

- Hot wire anemometer
- Electrically heated fine wire at controlled current
- Air moving past heated wire cools it
- Electrical resistance of wire dependent on temperature
- Thus relationship exisit between resistance of wire and air speed



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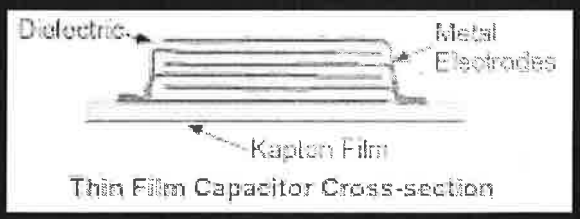
Relative Humidity

- Electrical hygrometers
- Thin film capacitor
  - Electrical resistance / capacitance dependent on humidity





- Sling Psychrometer
  - Dry and wet bulbs
  - Evaporation cools wet bulb
  - Temperature difference correlates to the relative humidity



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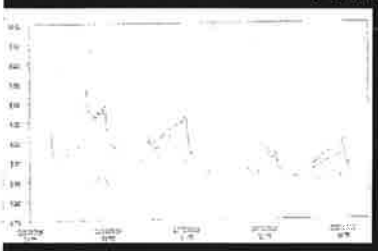
Chemical Parameters

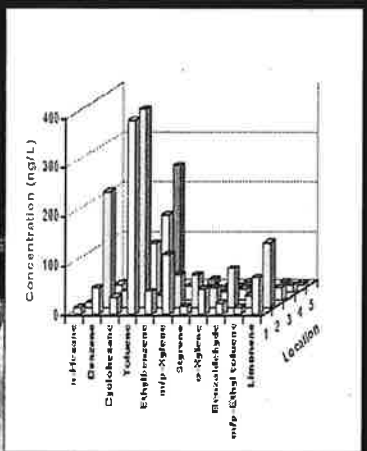
What is IAQ ? - CHEMICAL





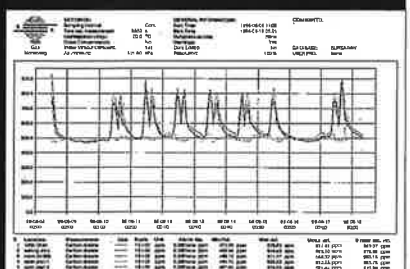












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SS 554 : 2009

Chemical parameters

	SS CP 554 (2009)
CO_2	Real-time non dispersive infra-red sensor or equivalent
TVOC	By real-time photoionisation detector or equivalent method.
CO	By real-time electrochemical sensor or equivalent method (NIOSH Manual of Analytical Methods 6604).
HCHO	By detection tubes, real-time electrochemical sensor or equivalent method for screening (ISO 16000-2).

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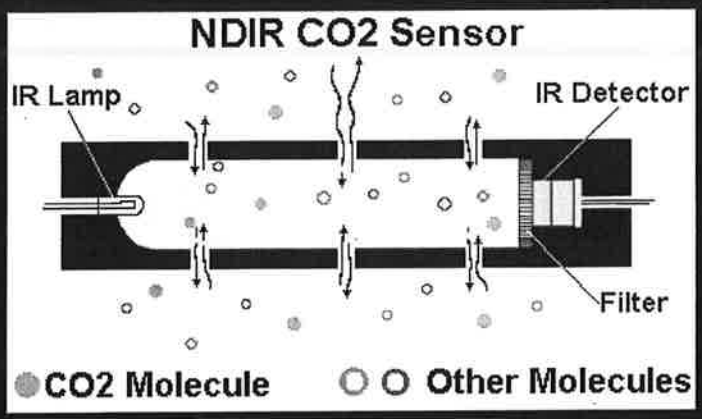
Real time non dispersive infra red detector

- measures carbon dioxide concentration by relying on one of the natural properties of CO2 molecules: CO2 molecules absorb light at a specific wavelength of 4.26 µm. This wavelength is in the infrared (IR) range. High concentrations of CO2 molecules absorb more light than low concentrations. This technique is called non-dispersive infrared (NDIR) detection. Refer to the schematic diagram, showing the major components of the NDIR CO2 detector



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Electro chemical sensors (for carbon monoxide)

- Use solid state galvanic cells to monitor partial pressures of gases eg CO
- The sensor operates as a battery: the electromotive force (EMF) changes a function of chemical modifications of the cathode in the presence of the gas

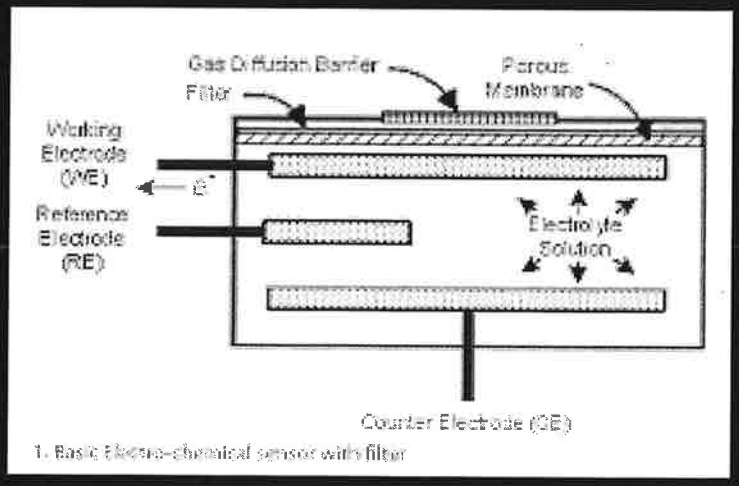

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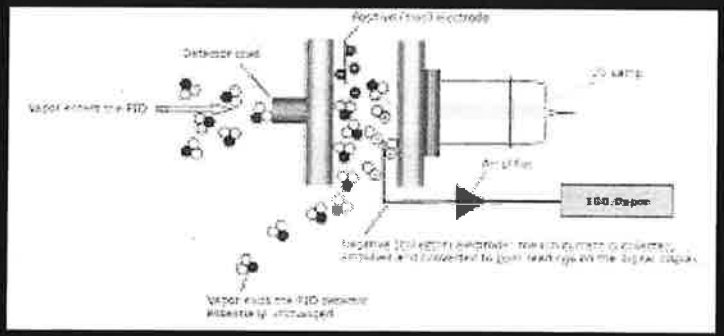
Photo ionization detector

TVOC

- High energy photons (in UV light range) breaks molecules into positively charged ions
- Ions produce current which is detected, amplified and shown as a signal proportional to the concentration of the gas





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Q trak

- The Q-TRAK Plus Model 8554 monitor simultaneously measures carbon dioxide, temperature, humidity and carbon monoxide, all within a single probe.
- Programmable real-time measurements and can log data unattended over an extended period of time.
- The Q-TRAK Plus IAQ monitor comes with TRAKPRO™ Data Analysis Software that supports:
  - program the Q-TRAK Plus Indoor Air Quality monitor for custom data logging sessions
  - download the data into your PC
  - create, view and print presentation quality charts illustrating how indoor air quality changes over time.



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Q trak

NDIR CO2 Sensing Technology

- gas molecules diffuse into the sensing chamber.
- IR light is directed through the sensing chamber towards the detector. The detector has a filter in front of it which eliminates all light except the 4.26 µm wavelength that CO2 molecules can absorb. Since other gas molecules do not absorb light at this wavelength, only the CO2 molecules affect the amount of light reaching the detector.
- The intensity of 4.26 µm light that reaches the detector is inversely related to the concentration of CO2 in the sensing chamber.
- When the concentration of CO2 in the chamber is zero, the detector will "see" the full light intensity. As the concentration of CO2 increases, the intensity of light striking the detector decreases.
- The exact relationship between IR light intensity and CO2 concentration is determined when the instrument is calibrated using pure nitrogen (0 ppm CO2) and a known concentration of CO2 such as 1000 or 5000 ppm.

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Qtrak

NDIR CO2 Sensing Technology

- The intensity of light striking the detector is described by Beer's Law:

Beer's Law:

$$I = I_0 e^{kP}$$

Where:

I = the intensity of light striking the detector
I_0 = the measured signal with 0 ppm CO_2
k = a system dependent constant
P = the concentration of CO_2

The IR light source is pulsed on and off by the microprocessor. This allows background fluctuations to be subtracted during the off-period.

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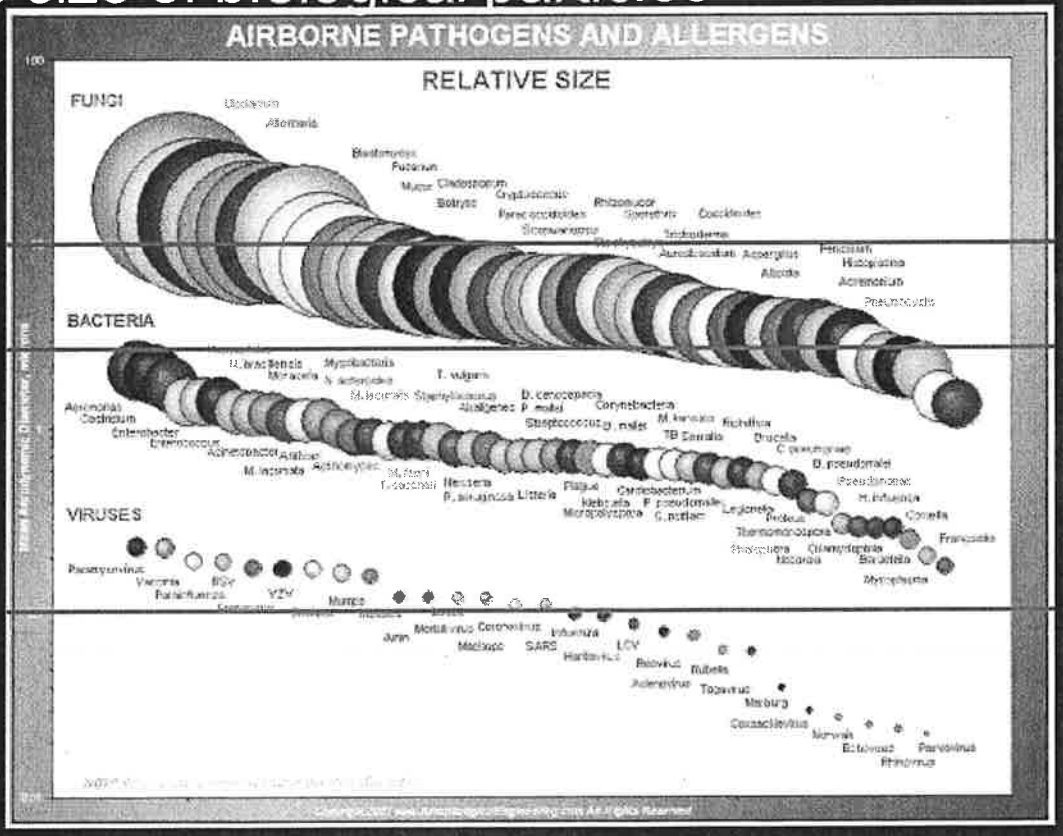
Biological Parameters

Relative size of biological particles



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SS 554 : 2009

Biological parameters

	SS CP 554 (2009)
Total Viable Bacteria Count	By Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 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 ^0C.
Total Viable Mould Count	By Andersen single-stage impactor (N6), or equivalent equipment designed for airborne microbial sampling, flow rate at 28.3 L/min (1 ft^3/min) for 4 minutes or equal volume of air. Mould is cultured by 2 % Malt Extract Agar (MEA) and incubated for 5 days at 25 ^0C.

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Andersen Sampler

- The N6 is comprised of an aluminum inlet cone, sampling stage, and a base plate held together by three spring clamps and sealed with O-ring gaskets. The sampling stage has 400 precision machined orifices.
- The collection and assessment of aerosol samples is very simple. A petri dish containing an agar medium appropriate for the microorganisms which may be encountered is placed in the instrument and a sample of air is drawn. The petri dish is then removed, inverted in its cover, incubated, and counted by an accepted method.



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Andersen Sampler

- Computing biological concentration from enumeration of colonies in agar plate in CFU/m^3



Sampling rate = 28.3 L/min
Sampling time = 4 min
Sampling Volume (V) = (28.3 x 4) / 1000 m^3
Number of colonies enumerated = N colonies
Concentration (C) = N / V CFU/m^3

Example:
N = 45
C = 45 / [(28.3 x 4) / 1000]
= 398 CFU/m^3

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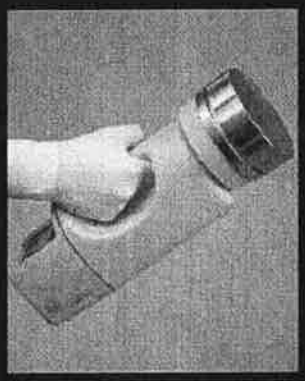
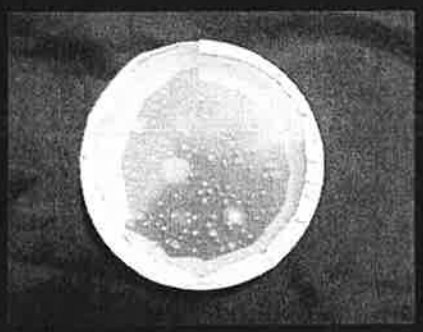
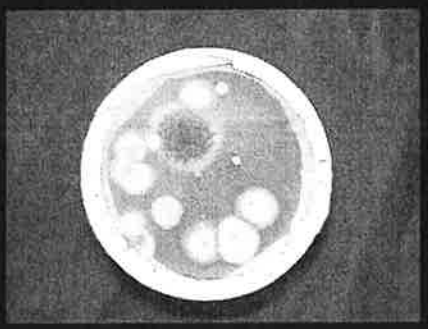
Other Microbial Air Samplers





Colonies of bacteria after incubation





Colonies of molds after incubation

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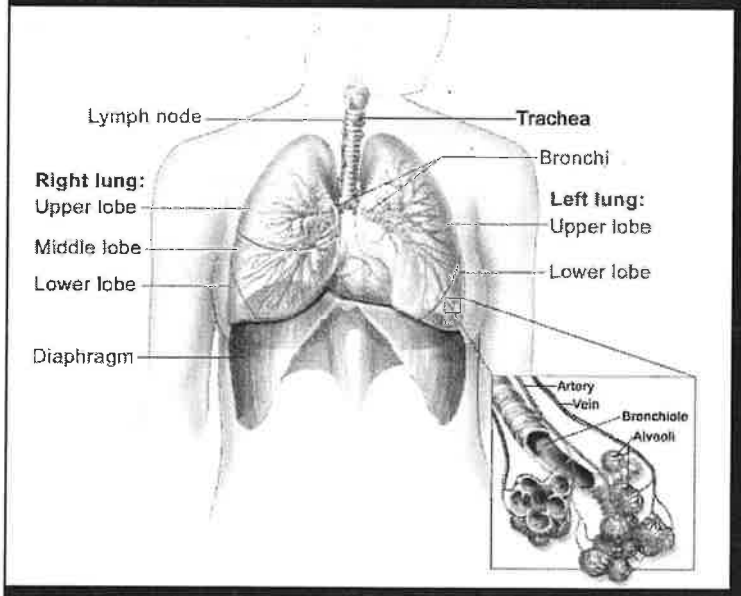
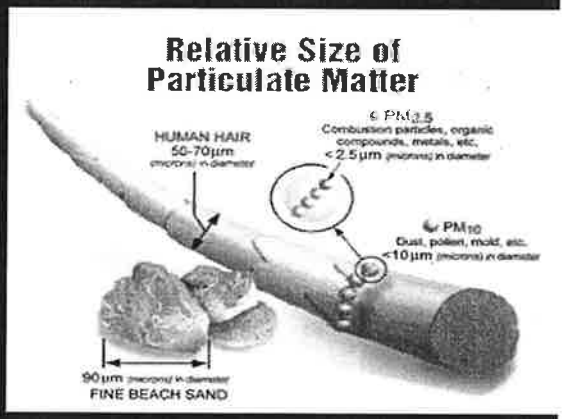
Dust Parameters

Exposure to Particles





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SS 554 : 2009

Dust parameters

	SS CP 554 (2009)
Respirable Suspended Particles	By real-time optical scattering or piezoelectric monitors or equivalent method

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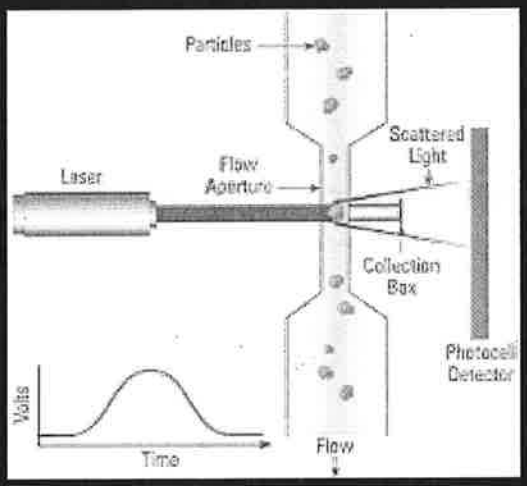
Optical Light Scattering

- An aerosol sample is drawn into the sensing chamber in a continuous stream.
- One section of the aerosol stream is illuminated with a small beam of laser light.
- Particles in the aerosol stream scatter light in all directions.
- A lens at 90° to both the aerosol stream and laser beam collects some of the scattered light and focuses it onto a photodetector.
- The detection circuitry converts the light into a voltage.
- This voltage is proportional to the amount of light scattered which is, in-turn, proportional to the mass concentration of the aerosol.
- The voltage is read by the processor and multiplied by an internal calibration constant to yield mass concentration.





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Target contaminants triggered by specific sources

Parameter	Acceptable limit	Unit	Measurement method / Analytical method
PM 2.5	35	$\mu g/m^3$	By real-time piezoelectric monitors or optical scattering or equivalent method
Ultra-fine particles	Not applicable	particles / cm^3	By a nuclei condensation counter or equivalent method. Note - This measurement may be helpful to trace the pollutant source, especially from emission processes.
Nitrogen dioxide	100	$\mu g/m^3$	By real-time chemiluminescence, diffusion tube passive samplers, chemical detector tubes or equivalent method. ISO 16000-15 / NIOSH Manual of Analytical Methods 6014.
Ozone	0.1	ppm	By real-time chemiluminescence, using potassium iodide in phosphate buffer as absorbing solution and analysed spectrophotometric, or chemical detector tubes or equivalent method.
Radon	150	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).
Asbestos	0.01	fibre / cc	By phase contrast microscopy or equivalent method, followed by Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM) for identification of fibre [5] ISO 8672 / ISO14966 / NIOSH Manual of Analytical Methods 9000/9002.
Nicotine	Not detected		By gas chromatography -nitrogen phosphorus detector. Air collected by XAD-2 tube. NIOSH Manual of Analytical Methods 2544/2551.
Pathogenic bacteria	Presence of specific species		Collect air sample by Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 28.3 L/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 °C. Transfer the suspected colony to its selective media for detecting the presence of specific pathogens. Incubate in accordance to the specific requirement of the suspected pathogen. Sampling from outdoor, indoor complaint area and non-complaint area. Confirmation by API strips or Polymerase Chain Reaction (PCR).
Pathogenic mould	Presence of specific species		Collect dust using 3-piece 37 mm cassette, preloaded with 0.45 µm pore-size filters with flow rate at 3 to 4 litres/min for 8 hours. Confirmation by culture by Polymerase Chain Reaction (PCR). Sampling from outdoor, indoor complaint area and non-complaint areas.
Semi volatile and volatile organic compounds (VOC)	PEL of toxic substances	ppm	ISO 16000-5 (Table 1 Sampling Strategy for VOC) ISO 16000-12 ISO 16017 (Pumped Sampling) ISO 16702 (semi-VOC) NIOSH Manual of Analytical Methods 2549

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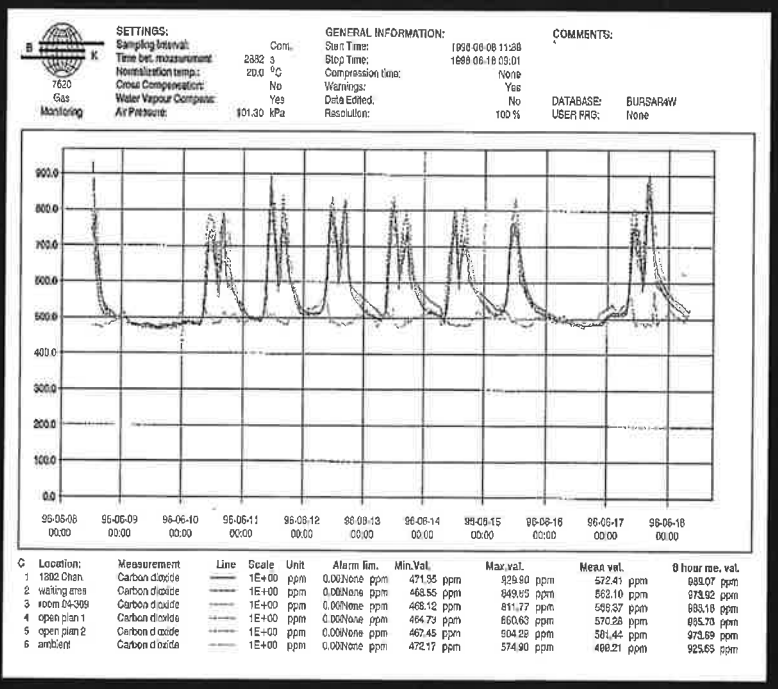
Source : SS 554 : 2009

Continuous Measurements And Air Change Rate

Continuous chemical sampling





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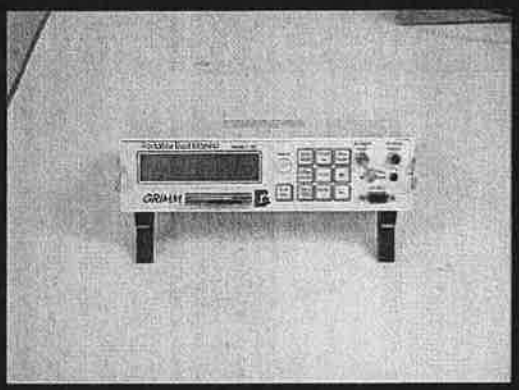
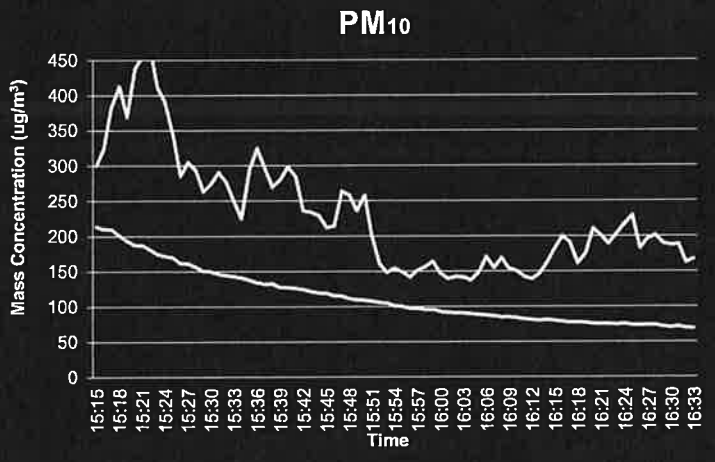
Dust sampling





Outdoor

Indoor

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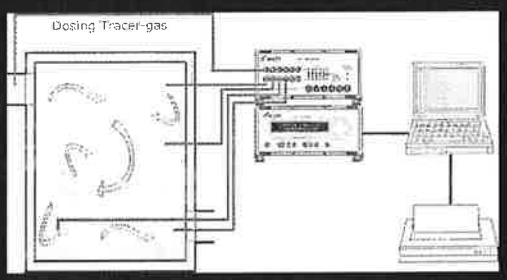
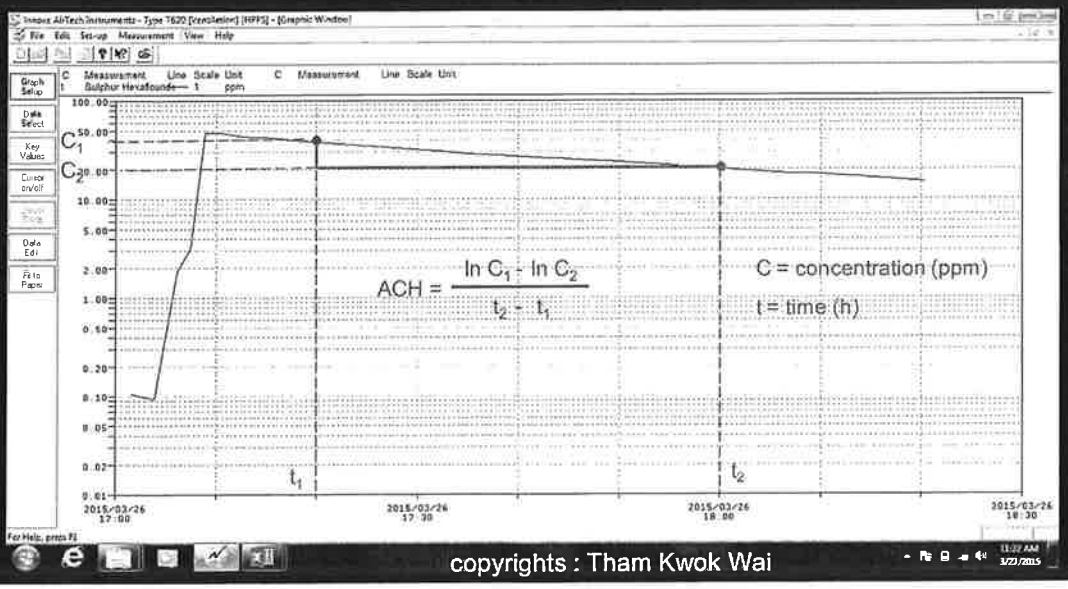
Air Exchange Study

- Tracer gas (sulfur hexafluoride) is dosed and uniformly mixed in room
- Decay curve is plotted
- Air change rate (ACH) computed





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Occupant Survey

Building and Construction Authority

GMOI v.1.1 Assessment Criteria

3-4 Post Occupancy Evaluation

(a) **Conduct yearly post occupancy evaluation** to assess occupant's satisfaction with the indoor environmental conditions
(2 points)

(b) List of corrective actions taken following the post occupancy evaluation (1 point)

3-4 Post Occupancy Evaluation

Please put a tick (√) in a box.

