BCA ACADEMY

Indoor Air Quality Management for Buildings

School of Graduate Development and Management

The Education and Research arm of the Building and Construction Authority

Indoor Air Quality Management for Buildings

Objective

The course will equip the participants with the knowledge of causes and mitigations of Indoor Air Quality (IAQ) issues, conduct of an IAQ investigation and procedures to execute appropriate remediation measures. This course will cover IAQ management for non-residential buildings where air conditioning is commonly used. It will emphasis on the air quality control in air conditioning & mechanical ventilation system for tropical climate. The participants will also be introduced to the SS 554 standards in indoor air quality for air conditioned buildings.

Award of Certificate

This course is assessment-based. To pass the course, a participant has to fulfil these requirements:

i. Achieved at least 75% class attendance; and
ii. Pass all the assessment(s) of the course.

A Certificate of Successful Completion (CSC) for the course will be issued to participants who have fulfilled the attendance and assessment requirements.

Indoor Air Quality Management for Buildings

Day 1 (8 May 2017)			
No	**Time**	**Lesson**	**Lecturer**
1.0	**9.00am – 10.00am**	**IAQ Parameters and Measurements for buildings** • Types of IAQ Parameters: - Thermal Comfort parameters - Chemical parameters - Biological parameters	Prof Tham Kwok Wai
	10.00am – 10.30am	**Tea Break**	
2.0	**10.30pm – 12.30pm**	**IAQ Parameters and Measurements for buildings (cont'd)** • Measurement and Verification requirements for IAQ	Prof Tham Kwok Wai
	12.30pm – 1.30pm	**Lunch**	
3.0	**1.30pm – 3.00pm**	**IAQ consideration in design, construction, renovation and commissioning works for building** • Design & construction for IAQ • 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
	3.00pm - 3.30pm	**Tea Break**	
4.0	**3.30pm – 5.00pm**	**IAQ Audit for Buildings** • IAQ audit methodology • IAQ audit procedures	Prof Tham Kwok Wai

Day 2 (9 May 2017)			
5.0	**9.00am – 10.30am**	**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
	10.30am – 11.00	**Tea Break**	
6.0	**11.00am – 12.00am**	**Air-Conditioning & Mechanical Ventilation (ACMV) for Good IAQ** • Inspection of ACMV System - Air quality - Air flow - Temperature & humidity level	Dr Ang Keng Been
	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

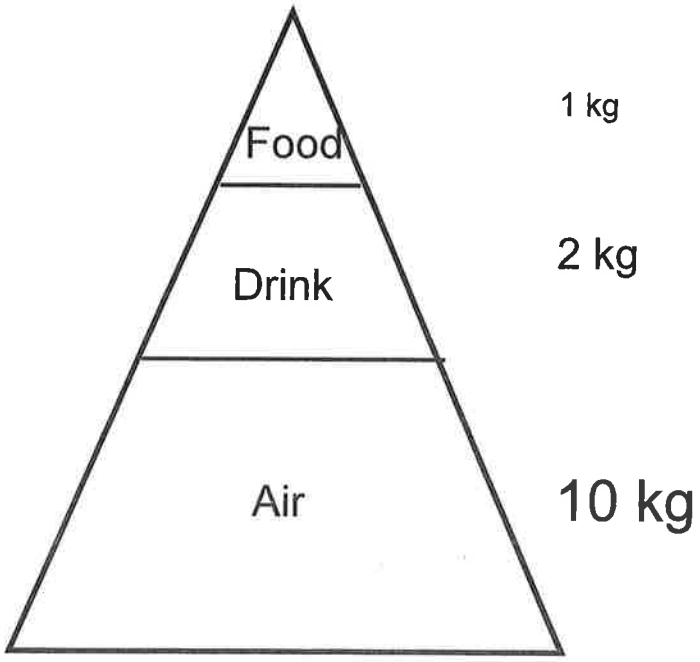
Update: 3/2/2017

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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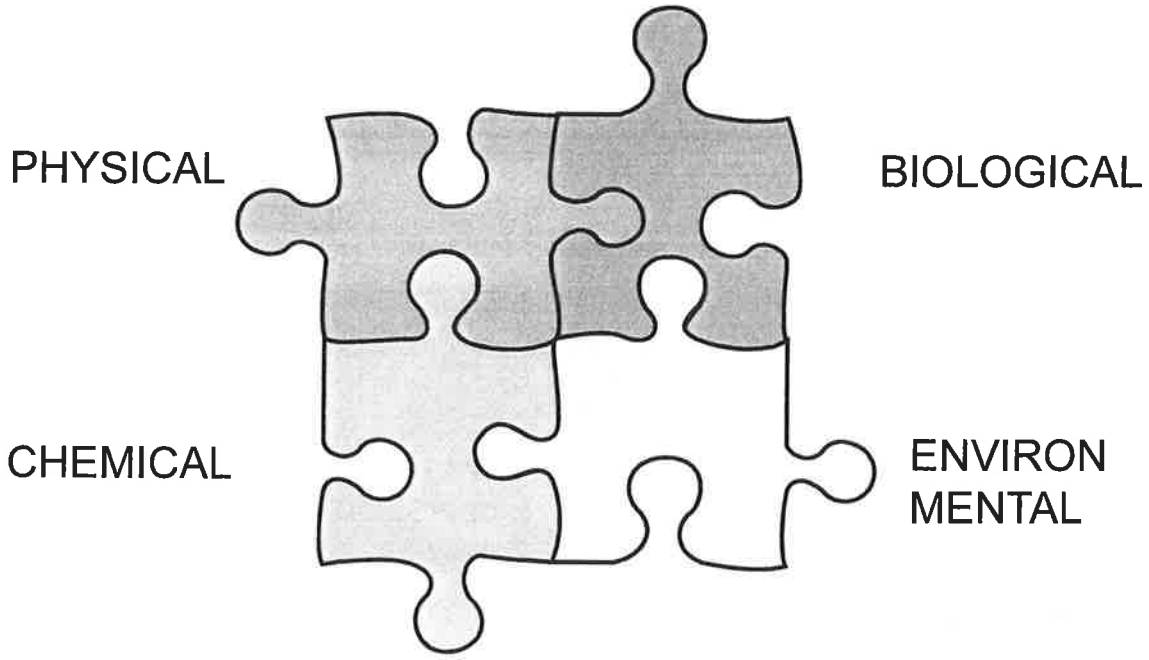
Building and Construction Authority

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.



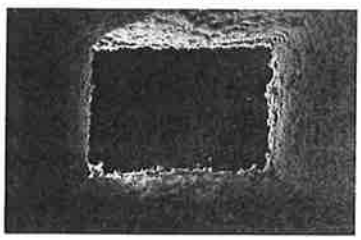
What is IAQ ?



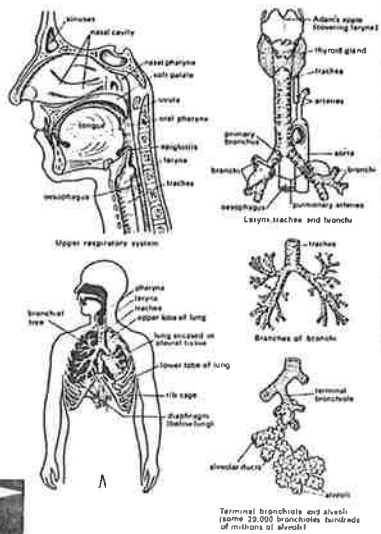
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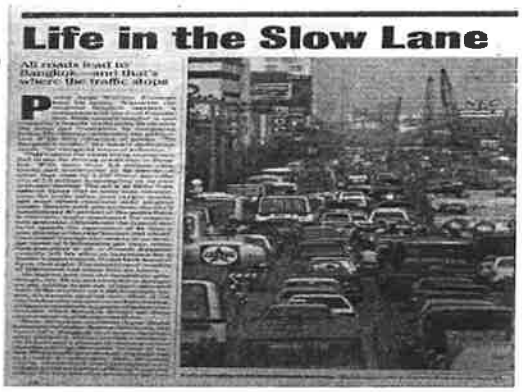
What is IAQ ? - PHYSICAL

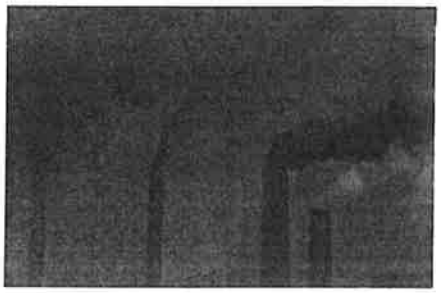






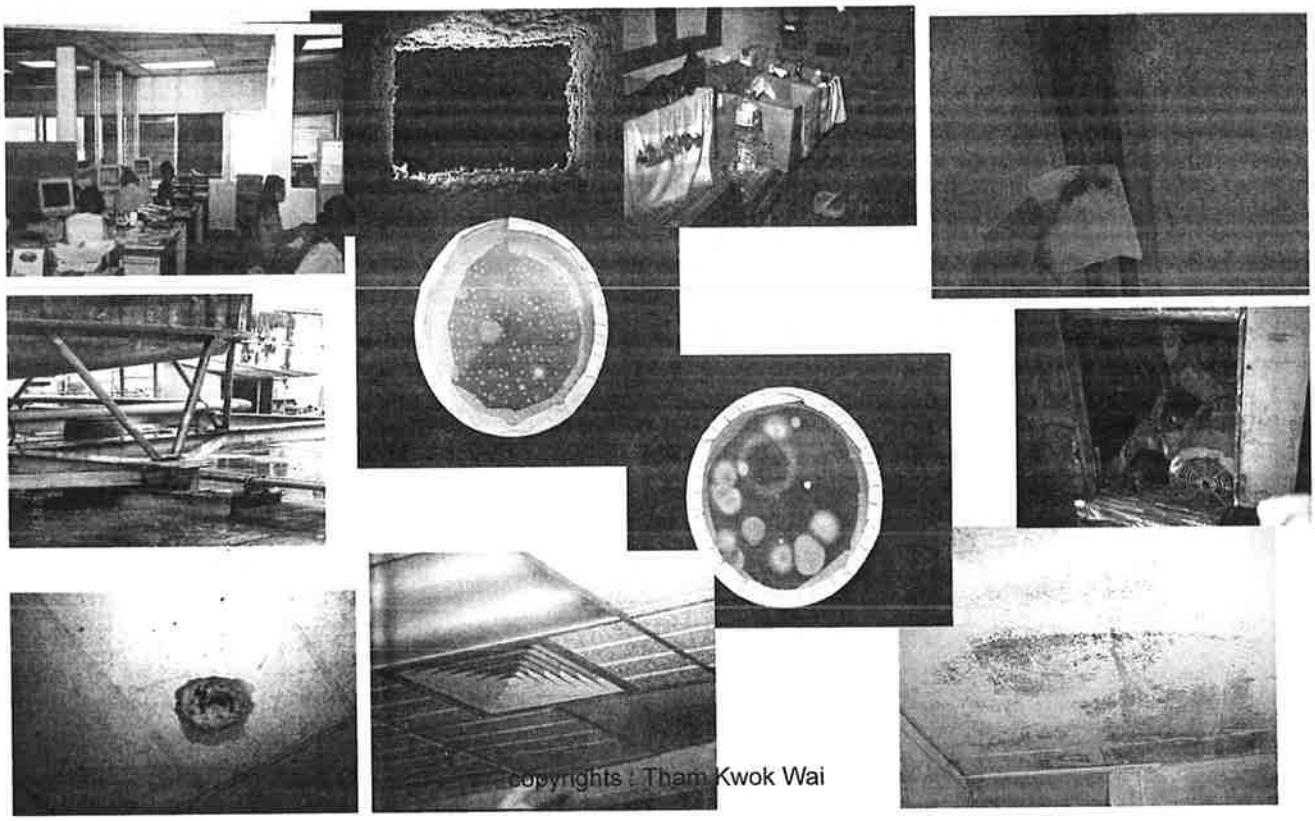




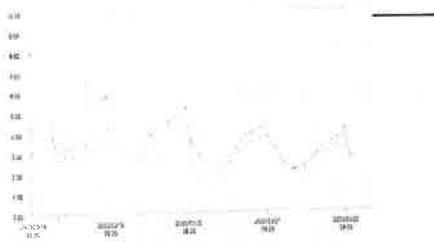


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What is IAQ ? - BIOLOGICAL



What is IAQ ? - CHEMICAL

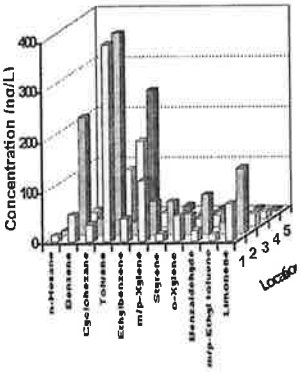




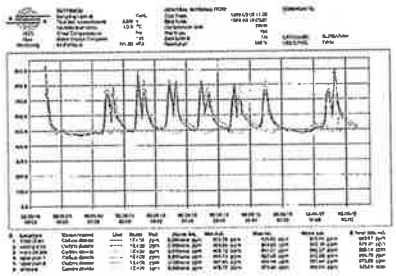








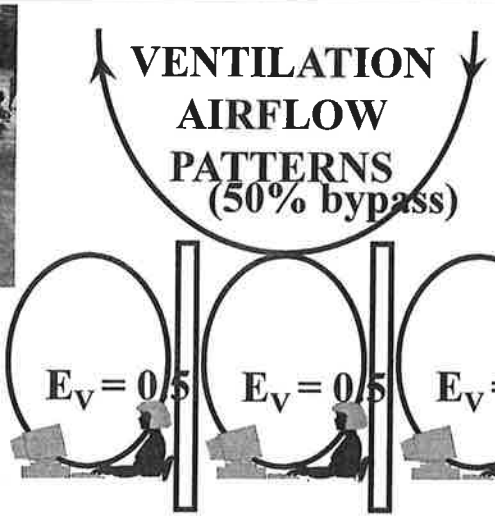




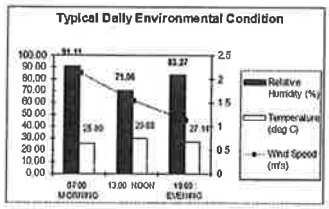
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What is IAQ ? - ENVIRONMENTAL



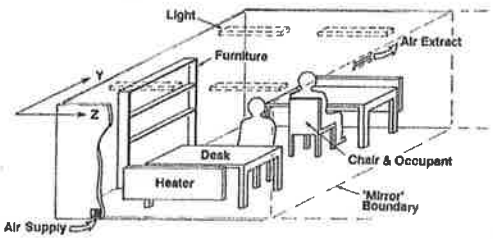




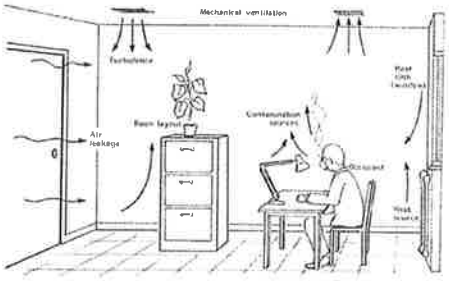




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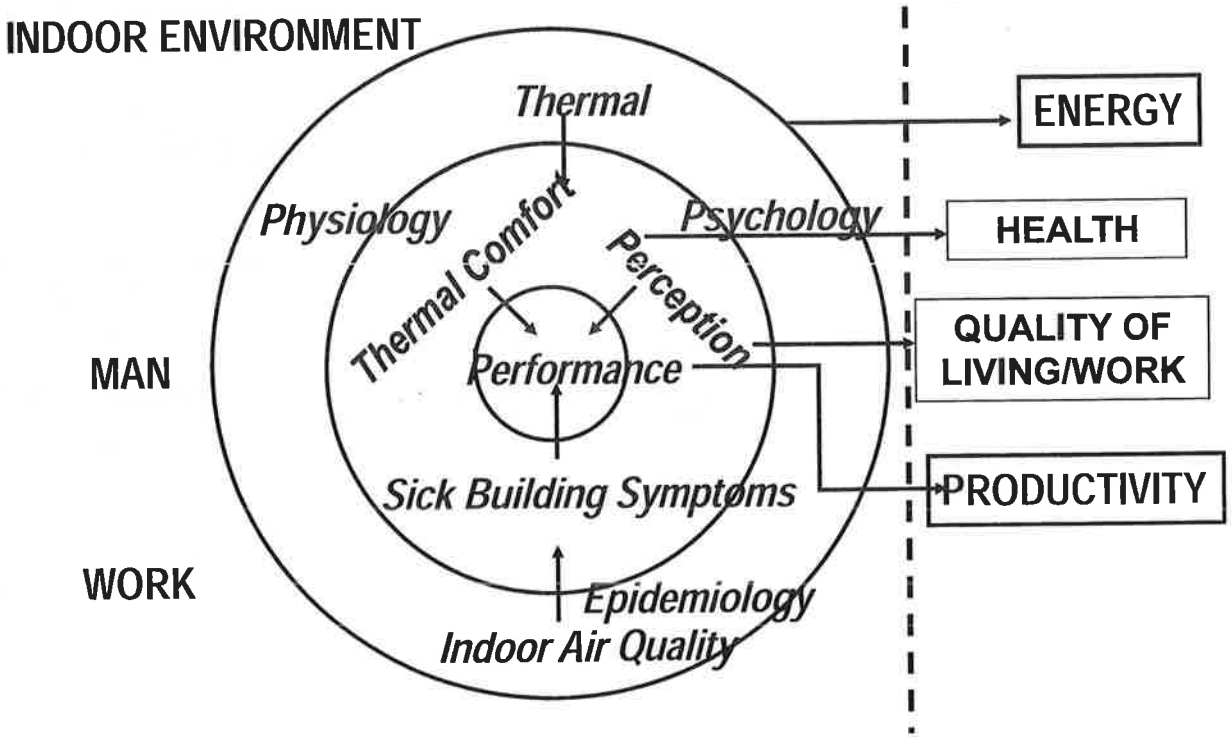
Challenges in the indoor environment

- 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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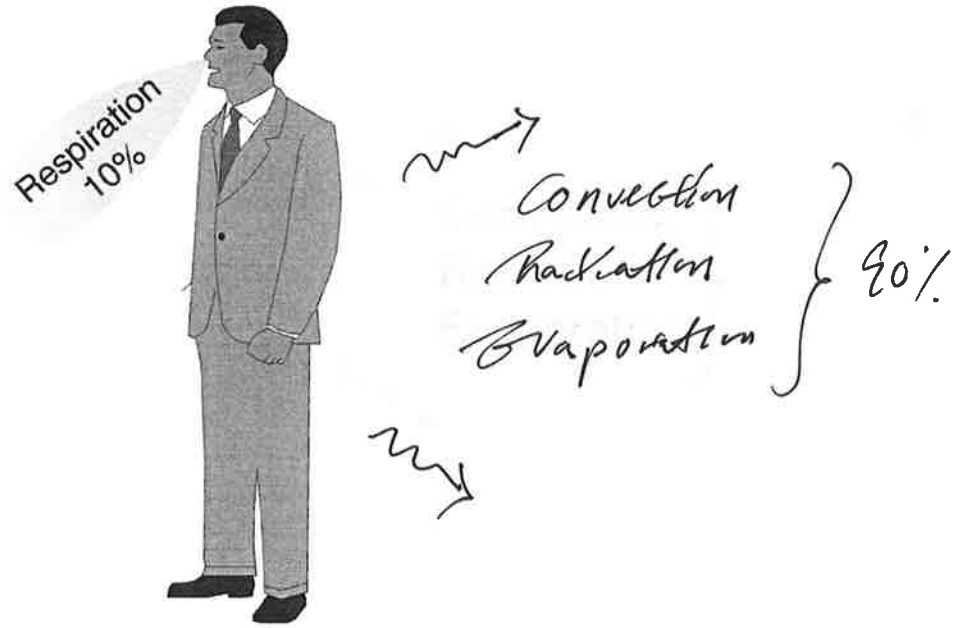
Why IAQ ?