(1 = Poor, 2 = Below average, 3= Average, 4 = Good, 5 = Excellent)

	1	2	3	4	5
1. How is the noise level at your work area?					
2. How is the air-condition temperature at your work area?					
3. How do you find the lighting level (i.e. Brightness) at your work area?					
4. How do you find the general cleanliness of the office?					
5. How do you rate your personal workspace?					



Building and Construction Authority

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SS 554 : Survey Questionnaire

Annex J
(informative)

Sample confidential questionnaire for building occupants

Note - This short questionnaire is to be given to building occupants to help determine the existence of health problems that may be related to the office environment. Their answers are to remain confidential.

1. **Personal information**
   - 1.1 Gender: Male / Female
   - 1.2 Age:
   - 1.3 No. of years you worked in this office:
   - 1.4 Building type: office/shopping centre/school/others
   - 1.5 Office level:

2. **Environmental conditions**
   - 2.1 Age of the building:
   - 2.2 **Type of workstation:** Enclosed room / Open concept
   - 2.2 **Floor carpeted:** Yes/No
   - 2.4 With wallpaper: Yes/No
   - 2.5 Infiltration of cigarette smoke: Yes/No
   - 2.6 Infiltration of vehicular exhaust: Yes/No
   - 2.7 No. of people who share your workstation:
   - 2.8 How is your area air-conditioned? Centralised unit / Fan coil unit
   - 2.9 **How is your workstation lighted? Fluorescent lighting / Non-fluorescent lighting**
   - 2.10 **Please indicate if you work with or near the following equipment:**
     - **Photocopier** : Yes/No
     - Server : Yes/No
     - Air cleaner : Yes/No
     - Others (Please specify: _____)
   - 2.11 **Do you have to put on extra clothing for comfort?** Regularly / Sometimes / Never
   - 2.12 Does the office air feel stuffy? Regularly / Sometimes / Never
   - 2.13 Does the office air have an unpleasant odour? Regularly / Sometimes / Never
   - 2.14 Visible mould : Yes/No
   - 2.15 Dusty air vent : Yes/No

3 **Nature of occupation**

- 3.1 No. of hours spent per day at your main workstation with a computer:
- 3.2 Please rate how you find the stress in your working conditions:
  - **Physical stress experience** : Low / Moderate / High
  - **Mental stress experience** : Low / Moderate / High
  - Climate of cooperation at work : Low / Moderate / High
- 3.3 What is your job category? Managerial / Professional / Secretarial / Clerical / Others (If Others, specify: _____)

4 **Health complaints**

- 4.1 **Please indicate your experience of the following symptoms at work during the past one month:**
  - Stuffy nose : Daily / 2-3 times weekly / Less
  - Dry throat : Daily / 2-3 times weekly / Less
  - Cough : Daily / 2-3 times weekly / Less
  - Skin rash/itchiness : Daily / 2-3 times weekly / Less
  - Eye irritation : Daily / 2-3 times weekly / Less
  - Headache : Daily / 2-3 times weekly / Less
  - Lethargy : Daily / 2-3 times weekly / Less
  - Drowsiness : Daily / 2-3 times weekly / Less
  - Dizziness : Daily / 2-3 times weekly / Less
  - Nausea/vomiting : Daily / 2-3 times weekly / Less
  - Shortness of breath : Daily / 2-3 times weekly / Less
- 4.2 No. of days in the past one month that you had to take off work because of these complaints:
- 4.3 When do these complaints occur?
  Mornings / Afternoons / No noticeable trend
- 4.4 When do you experience relief from these complaints?
  After I leave my workstation / After I leave the building / Never
- 4.5 Please indicate if you have any of these medical conditions:
  - Asthma : Yes, on medication / Yes, not on medication / No
  - Allergy : Yes, on medication / Yes, not on medication / No
  - Sinus : Yes, on medication / Yes, not on medication / No
  - Migraine : Yes, on medication / Yes, not on medication / No
- 4.6 If female, are you currently pregnant? Yes / No / Not sure

SS 554 : Survey Questionnaire

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  - Allergy : Yes, on medication / Yes, not on medication / No
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Purpose of Survey

- Obtain occupant feedback
  - Longer term exposure
  - Integrated response
- Limitations of objective measurements
  - Duration
  - Location
  - Parameters
- Determination of prevalence of sick building symptom
- Identifying specific problems
  - Occupants help pinpoint causes
  - Occupant help identify processes
  - Occupant help to identify episodic problems (eg food smell)

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Components of Survey

- Personal information
- Environmental conditions
- Nature of occupation
- Health complaints

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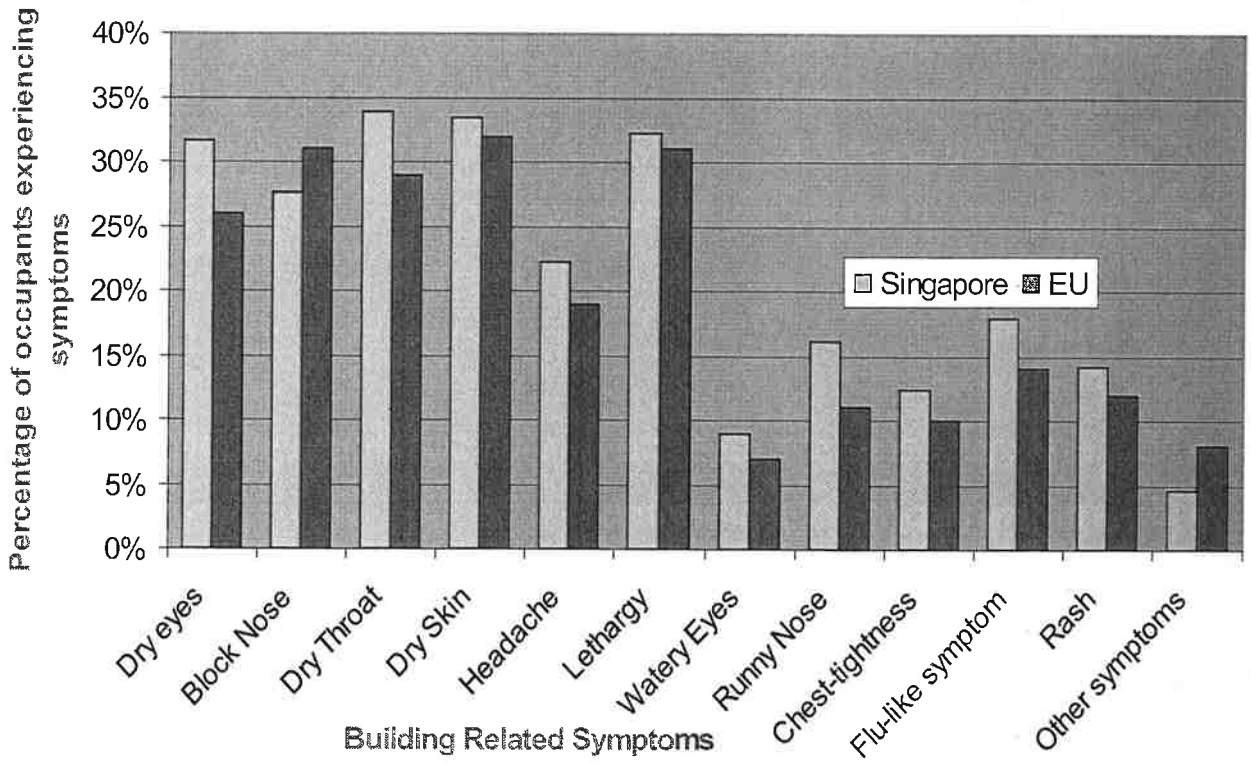
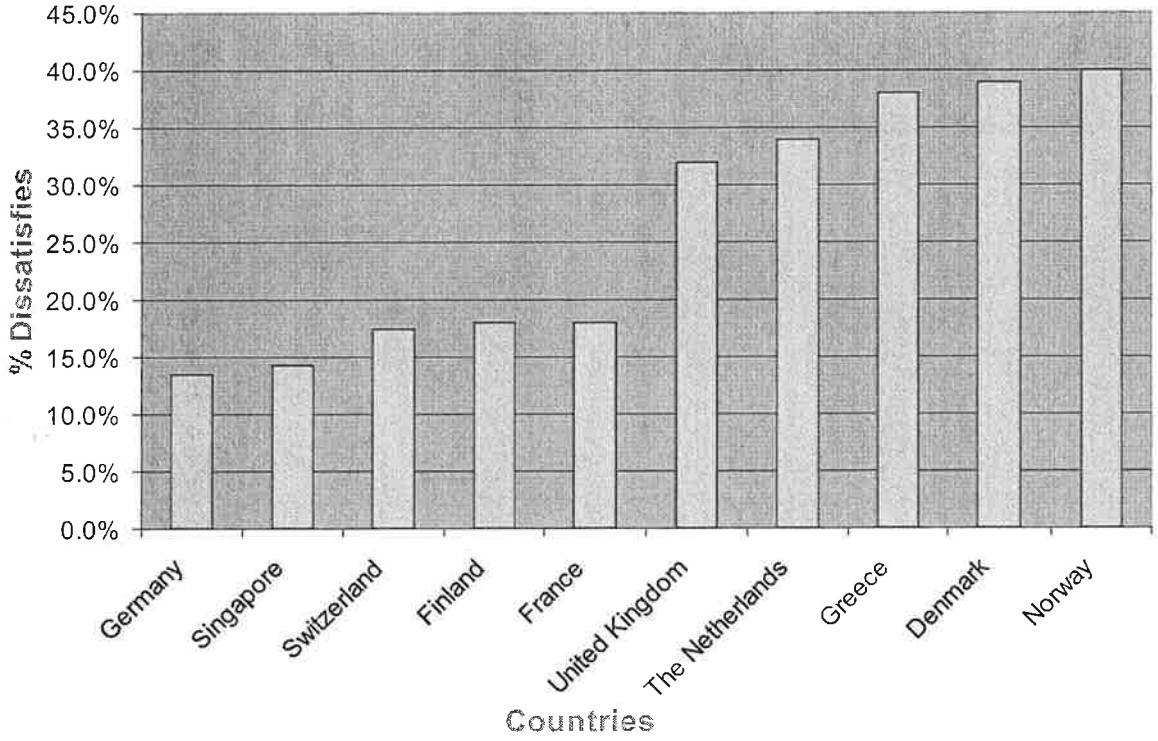
Building Related Symptoms - A comparison of Singapore and EU studies



Acceptability of Indoor Air Quality (% Dissatisfied) - A Comparison of Singapore and EU studies



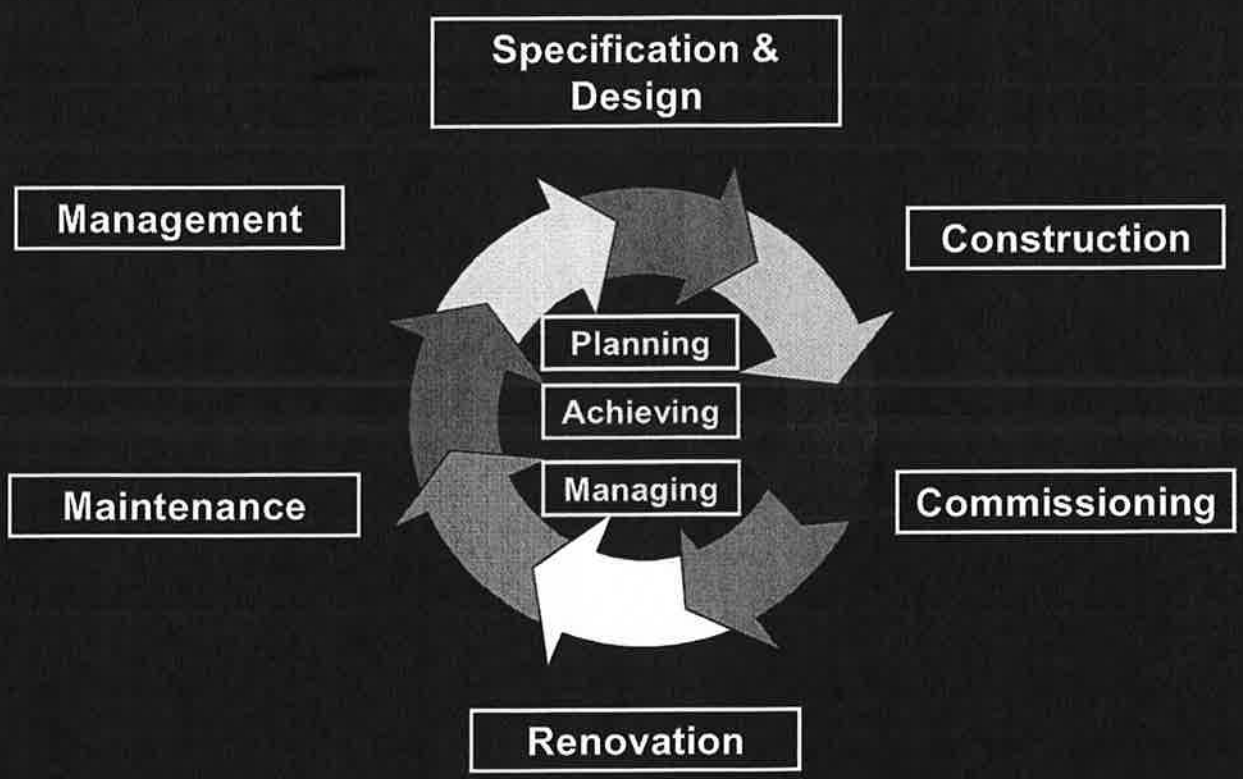
THANK YOU

IAQ Considerations for Buildings – Design and Construction

Tham Kwok Wai

National University of Singapore

Cycle of Building Delivery - Achieving Acceptable IAQ Buildings



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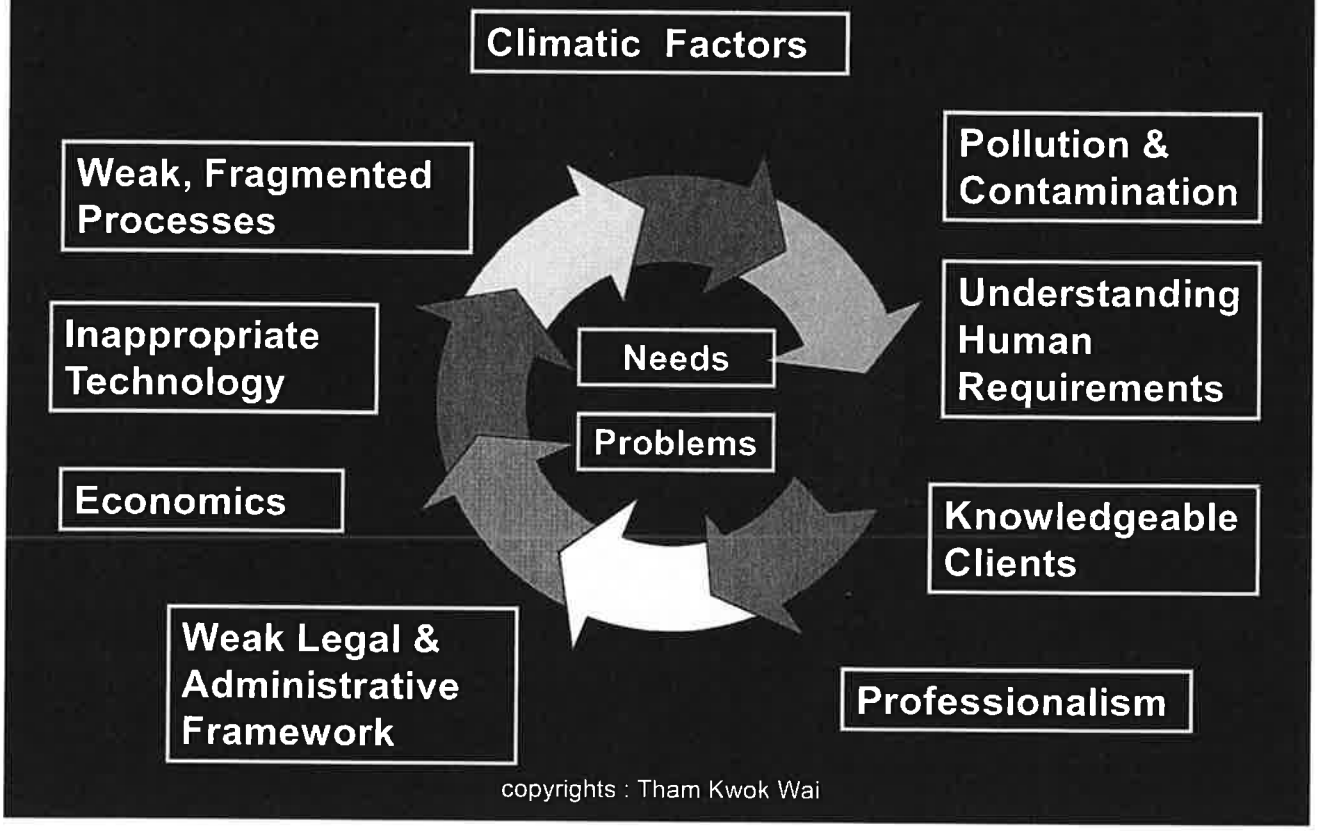
Challenges for Achieving Acceptable IAQ Buildings



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Responsibilities to Achieving Acceptable IAQ

Occupants	Awareness; Articulate IEQ requirements; Proactive feedback; Responsible occupancy
Evaluators/ Managers	Holistic assessment and facilities management; Responsible reporting; Audit & management; Budget allocation
Builders/ contractors	Responsible professional advisory; design implementation; materials use
Building scientist/ experts	Societal wellness and value focused; Responsible technological innovation; Ethical research dissemination;
Architects	Responsible client advisory; design; materials; innovative applications
Client/ Owner	Responsible performance targets; specifications, contract

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Design & Construction

1. Importance of Specifications
2. Translating Specifications to Design
3. Construction – adherence to design
4. Challenges

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Design & Construction

Responsible performance targets

↓

Specifications

↓

Contract

↓

Construction

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Design & Construction

Responsible performance targets
↓
Specifications
↓
Contract
↓
Construction

- Adopt SS 554 Recommendations
- Specify green materials and products
  - SGBC database (http://www.sgbc.sg/green-certifications/) or equivalent
- Understand design requirements
  - Spatial relationships (atriums, space connectivities)
  - Tenant mix and processes/activities

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Design & Construction

Responsible performance targets
↓
Specifications
↓
Contract
↓
Construction

- Appropriate ACMV design
  - Ventilation
  - Filtration
  - Zoning
  - Thermal and ventilation control
- Episodic challenges
  - Haze
  - Attacks (Chemical & Biological)

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Design & Construction



- Adherence to design during construction
  - Design variation
    - Impact of design change
    - Impact of materials substitution
  - Safety and exposure of workers
    - Adequate protection

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Performance Criteria and Values

SINGAPORE STANDARD

SS 554 : 2009

(ICS 13.040.20; 91.040.01)

CODE OF PRACTICE FOR

Indoor air quality for air-conditioned buildings

Published by
SPRING Singapore
2 Bukit Merah Central
Singapore 159835
SPRING Singapore Website: www.spring.gov.sg
Standards Website: www.standards.org.sg

SPRING singapore
Enabling Enterprise

Table 1 – Recommended IAQ parameters

Parameter	Acceptable limit (8 hours)	Unit	Measurement method / Analytical method
i. Thermal comfort parameters			
Operative temperature[1]	24 to 26	°C	Air temperature – by hot wire, thermistor, thermometer sling or equivalent method. Globe temperature – by Globe thermometer.
Relative humidity	< 65 (for new buildings) < 70 (for existing buildings) (under peak and common part load conditions)	%	By thin film capacitor, hygrometer, thermometer sling or equivalent method.
Air movement	0.10 - 0.30	m/s	By hot wire method for linear air velocity or Kata thermometer for omni-directional air velocity method or equivalent.
ii. Chemical parameters			
Carbon dioxide	700 above outdoor	ppm	By real-time non-dispersive infra-red sensor or equivalent method.
Carbon monoxide	9	ppm	By real-time electrochemical sensor or equivalent method (NIOSH Manual of Analytical Methods 6604).
Formaldehyde	120 0.1	µg/m³ ppm	By detection tubes, real-time electrochemical sensor or equivalent method for screening (ISO 16000-2). When formaldehyde concentration is higher than the limit, collect continuous air samples using dinitrophenylhydrazone (DNPH) cartridges and analyse by High Performance Liquid Chromatography (HPLC) using: NIOSH Manual of Analytical Methods 2016 or EPA Method 0100: Sampling for Formaldehyde and other Carbonyl Compounds. ISO 16000-3 or NIOSH Manual of Analytical Methods 2016.
Total volatile organic compounds (TVOC) that are photoionisable (10.6 eV)[2]	3000	ppb	By real-time photoionisation detector or equivalent method.
iii. Respirable suspended particles (aerodynamic diameter less than 10 µm sampled with a particle size-selective device having a median cut point of 4 µm)	90	µg/m³	By real-time optical scattering or piezoelectric monitors or equivalent method.

NOTES –

[1] 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 by:

$t_o = (t_a + t_r)/2$

t_o = operative temperature
t_a = air temperature
t_r = mean radiant temperature (see also ISO 7726 'Ergonomics of the thermal environment - Instruments for measuring physical quantities')

Mean radiant temperature for a fully clothed subject: $t_r = t_g + 2.44 \times \sqrt{V^{0.5}} (t_g - t_a)$

t_g is the globe temperature in °C
t_a is the air temperature in °C
V is the air speed in m/s

[2] When TVOC > 3000 ppb or when smell is perceived or when ventilation rate is less than the recommended rate by SS 553 or recommendation by competent person, specific VOCs should be identified (e.g. endocrine disrupting chemicals, microbial VOC, etc.) by identifying the individual VOC species.

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Source : SS 554

Performance Criteria and Values

Table 2 – Target contaminants triggered by specific sources

Parameter	Acceptable limit	Unit	Measurement method / Analytical method
PM 2.5	35	$\mu g/m^3$	By real-time piezoelectric monitors or optical scattering or equivalent method
Ultra-fine particles	Not applicable	particles / cm^3	By a nuclei condensation counter or equivalent method. Note - This measurement may be helpful to trace the pollutant source, especially from emission processes.
Nitrogen dioxide	100	$\mu g/m^3$	By real-time chemiluminescence, diffusion tube passive samplers, chemical detector tubes or equivalent method. ISO 16000-15 / NIOSH Manual of Analytical Methods 6014.
Ozone	0.1	ppm	By real-time chemiluminescence, using potassium iodide in phosphate buffer as absorbing solution and analysed spectrophotometric, or chemical detector tubes or equivalent method.
Radon	150	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).
Asbestos	0.01	fibre / cc	By phase contrast microscopy or equivalent method, followed by Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM) for identification of fibre [5] ISO 8672 / ISO14966 / NIOSH Manual of Analytical Methods 9000/9002.
Nicotine	Not detected		By gas chromatography -nitrogen phosphorus detector. Air collected by XAD-2 tube. NIOSH Manual of Analytical Methods 2544/2551.
Pathogenic bacteria	Presence of specific species		Collect air sample by Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 28.3 L/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 °C. Transfer the suspected colony to its selective media for detecting the presence of specific pathogens. Incubate in accordance to the specific requirement of the suspected pathogen. Sampling from outdoor, indoor complaint area and non-complaint area. Confirmation by API strips or Polymerase Chain Reaction (PCR).
Pathogenic mould	Presence of specific species		Collect dust using 3-piece 37 mm cassette, preloaded with 0.45 µm pore-size filters with flow rate at 3 to 4 litres/min for 8 hours. Confirmation by culture by Polymerase Chain Reaction (PCR). Sampling from outdoor, indoor complaint area and non-complaint areas.
Semi volatile and volatile organic compounds (VOC)	PEL of toxic substances	ppm	ISO 16000-5 (Table 1 Sampling Strategy for VOC) ISO 16000-12 ISO 16017 (Pumped Sampling) ISO 16702 (semi-VOC) NIOSH Manual of Analytical Methods 2549

NOTES -

1. The above contaminants may not be commonly found in a typical indoor space. These parameters should be monitored in a situation when a potential source is suspected.
2. When the complaint cannot be traced to IAQ problems, other factors such as ergonomic (e.g. lighting, noise) and work stressors covered in SS 514 'Code of Practice for 'Office Ergonomics' may be explored.
3. Whilst indoor ozone concentration levels are generally within the permissible exposure level (PEL), it is important to ensure that they are not elevated at all times. 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.
4. For background information on the airborne contaminants, mould remediation, prevention of mould in dwellings and clean up methods, refer to Annex H.
5. PCM is the accepted method for measuring the asbestos-in-air concentration. However, as the method does not allow for discrimination of fibres and may result in false results obtained from other fibres (e.g. fibre glass, gypsum, etc), it is therefore often used in conjunction with electron microscopy methods (such as Transmission Electron Microscope (TEM) or Scanning Electron Microscope (SEM)) when it is not certain whether other fibres are present.