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Thermal Comfort Parameters

Thermal balance



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Thermal balance

warmth or cold -comfort/discomfort sensed by skin

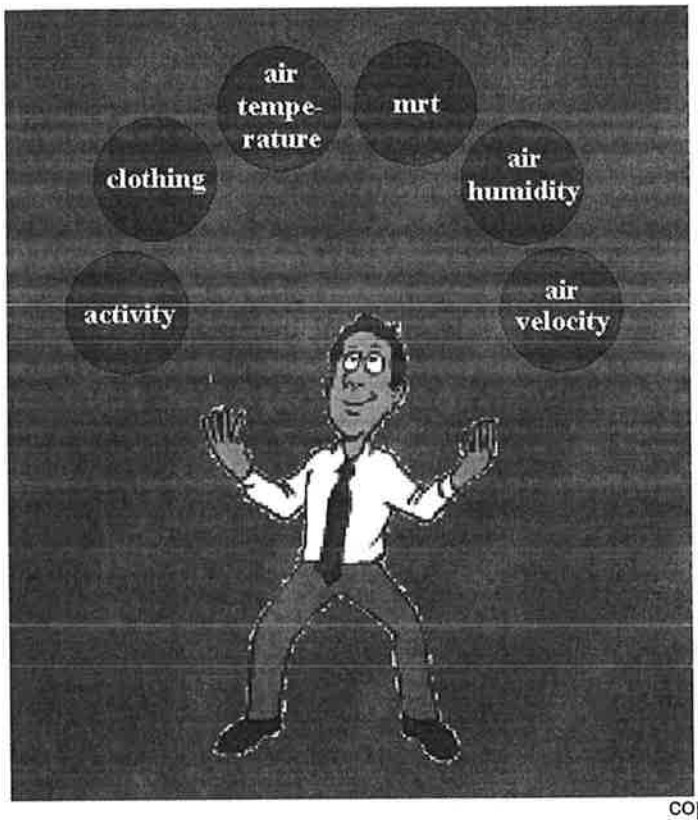
skin temp. range between 31⁰ C and 34⁰ C (averaged for the whole body surface) is the thermal comfort region

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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MRT – MEAN RADIANT TEMP

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

Heat Stroke

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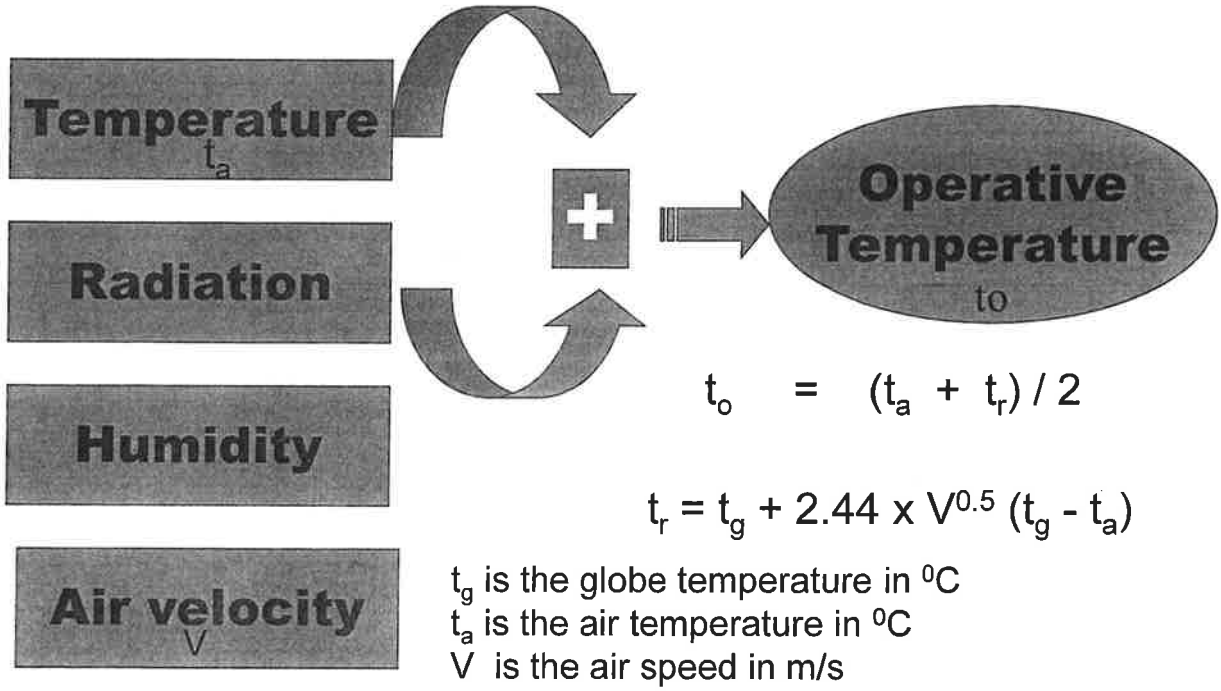
Thermal Comfort

Absence of irritation/discomfort due to heat or cold

A state of pleasantness

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Factors affecting Thermal Comfort (PHYSICAL FACTORS)



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

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

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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Factors affecting Thermal Comfort (Personal)

Metabolic rate (activity)



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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Thermal Comfort parameters

	SS CP 554 (2016)
Air temperature	23-25 °C
RH	• <65% (new building) • <70% (existing building during peak & common part-load conditions)
Air velocity	< 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

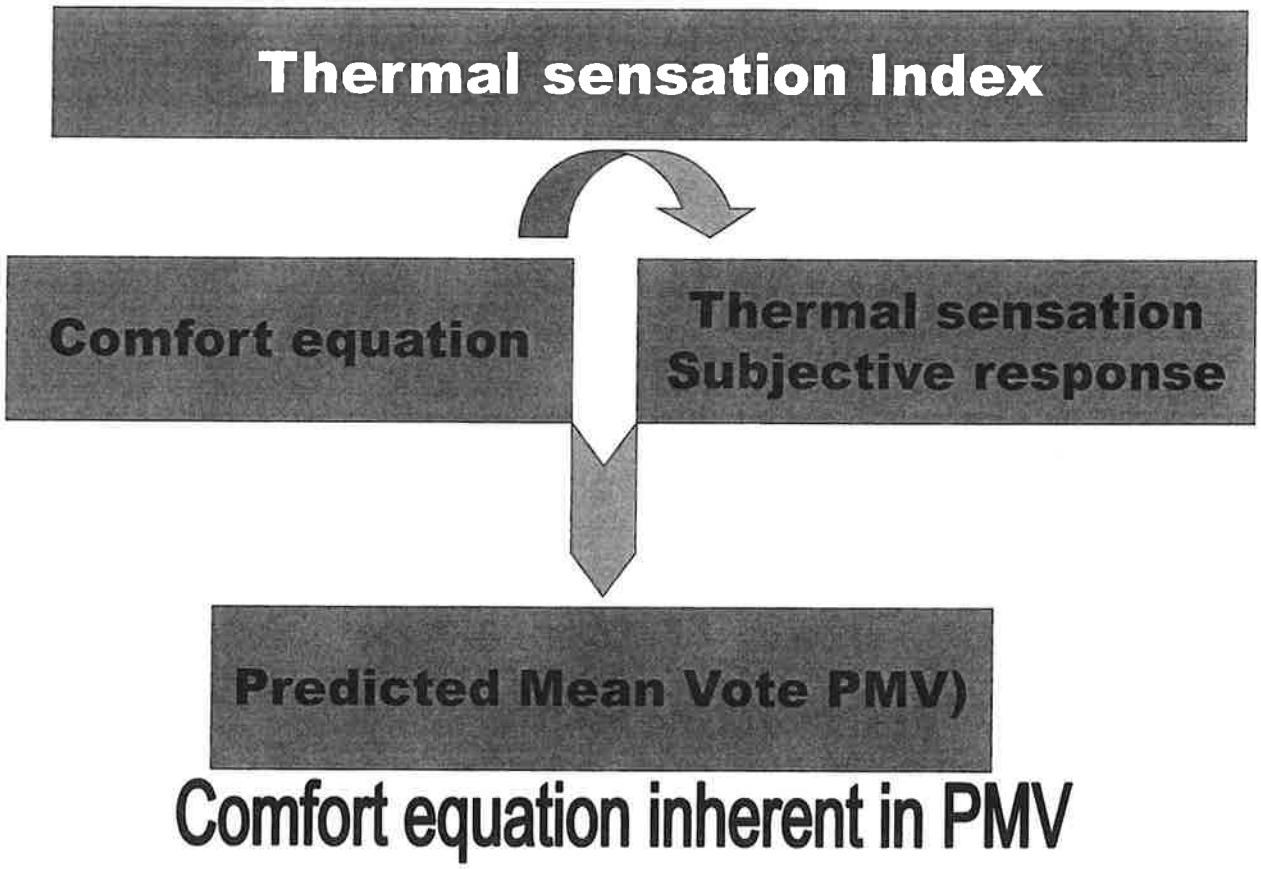
PMV Model of thermal comfort

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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

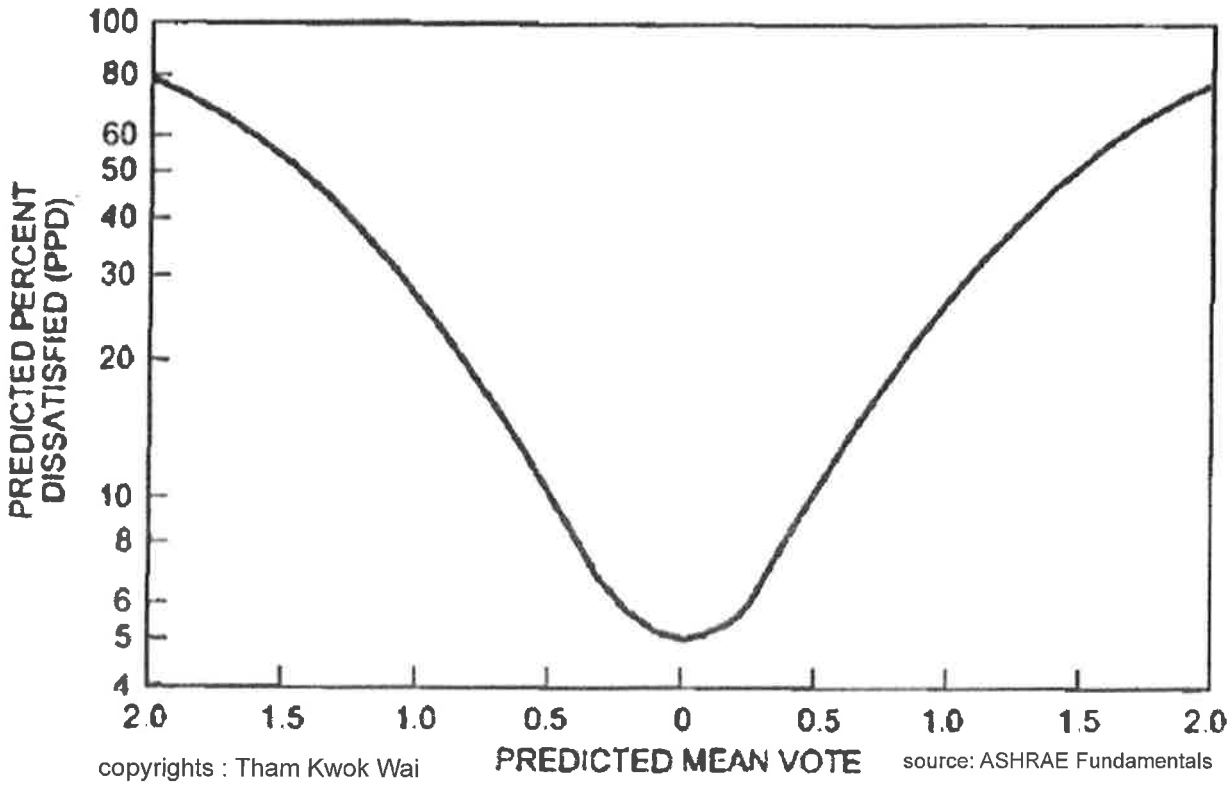
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Comfort equation inherent in PMV

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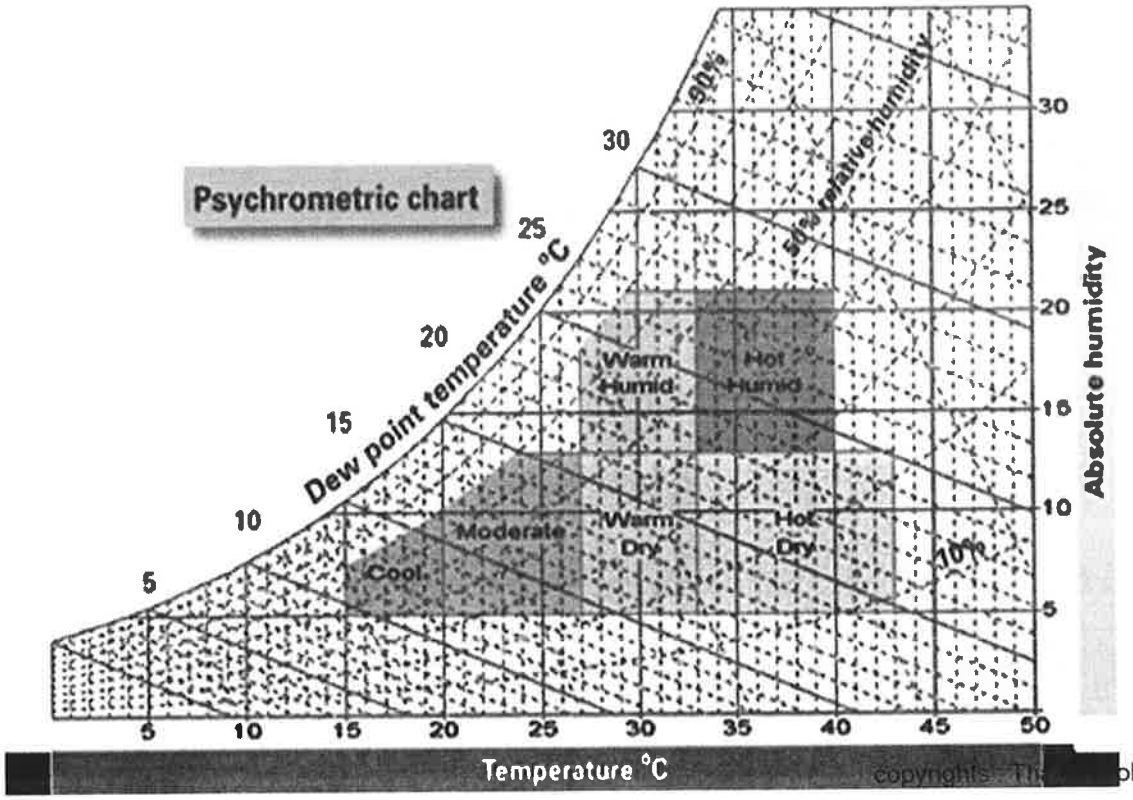
PMV vs PPD



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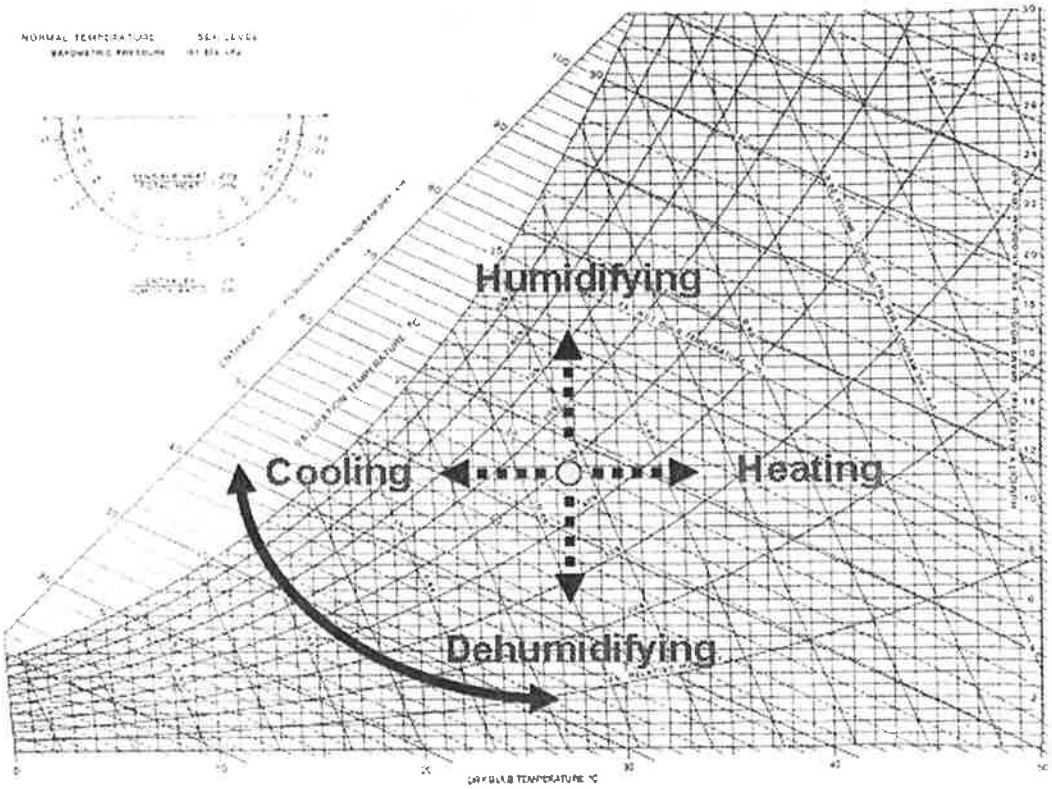
source: ASHRAE Fundamentals

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

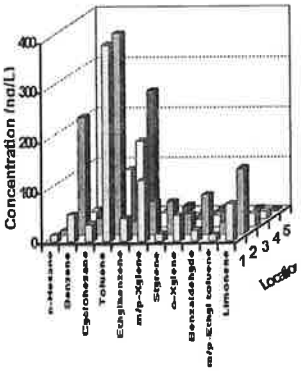




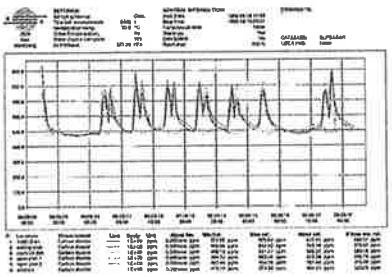












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SS 554 : ~~2009~~ 2016

Chemical parameters

		SS CP 554 (2016)
	CO_2	700 above ambient (8 hr)
Readily evaporate →	TVOC	~~3000~~ 1000 ppb
	CO	31 ppm (1 hr)
		9 ppm (8 hr)
Formaldehyde →	HCHO	0.08 ppm / 100 μg/m^3 (30 mins)

0.1 → 0.08

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Some causes of chemical related problems

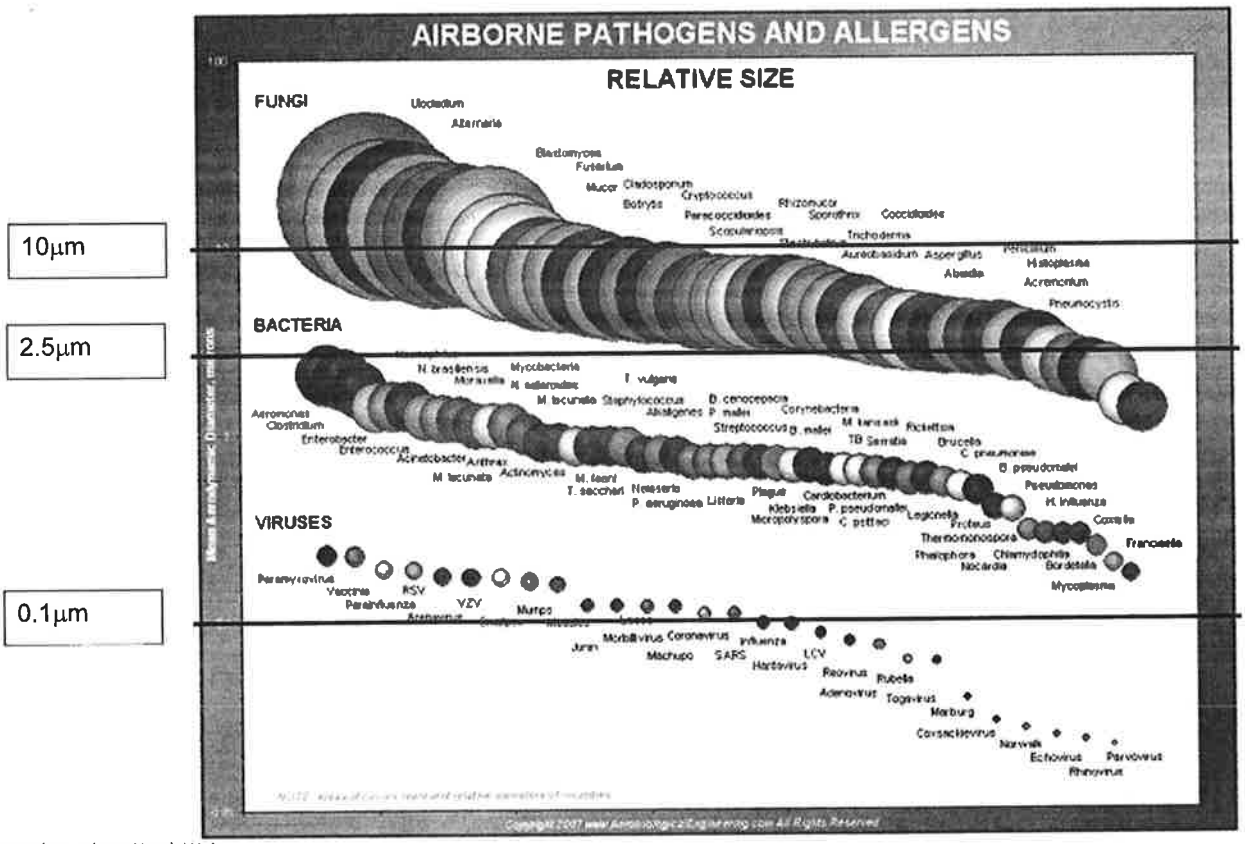
- Outdoor sources
  - Traffic
  - Industrial or other pollution sources
- Emissions from non green materials
  - Paints
  - Carpets
  - Fabric
  - furniture
- Polluting activities / equipment
  - Photocopiers / printers
  - Paper and stationery
- Poor air distribution
  - Inadequate ventilation in some 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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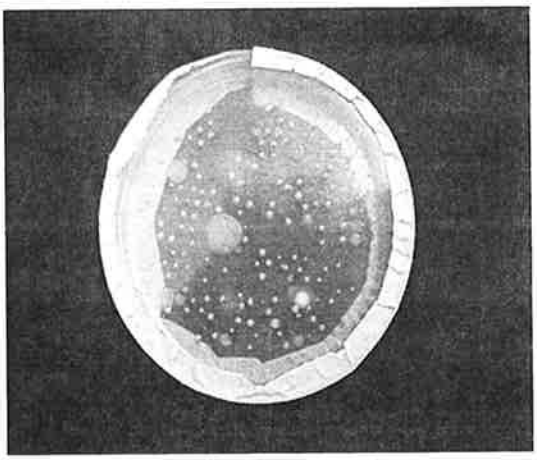
SS 554 : 2009

Biological parameters

SS CP 554 (2016)

Total Viable Bacteria Count

1000 cfu / m^3



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Some causes of Biological related problems

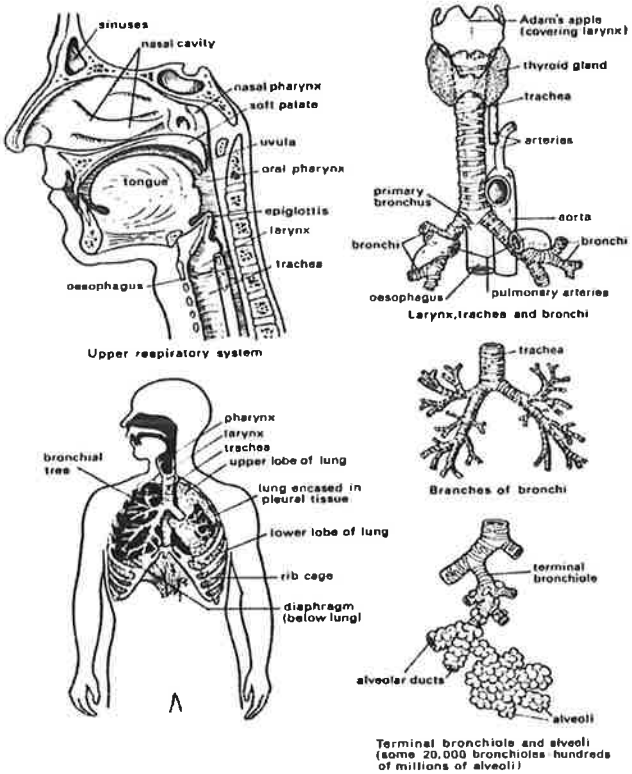
- Human density not matched with sufficient ventilation
- Outdoor sources
  - Fungi
  - Food exhaust
  - Cooling towers (Legionnaires Disease)
- Inadequate Maintenance / cleaning
  - Accumulation on filters
  - Office cleanliness
- Occupant activities
  - Food
  - Waste
- Dampness
  - Inadequate humidity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

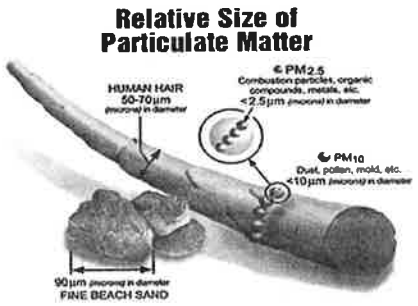
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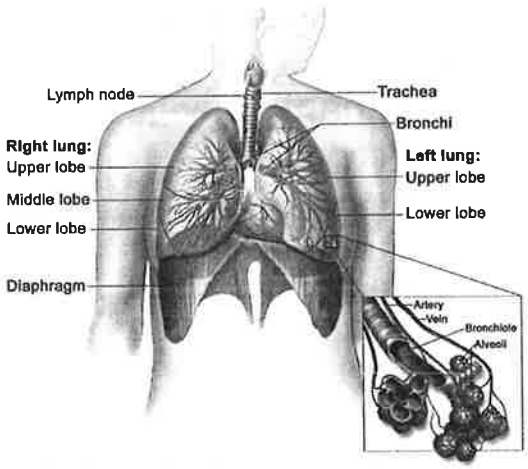
Dust Parameters

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Exposure to Particles







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SS 554 : 2009

Dust parameters

	SS CP 554 (2016)
Respirable Suspended Particles	50 µg / m^3 (24 hr)
$PM_{2.5}$	37.5 µg / m^3 (24 hr)

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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

copyrights : Tham Kwok Wai

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





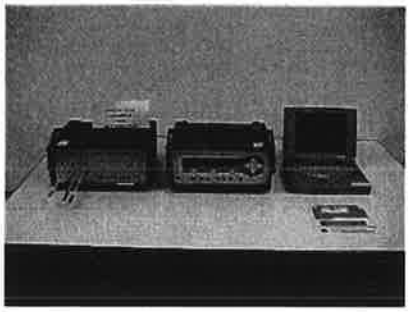






Continuous Monitoring

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









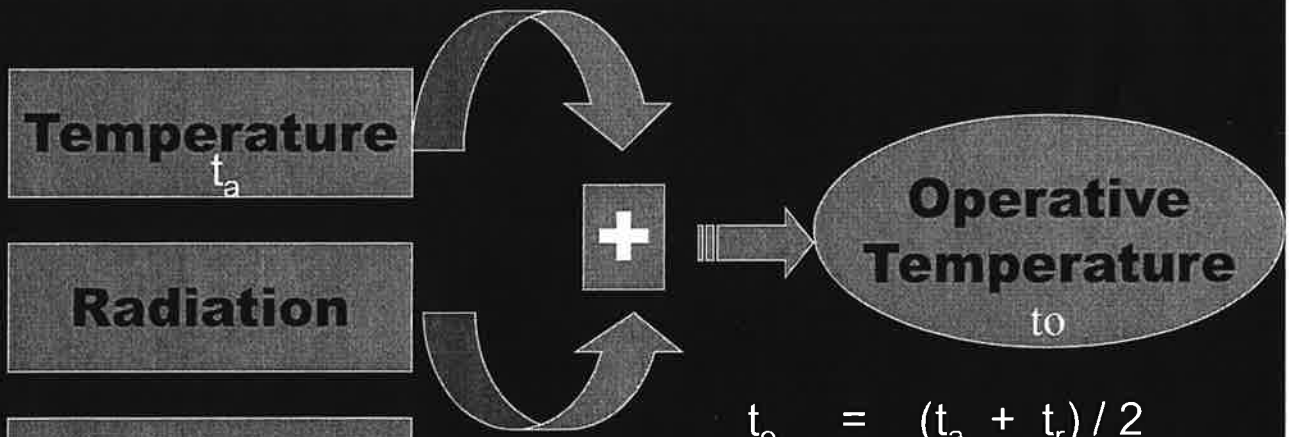
Thermal Comfort Parameters

Thermal Comfort parameters

	SS CP 554 (2016)
Air temperature	Air temperature – thermistor
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)



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

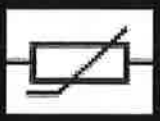
$$t_r = t_g + 2.44 \times V^{0.5} (t_g - t_a)$$

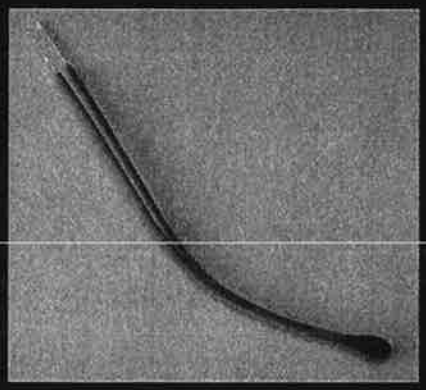
t_g is the globe temperature in ^{0}C
t_a is the air temperature in ^{0}C
V is the air speed in m/s

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Thermistor

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





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

copyrights : Tham Kwok Wai

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

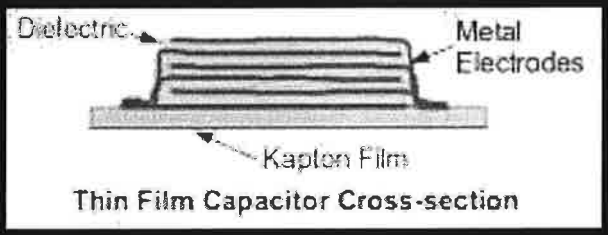
- Hot wire anemometer
- Electrically heated fine wire at controlled current
- Air moving past heated wire cools it
- Electrical resistance of wire dependent on temperature
- Thus relationship exisit between resistance of wire and air speed



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Relative Humidity

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





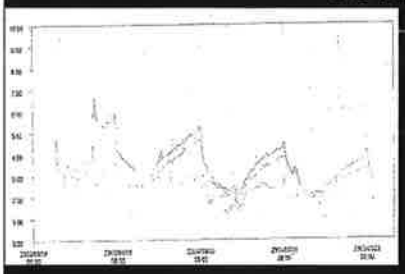
- Sling Psychrometer
  - Dry and wet bulbs
  - Evaporation cools wet bulb
  - Temperature difference correlates to the relative humidity



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Chemical Parameters

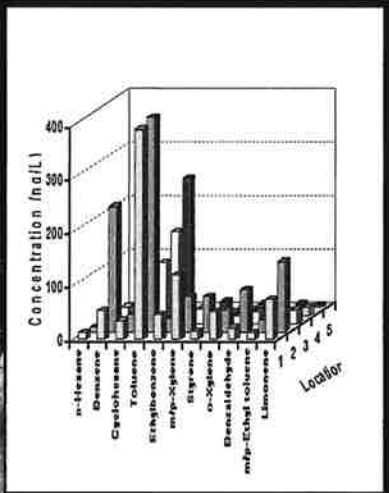
What is IAQ ? - CHEMICAL





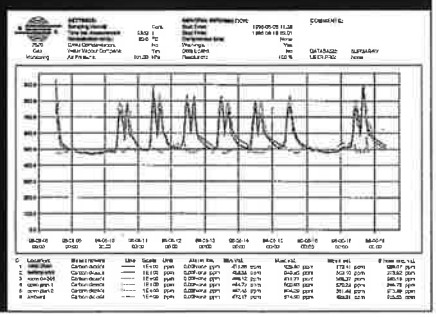












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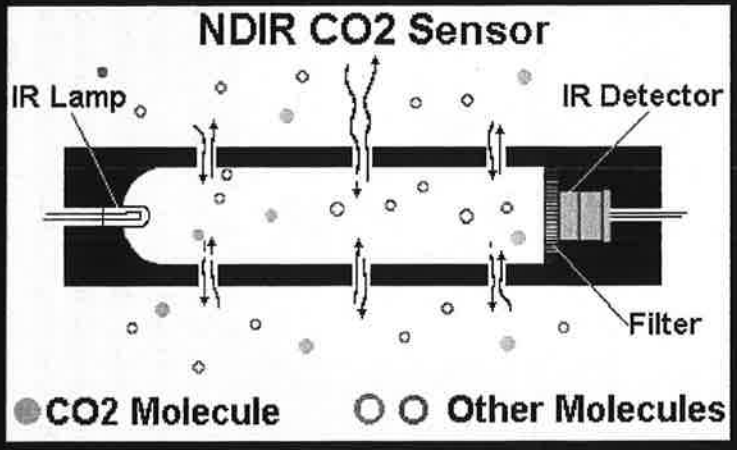
Chemical parameters

	SS CP 554 (2016)
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

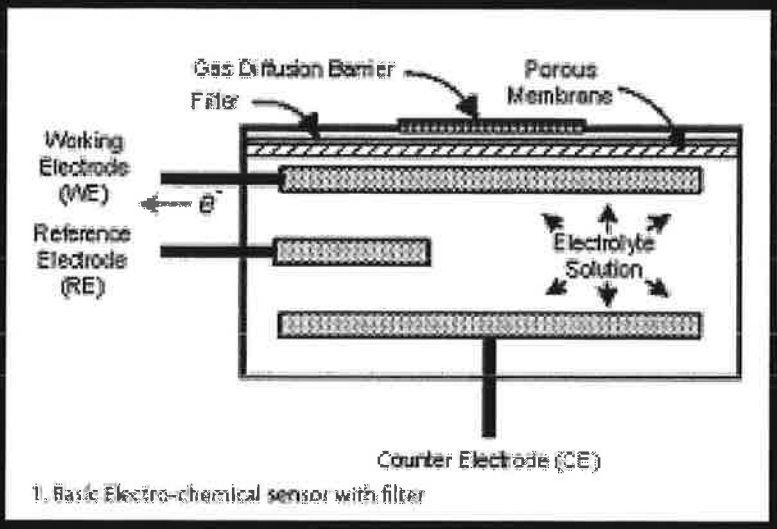
- measures carbon dioxide concentration by relying on one of the natural properties of CO2 molecules: CO2 molecules absorb light at a specific wavelength of 4.26 µm. This wavelength is in the infrared (IR) range. High concentrations of CO2 molecules absorb more light than low concentrations. This technique 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

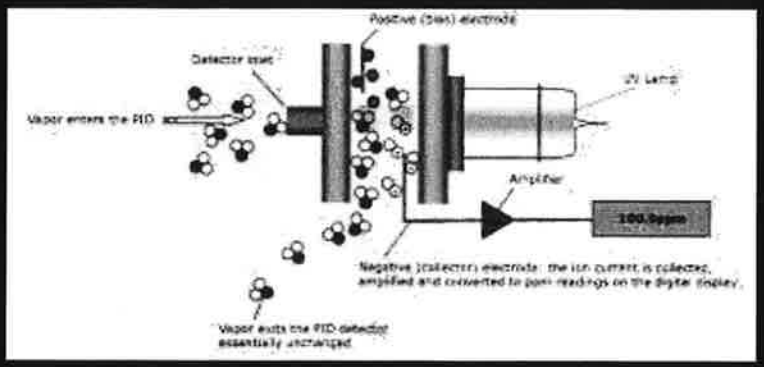


1. Basic Electro-chemical sensor with filter

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Photo ionization detector

- 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:

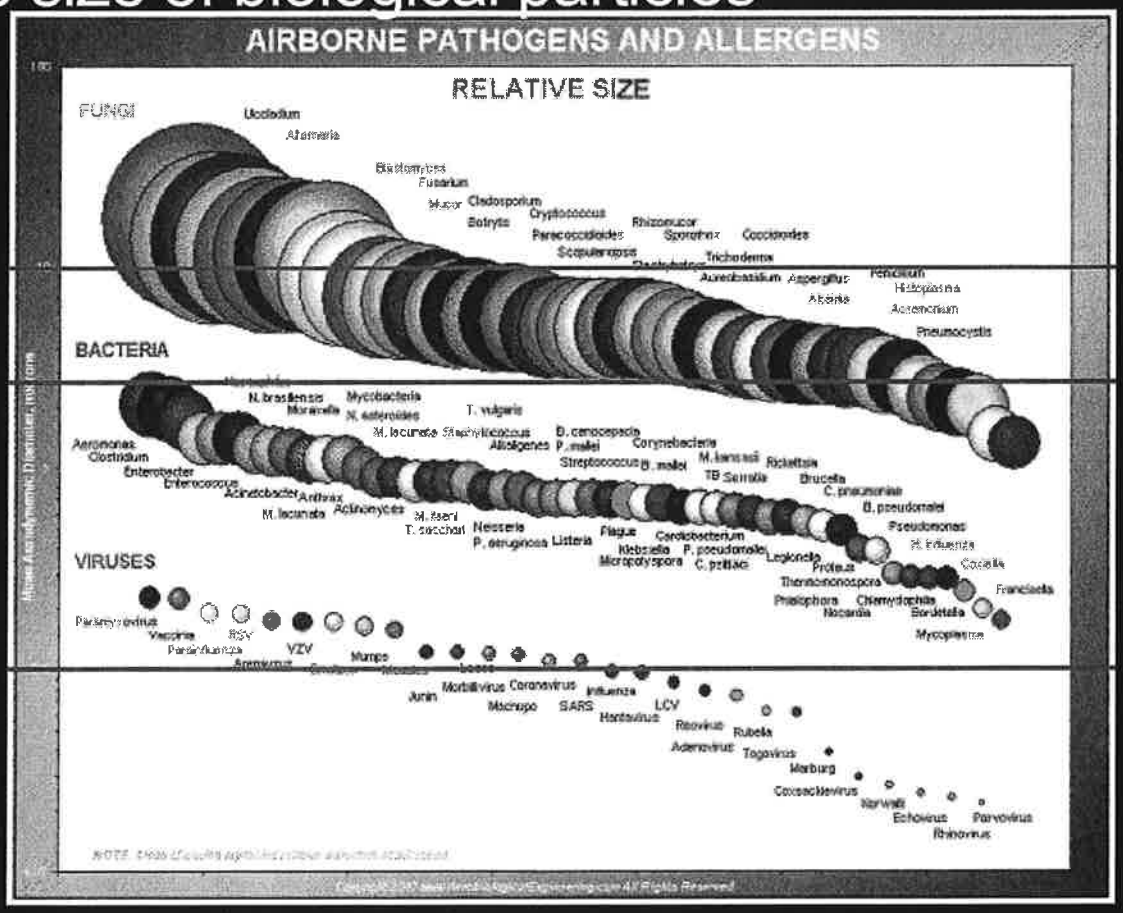
I = the intensity of light striking the detector
I_0 = the measured signal with 0 ppm CO_2
k = a system dependent constant
P = the concentration of CO_2

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 : 2016

Biological parameters

	SS CP 554 (2016)
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.

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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

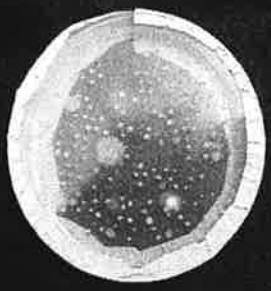
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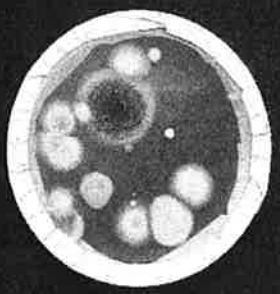
Other Microbial Air Samplers





Colonies of bacteria after incubation



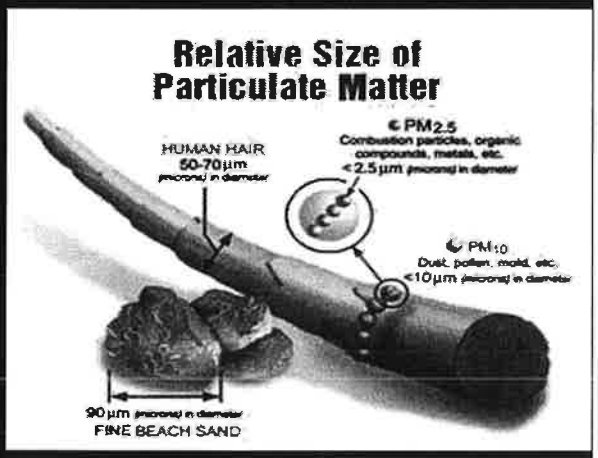


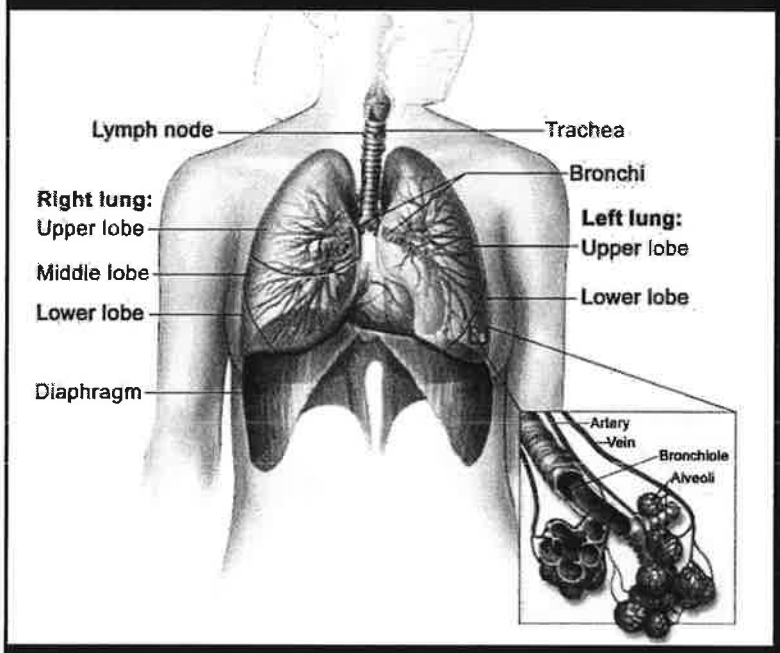
Colonies of molds after incubation

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Dust Parameters

Exposure to Particles





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SS 554 : 2016

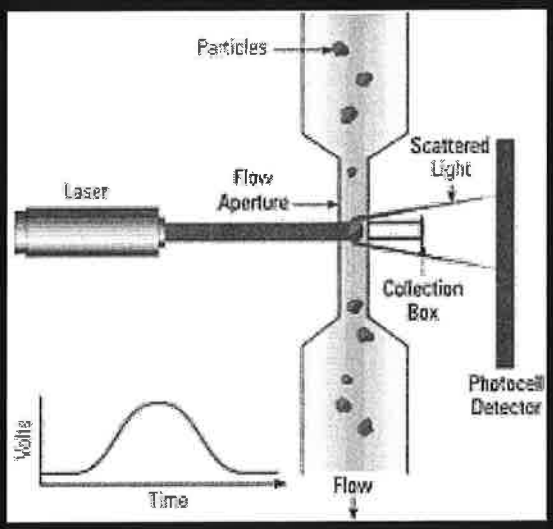
Dust parameters

	SS CP 554 (2016)
Respirable Suspended Particles	By real-time optical scattering or piezoelectric monitors or equivalent method

copyrights : Tham Kwok Wai

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

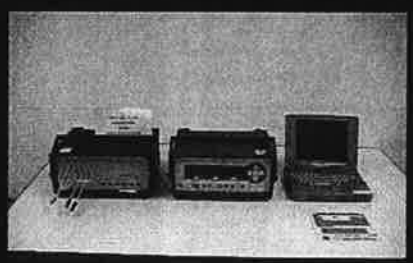
Parameter	Acceptable limit	Unit	Measurement method / Analytical method
PM 2.5	35	$\mu g/m^3$	By real-time piezoelectric monitors or optical scattering or equivalent method
Ultra-fine particles	Not applicable	particles / cm^3	By a nuclei condensation counter or equivalent method. Note - This measurement 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

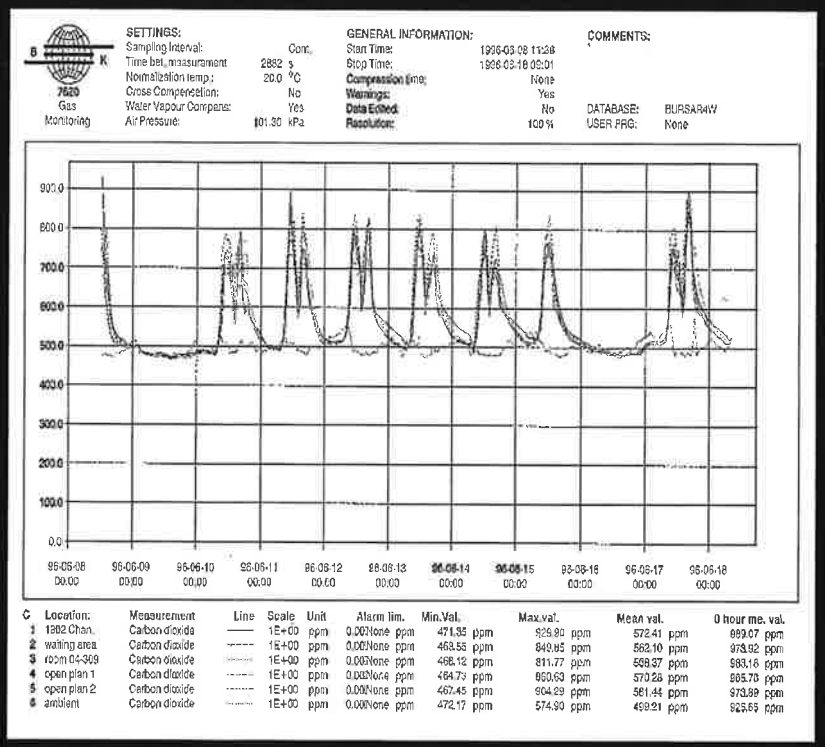
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Source : SS 554 : 2009