Table 1 – Recommended IAQ parameters (cont'd)

Parameter	Acceptable limit (8 hours)	Unit	Measurement method / Analytical method
iv. Biological parameters			
Total viable bacterial count	500	cfu/m^3	By Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 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 °C. When a single species dominating from the culture plate, speciation should be done (see Table 2). The samples on the culture plate should yield between 30 and 300 colonies for best results.
Total viable mould count	Up to 500 is acceptable, if the species present are primarily *Cladosporium*	cfu/m^3	By Andersen single-stage impactor (N6), or equivalent equipment designed for airborne microbial sampling, flow rate at 28.3 L/min (1 ft^3/min) for 4 minutes or equal volume of air. Mould is cultured by 2 % Malt Extract Agar (MEA) and incubated for 5 days at 25 °C. When a single species dominating from the culture plate, speciation should be done. The confirmation presence of 1 or more fungal species occurring as a significant percentage in indoor sample and not present in concurrent outdoor sample is an evidence of fungal growth. Air testing is used in some circumstances as part of an investigation to determine whether or not there is mould growth in a building, and is never a substitute for a building investigation. Surface sample should be taken from the growth area by tapes for microscopic identification.

NOTES –

Micro-organisms are ubiquitous in indoor environment and do not necessarily constitute a health hazard. The concentration at which contamination becomes a threat to health is unknown and may vary greatly with each individual. Culture-based methods are suitable for detection of culturable infection 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 counts and total viable mould counts are a measure of the sanitary conditions of the premises and may not correlate with the presence of any specific pathogen.

If in the professional judgement of a competent person, investigation into target contaminants is necessary, then Table 2 is to be followed.

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Source : SS 554



Design & Construction



SGBP Certification Scheme

Renewable Energy
1) Solar Photovoltaic Modules

Recycled Materials
1) Reclaimed Asphalt Pavement
2) Recycled Concrete Aggregate
3) Washed Copper Slag

Mechanical
1) Auto Tube Cleaning System
2) Chillers
3) Fans
4) Motors
5) Pumps
6) Variable Speed Drive
7) Cooling Towers

Interior System
1) Access Floors
2) Composite Wood
3) Insulation Products
4) Panel Board

Concrete & Structural
1) Blended Cement
2) Ready-Mixed Concrete
3) Steel

Electrical
1) Cables
2) Compact Fluorscent Lamps
3) Electronic Ballasts
4) Light Emitting Diodes
5) Switchboards
6) Transformers
7) Tubular Fluorescent Lamps

Façade & Envelope
1) Metal Cladding
2) Paints & Coatings
3) Window Films & Coatings

Finishes
1) Adhesives & Sealants
2) Ceramic Tiles
3) Timber Flooring & Decking
4) Wall Covering

Furniture & Furnishings
1) Modular Furniture System & Seating

Source : SGBC website

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Interrelationships – IAQ and spatial case study – shopping mall



Air Quality (M)
Vs
Spatial (S)

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ASHRAE 52.2 Minimum Efficiency Reporting Value (MERV)	Composite average particle size efficiency, % in size range, µm			Average *arrestance, % by ASHRAE 52.1
	0.3 to 1.0	1.0 to 3.0	3.0 to 10.0	
1	NA	NA	$E_3 < 20$	$A_{avg} < 65$
2	NA	NA	$E_3 < 20$	$65 \le A_{avg} < 70$
3	NA	NA	$E_3 < 20$	$70 \le A_{avg} < 75$
4	NA	NA	$E_3 < 20$	$75 \le A_{avg}$
5	NA	NA	$20 \le E_3 < 35$	NA
6	NA	NA	$35 \le E_3 < 50$	NA
7	NA	NA	$50 \le E_3 < 70$	NA
8	NA	NA	$70 \le E_3$	NA
9	NA	$E_2 < 50$	$85 \le E_3$	NA
10	NA	$50 \le E_2 < 65$	$85 \le E_3$	NA
11	NA	$65 \le E_2 < 80$	$85 \le E_3$	NA
12	NA	$80 \le E_2$	$90 \le E_3$	NA
13	$E_1 < 75$	$90 \le E_2$	$90 \le E_3$	NA
14	$75 \le E_1 < 85$	$90 \le E_2$	$90 \le E_3$	NA
15	$85 \le E_1 < 95$	$90 \le E_2$	$90 \le E_3$	NA
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	NA

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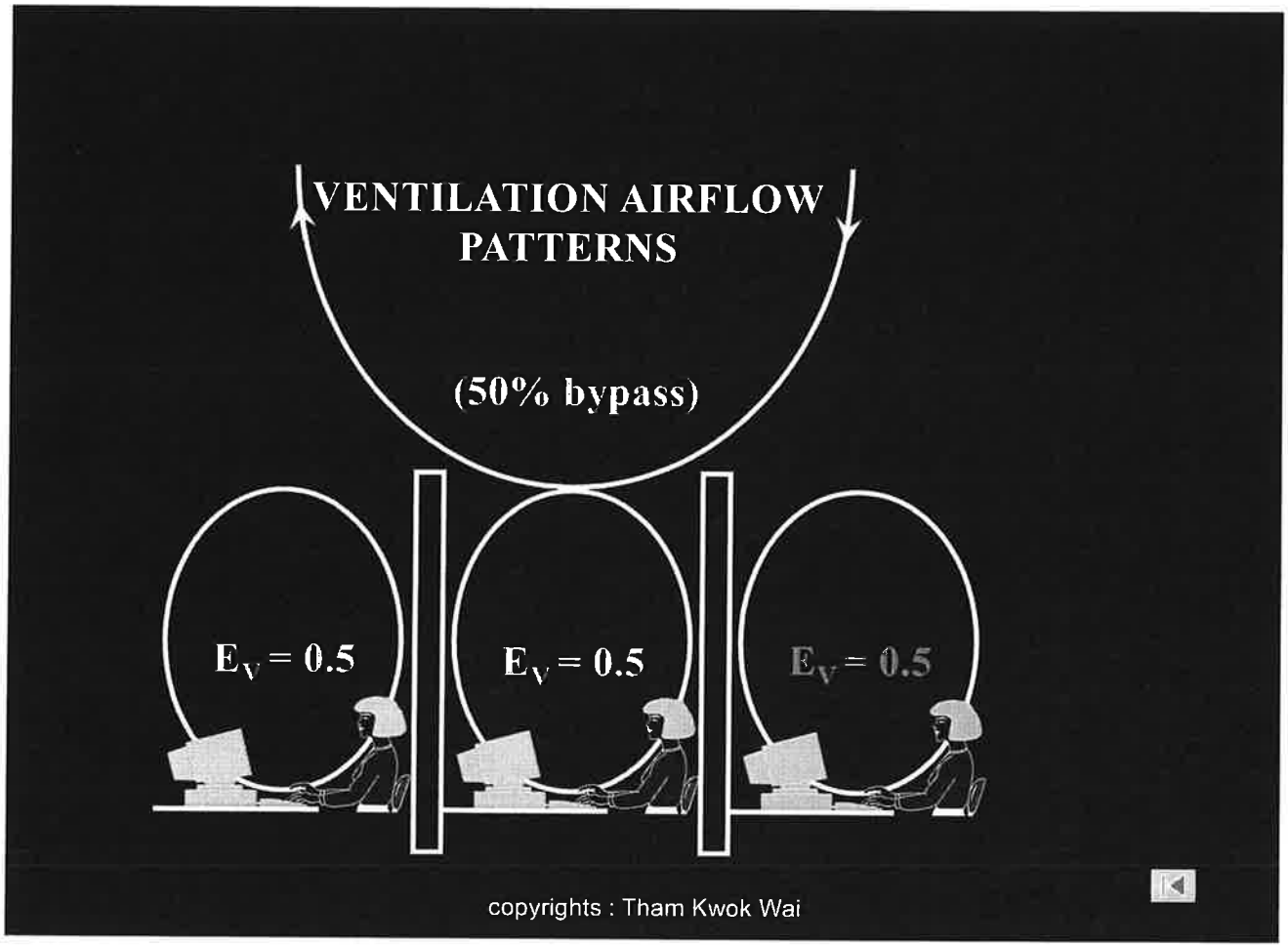
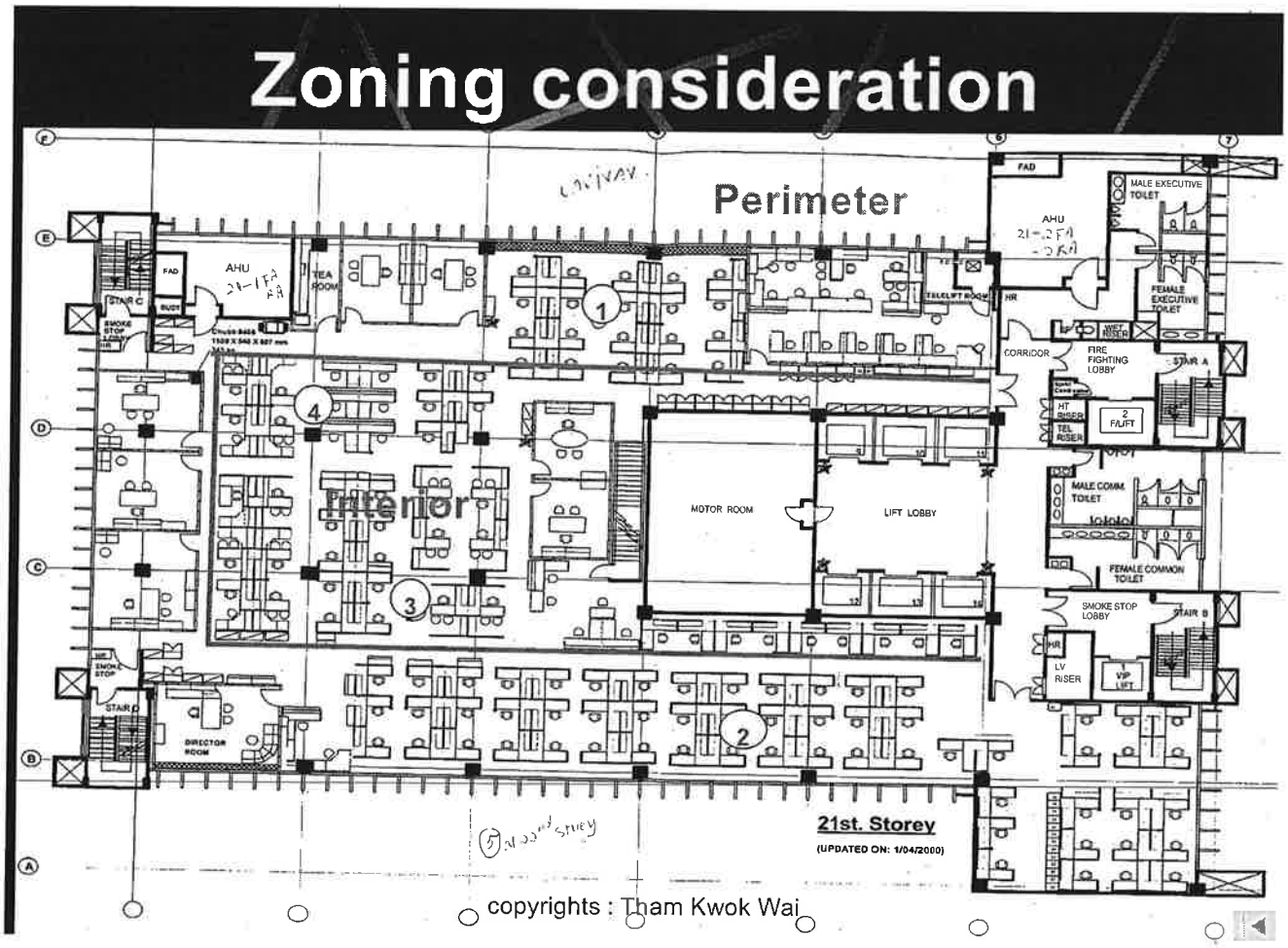
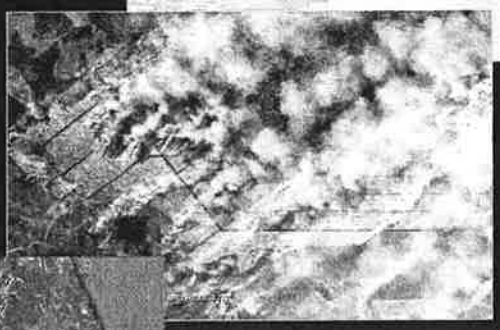
Source : SS 554


VENTILATION AIRFLOW PATTERNS
(50% bypass)
$E_V = 0.5$
$E_V = 0.5$
$E_V = 0.5$
copyrights : Tham Kwok Wai


Zoning consideration
Perimeter
Interior
21st. Storey
(UPDATED ON: 1/04/2000)
copyrights : Tham Kwok Wai

A Recurring Challenge : Haze Episodes







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THANK YOU

IAQ Considerations for Buildings : Renovation Commissioning Maintenance SBS Problems

Tham Kwok Wai

National University of Singapore

Commissioning & Renovation

- **Commissioning** is the process of assuring that all systems and components of a building are designed, installed, tested, operated, and maintained according to the operational requirements of the owner or final client.

- **Renovation** is the process of improving a broken, damaged, or outdated structure. Additionally, renovation can refer to making something new, or bringing something back to life.

source: wilkipaedia

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Commissioning & Renovation

- Commissioning and renovation should be :
  - performance-based
  - Referenced to specifications
  - Include user-acceptance

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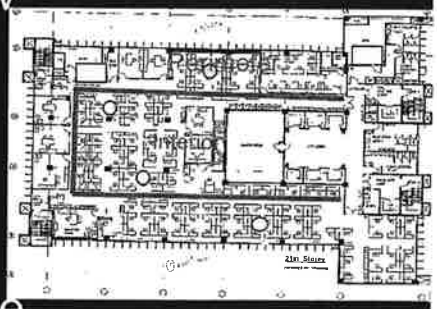
Commissioning & Renovation

- Things to consider:
  - Materials – emissions / green labelling
  - Air distribution should not be adversely affected
  - Air-balancing checks after completion of works
  - Ventilation provision to match new demands
    - Occupant density
    - Heat loads
    - processes
  - Zoning to be consistent with usage





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Commissioning & Renovation

- Things to consider:
  - Containment of pollution spread
    - Chemicals eg paints, varnishes, etc..
    - Particles eg dust
    - noise
  - Waste management – leakages
  - Air tightness and joints integrity
    - May lead to infiltration
    - Moisture movements



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Maintenance

- Types of maintenance:
  - Condition-based
  - Corrective
  - Planned
  - Predictive
  - preventive

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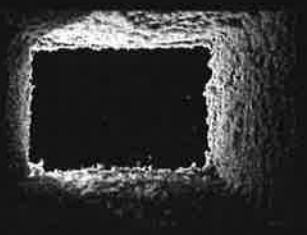
Maintenance

- Condition-based
  - Visual signs
    - HVAC systems
      - Filters
      - Cooling coils
      - Condensate pans
      - Dirt accumulation on fans
    - Office interiors
      - Furniture
      - wear and tear of carpets, fabric
      - cleanliness







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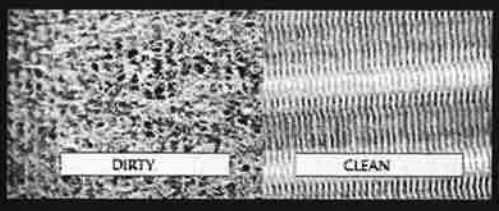
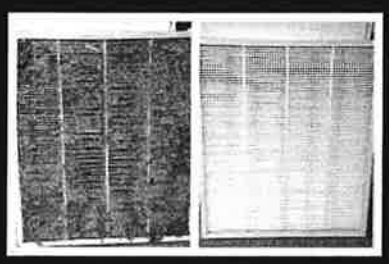
Maintenance

- Corrective-based
  - Drifts from setpoints
    - Sensors eg thermostats, CO_2 sensors
    - Office interiors



- Planned
  - Equipment scheduled eg HVAC
  - Consumables eg filters



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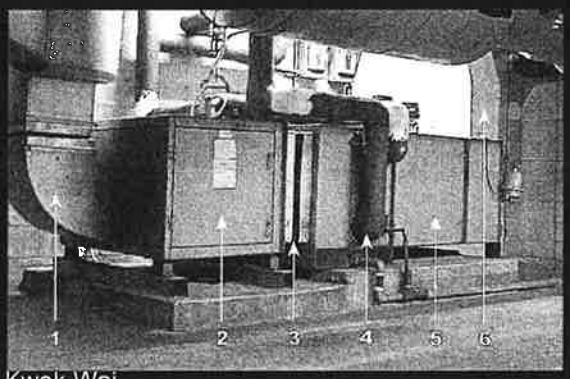
Maintenance

- Predictive
  - Increased Pressure drop across filters



Photo source : Google images

- Preventive
  - Scheduled cleaning of AHU
    - Cooling coils
    - filters



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Identification of Problems related to IAQ (Sick Building Syndrome)

Common Problems related to IAQ

- Thermal dissatisfaction
- Poor air distribution
- Smell or odour
- Molds
- Elevated Chemical levels
- Dust / Particulate Matter

Manifested as Sick Building Syndrome (SBS) symptoms

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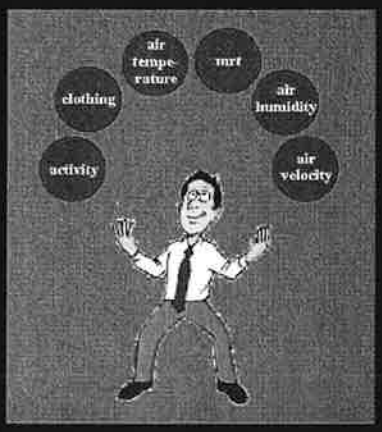
Identification of Problems related to IAQ (Sick Building Syndrome)

Thermal dissatisfaction

- Too warm / too cold
  - Near windows
  - Under air supply
- Stuffiness / lack of air movement
  - Office partitions
- Sensation of dampness



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Identification of Problems related to IAQ (Sick Building Syndrome)

Poor air distribution

- Short-circuiting
  - Supply and return air diffusers / grilles
- Ineffective "dead" or "nearly dead" zones
  - Inadequate arrangement of supply air diffusers to office plan / occupancy
  - partitions
- VAV systems at low partial loads
  - Reduced air supply volume
  - Throw of air may not have good mixing

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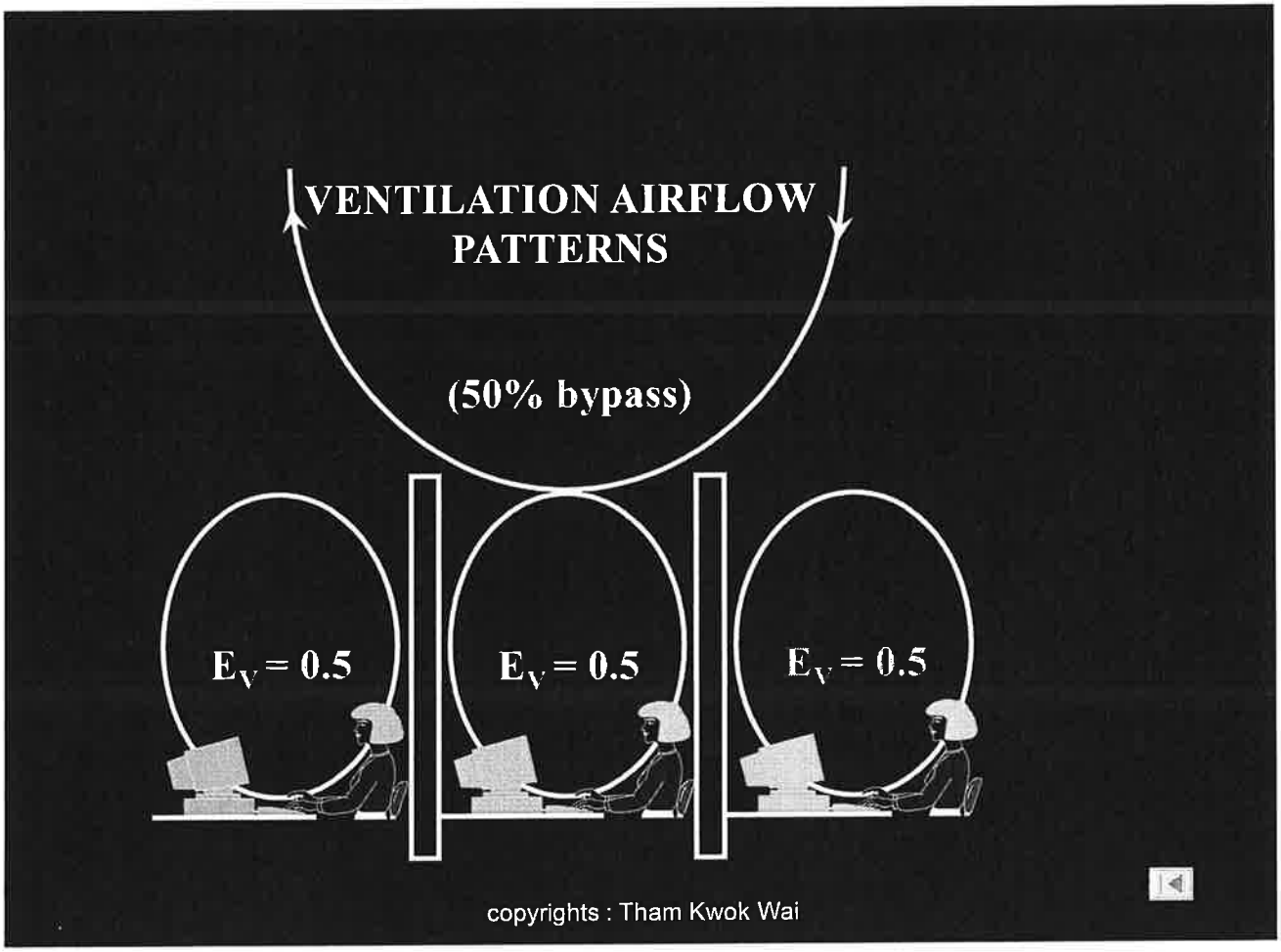

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Identification of Problems related to IAQ (Sick Building Syndrome)

Smell / odour

- Sources
  - Food
  - Waste
  - Inadequate ventilation
- Processes
  - Printers / odour generating processes
  - partitions
- Inadequate treatment of outdoor pollution
  - Traffic
  - haze
  - Exhaust from other buildings


Life in the Slow Lane

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Identification of Problems related to IAQ (Sick Building Syndrome)



Molds

- High humidity
  - Condensation (eg air supply grilles)
  - Inadequate dehumidification (cooling coils)
  - Unwanted infiltration
  - Intentional introduction of outdoor air directly into air-conditioned space
- Inadequately ventilated spaces
  - "trapped" air
- Adjoining "cold" zones (eg 24 hour cooling)
- Inadequate filtration of outdoor sources

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Identification of Problems related to IAQ (Sick Building Syndrome)

Elevated chemical levels

- Emissions from furniture and fabrics
  - Furniture with formaldehyde emissions
  - Carpets
  - Materials / stored materials – plastics, paints, ink, etc…
- Processes that generate chemical pollution
  - Printers
  - Cleaning (limonene eg lemon-scents; alcohols)
  - Deodorants / indoor aromatics



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Identification of Problems related to IAQ (Sick Building Syndrome)

Dust / Particulate Matter

- Inadequate filtration of outdoor dust
  - Traffic combustion by-products
  - Outdoor dusts
  - Materials / stored materials – plastics, paints, ink, etc…
- Indoor sources
  - Printers
  - Wood-pulp based products eg paper
  - Dust brought in by occupants (shoes, clothes, bags, etc..)



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Identification of Problems related to IAQ (Sick Building Syndrome)

Consequence of exposure to IAQ problems:

- Manifested as Sick Building Syndrome (SBS) symptoms
- Occupant dissatisfaction (complaints)

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Sick building syndrome



- Defined as an excess of work-related irritations of the skin and mucous membranes and other symptoms reported by occupants in modern office buildings (WHO)
- Presents with transient non-specific symptoms that are relieved upon leaving the premises
- Experienced by at least 20% of the occupants

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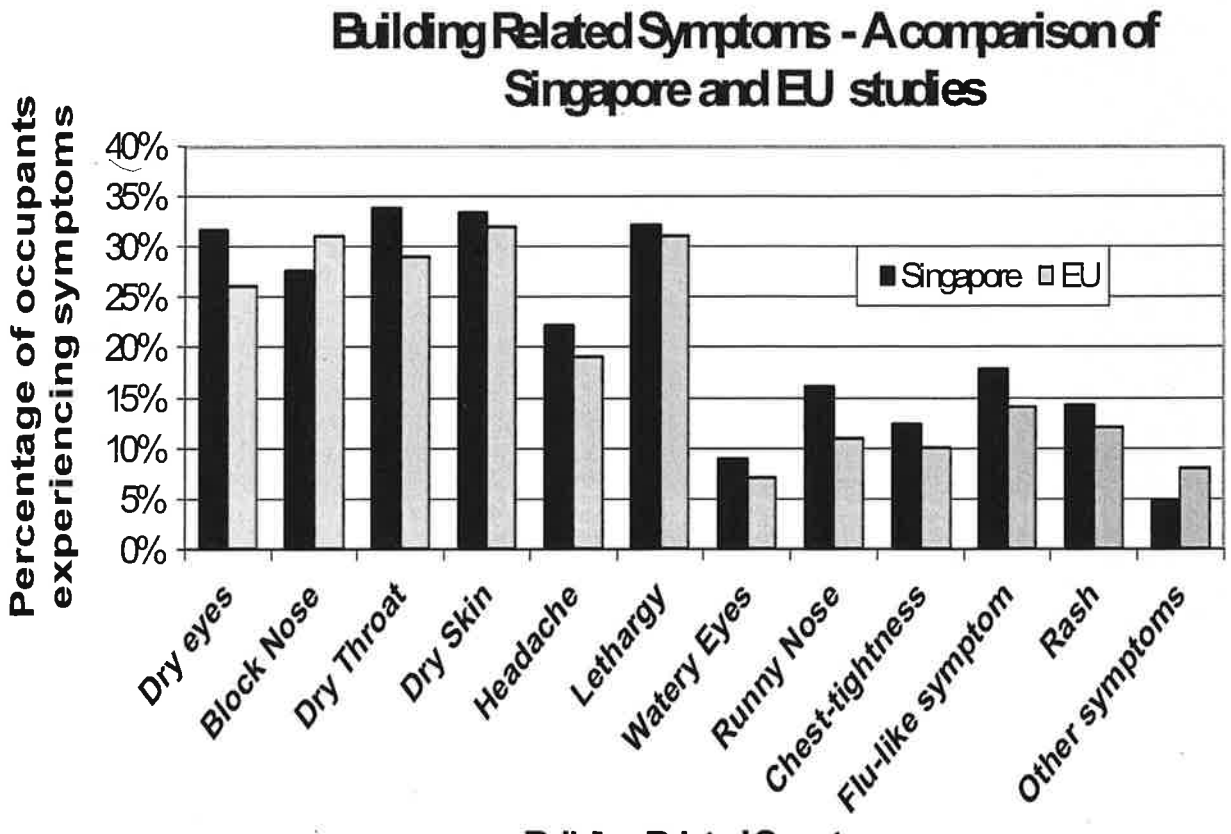

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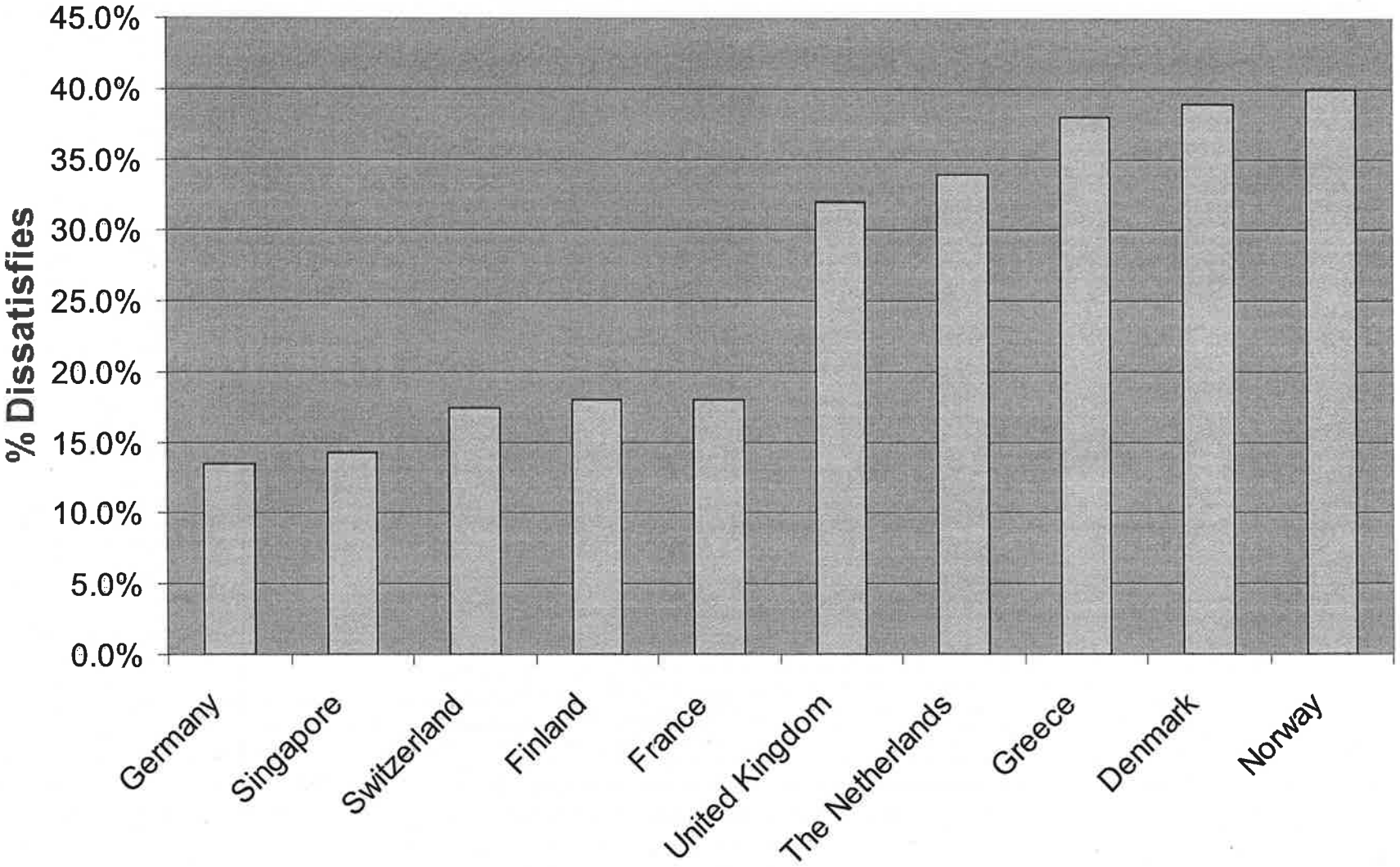
Acceptability of Indoor Air Quality (% Dissatisfied) - A Comparison of Singapore and EU studies



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Identification of Problems related to IAQ (Sick Building Syndrome)

Investigation

- Occupant survey (Annex J of SS554)
- Occupant complaints
- Sensory perceptions and visual observations

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Annex J
(informative)

Sample confidential questionnaire for building occupants

Note - This short questionnaire is to be given to building occupants to help determine the existence of health problems that may be related to the office environment. Their answers are to remain confidential.

---

1. Personal information

1.1 Gender: Male / Female
1.2 Age:
1.3 No. of years you worked in this office:
1.4 Building type: office/shopping centre/school/others
1.5 Office level:

2. Environmental conditions

2.1 Age of the building:
2.2 Type of workstation: Enclosed room / Open concept
2.2 Floor carpeted: Yes/No
2.4 With wallpaper: Yes/No
2.5 Infiltration of cigarette smoke: Yes/No
2.6 Infiltration of vehicular exhaust: Yes/No
2.7 No. of people who share your workstation:
2.8 How is your area air-conditioned? Centralised unit / Fan coil unit
2.9 How is your workstation lighted? Fluorescent lighting / Non-fluorescent lighting
2.10 Please indicate if you work with or near the following equipment:
Photocopier : Yes/No
Server : Yes/No
Air cleaner : Yes/No
Others (Please specify:_____)
2.11 Do you have to put on extra clothing for comfort? Regularly / Sometimes / Never
2.12 Does the office air feel stuffy? Regularly / Sometimes / Never
2.13 Does the office air have an unpleasant odour? Regularly / Sometimes / Never
2.14 Visible mould : Yes/No
2.15 Dusty air vent : Yes/No

3 Nature of occupation

3.1 No. of hours spent per day at your main workstation with a computer:

3.2 Please rate how you find the stress in your working conditions:
Physical stress experience : Low / Moderate / High
Mental stress experience : Low / Moderate / High
Climate of cooperation at work : Low / Moderate / High

3.3 What is your job category? Managerial / Professional / Secretarial / Clerical / Others
(if Others, specify: _____)

4 Health complaints

4.1 Please indicate your experience of the following symptoms at work during the past one month:

Stuffy nose : Daily / 2-3 times weekly / Less
Dry throat : Daily / 2-3 times weekly / Less
Cough : Daily / 2-3 times weekly / Less
i. Skin rash/itchiness: Daily / 2-3 times weekly / Less
ii. Eye irritation : Daily / 2-3 times weekly / Less
iii. Headache: Daily / 2-3 times weekly / Less
iv. Lethargy : Daily / 2-3 times weekly / Less
v. Drowsiness : Daily / 2-3 times weekly / Less
Dizziness : Daily / 2-3 times weekly / Less
Nausea/vomiting : Daily / 2-3 times weekly / Less
Shortness of breath : Daily / 2-3 times weekly / Less

4.1 No. of days in the past one month that you had to take off work because of these complaints:

4.2 When do these complaints occur?
Mornings / Afternoons / No noticeable trend

4.3 When do you experience relief from these complaints?
After I leave my workstation / After I leave the building / Never

4.4 Please indicate if you have any of these medical conditions:
Asthma : Yes, on medication / Yes, not on medication / No
Allergy : Yes, on medication / Yes, not on medication / No
Sinus : Yes, on medication / Yes, not on medication / No
Migraine : Yes, on medication / Yes, not on medication / No

4.5 If female, are you currently pregnant? Yes / No / Not sure

Source : SS554

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Annex J
(informative)

Sample confidential questionnaire for building occupants

Note - This short questionnaire is to be given to building occupants to help determine the existence of health problems that may be related to the office environment. Their answers are to remain confidential.

---

1. Personal information

1.1 Gender: Male / Female
1.2 Age:
1.3 No. of years you worked in this office:
1.4 Building type: office/shopping centre/school/others
1.5 Office level:

2. Environmental conditions

2.1 Age of the building:
2.2 Type of workstation: Enclosed room / Open concept
2.2 Floor carpeted: Yes/No
2.4 With wallpaper: Yes/No
2.5 Infiltration of cigarette smoke: Yes/No
2.6 Infiltration of vehicular exhaust: Yes/No
2.7 No. of people who share your workstation:
2.8 How is your area air-conditioned? Centralised unit / Fan coil unit
2.9 How is your workstation lighted? Fluorescent lighting / Non-fluorescent lighting
2.10 Please indicate if you work with or near the following equipment:
Photocopier : Yes/No
Server : Yes/No
Air cleaner : Yes/No
Others (Please specify:_____)
2.11 Do you have to put on extra clothing for comfort? Regularly / Sometimes / Never
2.12 Does the office air feel stuffy? Regularly / Sometimes / Never
2.13 Does the office air have an unpleasant odour? Regularly / Sometimes / Never
2.14 Visible mould : Yes/No
2.15 Dusty air vent : Yes/No

3 Nature of occupation

3.1 No. of hours spent per day at your main workstation with a computer:

3.2 Please rate how you find the stress in your working conditions:
Physical stress experience : Low / Moderate / High
Mental stress experience : Low / Moderate / High
Climate of cooperation at work : Low / Moderate / High

3.3 What is your job category? Managerial / Professional / Secretarial / Clerical / Others
(if Others, specify: _____)

4 Health complaints

4.1 Please indicate your experience of the following symptoms at work during the past one month:

Stuffy nose : Daily / 2-3 times weekly / Less
Dry throat : Daily / 2-3 times weekly / Less
Cough : Daily / 2-3 times weekly / L

[redacted]

i. Skin rash/itchiness: Daily / 2-3 times weekly / Less
ii. Eye irritation : Daily / 2-3 times weekly / Less
iii. Headache: Daily / 2-3 times weekly / Less
iv. Lethargy : Daily / 2-3 times weekly / Less
v. Drowsiness : Daily / 2-3 times weekly / Less
Dizziness : Daily / 2-3 times weekly / Less
Nausea/vomiting : Daily / 2-3 times weekly / Less
Shortness of breath : Daily / 2-3 times weekly / Less

4.1 No. of days in the past one month that you had to take off work because of these complaints:

4.2 When do these complaints occur?
Mornings / Afternoons / No noticeable trend

4.3 When do you experience relief from these complaints?
After I leave my workstation / After I leave the building / Never

4.4 Please indicate if you have any of these medical conditions:
Asthma : Yes, on medication / Yes, not on medication / No
Allergy : Yes, on medication / Yes, not on medication / No
Sinus : Yes, on medication / Yes, not on medication / No
Migraine : Yes, on medication / Yes, not on medication / No

4.5 If female, are you currently pregnant? Yes / No / Not sure

[redacted]

Source : SS554

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IAQ Audit for Buildings

Tham Kwok Wai

National University of
Singapore

Indoor Air Quality Audits

- Most readily adoptable strategy for immediate improvement of IAQ
- Likened to financial and health audits
- Constitutes basis for formulation and finetuning of an IAQ management plan
- Establish status quo of IAQ
- Effective tool for determining degree of conformance to statutory / guideline requirements

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Key Elements for Effective IAQ Audit

- Purpose
- Performance criteria and values
- Well identified and defined Scope of Audit
- Methodology
- Resources
- Expertise

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Purpose of Audit

- Problem-centered
- Conformance centered
- Performance (quality) centered

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Performance Criteria and Values

- Adopting Standards
  - SS 554 – Indoor Air Quality for Air-conditioned buildings
  - ASHRAE Standard 62
  - CEN CR 1752
- Establishing Values to be compared
  - Performance-based
  - Conformance-driven

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Performance Criteria and Values

SINGAPORE STANDARD

SS 554 : 2009

(ICS 13.040.20; 91.040.01)

CODE OF PRACTICE FOR

Indoor air quality for air-conditioned buildings

Published by
SPRING Singapore
2 Bukit Merah Central
Singapore 159835
SPRING Singapore Website: www.spring.gov.sg
Standards Website: www.standards.org.sg

SPRING singapore
Enabling Enterprise

Table 1 – Recommended IAQ parameters

Parameter	Acceptable limit (8 hours)	Unit	Measurement method / Analytical method
i. Thermal comfort parameters			
Operative temperature[1]	24 to 26	°C	Air temperature – by hot wire, thermistor, thermometer sling or equivalent method. Globe temperature – by Globe thermometer.
Relative humidity	< 65 (for new buildings) < 70 (for existing buildings) (under peak and common part load conditions)	%	By thin film capacitor, hygrometer, thermometer sling or equivalent method.
Air movement	0.10 - 0.30	m/s	By hot wire method for linear air velocity or Kata thermometer for omni-directional air velocity method or equivalent
ii. Chemical parameters			
Carbon dioxide	700 above outdoor	ppm	By real-time non-dispersive infra-red sensor or equivalent method.
Carbon monoxide	9	ppm	By real-time electrochemical sensor or equivalent method (NIOSH Manual of Analytical Methods 6604).
Formaldehyde	120 0.1	$\mu g/m^3$ ppm	By detection tubes, real-time electrochemical sensor or equivalent method for screening (ISO 16000-2). When formaldehyde concentration is higher than the limit, collect continuous air samples using dinitrophenylhydrazone (DNPH) cartridges and analyse by High Performance Liquid Chromatography (HPLC) using: NIOSH Manual of Analytical Methods 2016 or EPA Method 0100: Sampling for Formaldehyde and other Carbonyl Compounds. ISO 16000-3 or NIOSH Manual of Analytical Methods 2016
Total volatile organic compounds (TVOC) that are photoionisable (10.6 eV)[2]	3000	ppb	By real-time photoionisation detector or equivalent method.
iii. Respirable suspended particles (aerodynamic diameter less than 10 μm sampled with a particle size-selective device having a median cut point of 4 μm)	50	$\mu g/m^3$	By real-time optical scattering or piezoelectric monitors or equivalent method

NOTES –

[1] 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 by:

$t_o = (t_a + t_r) / 2$

t_o = operative temperature
t_a = air temperature
t_r = mean radiant temperature (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 is the globe temperature in °C
t_a is the air temperature in °C
V is the air speed in m/s

[2] When TVOC > 3000 ppb or when smell is perceived or when ventilation rate is less than the recommended rate by SS 553 or recommendation by competent person, specific VOCs should be identified (e.g. endocrine disrupting chemicals, microbial VOC, etc.) by identifying the individual VOC species.

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Source : SS 554

Performance Criteria and Values

Table 2 – Target contaminants triggered by specific sources

Parameter	Acceptable limit	Unit	Measurement method / Analytical method
PM 2.5	35	$\mu g/m^3$	By real-time piezoelectric monitors or optical scattering or equivalent method
Ultra-fine particles	Not applicable	particles / cm^3	By a nuclei condensation counter or equivalent method. Note - This measurement may be helpful to trace the pollutant source, especially from emission processes.
Nitrogen dioxide	100	$\mu g/m^3$	By real-time chemiluminescence, diffusion tube passive samplers, chemical detector tubes or equivalent method. ISO 16000-15 / NIOSH Manual of Analytical Methods 6014.
Ozone	0.1	ppm	By real-time chemiluminescence, using potassium iodide in phosphate buffer as absorbing solution and analysed spectrophotometric, or chemical detector tubes or equivalent method.
Radon	150	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).
Asbestos	0.01	fibre / cc	By phase contrast microscopy or equivalent method, followed by Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM) for identification of fibre [5] ISO 8672 / ISO14966 / NIOSH Manual of Analytical Methods 9000/9002.
Nicotine	Not detected		By gas chromatography -nitrogen phosphorus detector. Air collected by XAD-2 tube. NIOSH Manual of Analytical Methods 2544/2551.
Pathogenic bacteria	Presence of specific species		Collect air sample by Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 28.3 L/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 °C. Transfer the suspected colony to its selective media for detecting the presence of specific pathogens. Incubate in accordance to the specific requirement of the suspected pathogen. Sampling from outdoor, indoor complaint area and non-complaint area. Confirmation by API strips or Polymerase Chain Reaction (PCR).
Pathogenic mould	Presence of specific species		Collect dust using 3-piece 37 mm cassette, preloaded with 0.45 µm pore-size filters with flow rate at 3 to 4 litres/min for 8 hours. Confirmation by culture by Polymerase Chain Reaction (PCR). Sampling from outdoor, indoor complaint area and non-complaint areas.
Semi volatile and volatile organic compounds (VOC)	PEL of toxic substances	ppm	ISO 16000-5 (Table 1 Sampling Strategy for VOC) ISO 16000-12 ISO 16017 (Pumped Sampling) ISO 16702 (semi-VOC) NIOSH Manual of Analytical Methods 2549

NOTES -

1. The above contaminants may not be commonly found in a typical indoor space. These parameters should be monitored in a situation when a potential source is suspected.

2. When the complaint cannot be traced to IAQ problems, other factors such as ergonomic (e.g. lighting, noise) and work stressors covered in SS 514 'Code of Practice for 'Office Ergonomics' may be explored.

3. Whilst indoor ozone concentration levels are generally within the permissible exposure level (PEL), it is important to ensure that they are not elevated at all times. 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.

4. For background information on the airborne contaminants, mould remediation, prevention of mould in dwellings and clean up methods, refer to Annex H.

5. PCM is the accepted method for measuring the asbestos-in-air concentration. However, as the method does not allow for discrimination of fibres and may result in false results obtained from other fibres (e.g. fibre glass, gypsum, etc), it is therefore often used in conjunction with electron microscopy methods (such as Transmission Electron Microscope (TEM) or Scanning Electron Microscope (SEM)) when it is not certain whether other fibres are present.

Table 1 – Recommended IAQ parameters (cont'd)

Parameter	Acceptable limit (8 hours)	Unit	Measurement method / Analytical method
iv. Biological parameters			
Total viable bacterial count	500	cfu/m^3	By Andersen single-stage impactor (N6), or equipment designed for airborne microbial sampling, flow rate at 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 °C. When a single species dominating from the culture plate, speciation should be done (see Table 2). The samples on the culture plate should yield between 30 and 300 colonies for best results.
Total viable mould count	Up to 500 is acceptable, if the species present are primarily *Cladosporium*	cfu/m^3	By Andersen single-stage impactor (N6), or equivalent equipment designed for airborne microbial sampling, flow rate at 28.3 L/min (1 ft^3/min) for 4 minutes or equal volume of air. Mould is cultured by 2 % Malt Extract Agar (MEA) and incubated for 5 days at 25 °C. When a single species dominating from the culture plate, speciation should be done. The confirmation presence of 1 or more fungal species occurring as a significant percentage in indoor sample and not present in concurrent outdoor sample is an evidence of fungal growth. Air testing is used in some circumstances as part of an investigation to determine whether or not there is mould growth in a building, and is never a substitute for a building investigation. Surface sample should be taken from the growth area by tapes for microscopic identification.

NOTES –

Micro-organisms are ubiquitous in indoor environment and do not necessarily constitute a health hazard. The concentration at which contamination becomes a threat to health is unknown and may vary greatly with each individual. Culture-based methods are suitable for detection of culturable infection 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 counts and total viable mould counts are a measure of the sanitary conditions of the premises and may not correlate with the presence of any specific pathogen.

If in the professional judgement of a competent person, investigation into target contaminants is necessary, then Table 2 is to be followed.