Continuous Measurements And Air Change Rate

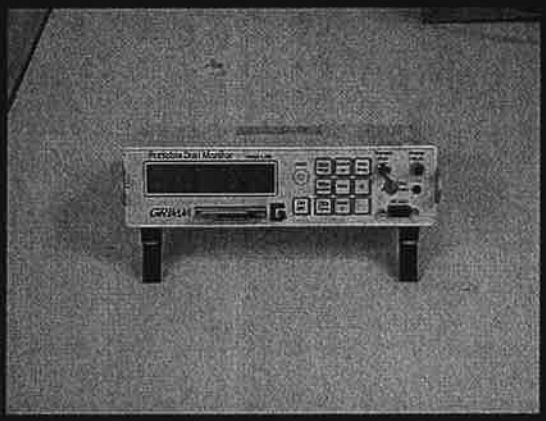
Continuous chemical sampling

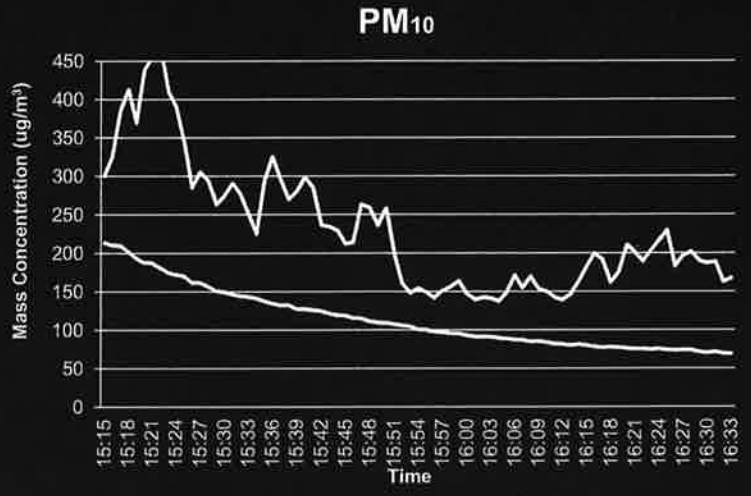




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Dust sampling





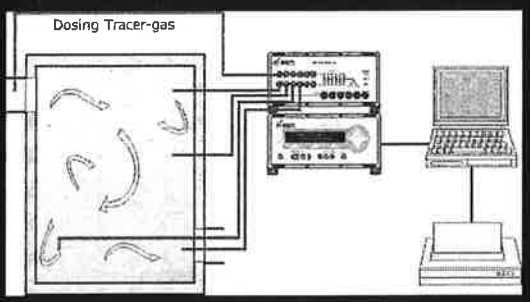
Outdoor

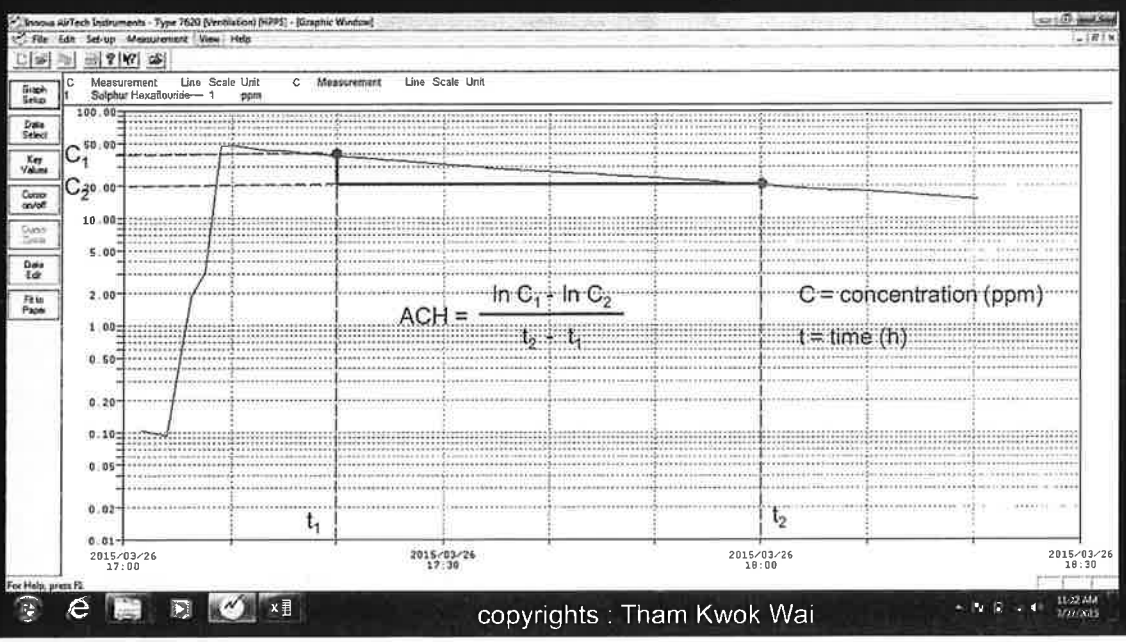
Indoor

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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?					



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

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)

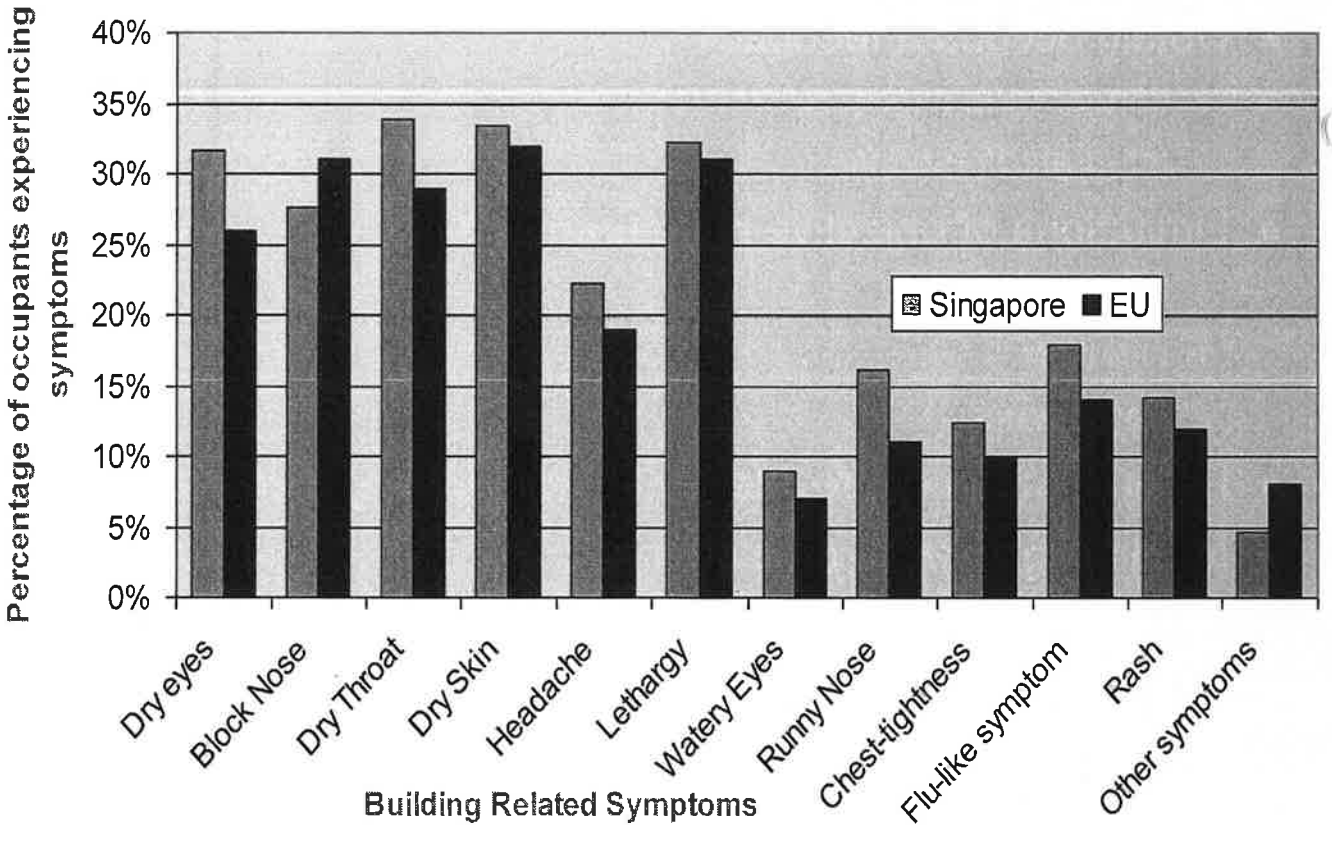
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Components of Survey

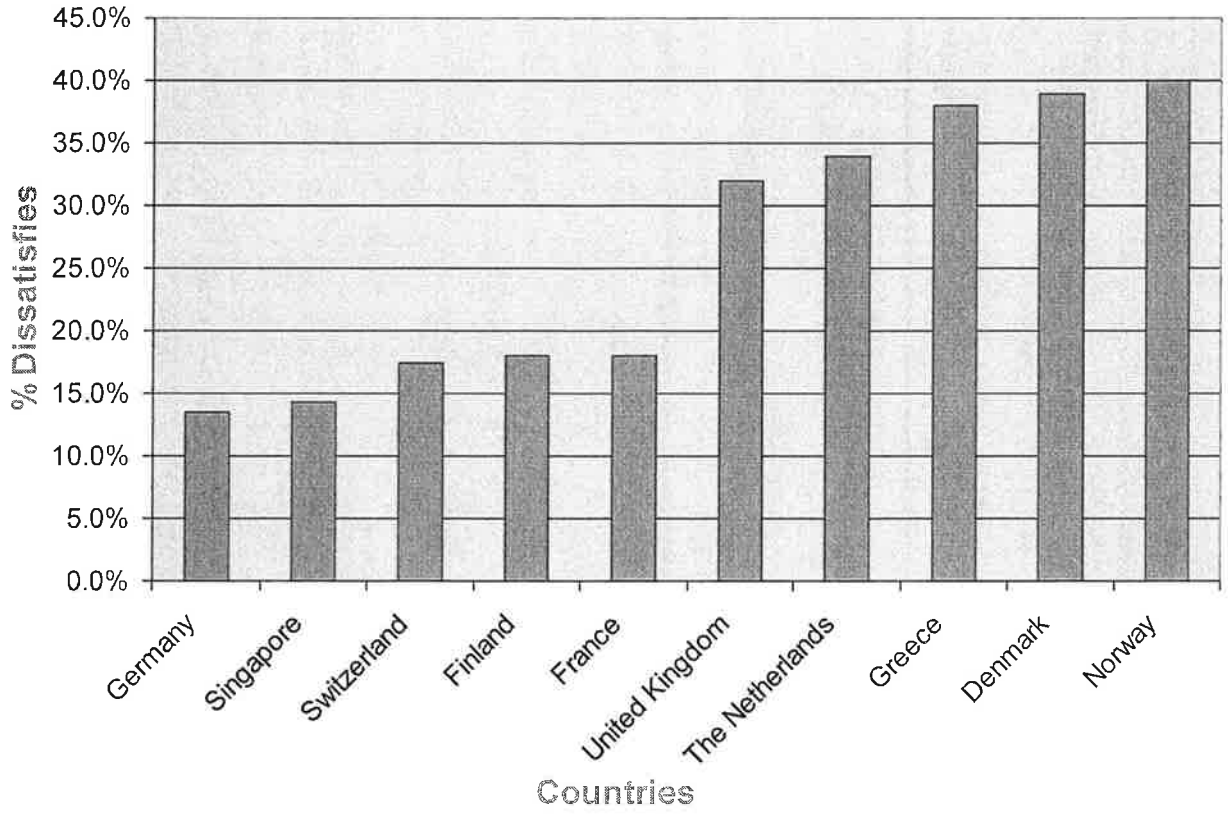
- Personal information
- Environmental conditions
- Nature of occupation
- Health complaints

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Building Related Symptoms - A comparison of Singapore and EU studies



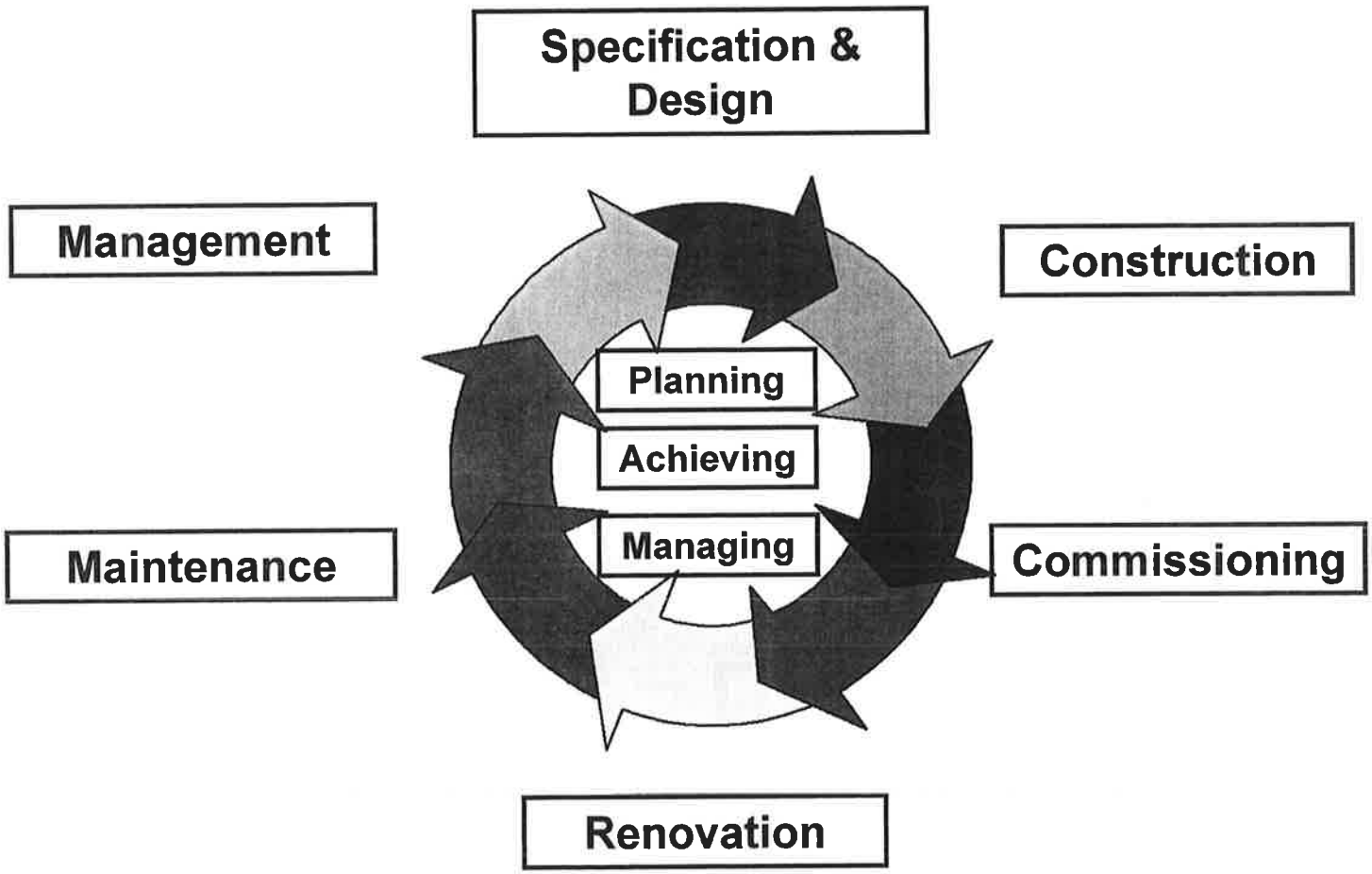
Acceptability of Indoor Air Quality (% Dissatisfied) - A Comparison of Singapore and EU studies



THANK YOU

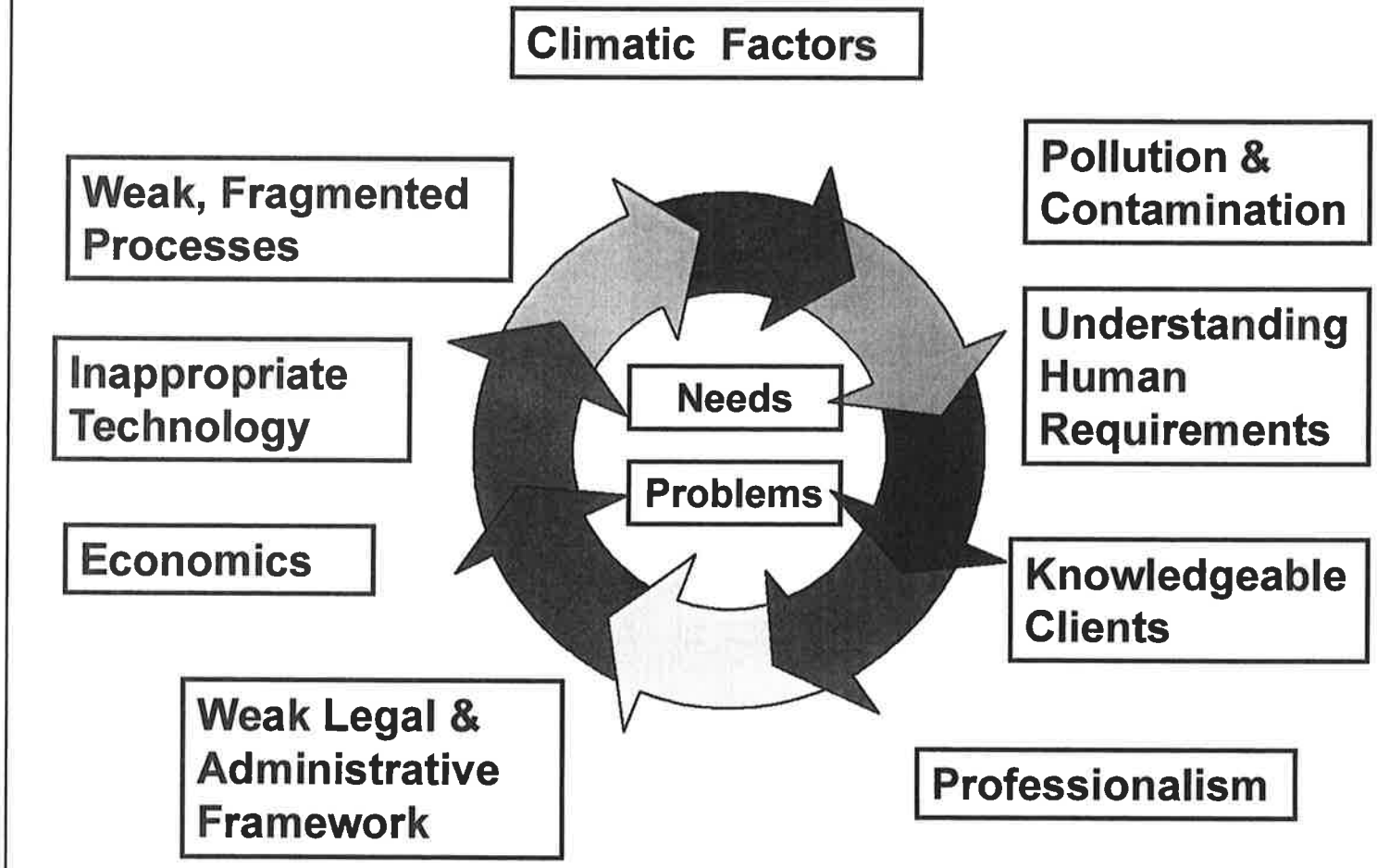
IAQ Considerations for Buildings – Design and Construction

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

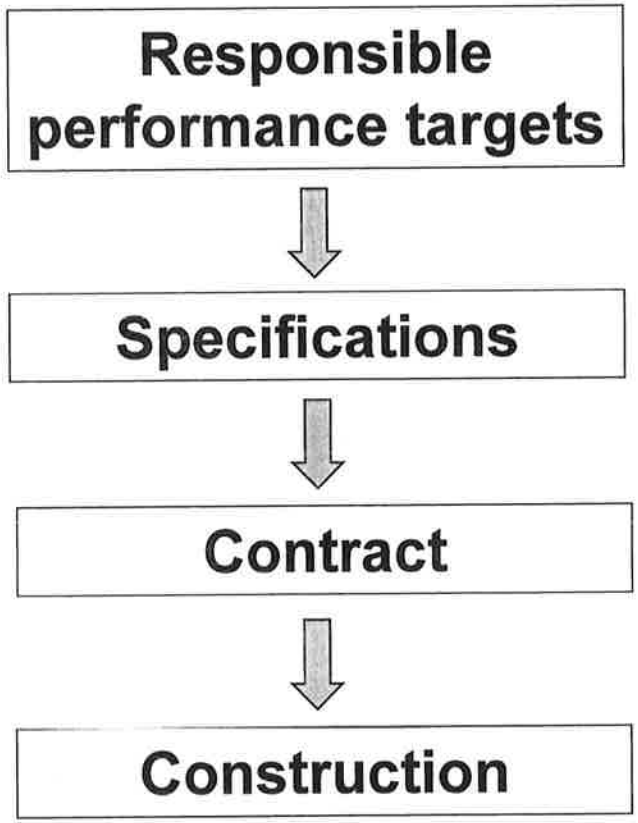
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Design & Construction

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

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Design & Construction



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Design & 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

- 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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THANK YOU

Performance Criteria and Values

STANDARDS COUNCIL

SS 554 : 2016
(ICS 13.040.20; 91.040.01)

Code of practice for indoor air quality for air-conditioned buildings

Complimentary

Published by SPRING

Parameter	Acceptable limit	Unit	Measurement method / Analytical method[1)]
i. Thermal comfort parameters			
Air temperature[2)]	23 to 26	°C	Air temperature – by hot wire, thermistor or thermometer sling method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the Predicted mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices and local thermal comfort criteria
Relative humidity	< 65 (for new buildings) < 70 (for existing buildings) (under peak and common part load conditions)	%	By thin film capacitor, hygrometer or thermometer sling method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
Air movement [3)]	< 0.30	m/s	By hot wire method for linear air velocity or Kata thermometer for omni-directional air velocity method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
ii. Chemical parameters			
Carbon dioxide	700 above outdoor (8-hour)	ppm	By real-time non-dispersive infra-red sensor method ISO 12039: Stationary source emissions - Determination of carbon monoxide, carbon dioxide and oxygen - Performance characteristics and calibration of automated measuring systems; or EPA IP-3A: Determination of Carbon Dioxide in Indoor Air Using Non-dispersive Infra-red (NDIR).
Carbon monoxide	31 (1-hr) 9 (8-hr)	ppm	By real-time electrochemical sensor method EPA IP-3C: Determination of Carbon Monoxide in Indoor Air Using Electrochemical Oxidation

copyrights : Tham Kwok Wai

Source : SS 554

Performance Criteria and Values

ii. Chemical parameters			
Carbon dioxide	700 above outdoor (8-hour)	ppm	By real-time non-dispersive infra-red sensor method ISO 12039: Stationary source emissions - Determination of carbon monoxide, carbon dioxide and oxygen - Performance characteristics and calibration of automated measuring systems; or EPA IP-3A: Determination of Carbon Dioxide in Indoor Air Using Non-dispersive Infra-red (NDIR).
Carbon monoxide	31 (1-hr) 9 (8-hr)	ppm	By real-time electrochemical sensor method EPA IP-3C: Determination of Carbon Monoxide in Indoor Air Using Electrochemical Oxidation
Formaldehyde	100 (30-min) 0.08 (30-min)	µg/m³ ppm	Reference method: By continuous air sampling with dinitrophenylhydrazone (DNPH) cartridges and analysis by High Performance Liquid Chromatography (HPLC). ISO 16000-3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air – Active sampling method; NIOSH 2016 Formaldehyde; EPA IP-6A/6B/6C: Determination of Formaldehyde and Other Aldehydes in Indoor Air Using Solid Sorbent Cartridge/continuous Colourmetric Analyser; or EPA method 0100: Sampling for aldehyde and other carbonyl compounds in indoor air or equivalent. Indicative method for screening.[4]: By detection tubes or real-time electrochemical sensor method. ISO 16000-2: Sampling strategy for formaldehyde
Total volatile organic compounds (TVOC) that are photo-ionisable (10.6 eV) [5] calibrated to isobutylene equivalent	1000 (8-hr)	ppb	Reference method: By continuous air sampling with Tenax tube and subsequent analysis using gas chromatography and mass spectrometry. ISO 16000-6: Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID; EPA IP-1B: Determination of volatile organic compounds (VOCs) in ambient or indoor air using solid sorbent tubes; or NIOSH Manual of Analytical Methods 2549: Volatile Organic Compounds Screening Indicative method for screening: By real-time photoionization detector method.