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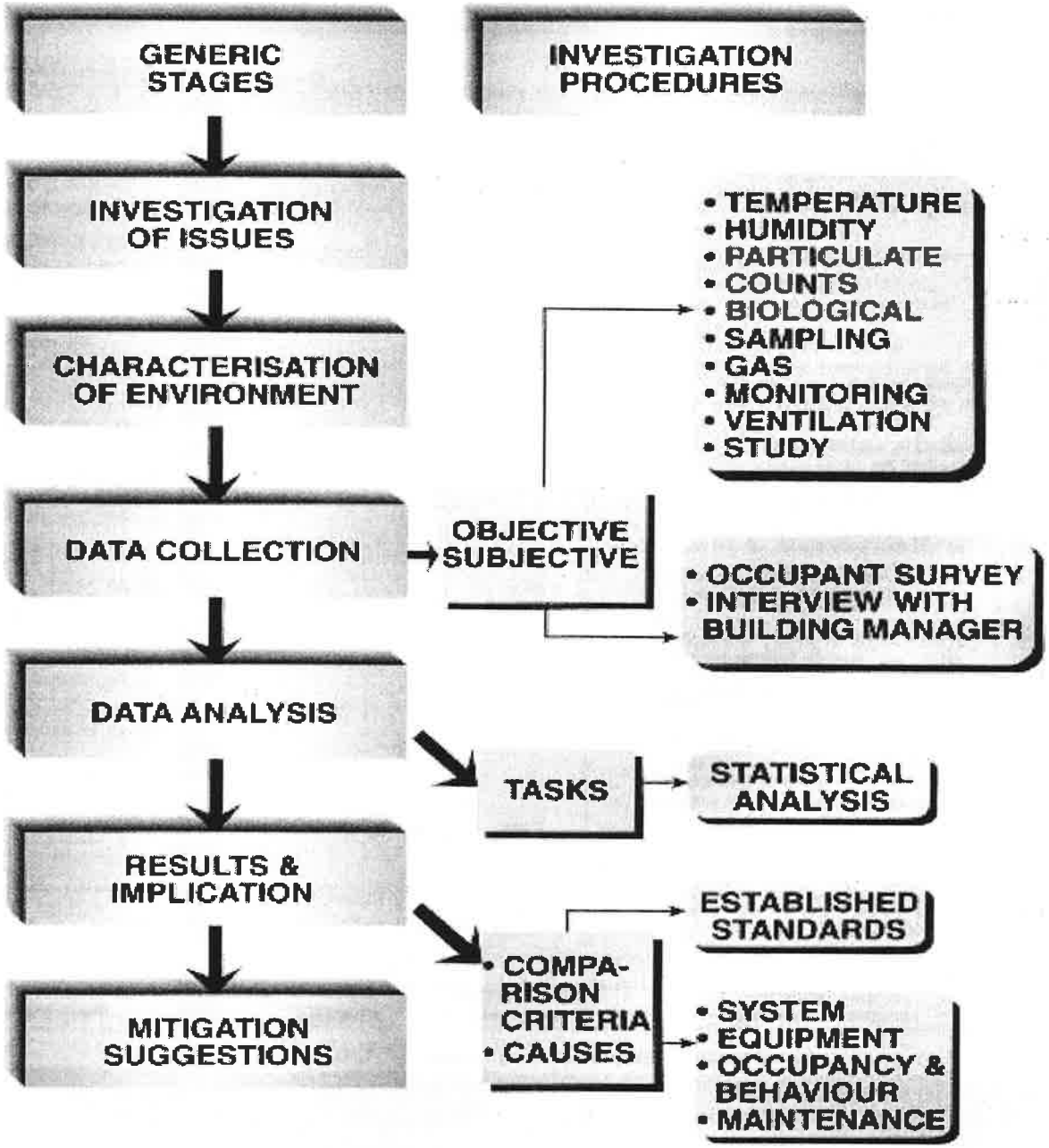
Source : SS 554

Indoor Air Quality Audit



▲ *Indoor Air Quality Audit Methodology developed through the Research Projects*

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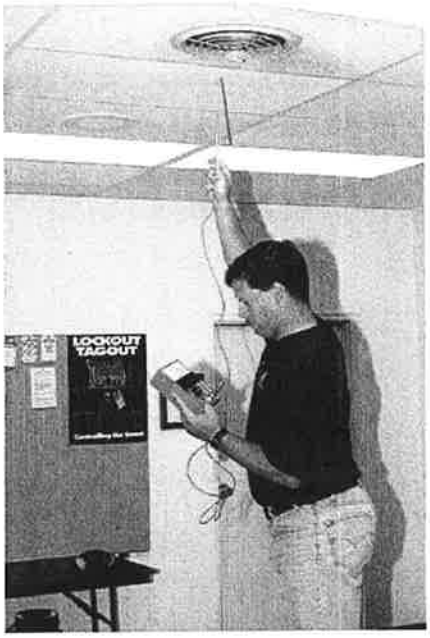
Building and Construction Authority

Recommended IAQ Measurements

- Outdoor Air Measurement (at least 1 point)
- Indoor Sampling Point(s):
  - Number of floors in the building
  - Floor area of each floor/premise and ventilation types
  - Indoor generated pollutants that could affect surrounding premises
- Additional Point(s)/Sample Position(s)





*Source: SS554

Building and Construction Authority

Recommended IAQ Measurements

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



*Source: SS554

Building and Construction Authority

Recommended IAQ Measurements

Sampling Requirements for Indoor Environment

Ventilation type	Area of floor (m^2)	Minimum number of sampling points
Centralised ventilation	-	1 sampling point per system
Non-centralised ventilation	Below 3000	1 per 500 m^2 (minimum 2 points) - new
	3000 - 5,000	6 + 1 per 1000 m^2
	5,000 - 10,000	8 + 1 per 1250 m^2
	10,000 - <15,000	12 + 1 per 1500 m^2
	Above 15,000	15 + 1 per 2000 m^2



*Source: SS554

Competent Person

A person who is qualified by training and experience, and has sufficient knowledge of IAQ, and is recognized by cognizant authorities to perform the work to be carried out.

Source : SS 554

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Issues

1. Level of Precision
   - Non-toxic versus toxic
2. Reliability
   - errors
3. Completeness of information
   - "M" shaped CO2 profile
   - Continuous versus spot

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Merits of Continuous measurements

1. Emission and de-sorption profiles
2. Ventilation & infiltration characteristics
3. Build-up & exposure levels
4. Trend recognition for causal analysis

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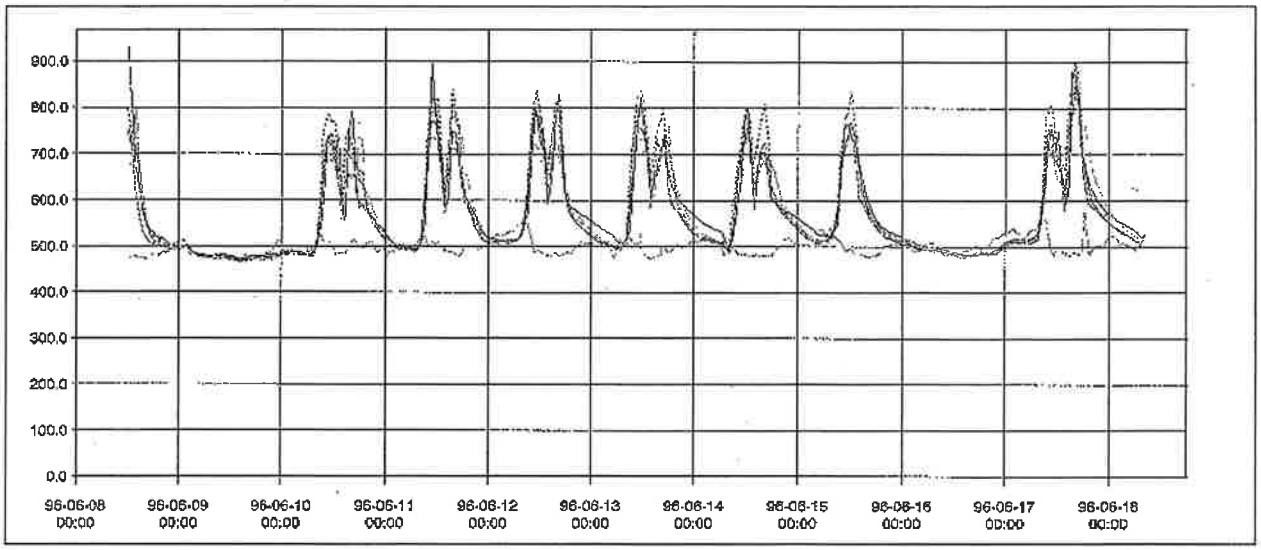
CONTINUOUS

B K 7620 Gas Monitoring

SETTINGS:			GENERAL INFORMATION:		COMMENTS:	
Sampling Interval:	Cont.		Start Time:	1996-06-08 11:28		
Time bet. measurement	2382	s	Stop Time:	1996-06-16 09:01		
Normalization temp.:	20.0	°C	Compression time:	None		
Cross Compensation:	No		Warnings:	Yes		
Water Vapour Compens:	Yes		Data Edited:	No	DATABASE:	BURSAR4W
Air Pressure:	101.30	kPa	Resolution:	100 %	USER PRG:	None



C	Location:	Measurement	Line	Scale	Unit	Alarm lim.	Min.Val.	Max.val.	Mean val.	8 hour me. val.
1	1302 Chan.	Carbon dioxide	———	1E+00	ppm	0.00None ppm	471.35 ppm	929.90 ppm	572.41 ppm	989.07 ppm
2	waiting area	Carbon dioxide	- - - -	1E+00	ppm	0.00None ppm	468.55 ppm	849.85 ppm	562.10 ppm	973.92 ppm
3	room 04-309	Carbon dioxide	·····	1E+00	ppm	0.00None ppm	468.12 ppm	811.77 ppm	568.37 ppm	983.18 ppm
4	open plan 1	Carbon dioxide	- - - -	1E+00	ppm	0.00None ppm	464.79 ppm	860.63 ppm	570.28 ppm	985.76 ppm
5	open plan 2	Carbon dioxide	- - - -	1E+00	ppm	0.00None ppm	467.45 ppm	904.29 ppm	581.44 ppm	973.89 ppm
6	ambient	Carbon dioxide	·····	1E+00	ppm	0.00None ppm	472.17 ppm	574.90 ppm	499.21 ppm	925.65 ppm

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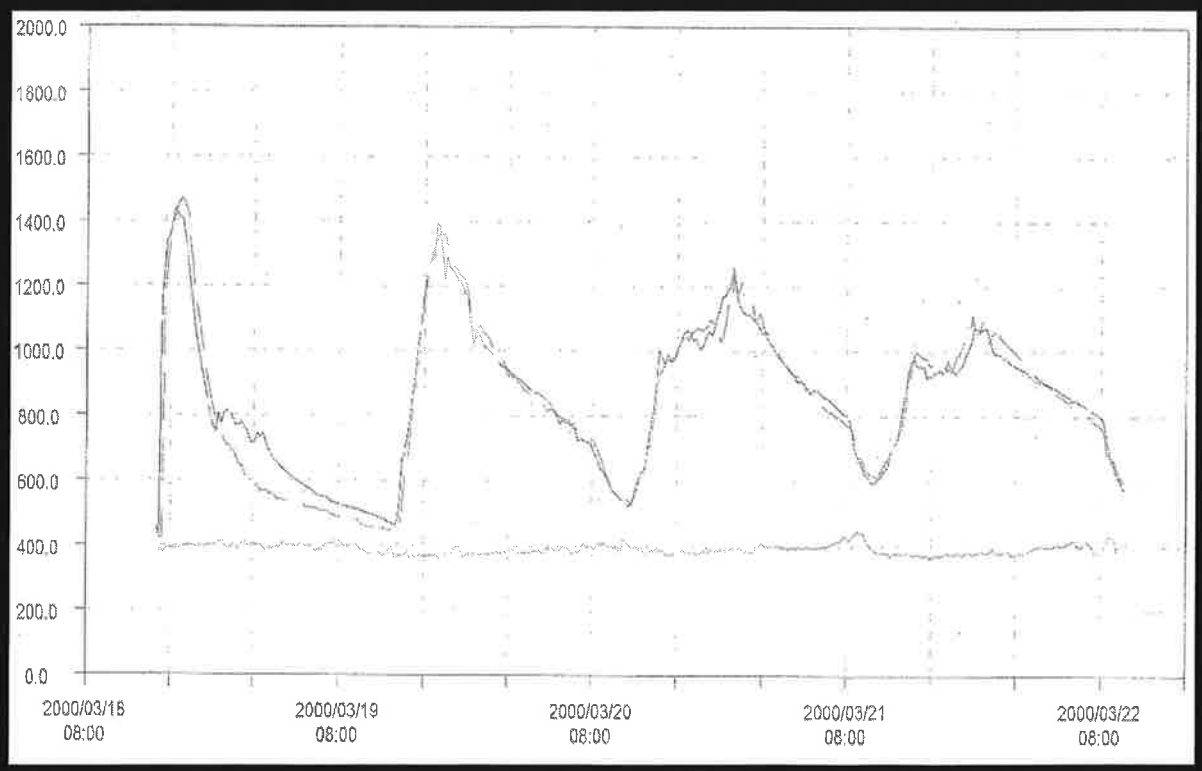
Carbon Dioxide Profiles



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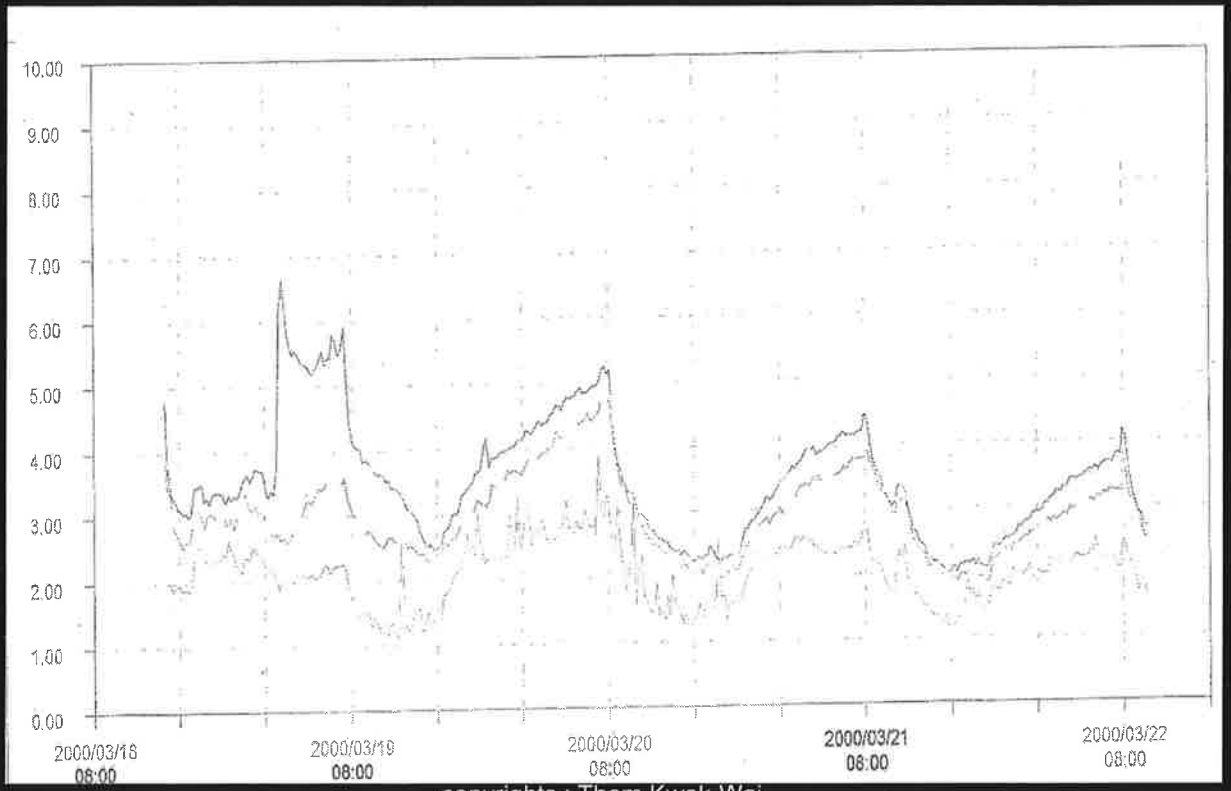
Total Volatile Organics (TVOC) Profiles



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Where to Measure IAQ Parameters ?

Some considerations

- How representative of the IAQ of the entire space ? (spatial)
- Accurate and reliable exposure assessment ? (breathing zone)
- Reflect strength and effects of suspected contaminant sources? (shelves, computers)
- Sufficient reference to adjoining spaces / ambient?

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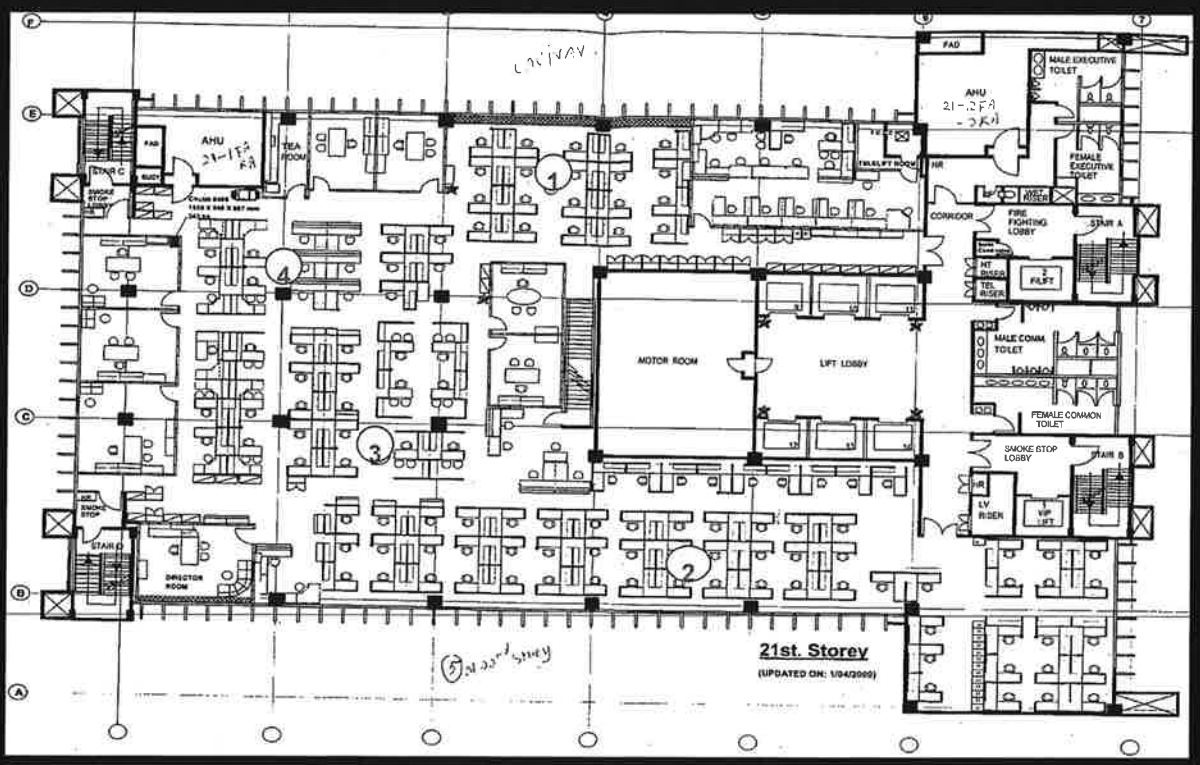
Sampling Locations



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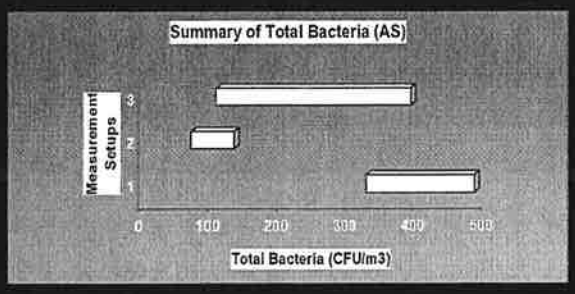
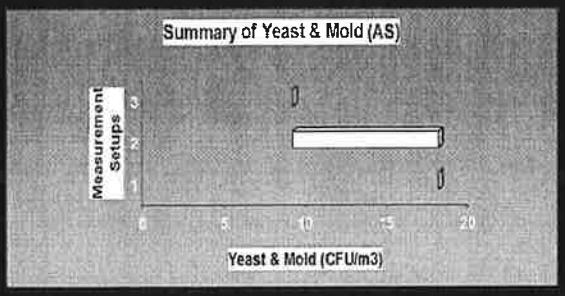
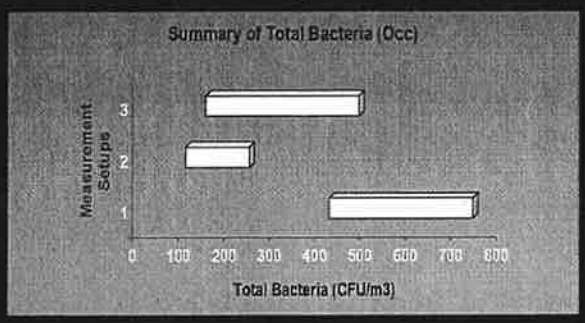
Microbial Contamination (Supply Vs Breathing Zone)



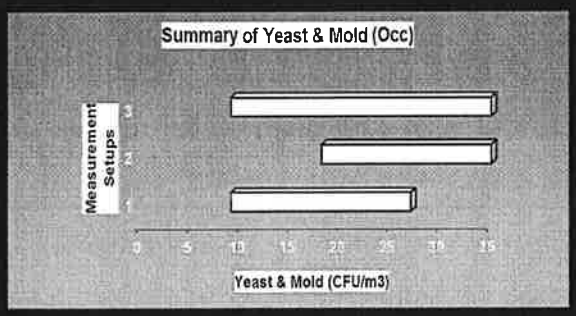
Total Viable bacteria (Air supply)



Total Viable Yeasts & Molds (Air Supply)



Total Viable bacteria (Occupied area)



Total Viable Yeasts & Molds (Occupied area)

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When to Measure IAQ Parameters ?

A Question of Timing

- How much of a day must one see of a place to get an accurate impression of what goes on throughout the day?
- When and how many times must one observe the traffic along a road to provide an answer on the daily traffic condition?

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Factors Affecting Contaminant Profile

- Occupancy patterns
- Ventilation and air-conditioning schedules
- Operation and maintenance schedules
- Materials used
- External contaminant profiles
- Infiltration characteristics
- Air change rates
- Etc…

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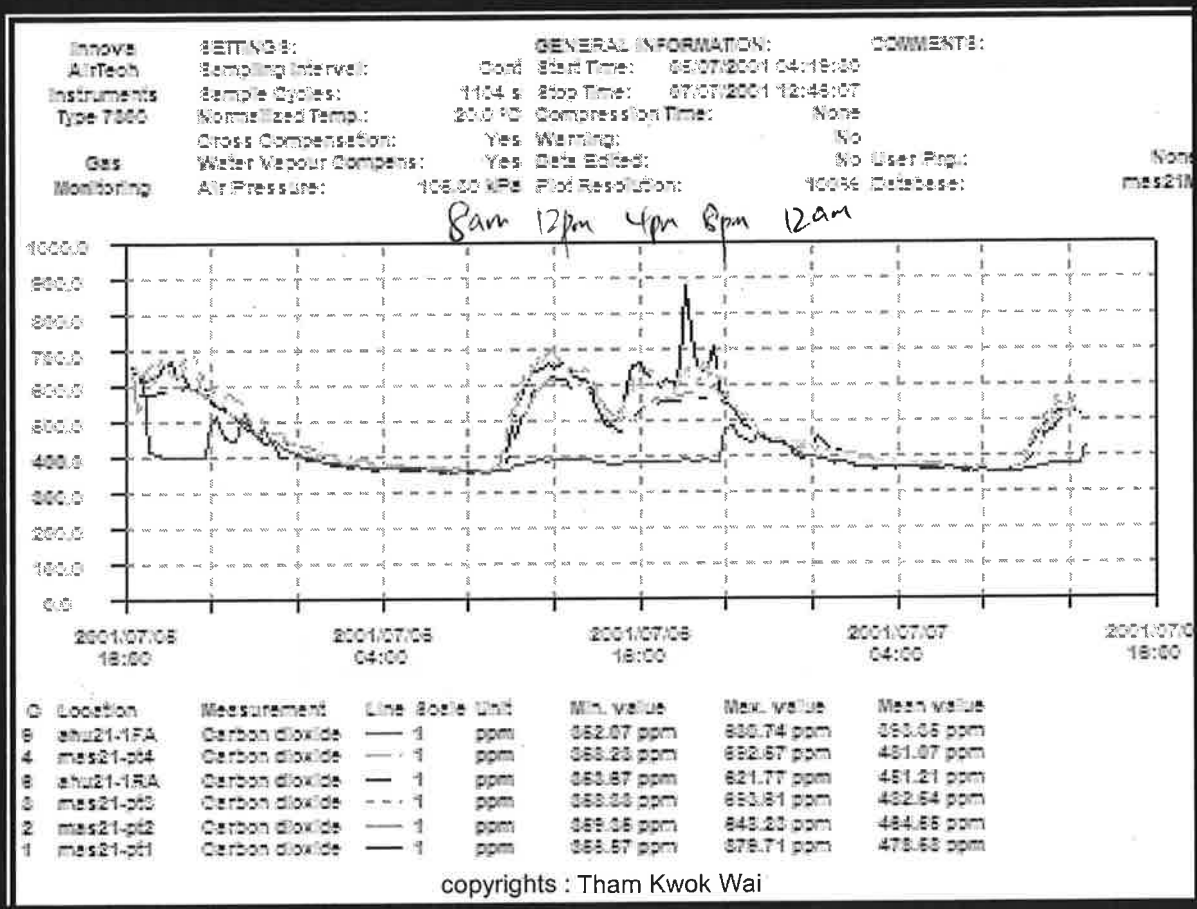
CO_2



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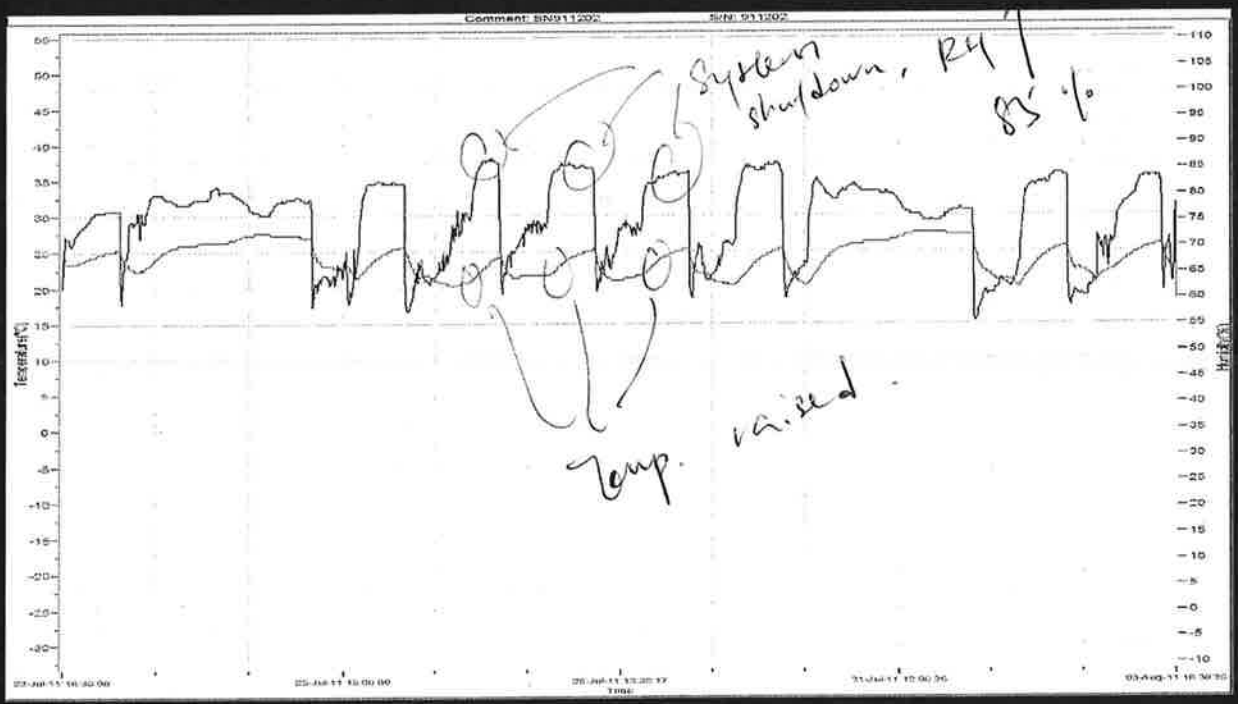
Temperature and RH profiles over a week



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Some Considerations

- Optimize frequency of measurement to capture essential dynamic characteristics
- Plan for "time series" measurement to provide trends associated with occupancy, equipment and processes
- Plan for intervals of measurement to capture "transients" eg TVOC decay profile due to system start up

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Why Measure IAQ Parameters ?

Some Reasons

- Establish status quo for conformance to requirements
- Problem-solving
- Identifying areas and extent of improvement
- Evaluating impacts of changes

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Identifying Trends

- Nature of trend – benign or drift
- Magnitude of change – slow or rapid
- Cyclical characteristics ?

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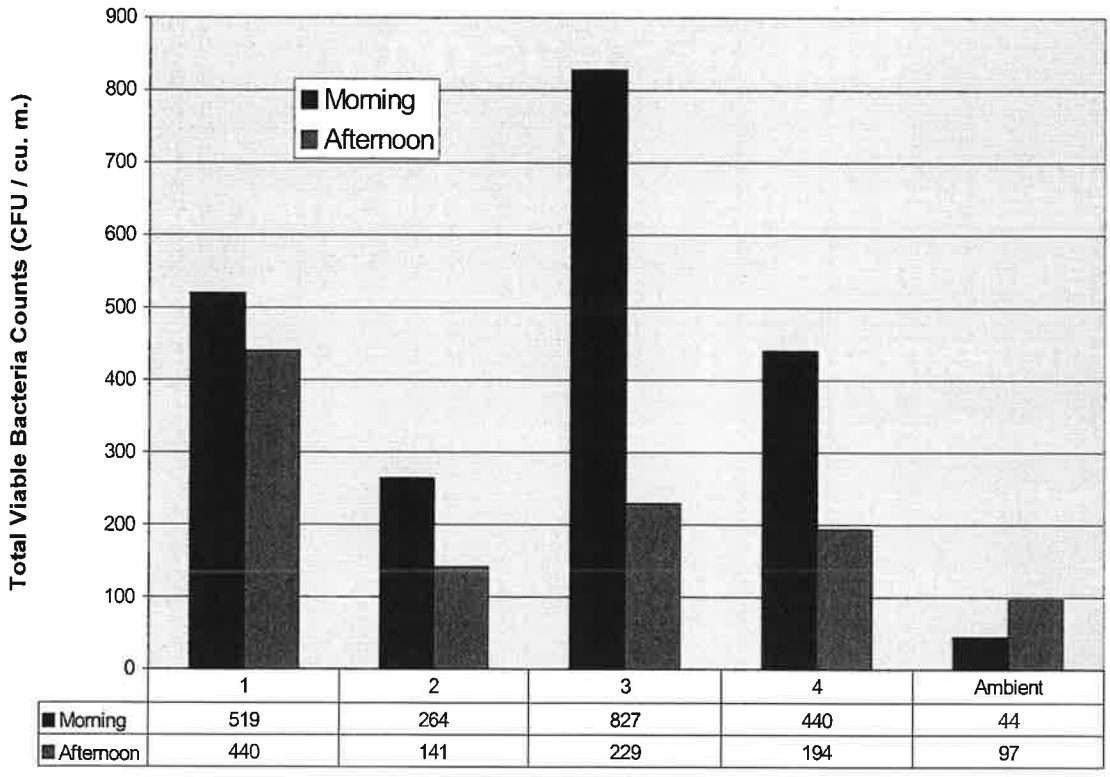
Total Viable Bacteria Counts for 21st Floor (CFU / cu. m.)



	1	2	3	4	Ambient
Morning	519	264	827	440	44
Afternoon	440	141	229	194	97

Location

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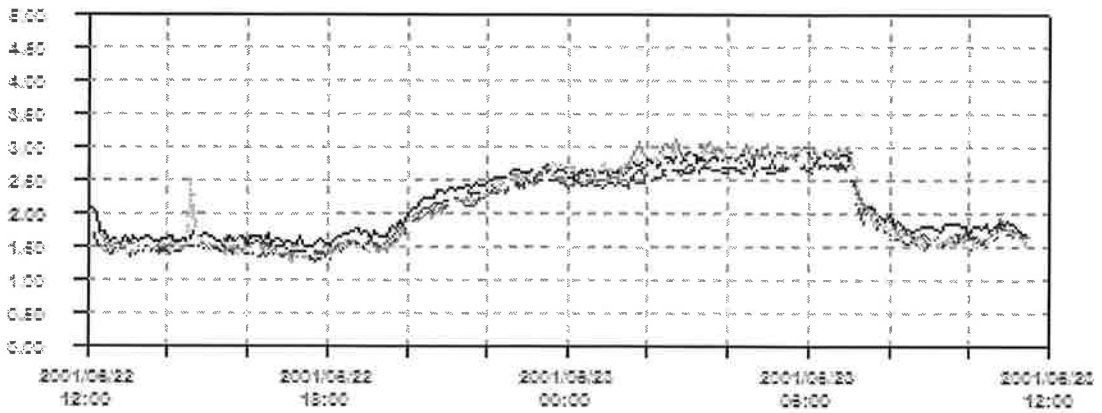
TVOC

Innova AirTech Instruments Type 7000 — Gas Monitoring

SETTINGS:
Sampling Interval: Cont
Sample Cycles: 876 s
Normalized Temp.: 20.0 °C
Cross Compensation: Yes
Water Vapour Compens.: Yes
Air Pressure: 101.00 kPa

GENERAL INFORMATION:
Start Time: 22/06/2001 12:00:00
Stop Time: 23/06/2001 11:53:05
Compression Time: None
Warning: Yes
Data Edited: No
Pict Resolution: 100%

COMMENTS:
User Prg.: None
Database: r_mast1



C	Location	Measurement	Line	Scale	Unit	Min. value	Max. value	Mean value
6	1flr-pt5	TVOC ref. Toluene	——	1	ppm	1.93 ppm	3.10 ppm	2.06 ppm
5	2flr-pt4	TVOC ref. Toluene	——	1	ppm	1.23 ppm	3.02 ppm	2.07 ppm
4	2flr-pt2	TVOC ref. Toluene	—	1	ppm	1.26 ppm	3.77 ppm	1.86 ppm
3	2flr-pt1	TVOC ref. Toluene	- -	1	ppm	1.25 ppm	2.87 ppm	2.04 ppm
2	ahu1-1RA	TVOC ref. Toluene	——	1	ppm	1.34 ppm	2.82 ppm	2.02 ppm
1	ahu1-1FA	TVOC ref. Toluene	——	1	ppm	1.48 ppm	2.96 ppm	2.17 ppm

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Identifying Patterns

- Commonly occuring versus Localised
- Common sources of contamination
  - Computers, high occupant density
- Undesirable leakages
- Undesirable build-up of contaminants (ductworks, filters, etc…)

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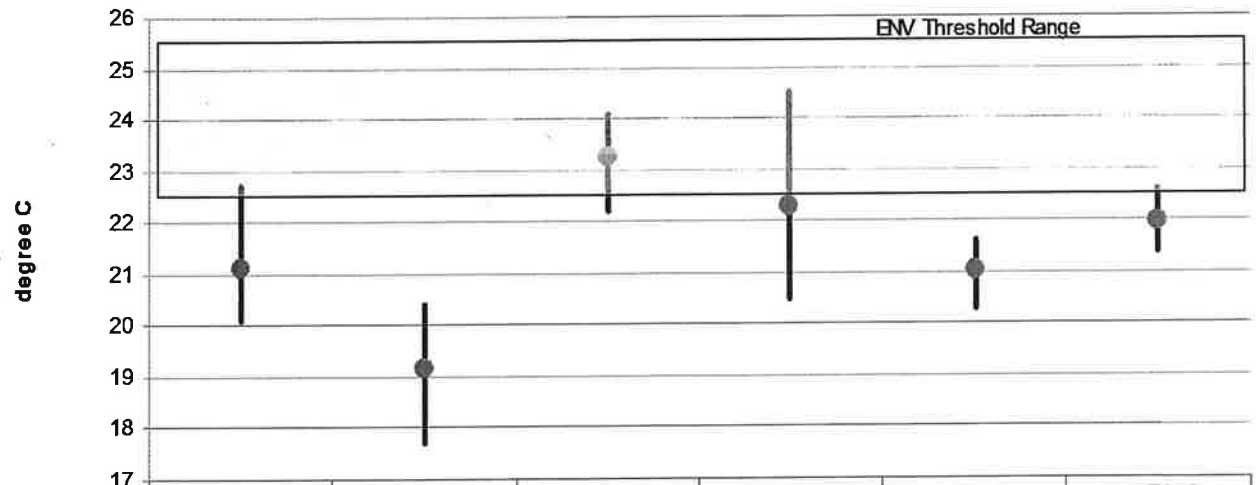
Temperature for 3 Zones



	BMCL-1	BMCL-2	QUCL-1	QUCL-2	TPRL-1	TPRL-2
min	20.1	17.7	22.2	20.5	20.3	21.4
max	22.7	20.4	24.1	24.5	21.6	22.6
● mean	21.1	19.1	23.3	22.3	21.0	22.0

Library by Set-up

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Causal Analysis

- Chain effects traced
- Knowledge-based associations

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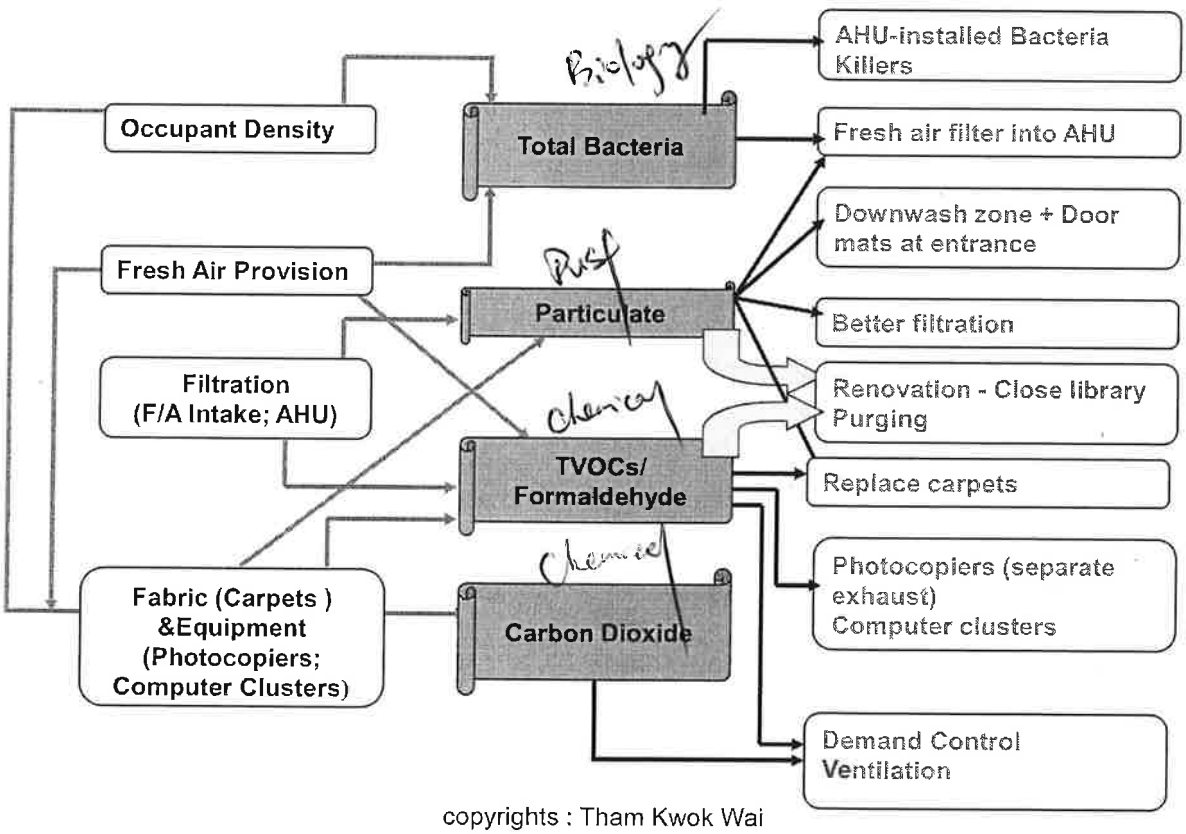
Causal Analysis



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Resources

- Adequate repertoire of equipment
- Means for capturing and storing information
- Well equipped laboratory facilities

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Expertise

- Knowledge-intensive process
- Multi-disciplinary
- Informed judgment
- experience
- Good grasp of the situation
- Intuition of plausible problems
- Cohesive framework

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Integrated IAQ Audit

- Integration
  - Measurements planned and executed with reference to each other
  - Mutual effects of building and occupant characteristics captured
  - Provide different perspectives to overall IAQ
  - Total approach

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Integrated IAQ Audit

- Subjective and Objective Information
  - Scientific rigor
  - Statistical reliability and validity
  - Live-in responses
- Appropriate combination of monitoring and survey techniques
  - Economic
  - Optimal
  - Effective, sufficient but not overly provisioned

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Some Caveats

- Bias
- What is left uninvestigated sometimes more telling than what has been investigated
- Independent expertise recommended

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THANK YOU

Indoor Air Quality Management for Buildings (Part I)

Prepared for:
Green Mark Facilities Professional (GMFP)
Green Mark Professional (GMM)

Dr.-Ing. Ang Keng Been EUR. ING
2015

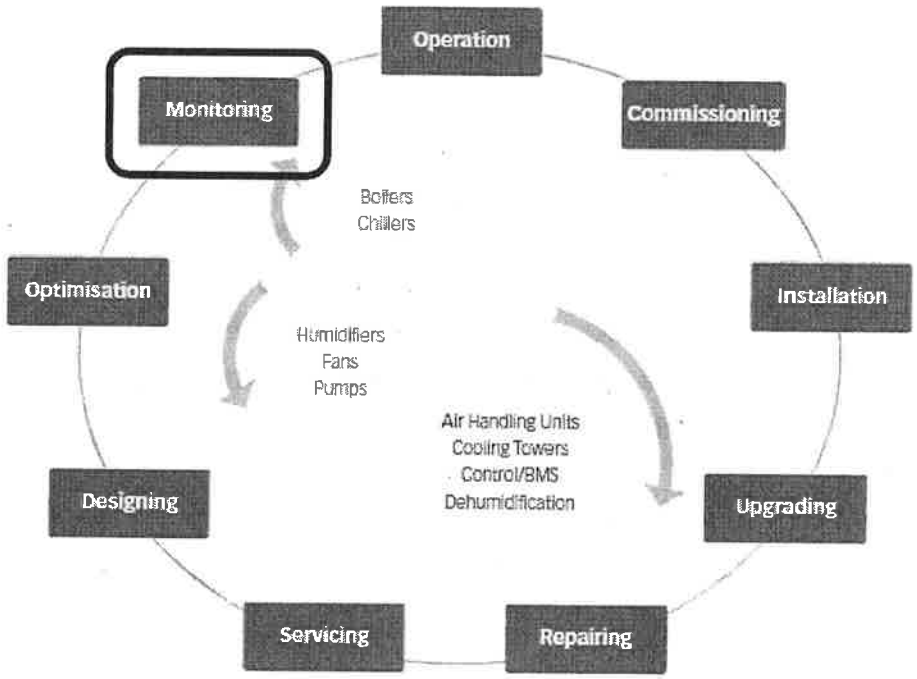
Topics

- Air Conditioning & Mechanical Ventilation (ACMV) for Good IAQ
  - **Inspection of ACMV System**
  - ACMV Operations and Maintenance
  - Ventilation and Filtration Systems
  - Causes of Poor IAQ in Tropical Climate
  - Energy Efficient Methods of Control
  - Relative Humidity to improve IAQ
- Measurement and Instrumentation

Background

- All occupied buildings require a supply of outdoor air.
- As outdoor air is drawn into the building, indoor air is exhausted or allowed to "escape", thus removing indoor air pollutants.

ACMV System and Key Activities



Roles and Responsibilities

- **Building Owner**: Policies and strategies drive the process for setting up the implementation of maintenance contracts and efficiency measures
- **Facilities Managers**: Overall responsible for managing building operations
- **Building Occupants**: Be familiar with systems that serve tenancy areas and common areas.
- **Maintenance Service Provider**: To proactively identify potential issues that affect ACMV systems due to poor operation

Inspection of ACMV Systems

Inspection of ACMV Systems

Primary Objective:

- To inspect components and systems, and to and verify against **design** and/or **complaints,** whether these systems are:
  - contaminated with accumulation of particulate or microbial growth
  - if ACMV performance is compromised due to contamination build-up

Poor Indoor Air Quality due to ACMV Systems (I)

- Location of air intakes and exhausts
- Design for supplied outdoor air (OA)
- Pressure differentials between rooms
- Design and distribution of air flow
- Position of dampers
- Local exhaust ventilation (LEV)

Poor Indoor Air Quality due to ACMV Systems (II)

- Air-cleaning equipment
- ACMV operating times
- Equipment cleaning and disinfecting
- Presence of water leaks or standing water
- Water-damaged building materials
- Bacteriological contamination

Location of Air Intakes and Exhaust Design for Supplied Outdoor Air

- Outdoor air intakes should be placed where the **air admitted is likely to be cleanest**, taking into consideration:
  - Singapore ambient air quality standards (and targets)
  - Position of the building, the exhaust opening position, traffic routes, carparks, unloading bays, refuse chutes and other nearby sources of pollution.
- Intakes should not be located below ground level or close to evaporative cooling towers.

Singapore Pollutant Standard Index (PSI)

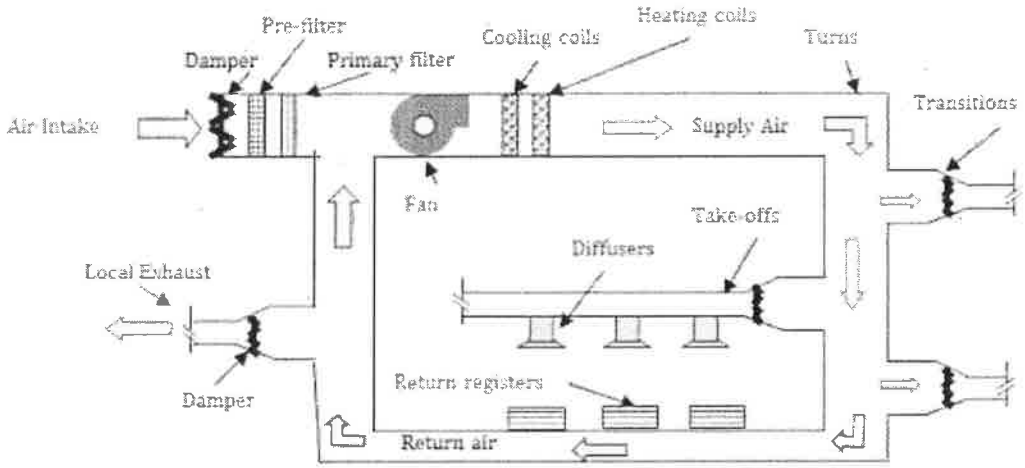
- PSI is computed based on 24-hour average concentrations of PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3, CO.

PSI Value	PSI Descriptor
0 - 50	Good
51 - 100	Moderate
[illegible]	[illegible]
[illegible]	[illegible]
Above 300	Hazardous

Pressure Differentials between Rooms

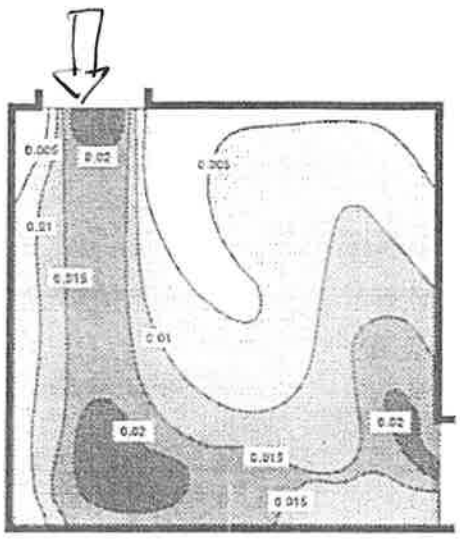
- Managing differential pressure between the inside and outside, and between different areas of the building by regulating supply and return air volumes is a key means of controlling the migration of contaminants.
- Airborne contaminants can be migrated from areas of relatively high to low differential pressure.
- Verifying and maintaining building pressures is essential in preventing infiltration of outdoor contaminants and moisture into the building envelope.

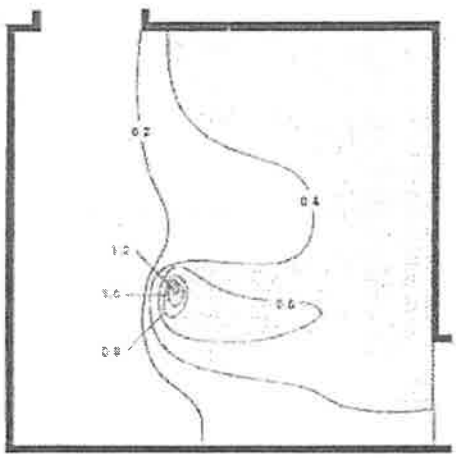
Typical System affecting Pressures



Source: TSI

Design and Distribution of Air Flow





Turbulence Diffusion Profile

Air Pollutant Dispersion Profile

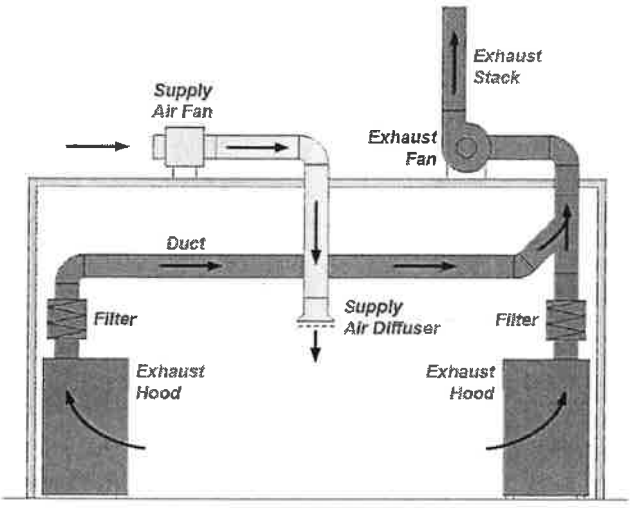
Source: Yamamoto et. al.

Position of Dampers

- Dampers are used as controls to restrict airflow. Damper positions may be relatively fixed (e.g., set manually during system testing and balancing) or may change in response to signals from the control system.
- The amount of outdoor air introduced in the occupied mode should be sufficient to meet needs for ventilation and exhaust make-up. Damper may be fixed at a constant volume or may vary with the outdoor conditions.
- When dampers that regulate the flow of outdoor air are arranged to modulate, they are usually designed to bring in a minimum amount of outdoor air (in the occupied mode) under extreme conditions.

Local Exhaust Ventilation (LEV)

- Kitchens, laboratories, carparks, bin centres, toilet, and other specialised areas may be a source of pollutants when they lack adequate local exhaust ventilation.