iii. Particulate Matter			
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 (24-hr)	µg/m³	Reference method: By gravimetric analysis, beta-attenuation, tapered element oscillating microbalance (TEOM) or indicative method calibrated to gravimetric method. EPA IP-10A/10B: Determination of Respirable Particulate Matters In Indoor Air using size specific impactor/continuous particulate monitor; or EN 12341: Standard gravimetric measurement method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter. Indicative method for screening[6]: By real-time optical scattering or piezoelectric monitoring method.
PM 2.5	37.5 (24-hr)	µg/m³	
iv. Biological parameters[7]			
Total viable bacterial count	500 (good) 1000 (acceptable)	cfu/m³	By single-stage airborne microbial-viable impactor method with performance equivalent to Anderson (N6) or equipment with flow rate of 28.3 L/min (1 ft³/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. The samples on the culture plate should yield between 30 and 300 colonies for best results. NIOSH 0800: Bioaerosol Sampling-Indoor Air When a single species dominating from the culture plate, speciation should be done

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Source : SS 554

Design & Construction



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

Furniture & Furnishings

1) Modular Furniture System & Seating

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

Source : SGBC website

copyrights : Tham Kwok Wai

Interrelationships – IAQ and spatial case study – shopping mall



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Air Quality (M)
Vs
Spatial (S)

Bdg Integrity (I, E)
Vs
Visual (I, E)

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

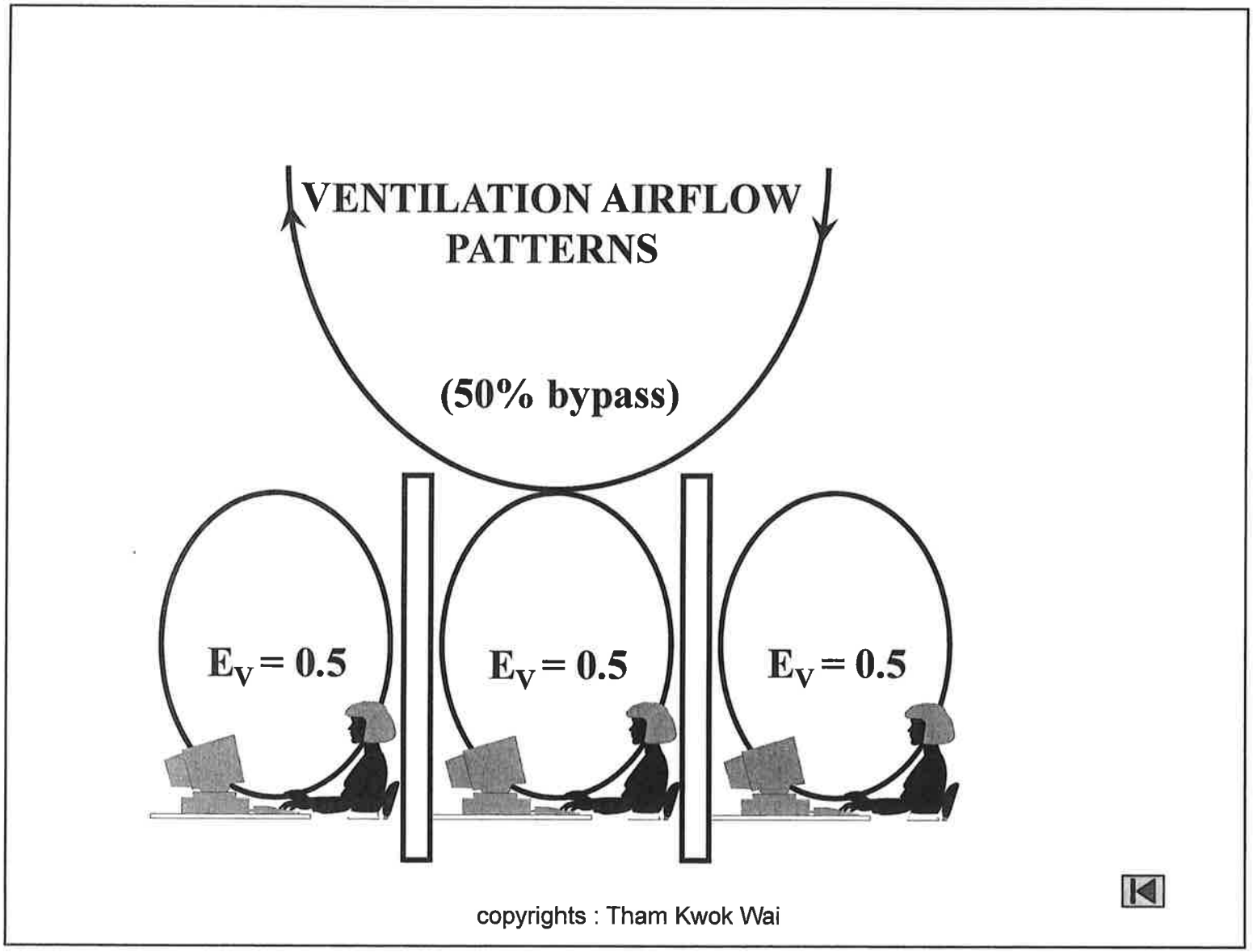
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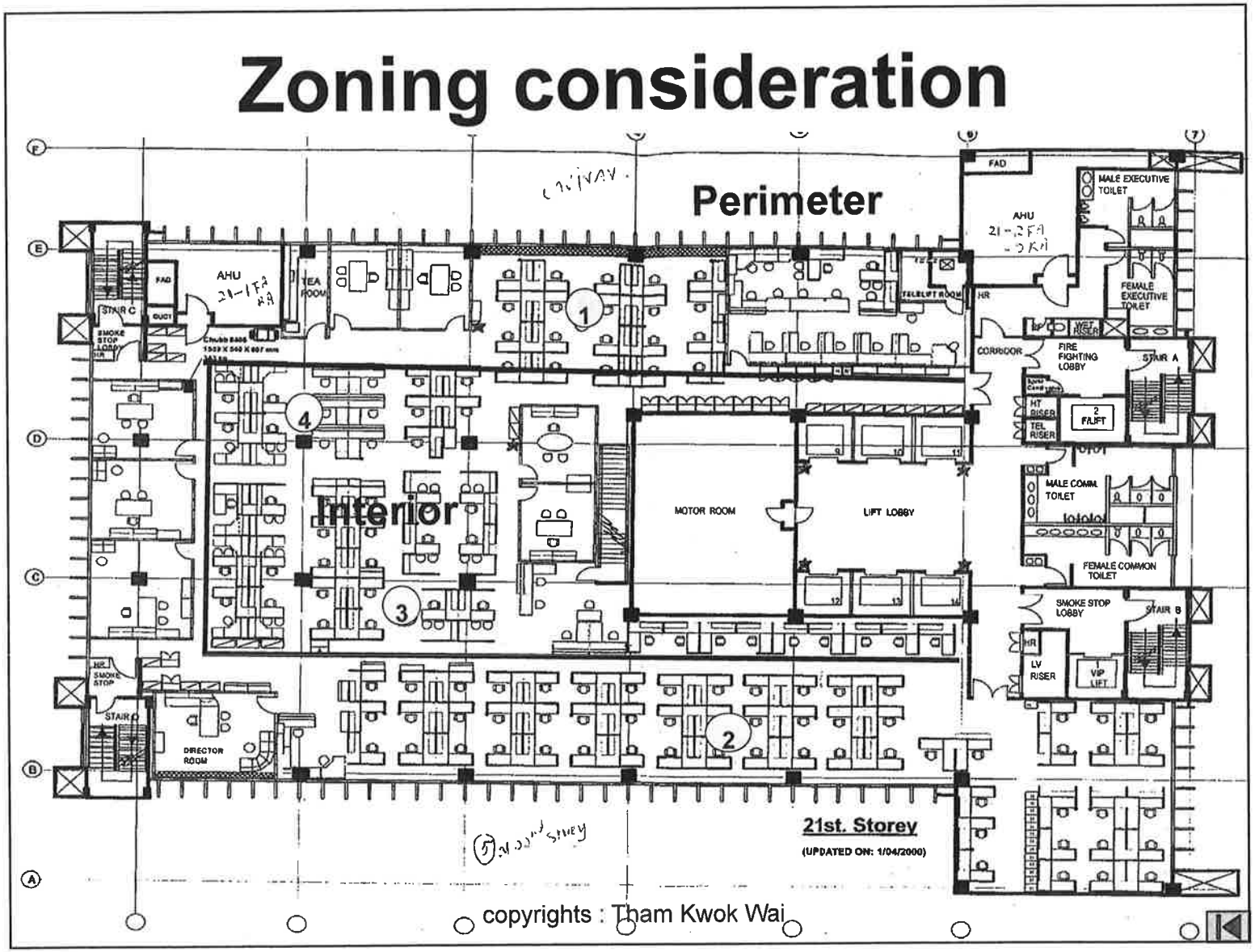
ASHRAE 52.2 MERV	EN779/EN1822 Class	Possible applications
1	G1	Remove coarse dust
2	G2	
3		
4		
5	G3	
6		
7	G4	
8		
9		Remove coarse dust that cause plugging to the cooling coil
10	F5	
11	F6	
12		
13	F7	
14	F8	Reduce indoor contaminants and provide better protection for AHU and cleaner ductwork
15	F9	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	

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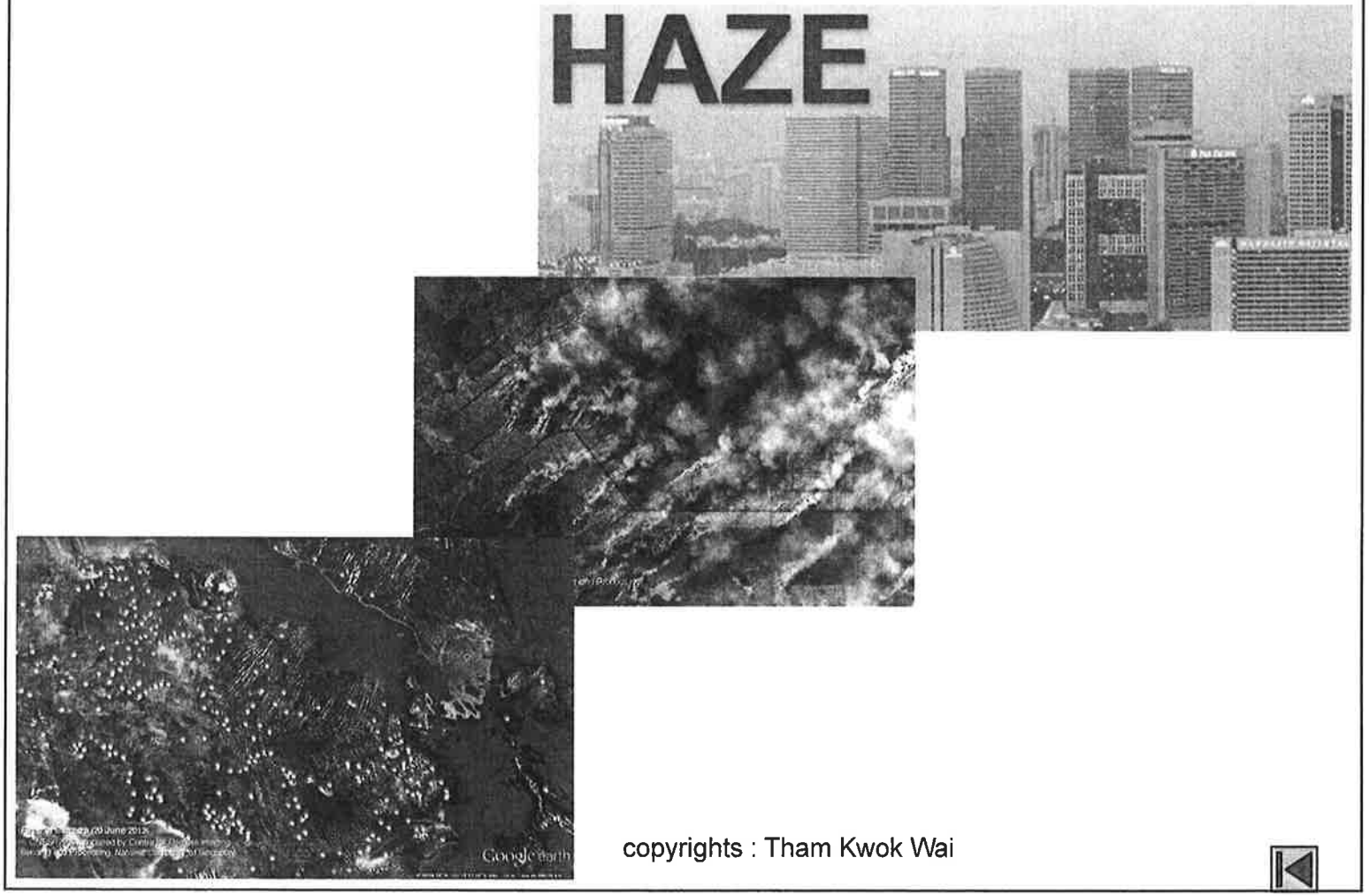
Source : SS 554


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

Zoning consideration



A Recurring Challenge : Haze Episodes



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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

copyrights : Tham Kwok Wai

Commissioning & Renovation

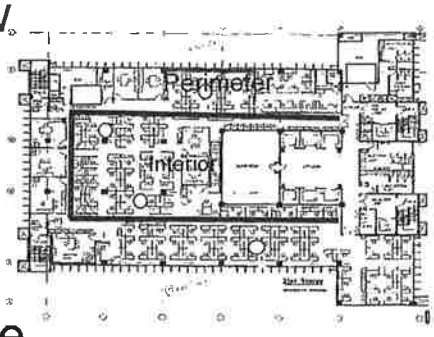
- Commissioning and renovation should be :
  - performance-based
  - Referenced to specifications
  - Include user-acceptance

copyrights : Tham Kwok Wai

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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Photo source : Google images

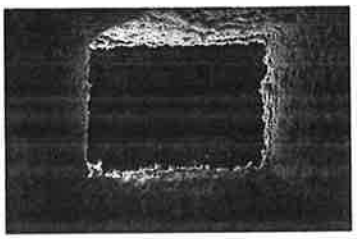
Maintenance

- 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



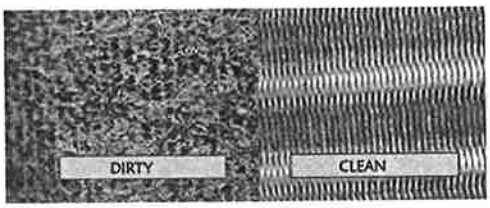




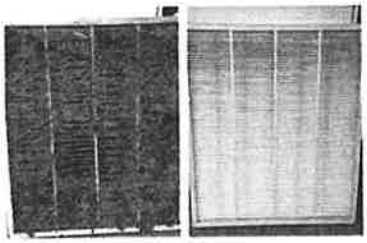
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Maintenance

- 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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Photo source : Google images

Maintenance

- Predictive
  - Increased Pressure drop across filters

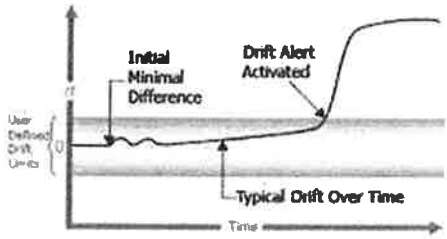
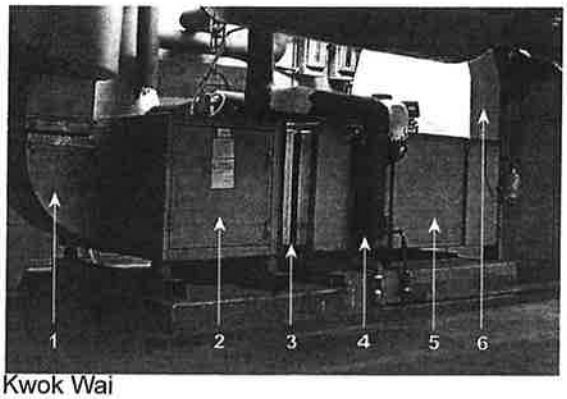


Photo source : Google images

- 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



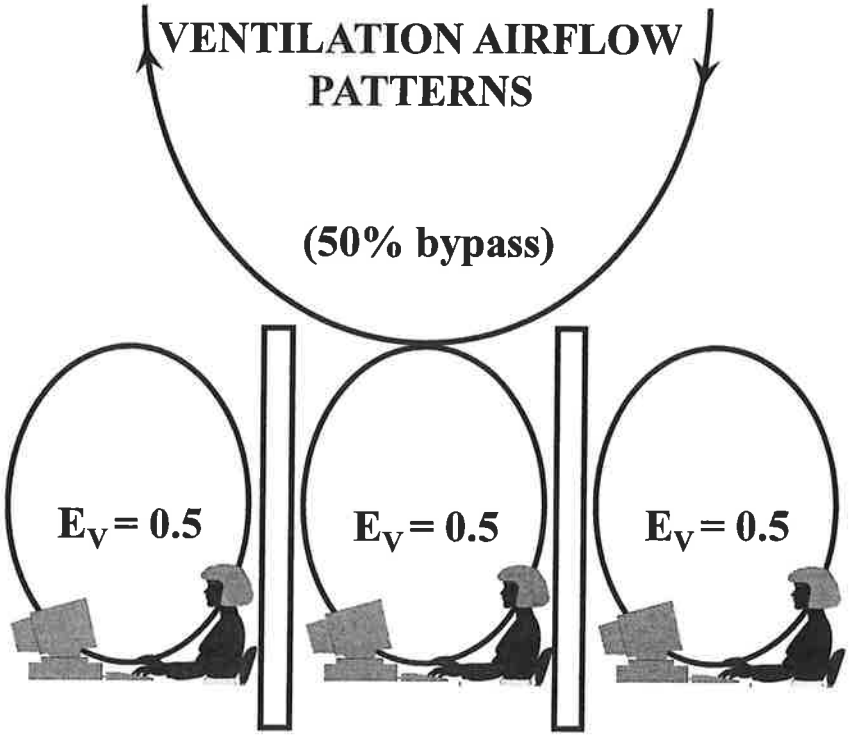
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Identification of Problems related to IAQ (Sick Building Syndrome)

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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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

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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)

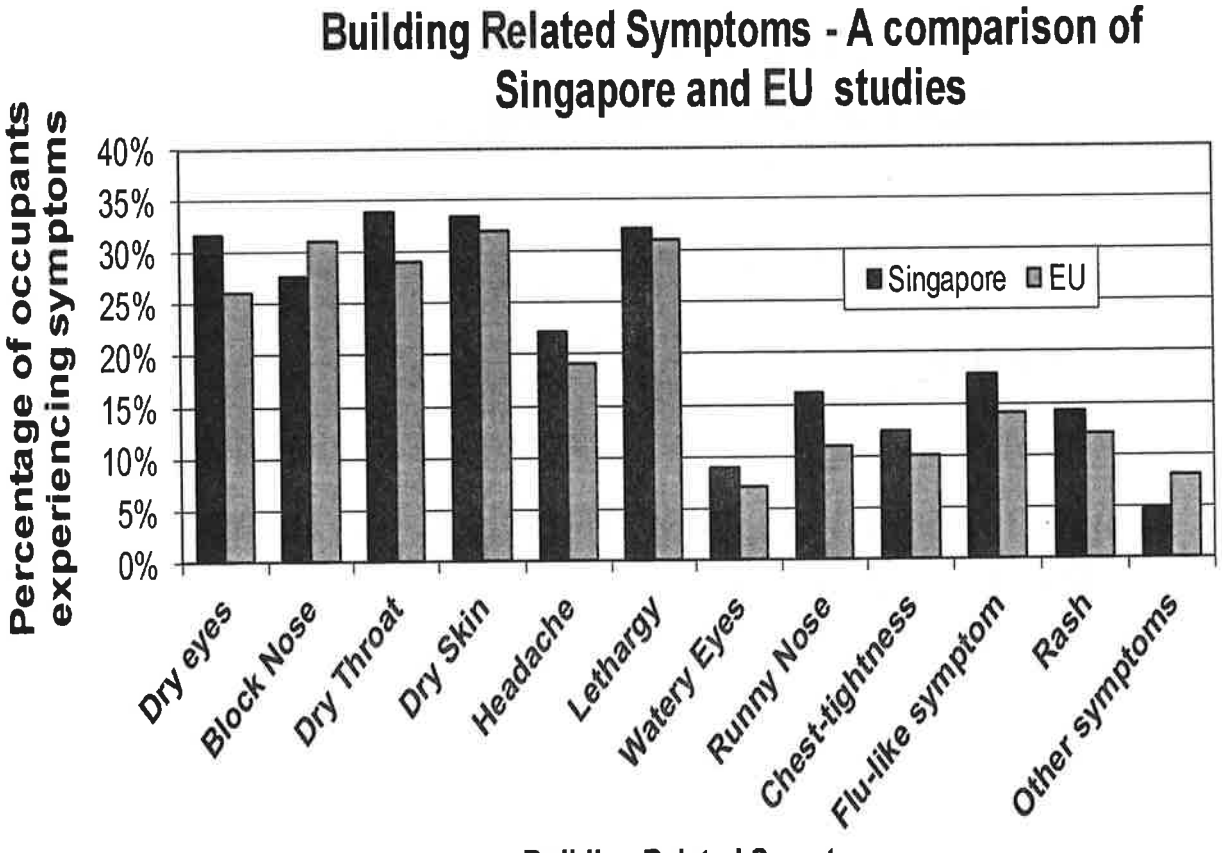
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Sick building syndrome