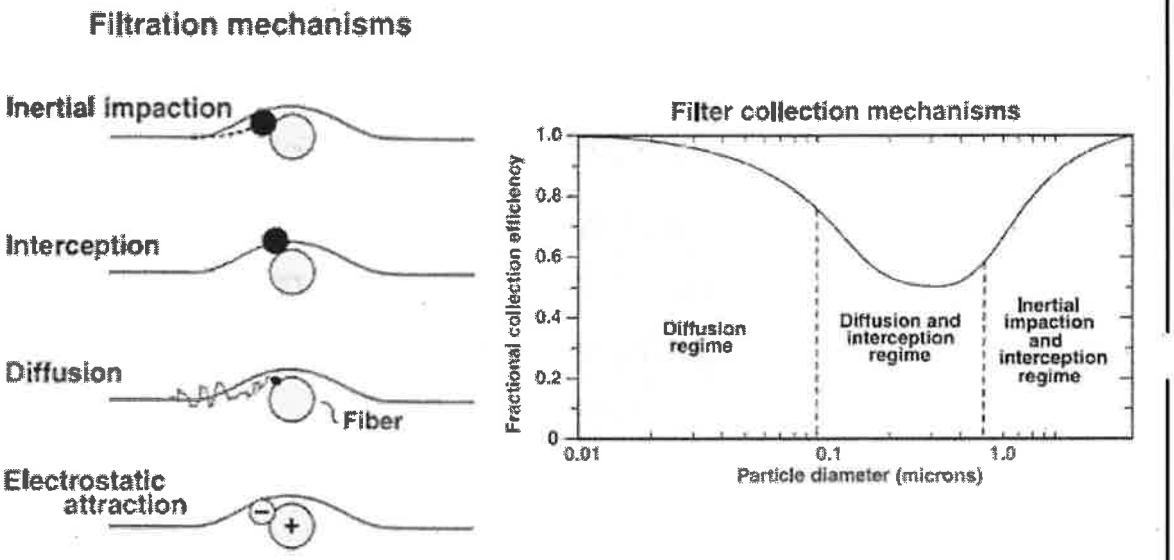
Air Cleaning Equipment

- Filtration and air cleaning remove unwanted material from an air stream. For ACMV applications, this involves air filtration and, in some cases, air cleaning (for gas and vapour removal). The collection mechanisms for particulate filtration and air-cleaning systems are very different.

Particulate Air Filtration (I)

- Particulate air filters are classified as either:
  - mechanical filters
  - electrostatic filters (electrostatically enhanced filters; electrostatic precipitator)

Primary Mechanical Filtration Mechanisms



Electrostatic Precipitator $< 2.5 m/s$

- Requires power and charged plates to attract and capture particles
- Contain electrostatically enhanced fibers, which attract the particles to the fibers, in addition to retaining them
- Relies on charged fibers to dramatically increase collection efficiency for a given pressure drop across the filter.

Particulate Air Filtration (II)

- As mechanical filters load over time, the collection efficiency and pressure drop increase. Eventually, the increased pressure drop significantly inhibits airflow, and the filters must be replaced. Hence, pressure drop across mechanical filters is often monitored.
- Electrostatic filters, which are composed of polarized fibers, may lose their collection efficiency over time or when exposed to certain chemicals, aerosols, or high relative humidities.

Gas-Phase Air Cleaning

- Sorbent filters (collect only) are designed to remove pollutant gases and vapours.
- Mechanisms for capturing and controlling gas-phase air contaminants: physical adsorption and chemisorption.
- Both capture mechanisms remove **specific** types of gas-phase contaminants from indoor air

Equipment Cleaning and Disinfecting

- Equipment may refer to any part of the ACMV system (eg. duct).
- Cleaning and disinfecting equipment may dislodge contaminants into indoor air.

Duct Cleaning

- Duct cleaning may be appropriate in the following circumstances:
  - Permanent or persistent water damage in ducts
  - Slime or microbial growth observed in ducts
  - Debris build-up in ducts that restricts airflow
  - Dust discharging from supply diffusers
  - Offensive odours originating in ductwork, or from ACMV components.

Cannot measure

Presence of Water Leaks or Standing Water

- **Legionnaires' disease bacteria (LDB)** cannot survive without water, and a properly operated, well-maintained ACMV system is unlikely to be a source of problems unless water contaminated with the bacteria enters the system.
- Maintenance failures can produce stagnant water that can become an ideal environment for LDB growth if sufficiently warm;
- Improperly drained condenser pans may produce tepid conditions that can encourage microbial and fungal growth.
- Direct evaporative air coolers with sprays or misters used as humidifiers include sumps, which may stagnate when not in use.

Water-Damaged Building Material

- Dampness is a problem in buildings because it provides the moisture that supports the growth of bacteria, fungi (i.e., mould), and insects. Dampness becomes a problem when various materials in buildings (e.g., rugs, walls, ceiling tiles) become wet for extended periods of time.
- Dampness results from water incursion either from internal sources (e.g. leaking pipes) or external sources (e.g. rainwater).
- Excessive moisture in the air (i.e., high relative humidity) that is not properly controlled with air conditioning can also lead to excessive dampness..

Spotlight

NIOSH Alert: Preventing Occupational Respiratory Disease from Exposures Caused by Dampness in Office Buildings, Schools, and Other Nonindustrial Buildings



Office buildings, schools, and other nonindustrial buildings may develop moisture and dampness problems from roof and window leaks, high indoor humidity, and flooding events, among other things. For this Alert, we define "dampness" as the presence of unwanted and excessive moisture in buildings [AIHA 2008]. This can lead to the growth of mold, fungi, and bacteria; the release of volatile organic compounds; and the breakdown of building materials. We use the term "mold" for a group of fungi that are common on wet materials. Outdoors, molds live in the soil, on plants, and on dead or decaying matter. There are thousands of species of molds and they can be any color. Different mold species can adapt to different moisture conditions. Research studies have shown that exposures to building dampness and mold have been associated with respiratory symptoms, asthma, hypersensitivity pneumonitis, rhinosinusitis, bronchitis, and respiratory infections. Individuals with asthma or hypersensitivity pneumonitis may be at risk for progression to more severe disease if the relationship between illness and exposure to the damp building is not recognized and exposures continue.

NIOSH Alert: Preventing Occupational Respiratory Disease from Exposures Caused by Dampness in Office Buildings, Schools, and Other Nonindustrial Buildings
DHHS (NIOSH) Publication No. 2013-102 (November 2012)

Source: CDC

The End

Indoor Air Quality Management for Buildings (Part II)

Prepared for:
Green Mark Facilities Professional (GMFP)
Green Mark Professional (GMM)

Dr.-Ing. Ang Keng Been EUR. ING
2015

Topics

- Air Conditioning & Mechanical Ventilation (ACMV) for Good IAQ
  - Inspection of ACMV System
  - **ACMV Operations and Maintenance**
  - **Ventilation and Filtration Systems**
  - **Causes of Poor IAQ in Tropical Climate**
  - **Energy Efficient Methods of Control**
  - **Relative Humidity to improve IAQ**
- Measurement and Instrumentation

ACMV Operation and Maintenance

ACMV Operation & Maintenance Chillers (I)

- Manufacturers' guidelines and advice regarding maintenance must be followed.
- Heat exchangers to be maintained in a clean state.
- Water-cooled condensers to be cleaned regularly, and/or when fouling is noted through high temperature approach values.

ACMV Operation & Maintenance Chillers (II)

- **Performance-based maintenance** should be performed on chillers, in addition to scheduled replacement of components as stated in manufacturer's instructions.

- **Regular measurements** of parameters (temperature and pressure drops through heat exchanges and monitoring of chiller COP) through a BMS. May also be achieved through regular recording of the data on maintenance log books.

ACMV Operation & Maintenance Chillers (III)

- The **refrigerant charge** to be **regularly checked** and any leaks repaired promptly

- Check pipework **insulation** on chiller and chilled water pipework and components

- Regular checks and rectification to be performed for **water leaks** from chillers and the chilled water distribution system, with a re-instatement of water treatment chemicals.

ACMV Operation & Maintenance Chillers (IV)

- Ensure chiller control temperature **sensors are calibrated**

- **Installation of dedicated supplementary ACMV systems** to serve small after-hours loads rather than using central chiller plant.

ACMV Operation & Maintenance Cooling Towers (I)

- Manufacturers' guidelines and advice regarding maintenance must be followed.

- Ensure **no overflow** of water from the cooling tower basin due to:
  - Faulty water level controls
  - The volume of water within the high level return line draining to the sump, when the tower stops operating
  - Where multiple towers are installed, a lack of a balance pipe to equalise water levels

ACMV Operation & Maintenance Cooling Towers (II)

- Water leaks from pipes and faulty valves to be eliminated
- Optimise the water bleed rate in accordance with the quality of the mains water, the water treatment regime and the type of cooling tower. Where automatic controls are installed, controls must be calibrated and adjusted correctly.

ACMV Operation & Maintenance Cooling Towers (III)

- Type and condition of splash guards and drift eliminators must be checked to ensure that water wastage due to poor design and/or condition of the splash guards and drift eliminators is minimised.
- The cooling tower fill must not be allowed to gather excessive fouling and regular inspection should be carried out.

ACMV Operation & Maintenance Cooling Towers (IV)

- The **airflow around cooling towers must not be restricted**. Discharge air from cooling towers must not be allowed to re-cycle into the intake.

- **Monitoring of energy and water usage**, including the following:
  - Monitoring water consumption via BMS.
  - Monitoring of cooling tower fan energy consumption, together with other performance indicators
  - Installing Total dissolved solids (TDS) sensors, independent from the TDS control sensor with alarms

ACMV Operation & Maintenance AHUs (I)

- Ensure cooling coils are kept clean

- **Replace or clean air filters regularly**, in accordance with the maintenance schedules. Filter differential pressure gauges installed across the air filter banks are essential to assess the cleanliness of filters.

- Assess whether the efficiency of the installed air filters is appropriate for the application.

ACMV Operation & Maintenance AHUs (II)

- Regularly inspect and eliminate all sources of air leakage through damaged flexible connections, poor ductwork joints and access doors/panels

- Ensure that the **economy cycle for dampers/control actuators and temperature/humidity sensors** are set up correctly functions satisfactorily.

ACMV Operation & Maintenance AHUs (III)

- Installation and operation of branch dampers to minimise wasteful after-hours air conditioning and the air conditioning of vacant zones

- Investigate whether AHUs are performing active de-humidification

- Ensure that service lights inside AHUs are not left continuously in operation

ACMV Operation & Maintenance AHUs (IV)

- Check the accuracy and location of zone temperature sensors.
- **Control fan coils using room air temperature sensors**, rather than return air sensors
- Ensure that alterations carried out during tenancy fit-outs do not affect airflows into the zones.

ACMV Operation & Maintenance AHUs (V)

- If monitoring indicates issues which are due to a lack of air balancing, then it will be advisable for systems to be **re-balanced and re-commissioned**

ACMV Operation & Maintenance Fans

- Ensure that all fans are **automatically switched off** when the systems they serve are not in operation
- **Remove unnecessary restrictions** from the system including excessive and/or squashed lengths of flexible ductwork on the index circuits
- Ensure that belts and pulleys are **correctly tensioned and accurately aligned**

ACMV Operation & Maintenance Split AC Systems (I)

- Ensure systems are regularly serviced in accordance with manufacturer's instructions.
- The filters must be replaced, heat exchangers (evaporator and condenser) cleaned and the refrigerant charge checked and topped up where necessary.
- Minimising the operation of individual units, based on time and temperature controls.

ACMV Operation & Maintenance Split AC Systems (II)

- Lock the control thermostats in the desired position and/or label them accordingly
- Control fan coils using room air temperature sensors, rather than return air sensors
- Install automatic controls to shut down supplementary split AC systems automatically.

ACMV Operation & Maintenance Split AC Systems (III)

- Where supplementary split AC systems are connected to BMS, ensure that the systems have control interlocks to prevent counter-acting with the central system

ACMV Operation & Maintenance Building Management Systems (I)

- Important for the Facilities Manager to **familiarise** with the capabilities and operational parameters of the BMS

- Important for Maintenance Contractors to **have access to the BMS**, for ACMV system maintenance and operational purposes. The protocols and procedures for making changes to the BMS and documentation of any changes will need to be agreed between the Facilities Manager and the Maintenance Contractor. It is essential for key members in the Maintenance Contractors team to have a good working knowledge of the BMS operation including monitoring and trending functions.

ACMV Operation & Maintenance Building Management Systems (II)

- Diagnostic screens are set up for the verification of key ACMV system functions including the economy cycle, operation of VAV boxes, modulation of fans and pumps through VSDs, chiller operation including flow temperature re-set and leaking valves

- Ensure ACMV equipment is correctly scheduled to operate only when required and local public holidays are programmed.

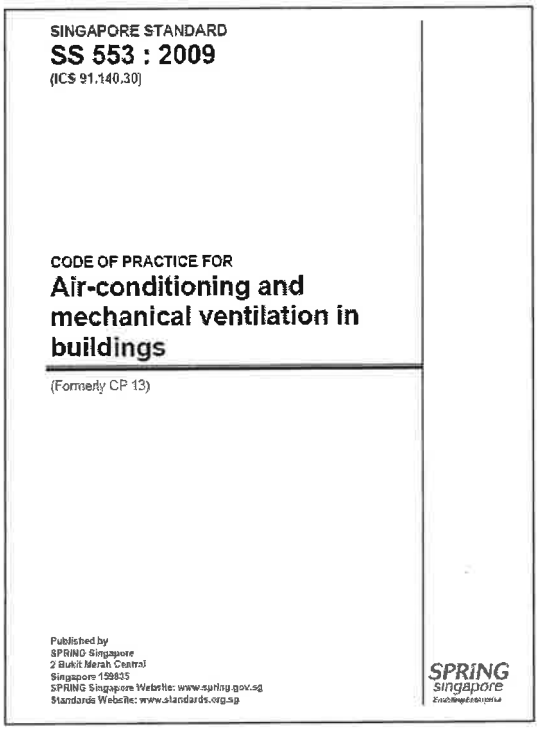
ACMV Operation & Maintenance Building Management Systems (III)

- Ensure control parameters such as temperature, RH and operating times are not wasteful.

- Ensure sensors are calibrated, at least annually and that sensors are not affected by extraneous factors including solar gains, heat output from office equipment, air leakage through unsealed cable entries.

Ventilation and Filtration Systems

Ventilation and Filtration Systems


SINGAPORE STANDARD
SS 553 : 2009
(ICS 91.140.30)

CODE OF PRACTICE FOR
Air-conditioning and mechanical ventilation in buildings

(Formerly CP 13)

Published by
SPRING Singapore
2 Bukit Merah Central
Singapore 159835
SPRING Singapore Website: www.spring.gov.sg
Standards Website: www.standards.org.sg

SPRING singapore

Ventilation:

"The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned."

Source: SS553:2009

Ventilation Rates

- **Outdoor Air Intakes**
  - Design and Location
- **Air Classification and Recirculation**
  - Air leaving/recirculated each space is designated at air0quality classification based on relative contaminant concentration
- **Outdoor Air Supply**
  - Design and requirement of outdoor air supply

Outdoor Air Intakes Requirements

- Location shall take into account of any other intake openings for ventilation/exhaust.
- Shall be located at external walls/roof level to pick up outdoor air free of contaminants
- To be covered with insect screen and rain entrainment
- Minimum distance away from exhaust discharges
- Protected from cooling towers
- Minimum height requirement above ground

Air Classification and Recirculation

Class 1 – Air with low contaminant concentration, low sensory-irritation intensity and inoffensive odour.

Class 2 – Air with moderate contaminant concentration, mild sensory-irritation intensity or mildly offensive odour. Class 2 air also includes air that is not necessarily harmful or objectionable but that is inappropriate for transfer or recirculation to spaces used for different purposes.

Class 3 – Air with significant contaminant concentration, significant sensory-irritation intensity or offensive odour.

Class 4 – Air with highly objectionable fumes or gases or with potentially dangerous particles, bioaerosols, or gases, at concentrations high enough to be considered harmful.

Source: SS553:2009

Outdoor Air Supply Requirement for Comfort Air-Conditioning

Type of building/ Occupancy	Minimum outdoor air supply			
	l/s per m^2 floor area	m^3 /h per m^2 floor area	l/s per person	Air class [1]
Restaurants	3.4	12.2	5.1	2
[(i)] Dance halls	7.0	25.0	10.5	1
Offices	0.6	2.0	5.5	1
[(ii)] Shops, supermarkets and department stores	1.1	3.8	5.5	1 or 2
Theatres and cinemas seating area	2.0	7.3	3.0	1
Lobbies and corridors	0.3	1.1	3.3	1
Concourses	1.1	4.0	3.3	1
[(iii)] Hotel guest rooms	15.0 l/s per room	54.0 m^3 /h per room	5.5	1
[(iv)] Classrooms				
Primary school children and above	2.8	10.0	4.2	1
Childcare centres	2.8	10.0	8.4	1

Source: SS553:2009

Outdoor Air Supply for Mechanical Ventilation in non AC Buildings or Parts of Building with No Natural Ventilation

Type of building/ Occupancy	Minimum outdoor air supply air-change/h
Offices	6
Restaurants, canteens	10
Shops	6
Workshops, factories	6
Classrooms	8
[(i)] Car parks	6
[(ii)] Toilets, bathrooms	10
[(iii)] Lobbies , concourse, corridors, staircases and exits	4
Kitchens (commercial, institutional and industrial)	[(iv)] 20

Source: SS553:2009

Air Filtration (I)

The particulate contaminants in the air in an air-conditioned space should be continuously removed in order to maintain the cleanliness of the air.

7.5.1 Outdoor air for ventilation and indoor air that is to be recirculated should be filtered for particulate.

7.5.2 An air filter should be placed specifically for cleaning the outdoor air only. The Minimum Efficiency Reporting Value (MERV) of the pre-filter for cleaning the outdoor air should be MERV 1 or better.

7.5.3 The Minimum Efficiency Reporting Value (MERV) of the primary filter for cleaning the recirculated air or mixed air should be MERV 5 or better.

7.5.4 Air filters should be installed such that no unfiltered air can bypass the filters and enter the air handling system.

7.5.5 It should be possible to assess at any time the condition of the air filter and the pressure drop across it.

7.5.6 For a better indoor air quality, it is recommended that a filter of 80% dust spot efficiency or better be used as the secondary filter for cleaning the recirculated air or mixed air in places for continuous occupancy. The use of such filter can be helpful when the quality of outdoor air is poor. It can also reduce the need to clean the air ducts of dust cake that will form with time which can support the growth of micro-organisms.

Source: SS553:2009

Air Filtration (II)

7.5.7 Where no secondary filter is used, it is recommended that the recirculated air or mixed air or outdoor air is further cleaned of fine particles whenever the pollution standard index of the outdoor air exceeds 100 based on PM10 over 24 hours.

7.5.8 To meet the requirement stated in 7.5.7, an air filter of 80% dust spot efficiency or better can be inserted into the stream of recirculated air or mixed air after the primary filter. For this purpose the fan motor needs to have been sized accordingly such that the required air flow rate can be maintained.

7.5.9 The requirement of 7.5.7 can similarly be met, if an air filter of 80% dust spot efficiency or better is used to filter the intake outdoor air further after the pre-filter.

7.5.10 The requirement stated in 7.5.7 or 7.5.8 can also be met by other types of air cleaning devices of similar performance.

Source: SS553:2009

Causes of Poor IAQ in Tropical Climate

Tropical Climate and IAQ

- Tropical climate eliminate the need to heat indoor air for comfort; buildings are usually mechanically air-conditioned.

- For economic reasons, buildings are planned as closed structure, and seldom with natural ventilation incorporated in the plans.

Indoor Sources!

Outdoor Sources

Potential Sources:

- Local
- **Background (eg. transboundary haze)**

Haze

- Singapore is affected by smoke haze due to forest fires in the region periodically, due to practice of open burning to clear land for agricultural uses.
- Worsen by dry seasons, changes in wind direction and poor precipitation
- Prevailing winds sometimes carry smoke haze produced by the forest fires over Singapore's skies, especially so during the Southwest Monsoon Season.

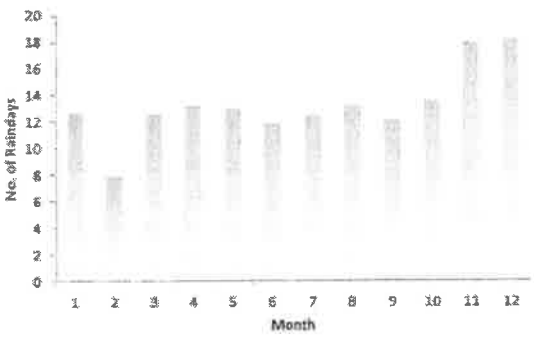
Climate of Singapore

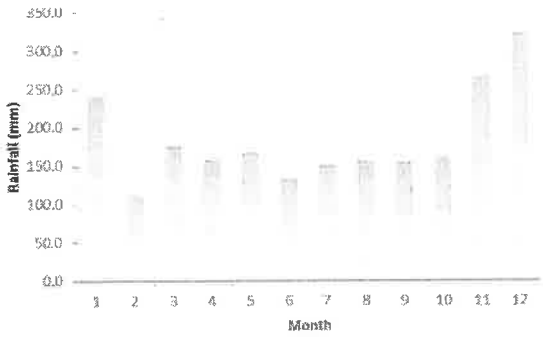
- Singapore is situated near the equator and has a typically tropical climate, with abundant rainfall, high and uniform temperatures, and high humidity all year round.
- Many of its climate variables, such as temperature and relatitve humidity, do not show large month-to-month variation. However, many variables exhibit prominent diurnal (or daily) variations from hour to hour, indicating the strong influence that solar heating has on the local climate.

Rainfall

(based on long-term records from 1869 to 2014)

- Average annual rainfall of 178 days
- Average annual rainfall of 2338.5mm



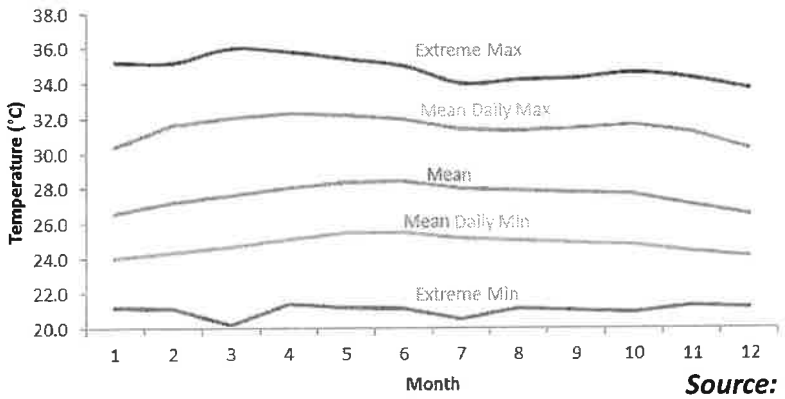


Source: weather.gov.sg

Temperature

(based on long-term records from 1982 to 2014)

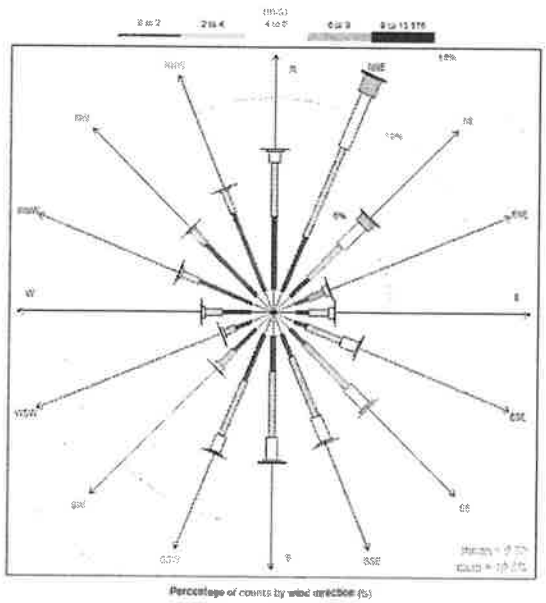
- Daily temperature range not falling below 23 - 25 ºC during the night, and max. not rising above 31 - 33 ºC during the day.
- May and June has the highest average monthly temperature (24-hour mean of 27.7 ºC and 27.8 ºC respectively) and December and January are the coolest (24-hour mean of 26.0 ºC).



Source: weather.gov.sg

Surface Wind

(based on long-term records from 1982 to 2014)



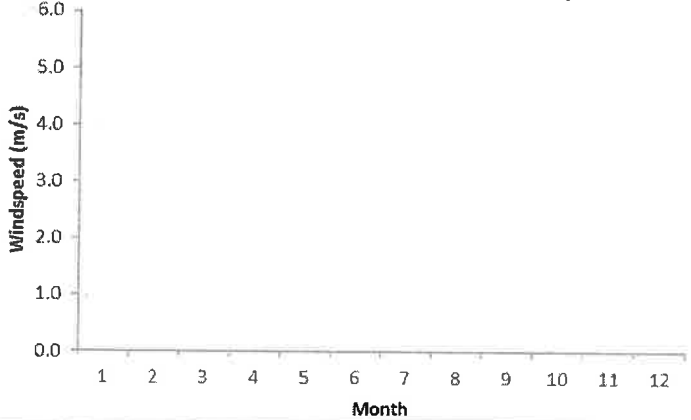
- Wind directions are mainly from northerly to northeasterly during the Northeast Monsoon (December to March) and southerly to southeasterly during the Southwest Monsoon (June to September).
- Wind strength is greater during the Northeast Monsoon. The inter-monsoon months (April, May, October and November) are transition periods between the monsoons and show lighter and more variable winds.