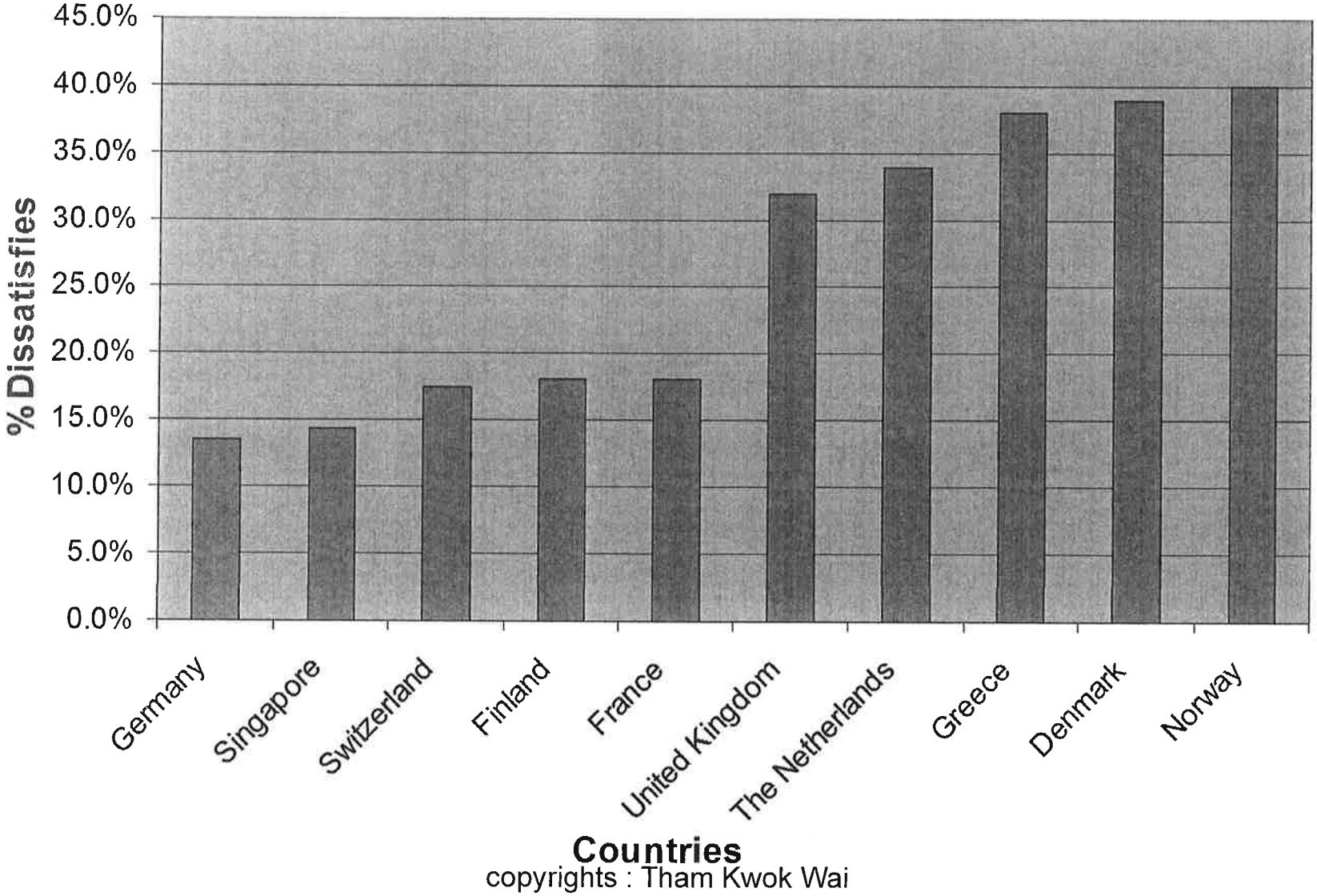
- Defined as an excess of work-related irritations of the skin and mucous membranes and other symptoms reported by occupants in modern office buildings (WHO)
- Presents with transient non-specific symptoms that are relieved upon leaving the premises
- Experienced by at least 20% of the occupants

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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 I of SS554)
- Occupant complaints
- Sensory perceptions and visual observations

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Annex I
(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
   - 2.3 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? Centralized 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

Source : SS554

copyrights : Tham Kwok Wai

THANK YOU

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

STANDARDS COUNCIL

SS 554 : 2016
(ICS 13.040.20; 91.040.01)

Code of practice for indoor air quality for air-conditioned buildings

Parameter	Acceptable limit	Unit	Measurement method / Analytical method[1)]
I. Thermal comfort parameters			
Air temperature[2)]	23 to 25	°C	Air temperature – by hot wire, thermistor or thermometer sling method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the Predicted mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices and local thermal comfort criteria
Relative humidity	< 65 (for new buildings) < 70 (for existing buildings) (under peak and common part load conditions)	%	By thin film capacitor, hygrometer or thermometer sling method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
Air movement [3)]	< 0.30	m/s	By hot wire method for linear air velocity or Kata thermometer for omni-directional air velocity method. ISO 7730: Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
II. Chemical parameters			
Carbon dioxide	700 above outdoor (8-hour)	ppm	By real-time non-dispersive infra-red sensor method ISO 12039: Stationary source emissions - Determination of carbon monoxide, carbon dioxide and oxygen - Performance characteristics and calibration of automated measuring systems; or EPA IP-3A: Determination of Carbon Dioxide in Indoor Air Using Non-dispersive Infra-red (NDIR).
Carbon monoxide	31 (1-hr) 9 (8-hr)	ppm	By real-time electrochemical sensor method EPA IP-3C: Determination of Carbon Monoxide in Indoor Air Using Electrochemical Oxidation

Complimentary

Published by SPRING Enabling Enterprise

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Source : SS 554

Performance Criteria and Values

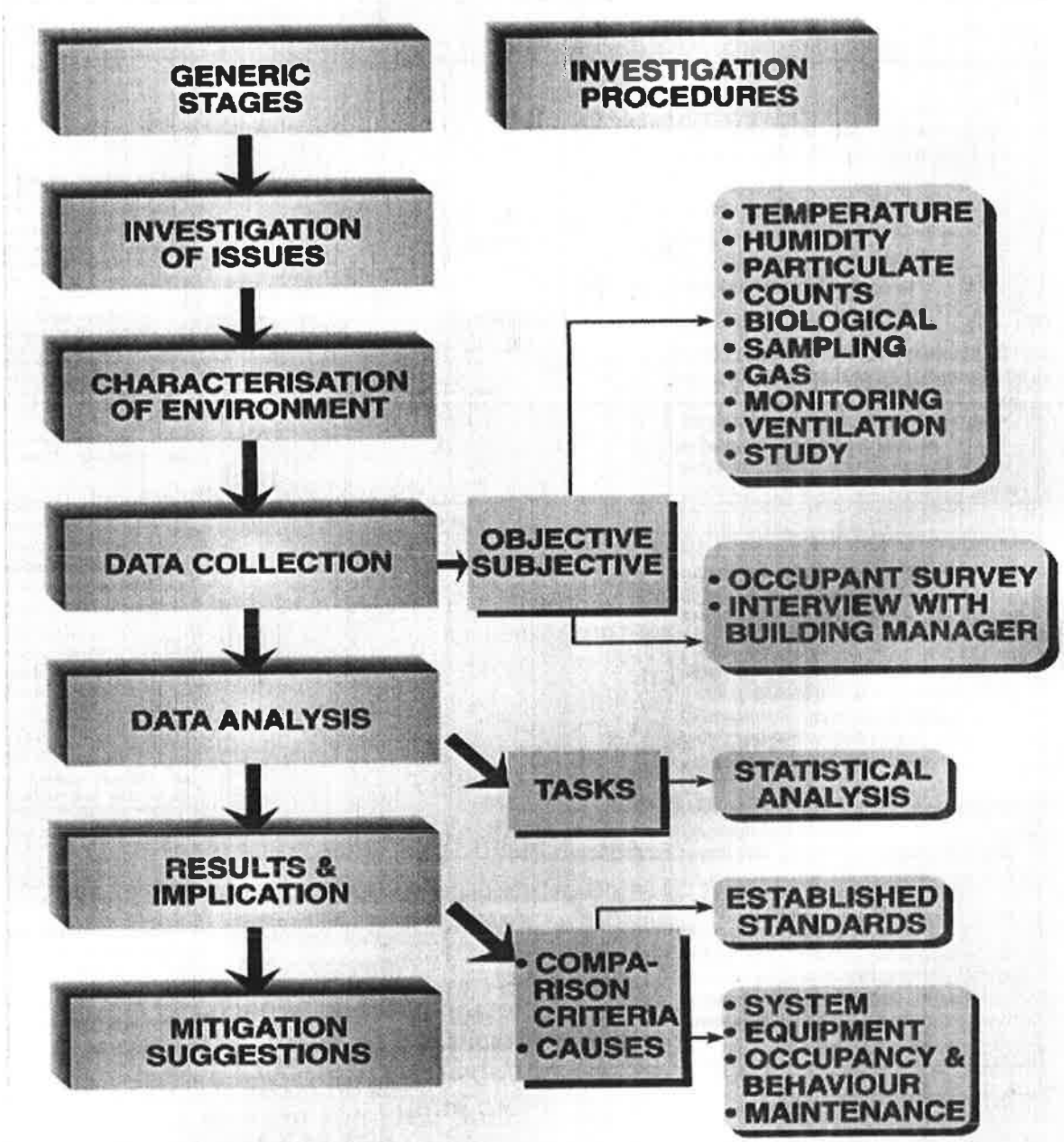
ii. Chemical parameters			
Carbon dioxide	700 above outdoor (8-hour)	ppm	By real-time non-dispersive infra-red sensor method ISO 12039: Stationary source emissions - Determination of carbon monoxide, carbon dioxide and oxygen - Performance characteristics and calibration of automated measuring systems; or EPA IP-3A: Determination of Carbon Dioxide in Indoor Air Using Non-dispersive Infra-red (NDIR).
Carbon monoxide	31 (1-hr) 9 (8-hr)	ppm	By real-time electrochemical sensor method EPA IP-3C: Determination of Carbon Monoxide in Indoor Air Using Electrochemical Oxidation
Formaldehyde	100 (30-min) 0.08 (30-min)	µg/m³ ppm	Reference method: By continuous air sampling with dinitrophenylhydrazone (DNPH) cartridges and analysis by High Performance Liquid Chromatography (HPLC). ISO 16000-3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air – Active sampling method; NIOSH 2016 Formaldehyde; EPA IP-6A/6B/6C: Determination of Formaldehyde and Other Aldehydes in Indoor Air Using Solid Sorbent Cartridge/continuous Colourmetric Analyser; or EPA method 0100: Sampling for aldehyde and other carbonyl compounds in indoor air or equivalent. Indicative method for screening.[4]: By detection tubes or real-time electrochemical sensor method. ISO 16000-2: Sampling strategy for formaldehyde
Total volatile organic compounds (TVOC) that are photo-ionisable (10.6 eV) [5] calibrated to isobutylene equivalent	1000 (8-hr)	ppb	Reference method: By continuous air sampling with Tenax tube and subsequent analysis using gas chromatography and mass spectrometry. ISO 16000-6: Indoor air - Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID; EPA IP-1B: Determination of volatile organic compounds (VOCs) in ambient or indoor air using solid sorbent tubes; or NIOSH Manual of Analytical Methods 2549: Volatile Organic Compounds Screening Indicative method for screening: By real-time photoionization detector method.

iii. Particulate Matter			
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 (24-hr)	µg/m³	Reference method: By gravimetric analysis, beta-attenuation, tapered element oscillating microbalance (TEOM) or indicative method calibrated to gravimetric method. EPA IP-10A/10B: Determination of Respirable Particulate Matters In Indoor Air using size specific impactor/continuous particulate monitor; or EN 12341: Standard gravimetric measurement method for the determination of the PM10 or PM2.5 mass concentration of suspended particulate matter. Indicative method for screening[6]: By real-time optical scattering or piezoelectric monitoring method.
PM 2.5	37.5 (24-hr)	µg/m³	
iv. Biological parameters[7]			
Total viable bacterial count	500 (good) 1000 (acceptable)	cfu/m³	By single-stage airborne microbial-viable impactor method with performance equivalent to Anderson (N6) or equipment with flow rate of 28.3 L/min (1 ft³/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. The samples on the culture plate should yield between 30 and 300 colonies for best results. NIOSH 0800: Bioaerosol Sampling-Indoor Air When a single species dominating from the culture plate, speciation should be done

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Source : SS 554

Indoor Air Quality Audit



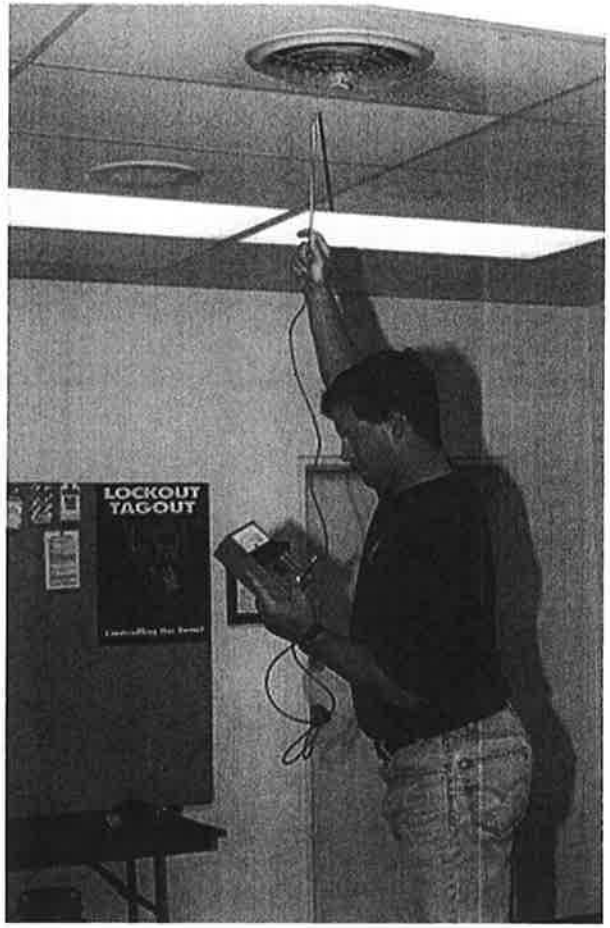
▲ *Indoor Air Quality Audit Methodology developed through the Research Projects*

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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:

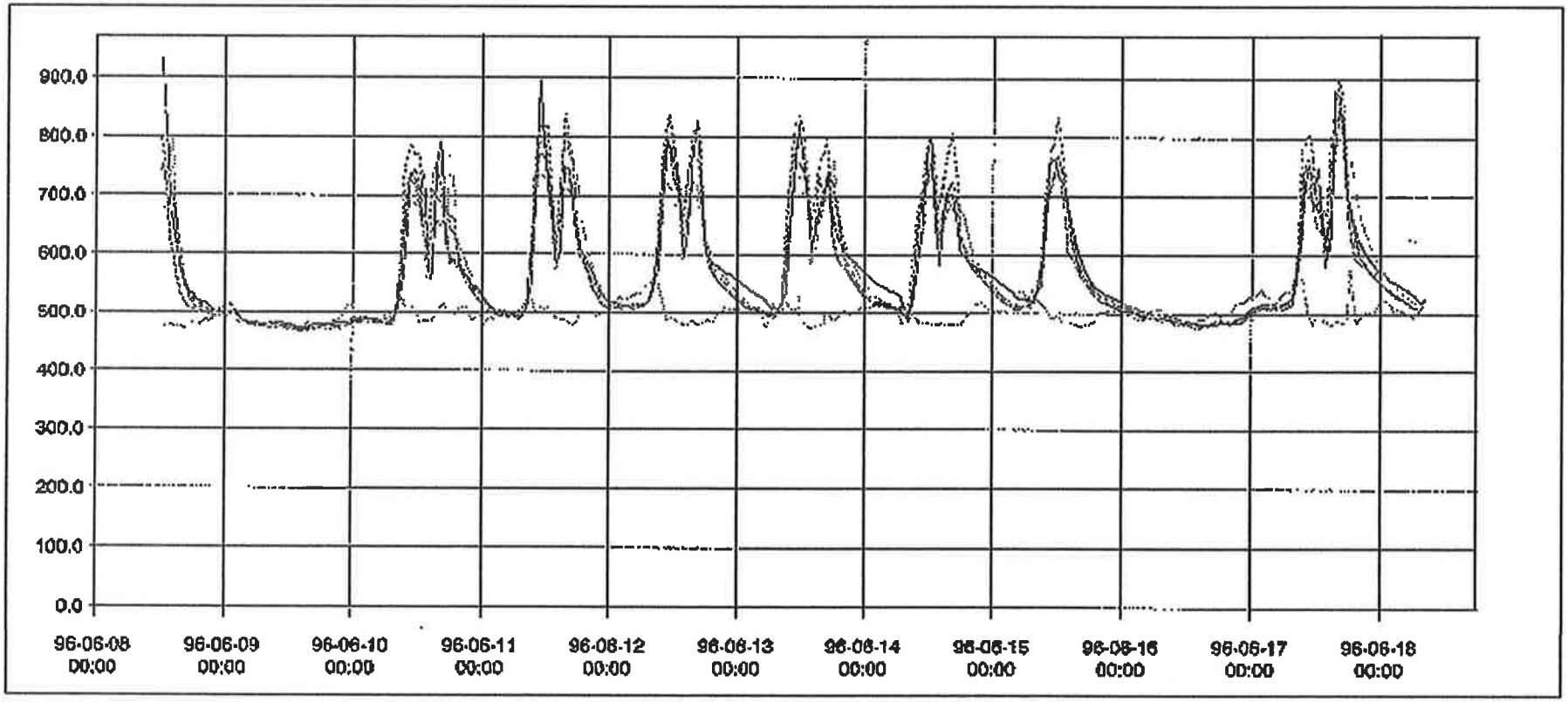
Sampling interval:		Cont.
Time bet. measurement	2882	s
Normalization temp.:	20.0	°C
Cross Compensation:		No
Water Vapour Compens:		Yes
Air Pressure:	101.30	kPa

GENERAL INFORMATION:

Start Time:	1996-06-08 11:38
Stop Time:	1996-06-16 09:01
Compression time:	None
Warnings:	Yes
Data Edited:	No
Resolution:	100 %

COMMENTS:

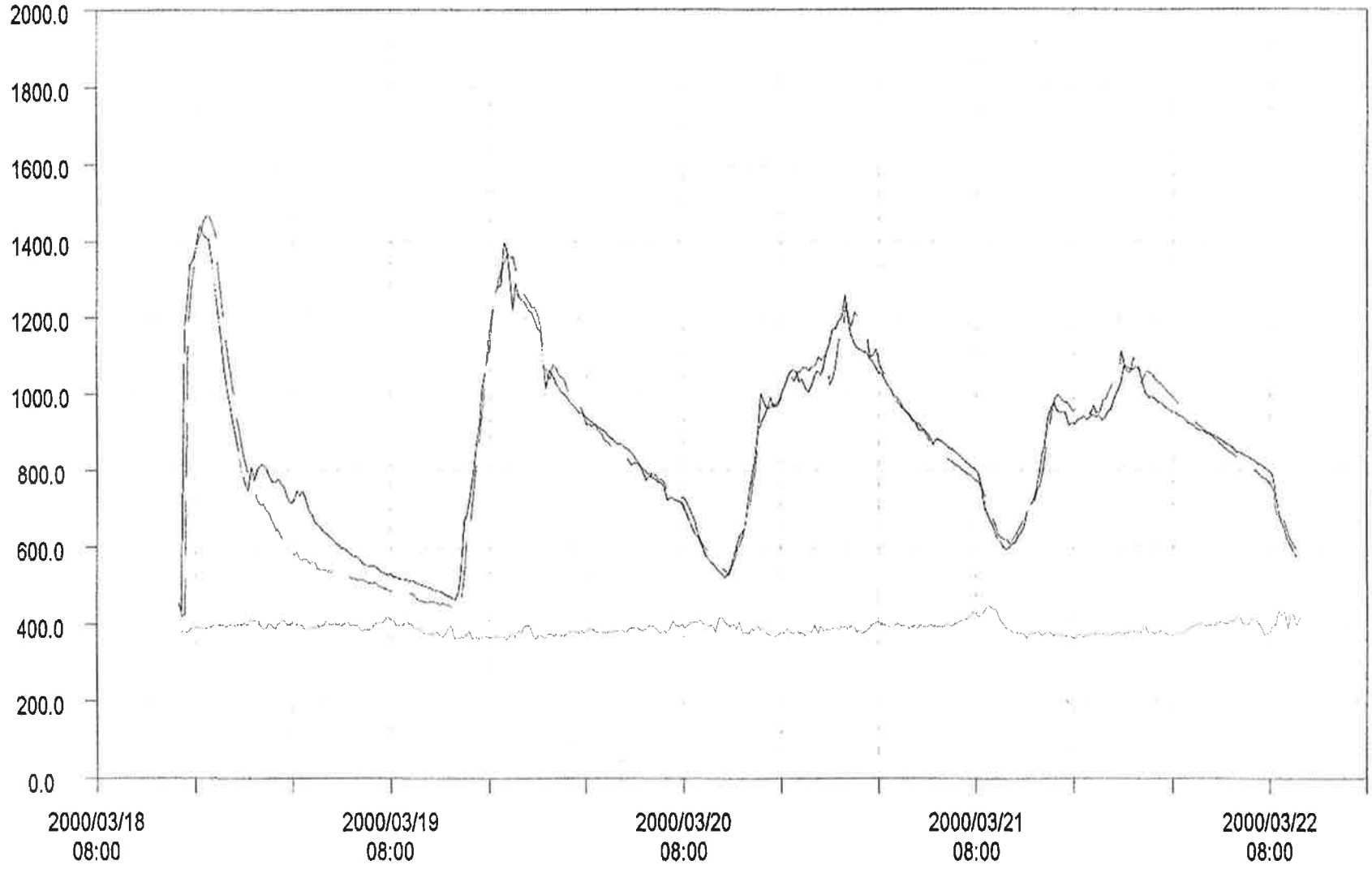
DATABASE: BURSAR4W
USER PRG: None



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	978.92 ppm
3	room 04-309	Carbon dioxide	·····	1E+00	ppm	0.00None ppm	468.12 ppm	811.77 ppm	556.37 ppm	969.16 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