Source: weather.gov.sg

Windspeed

(based on long-term records from 1983 to 2014)

- Winds with diurnal variation, with lighter winds during the night and stronger winds during the day.
- The strongest winds occur during the Northeast Monsoon in January and February.
- Mean surface wind speed normally less than 2.5 m/s.



Source: weather.gov.sg

Energy Efficient Methods of Control

Energy Efficient Methods of Control

- The maintenance and operation of ACMV Systems in commercial buildings has traditionally been performed with a focus on complying with statutory requirements for providing thermal comfort conditions for building occupants.
- Due to short term commercial pressure, the lowest tender price submission from maintenance contractors is often accepted, with little consideration given to long term value for money.
- Opportunities for achieving energy and water efficiency gains are neglected and life cycle costs are not given due consideration.
- The consequences of higher energy and water costs are frequently accepted as being inevitable and passed on to building occupants.

Trends in Energy Efficient Control Methods (I)

- **Variable Speed Drives**: Variable speed drives (VSD) have become a ubiquitous feature of modern air-conditioning systems, particularly as a means of controlling fans and pumps.
- **Building Control Systems**: A modern, well-configured building control system is an invaluable tool for enhancing the efficiency of a building.
- **Chillers**: Chiller technology has maintained a steady state of advancement for many decades.

Trends in Energy Efficient Control Methods (II)

- **Split AC Systems**: The application of variable speed drives has a significant impact in the performance of small air-cooled packaged cooling systems such as split systems.
- **ACMV System Types:**
  - Single-coil twin fan systems
  - Variable air-volume systems
  - Variable refrigerant flow systems
  - Passive chilled beams

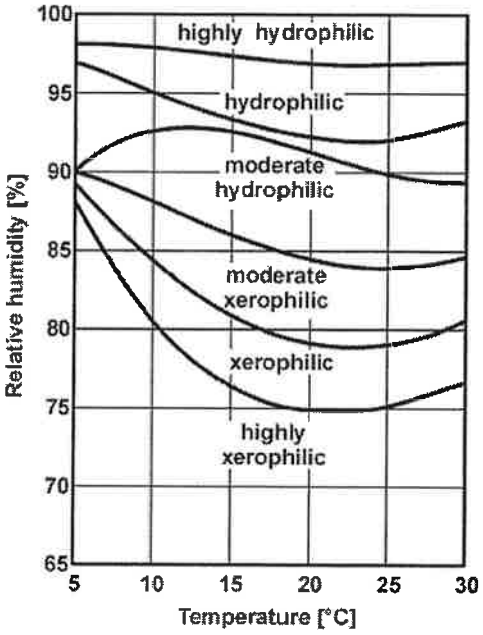
Relative Humidity to improve IAQ

Indoor Thermal Environment

- When the air-conditioning system is in operation, the operative temperature should be maintained within 24 to 26 °C, and the air movement should not exceed 0.30 m/s, and the average relative humidity should not exceed **65 % for new buildings**, and **70 % for existing buildings**.

Mould Growth Conditions

- Mould growth does not require the presence of standing water; it can occur when high relative humidity or the hygroscopic properties (the tendency to absorb and retain moisture) of building surfaces allow sufficient moisture to accumulate.



Source: Clarke

The End

Indoor Air Quality Management for Buildings (Part III)

Prepared for:
Green Mark Facilities Professional (GMFP)
Green Mark Professional (GMM)

Dr.-Ing. Ang Keng Been EUR. ING
2015

Topics

- Air Conditioning & Mechanical Ventilation (ACMV) for Good IAQ
  - Inspection of ACMV System
  - ACMV Operations and Maintenance
  - Ventilation and Filtration Systems
  - Causes of Poor IAQ in Tropical Climate
  - Energy Efficient Methods of Control
  - Relative Humidity to improve IAQ

- **Measurement and Instrumentation**

Pollutant Standard Index (PSI)

Pollutant Standard Index (PSI)

- The PSI is based on **6 pollutants**:
  - PM_{10}
  - $PM_{2.5}$
  - SO_2 (West side of Singapore)
  - CO
  - O_3 (Early morning)
  - NO_2 (Vehicular Exhaust)
- For each pollutant, a **sub-index** is calculated from a segmented linear function that transforms ambient concentrations onto a scale extending from 0 through 500.

6-Pollutant Sub-Indices

Index Category	PSI	24-hr $PM_{2.5}$ ($\mu g/m^3$)	24-hr PM_{10} ($\mu g/m^3$)	24-hr SO_2 ($\mu g/m^3$)	8-hr CO (mg/m^3)	8-hr O_3 ($\mu g/m^3$)	1-hr NO_2 ($\mu g/m^3$)^
Good	0 – 50	0 – 12	0 – 50	0 – 80	0 – 5.0	0 – 118	-
Moderate	51 – 100	13 – 55	51 – 150	81 – 365	5.1 – 10.0	119 – 157	-
Unhealthy	101 – 200	56 – 150	151 – 350	366 – 800	10.1 – 17.0	158 – 235	1130
Very Unhealthy	201 – 300	151 – 250	351 – 420	801 – 1600	17.1 – 34.0	236 – 785*	1131 – 2260
Hazardous	301 – 400	251 – 350	421 – 500	1601 – 2100	34.1 – 46.0	786 – 980*	2261 – 3000
	401 – 500	351– 500	501 – 600	2101 – 2620	46.1 – 57.5	981 – 1180*	3001– 3750

(Note: *When 8-hour ozone concentration exceeds 785$\mu g/m^3$, the PSI sub-index is calculated using the 1-hour concentration; ^Sub-index for nitrogen dioxide is reported only when the 1-hour concentration equals or exceeds 1130 $\mu g/m^3$.)

Source: haze.gov.sg

Calculating PSI

Each sub-index i, is calculated by using a segmented linear function that relates pollutant concentration, X_i to sub-index value, I_i. A segmented linear function consists of straight-line segments joining discrete co-ordinates (i.e. breakpoints). For pollutant i and segment j, the co-ordinates of the jth breakpoints are represented by sub-index value $I_{i,j}$ and the concentration $X_{i,j}$ giving the ordered pair ($X_{i,j}$, $I_{i,j}$). If the observed concentration is X_i the corresponding sub-index value I_i is calculated using the following equation over the concentration range:

Equation 1:

$$I_i = \frac{I_{i,j+1} - I_{i,j}}{X_{i,j+1} - X_{i,j}} (X_i - X_{i,j}) + I_{i,j}$$

for $X_{i,j} \leq X_i \leq X_{i,j+1}$

where
- X_i = Observed concentration for the ith pollutant
- $I_{i,j}$ = PSI value for the ith pollutant and the jth breakpoint as given in the table
- $I_{i,j+1}$ = PSI value for the ith pollutant and the $(j+1)^{th}$ breakpoint as given in the table
- $X_{i,j}$ = Concentration for the ith pollutant and j^{th} breakpoint as given in the table
- $X_{i,j+1}$ = Concentration for the ith pollutant and $(j+1)^{th}$ breakpoint as given in the table

Finally, the overall index is calculated as the maximum of sub-indices:

$$PSI = \text{maximum } (I_1, I_2, I_3, I_4, I_5, I_6)$$

Source: haze.gov.sg

Measurement and Instrumentation

Acceptable Limit Values

Parameter	Acceptable Limit for 8 h
Operative Temperature	26 – 26 °C
Relative Humidity	<65 % (new buildings); <70 % (existing building)
Air Movement	0.10 – 0.30 m/s
CO_2	700 ppm above outdoor
CO	9 ppm
HCHO	120 µg/m³; 0.1 ppm (if concentration > limit)
TVOC	3000 ppb
RSP	50 µg/m³
Total Viable Bacterial Count	500 cfu/m³
Total Viable Mould Count	500 cfu/m³

Source: SS554:2009

Outdoor

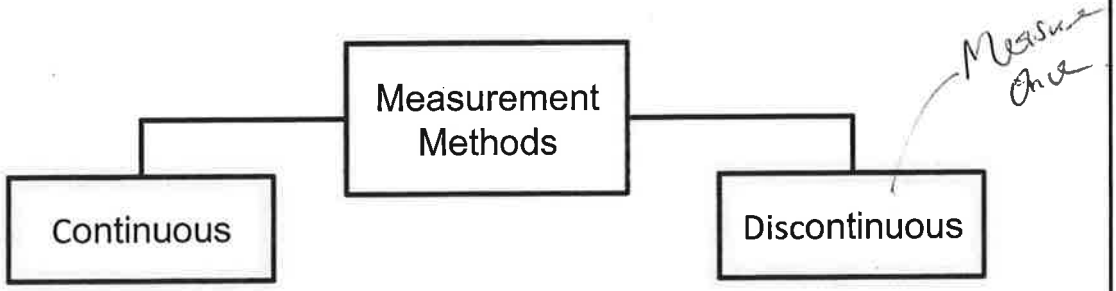
Acceptable Limit Values

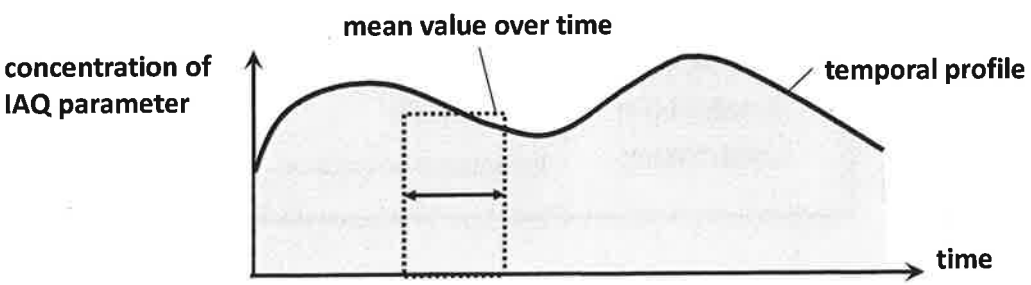
Parameter	Acceptable Limit for 8 h
PM 2.5	35 µg/m^3
Ultra-fine particles	-
NO2	100 µg/m^3
O3	0.1 ppm
Radon	150 Bq/m^3
Asbestos	0.01 fibre/cc
Nicotine	-
Pathogenic Bacteria	Presence of Specific Species
Pathogenic Mould	Presence of Specific Species
SVOC	PEL of Toxic Substances

Semi VOC

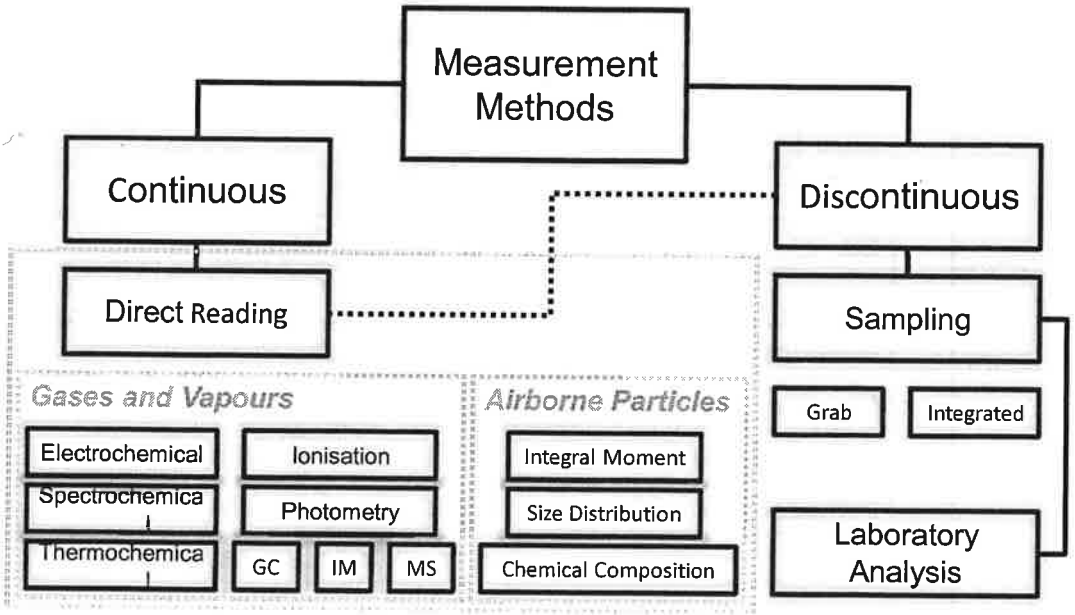
Source: SS554:2009

Measuring IAQ Parameters





Measurement Methods for
Gases, Vapours & Airborne Particles



Continuous and Discontinuous Measurement Methods

	Advantages	Disadvantages
Direct Reading Instruments	Uninterrupted monitoring Good temporal resolution Fast responses	Low sensitivity Low selectivity **Expensive*
Sampling/ Analysis in Laboratory	Good spatial resolution High accuracy Referenced as standard	Additional cost for analyses Poor temporal resolution Long exposition time

Measurement and Instrumentation

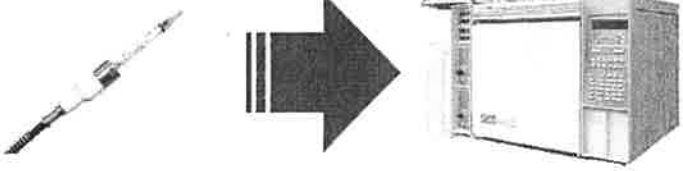
Direct Reading

Automatic measuring instruments based on physical, chemo-physical or chemical measuring principles



Sampling in Field/Analysis in Laboratory

Manual or automated process for sampling, followed by analyses in laboratory



Source: TSI; Agilent Technologies

Measurement Methods for Airborne Particles

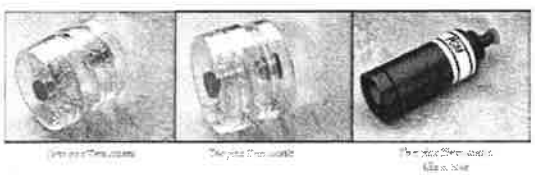
Direct Reading

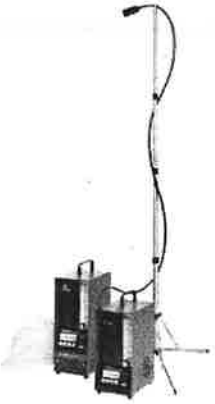
Measurement of number concentration, mass concentration, chemical composition, and surface area



Sampling in Field/Analysis in Laboratory

Gravimetric method, counting method





Source: TSI; Sensidyne

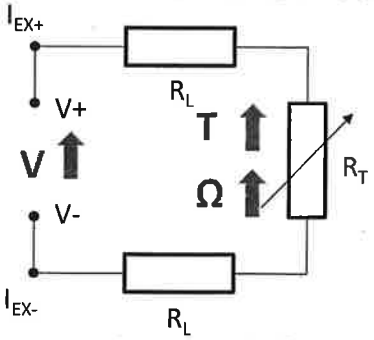
Choice of Indoor Air Quality Instruments

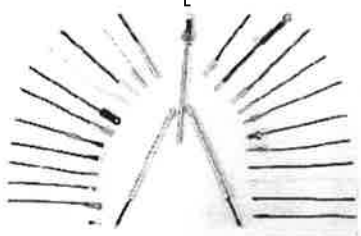
- Simple, problem-solving tools
- Trace the cause of even the most elusive IAQ problems
- Portable, light-weight, easy to use
- Real - time displays
- Survey or data logging modes
- Generate investigative reports

Thermal Comfort Parameters

& Air speed

Measurement Method for Air Temperature





Type: Hot wire,*thermistor, thermometer sling

*Measurement principle:
Thermistor are thermally sensitive semiconductors whose resistance varies with temperature

Unit of Measurement: °C

*Typical Characteristics:
- High sensitivity; very responsive to temperature changes
- Use up to ~ 300 °C
- Change in resistance is not linearly proportional to change in temperature

Source: Cantherm

Thermal Comfort Parameters

Measurement Method for Globe Temperature



Type: Globe thermometer

Principle of Operation:

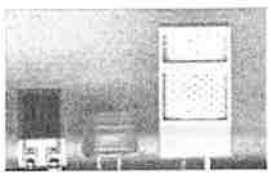
- A hollow globe coated on the outside with matt-black paint absorbs the radiant heat from surrounding object.
- The temperature at the center of the globe is the measure of radiant heat, and not of the surrounding air.

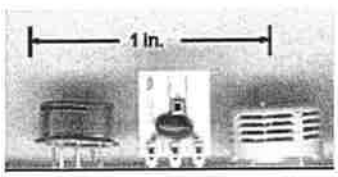
Unit of Measurement: °C

Source: Metrel

Thermal Comfort Parameters

Measurement Method for Relative Humidity





Type: *Thin-film capacitive, hygrometer, thermometer sling

*Measurement principle:
As humidity changes, it changes the capacity of the sensor

Unit of Measurement: %

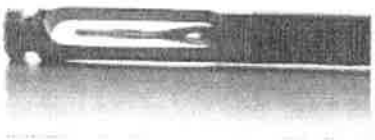
*Typical Characteristics:

- Good recovery from condensation
- Reasonable resistance to chemical vapours
- Use up to ~ 200 °C
- Change in dielectric constant is nearly proportional to change in surrounding R.H

Source: Roveti

Thermal Comfort Parameters

Measurement Method for Air Movement



Type: Hot wire method, kata thermometer, *thermo-anemometer

*Measurement principle:
Heat transfer

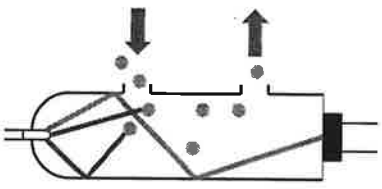
Unit of Measurement: m/s

*Typical Characteristics:
- Accurate in low velocity region
- Accurate across a wide dynamic range

Source: Kanomax

Chemical Parameters

Measurement Method for Carbon Dioxide CO_2



Type: *Non-Dispersive IR

*Measurement principle:
Intensity of light reaching detector is proportional to CO_2 concentration

Unit of Measurement: ppm

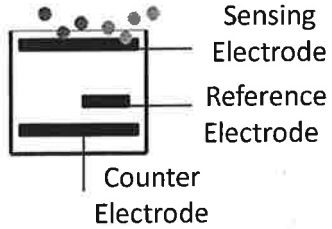


*Typical Characteristics:
- High sensitivity; very responsive to temperature changes
- Use up to ~ 300 °C
- Change in resistance is not linearly proportional to change in temperature

Source: Draeger

Chemical Parameters

Measurement Method for Carbon Monoxide CO





Type: *Electrochemical

*Measurement principle:
Reacting with gas of interest and producing a signal proportional to the gas concentration

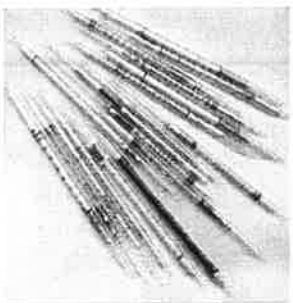
Unit of Measurement: ppm

*Typical Characteristics:
- Minimally affected by pressure changes
- Sensitive to temperature

Source: Chou

Chemical Parameters

Measurement Method for Formaldehyde HCHO



Type: Detection tubes, electrochemical

Measurement principle:
Colour change measurements via gradations on vial

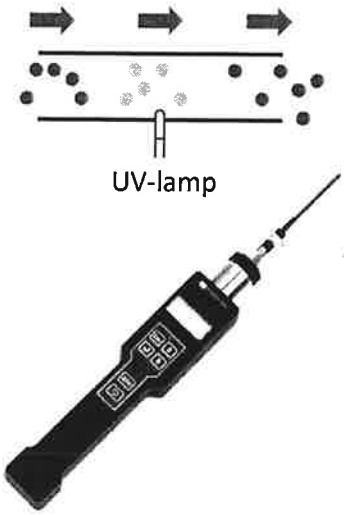
Unit of Measurement: $\mu g/m^3$, ppm

Note:
When HCHO concentration exceeds limit, collect continuous air samples using DNPH cartridges. The contents of the cartridge are extracted using organic solvent and the eluate is analysed by HPLC.

Source: Gastec

Chemical Parameters

Measurement Method for TVOC



Type: Real-time photoionisation detector

Measurement principle:
Measurement of ionisation potential of TVOC; the electric current produced by the positively charged TVOC is proportional to a concentration

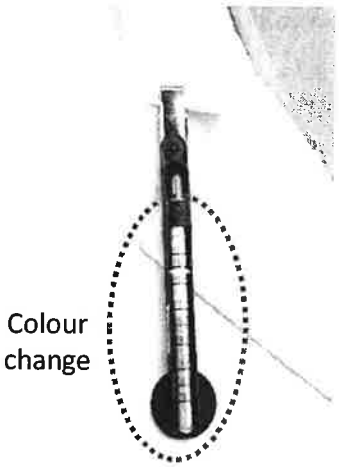
Measurement: ppb

Typical Characteristics:
- Fast response
- Some VOCs have no response (e.g. HCHO, CH_4)
- Cannot determine the exact proportion of different HC within the TVOC stream

Source: Ion Science

Chemical Parameters

Measurement Method for Nitrogen Dioxide NO_2



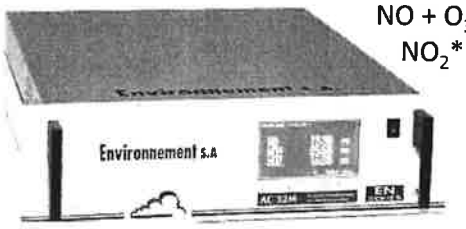
Type: Real-time chemiluminescence, diffusive tube passive samplers, chemical detector tubes

Measurement: µg/m³

Chemiluminescence Methodology Principle:

$NO + O_3 \rightarrow NO_2^* + O_2$

$NO_2^* \rightarrow NO_2 + hv$



Source: Draeger; Environnement S.A.

Chemical Parameters

Measurement Method for Ozone O_3





Type: Real-time chemiluminescence, chemical detector tubes

Measurement: ppm

Note:
Indoor O_3 concentrations are generally below the Permissible level.

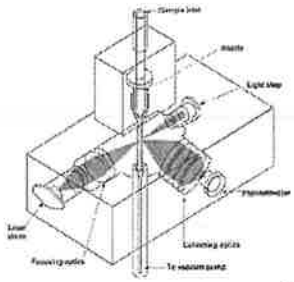
Elevated O_3 levels in the indoor environment can trigger indoor chemistry involving O_3 and VOC, resulting in oxidation products.

Source: Gastec; Aeroqual

Airborne Particles

Measurement Method for Respirable Suspended Particles

RSP





Type: *Real-time optical scattering, piezoelectric monitors

*Measurement principle:
Photometric

Unit of Measurement: $\mu g/m^3$

Typical Characteristics:
refer to comparison Tables 1 and 2

Source: TSI

Biological Parameters

Measurement Method for Total Viable Bacterial Count





Type: *Andersen single-stage impactor (N6)

Measurement method:
Active airborne microbial sampling with impactor, based on inertia impact principle

Bacteria to be cultured by Tryptone Soya Agar media

Speciation to be performed when a single species dominate from the culture plate

Unit of Measurement: cfu/m^3

Source: SKC; Thermo

Biological Parameters

Measurement Method for Total Viable Mound Count





Type: Andersen single-stage impactor (N6)

Measurement method:
Active airborne microbial sampling with impactor, based on inertia impact principle

Bacteria to be cultured by Malt Extract Agar media

Speciation to be performed when a single species dominate from the culture plate

Surface sample from growth area to be taken for Microscopic identification

Unit of Measurement: cfu/m^3

Source: SKC; Thermo

Radioactive Parameter

Measurement Method for Radon





Type: Electronic radon monitor

Measurement principle:
Measurement of electrostatic deposition of the radon decay product on the surface of the alpha-detector, and subsequent determination of radioactivity with alpha-spectroscopy

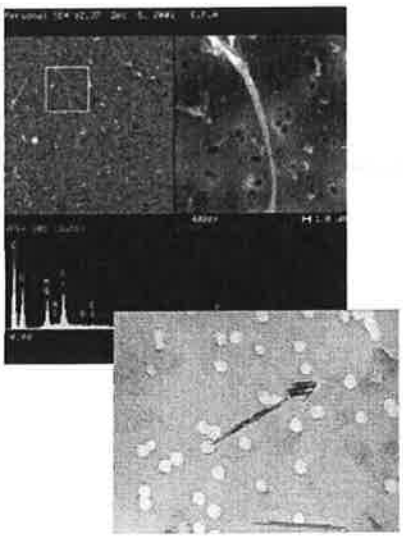
Measurement: Bq/m_3

Typical Characteristics:
- Provides near instantaneous results
- Equipment must be regularly calibrated
- Costly

Source: Radalink

Asbestos

Measurement Method



Type: Phase contrast microscopy, followed by SEM/TEM

Measurement principle:
Morphological identification of asbestos fibres

Measurement: fibre/cc

Note:
Energy-Dispersive X-Ray spectroscopy could be performed to identify the elemental composition of the fibres.

Asbestos can normally be identified by their fibrous morphological structure and theelemental composition of O, Si, Al and Mg.

Source: RTI

The End