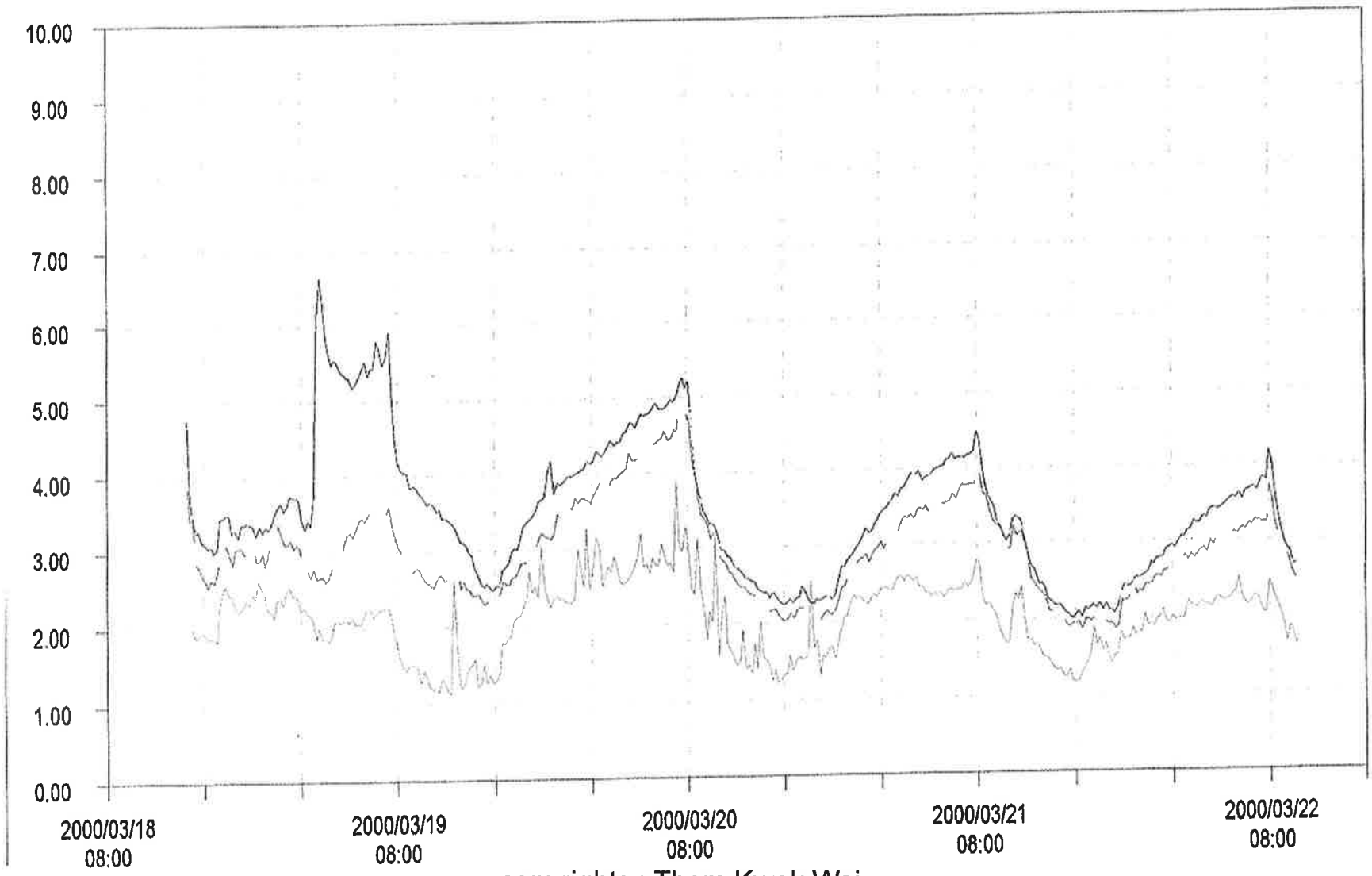
copyrights : Tham Kwok Wai

Carbon Dioxide Profiles



copyrights : Tham Kwok Wai

Total Volatile Organics (TVOC) Profiles



copyrights : Tham Kwok Wai

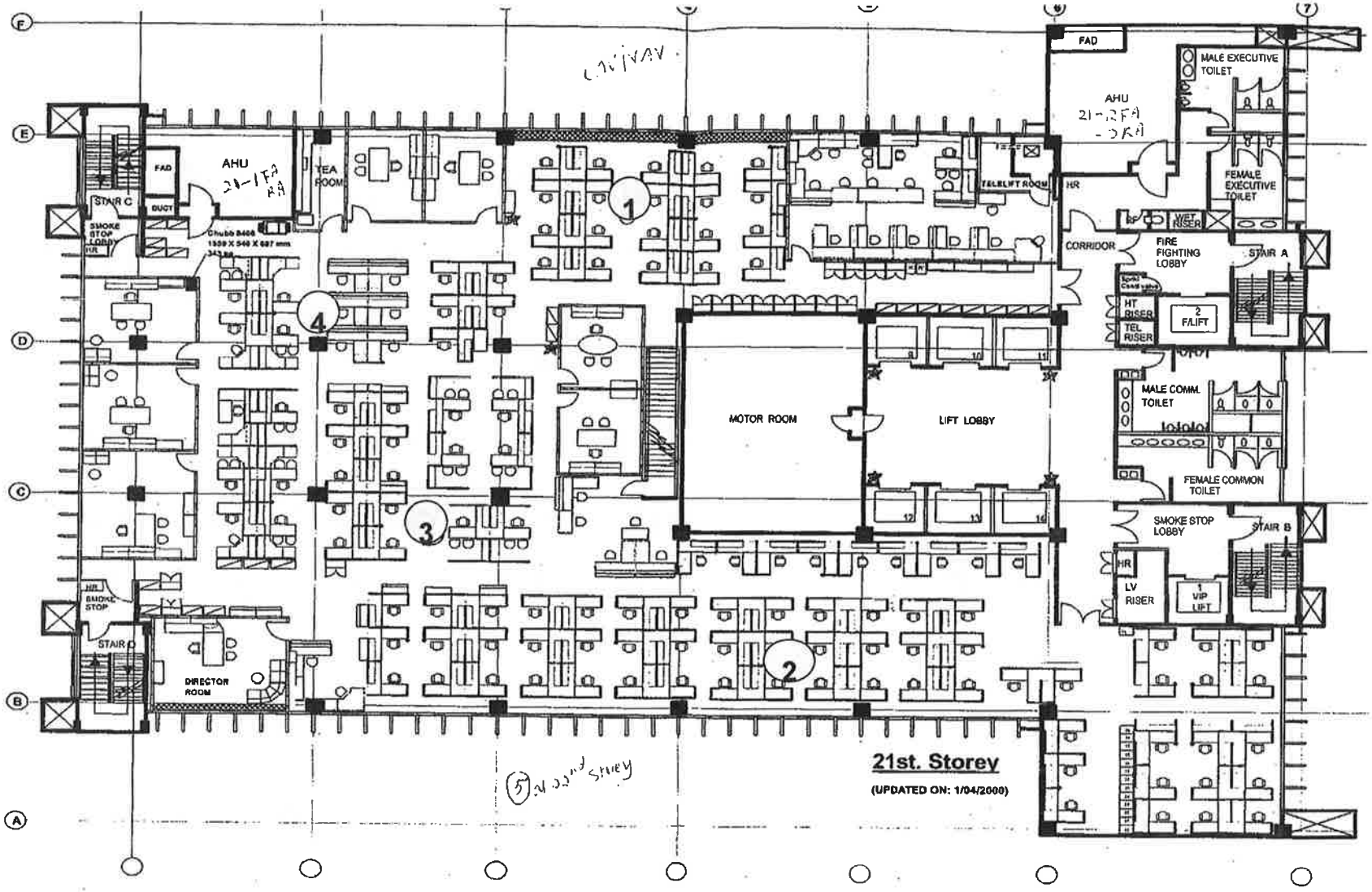
Where to Measure IAQ Parameters ?

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?

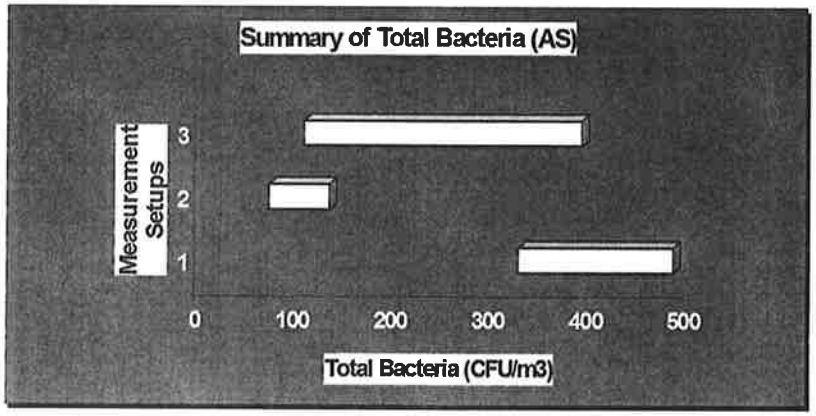
copyrights : Tham Kwok Wai

Sampling Locations

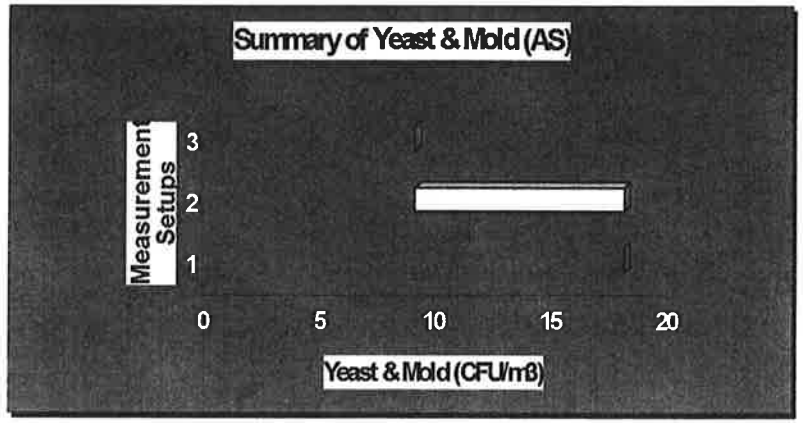


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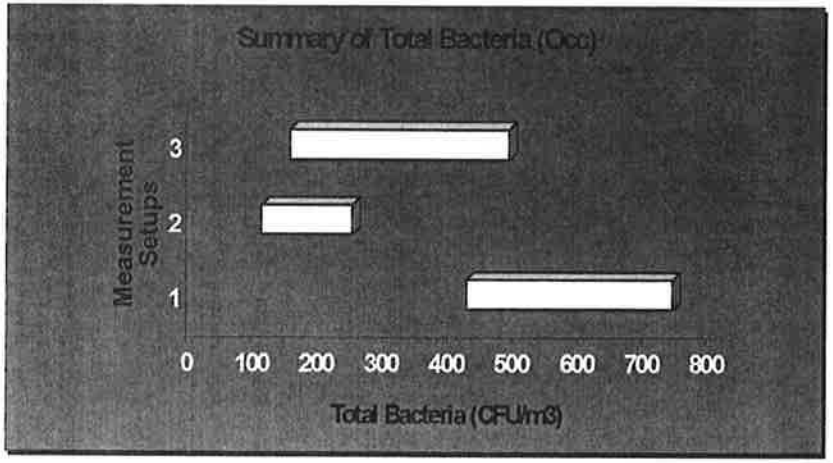
Microbial Contamination (Supply Vs Breathing Zone)



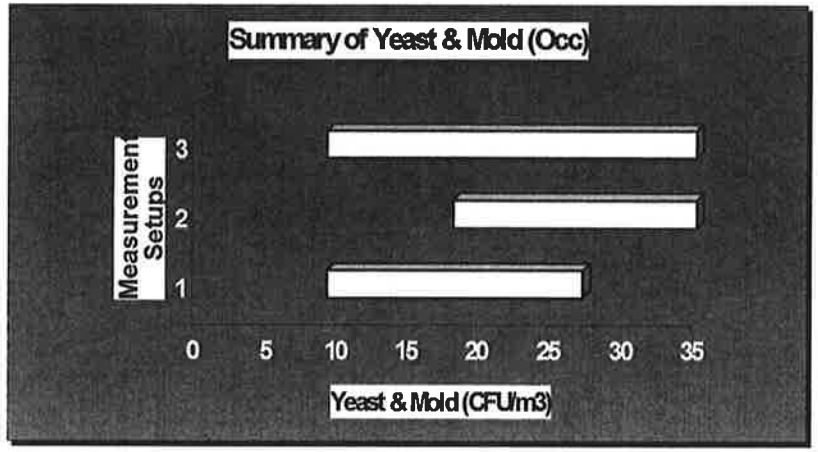
Total Viable bacteria (Air supply)



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?

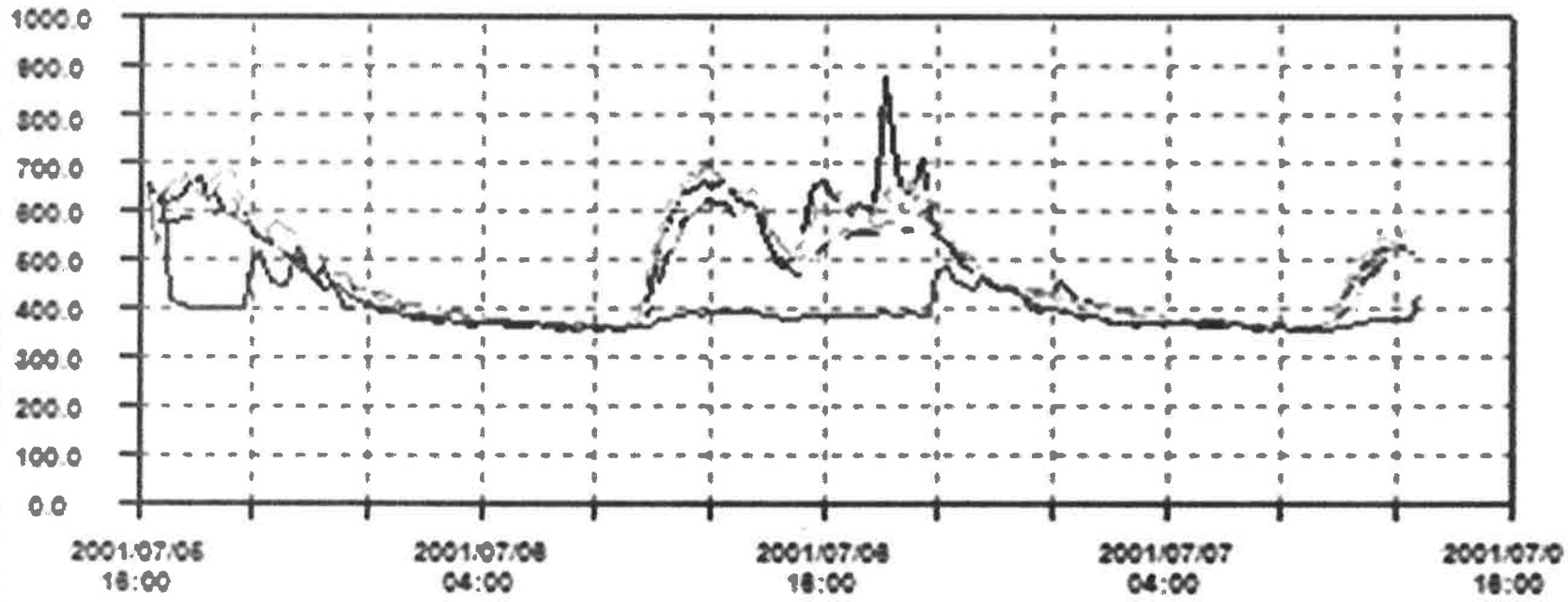
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Factors Affecting Contaminant Profile

- 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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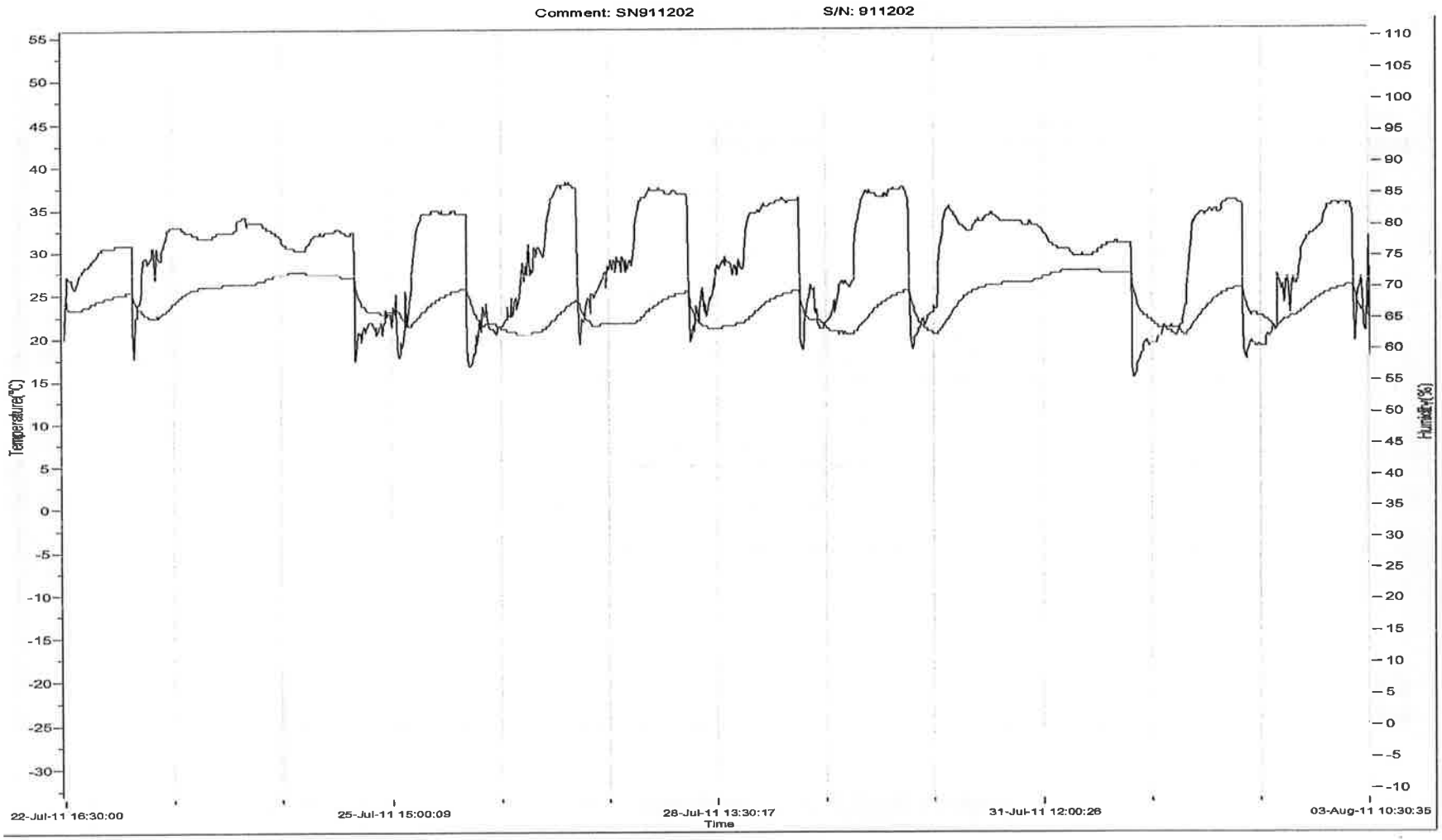
Innova AirTech Instruments Type 7300	SETTINGS:		GENERAL INFORMATION:		COMMENTS:	
	Sampling Interval:	Cont	Start Time:	05/07/2001 04:19:30		
	Sample Cycles:	1104 s	Stop Time:	07/07/2001 12:48:07		
	Normalized Temp.:	20.0 °C	Compression Time:	None		
	Cross Compensation:	Yes	Warning:	No		
Gas	Water Vapour Compens:	Yes	Data Edited:	No	User Prg.:	None
Monitoring	Air Pressure:	105.30 kPa	Plot Resolution:	100%	Database:	mes21li



C	Location	Measurement	Line	Scale	Unit	Min. value	Max. value	Mean value
9	shu21-1FA	Carbon dioxide	—	1	ppm	362.07 ppm	630.74 ppm	393.36 ppm
4	mes21-pt4	Carbon dioxide	- -	1	ppm	363.23 ppm	692.67 ppm	481.07 ppm
8	shu21-1RA	Carbon dioxide	—	1	ppm	363.87 ppm	621.77 ppm	461.21 ppm
3	mes21-pt3	Carbon dioxide	- -	1	ppm	368.33 ppm	693.81 ppm	482.64 ppm
2	mes21-pt2	Carbon dioxide	—	1	ppm	369.36 ppm	648.23 ppm	484.66 ppm
1	mes21-pt1	Carbon dioxide	—	1	ppm	368.67 ppm	678.71 ppm	478.68 ppm

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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

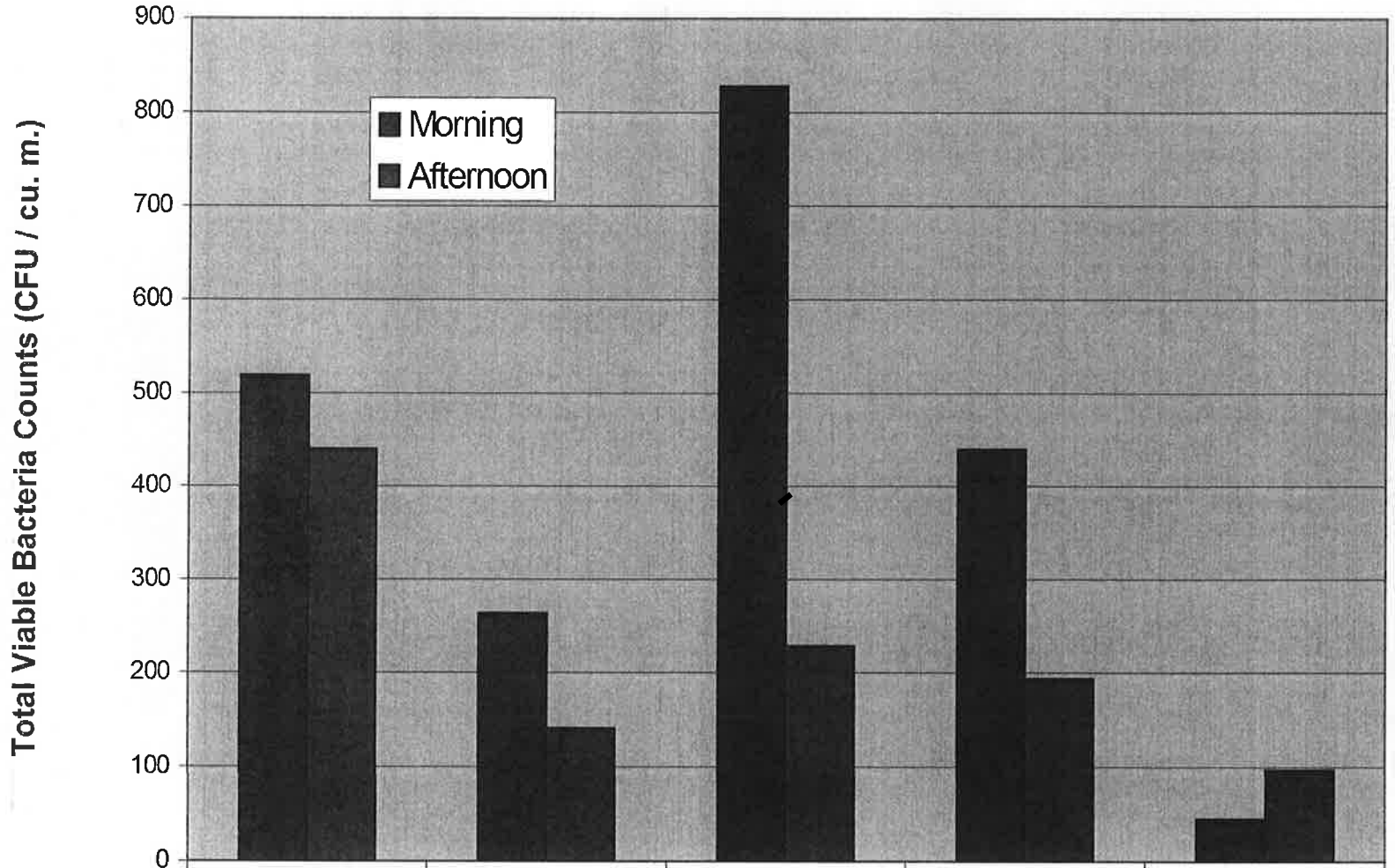
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Identifying Trends

- 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

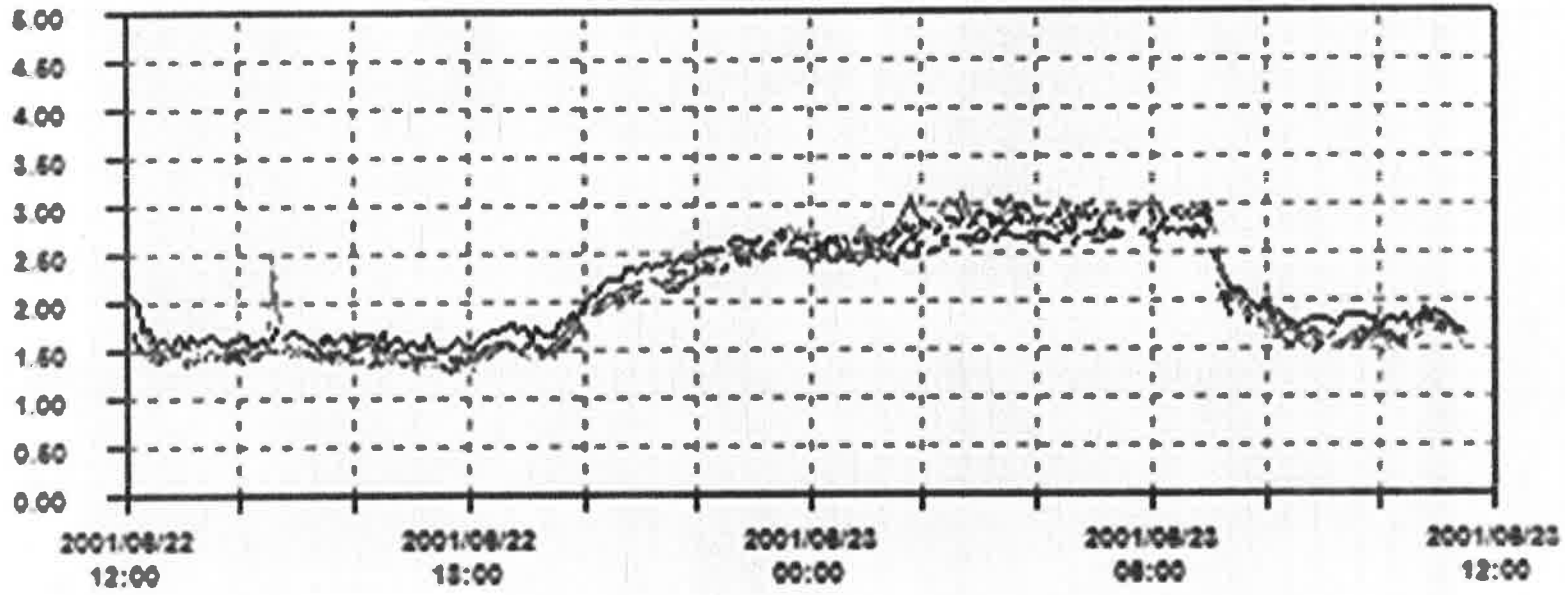
Location

copyrights : Tham Kwok Wai

Innova AirTech Instruments Type 7300

Gas Monitoring

SETTINGS:		GENERAL INFORMATION:		COMMENTS:	
Sampling Interval:	Cont	Start Time:	22/08/2001 12:00:00		
Sample Cycles:	375 s	Stop Time:	23/08/2001 11:33:08		
Normalized Temp.:	20.0 °C	Compression Time:	None		
Cross Compensation:	Yes	Warning:	Yes		
Water Vapour Compens:	Yes	Data Edited:	No	User Prg.:	None
Air Pressure:	101.20 kPa	Plot Resolution:	100%	Database:	r_mast



C	Location	Measurement	Line	Scale	Unit	Min. value	Max. value	Mean value
6	1flr-ot5	TVOC ref. Toluene	—	1	ppm	1.33 ppm	3.10 ppm	2.08 ppm
5	2flr-ot4	TVOC ref. Toluene	—	1	ppm	1.28 ppm	3.02 ppm	2.07 ppm
4	2flr-ot2	TVOC ref. Toluene	—	1	ppm	1.26 ppm	2.77 ppm	1.98 ppm
3	2flr-ot1	TVOC ref. Toluene	- -	1	ppm	1.28 ppm	2.97 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	1.49 ppm	2.86 ppm	2.17 ppm

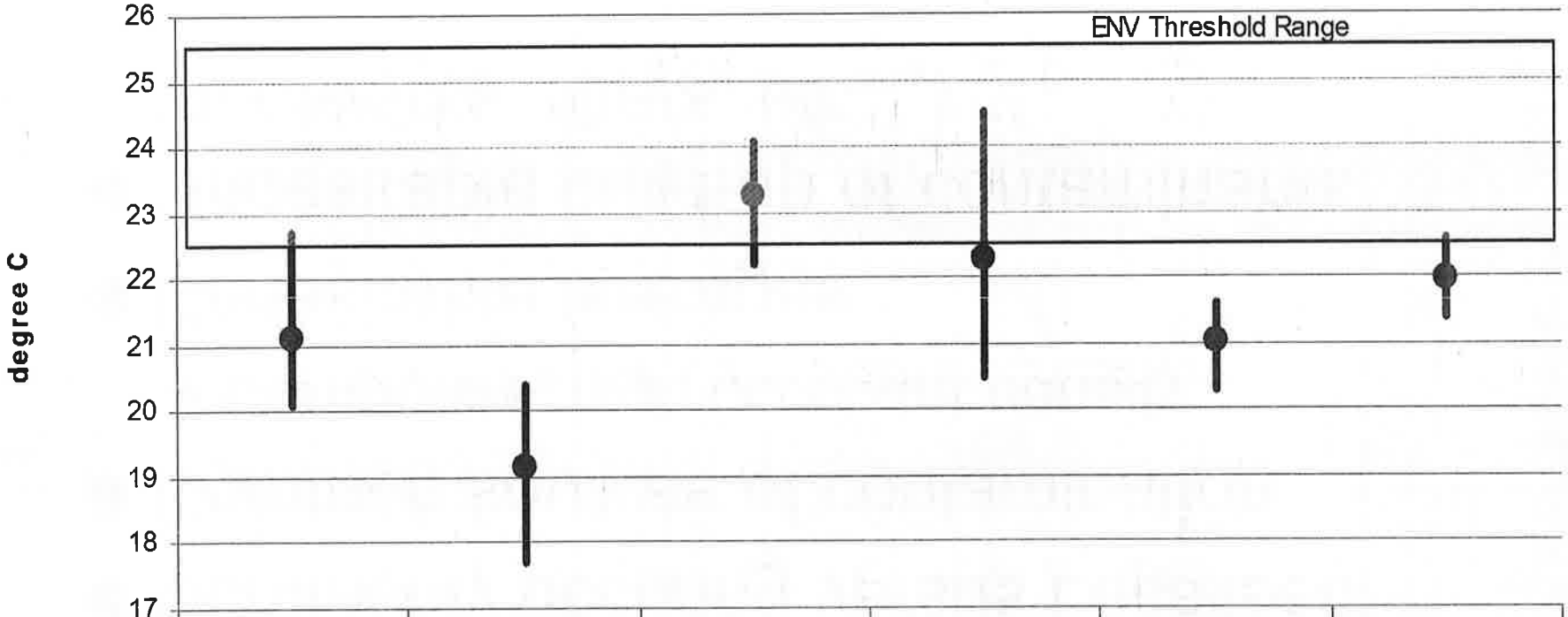
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Identifying Patterns

- 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

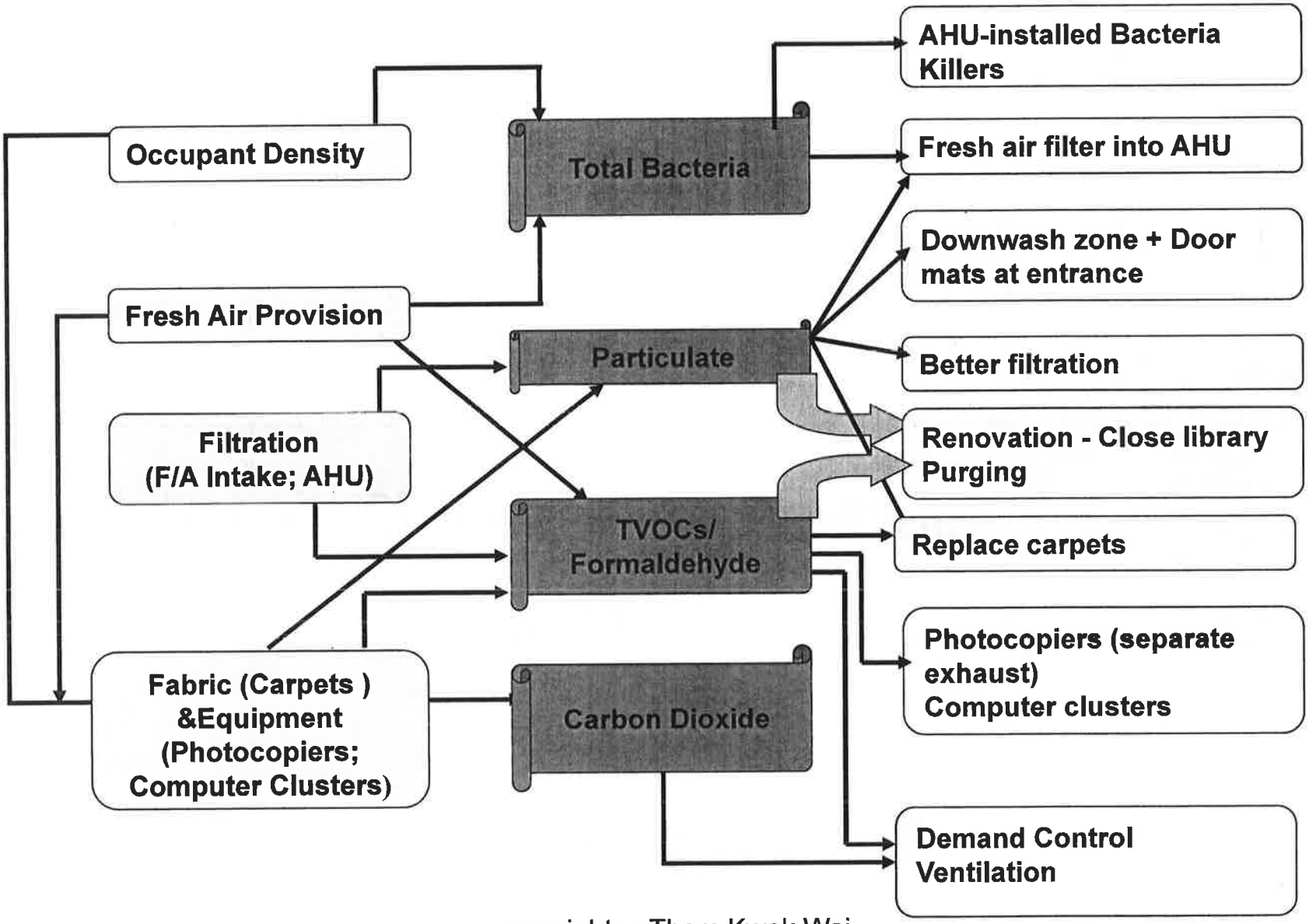
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Causal Analysis

- 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

Green Mark Requirements for INDOOR AIR QUALITY – an Overview

Building and Construction Authority

We shape a safe, high quality, sustainable and friendly built environment.

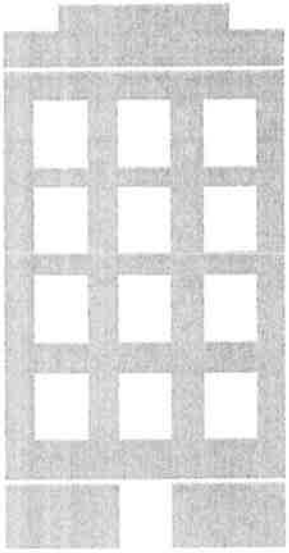
BCA GREEN MARK

Lee Jang Young
Senior Manager
Green Mark Dept (Existing Buildings)
Building and Construction Authority

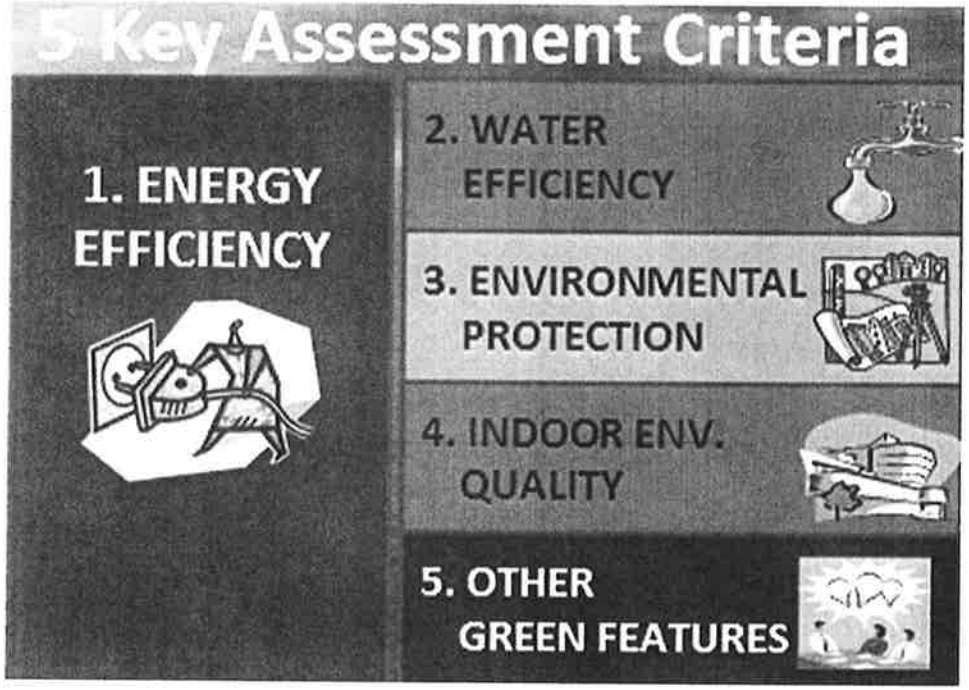
Presentation Outline

- ❑ BCA Green Mark Scheme
- ❑ Green Building Masterplans
- ❑ IAQ's Impact on Health and Productivity
- ❑ IAQ Standards in GM for NRB 2015
- ❑ GM for Existing Buildings
- ❑ GM for Office Interior





The BCA Green Mark Scheme



BCA GREEN MARK

- A green building rating program for the tropics
- Face to face assessments
- On-site verifications

Green Mark	Try Again	Certified	Gold	GoldPlus	Platinum
Score	0 – 49	50 – 74	75 – 84	85 – 89	90 – 100

Green Building Masterplans

2005

BCA GREEN MARK

2006



➢ ***New Buildings***

2009

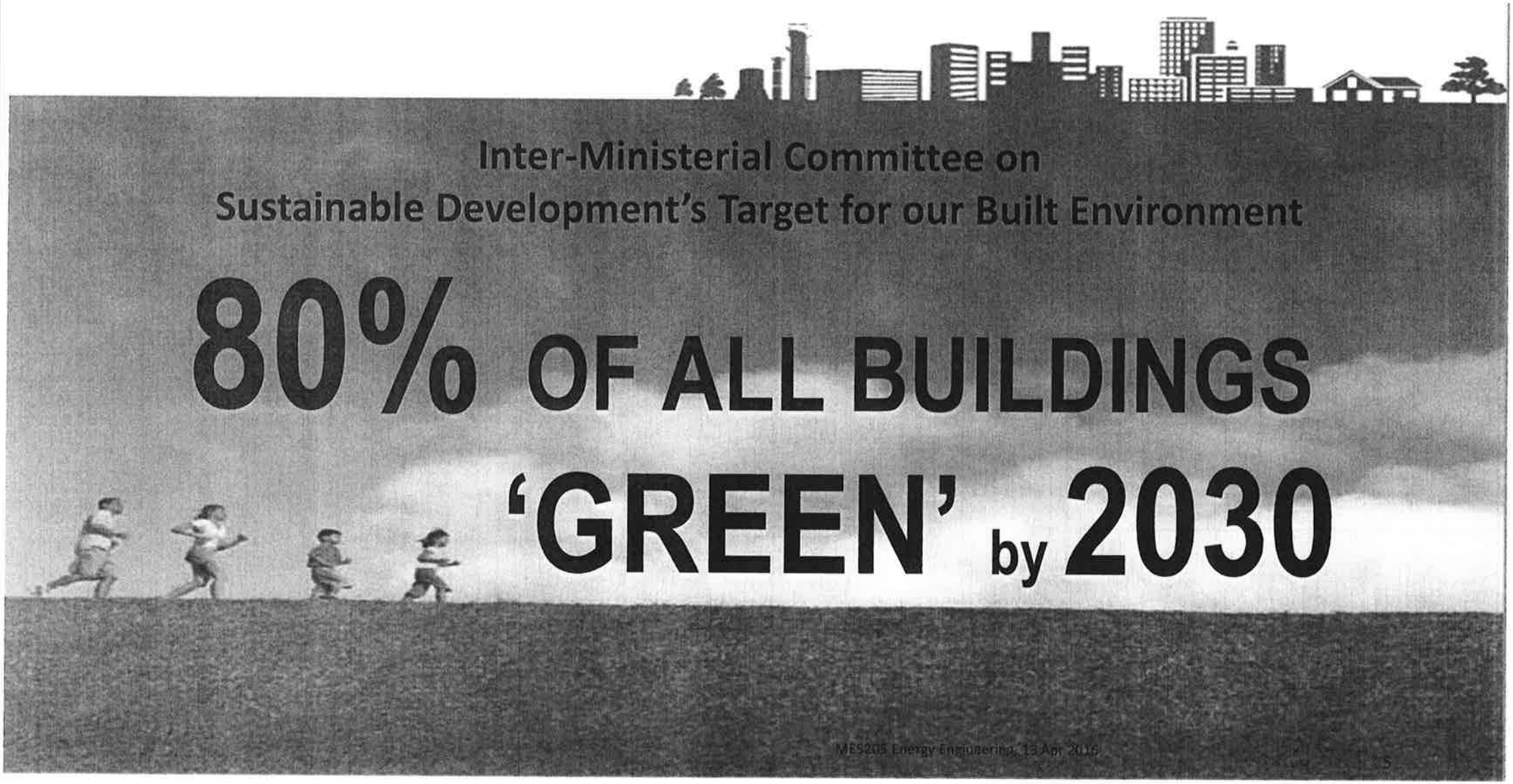


➢ ***Existing Buildings***

2014



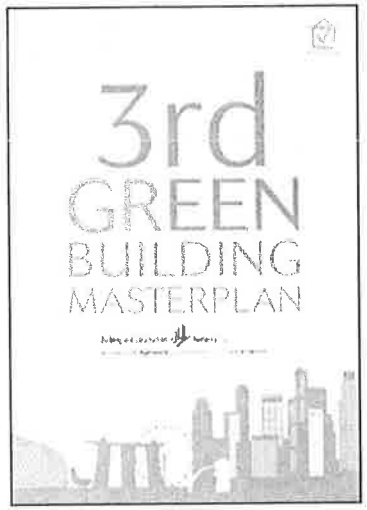
➢ ***Within Buildings & Occupants***


Inter-Ministerial Committee on
Sustainable Development's Target for our Built Environment
80% OF ALL BUILDINGS
'GREEN' by 2030

Green Building Masterplans









Green Building Masterplans

Government taking the lead



New / Existing govt buildings → Green Mark Platinum / Goldplus



Tenancy → Lease from at least Goldplus rated buildings



Office Interior → New or under renovation offices to achieve at least Gold rating



Green Procurement → Events to be held in GM certified places



Govt Land Sales Condition — Key growth areas to attain min. Goldplus

Green Building Masterplans

Spurring the private sector

Incentives for the Private Sector	
S$20 million Green Mark Incentive Scheme for New Buildings	Fully Committed
S$5 million Green Mark Incentive Scheme for Design Prototype	**S$2M Committed**
Bonus Gross Floor Area for Higher Tier Green Mark ratings	**>59,000 sq m Committed**
S$100 million Green Mark Incentive Scheme for Existing Buildings	**Fully Committed**
Building Retrofit Energy Efficiency Financing (BREEF) Scheme	**10 Projects**
S$50 million Green Mark Incentive Scheme for Existing Building and Premises (GMIS-EBP)	**~S$7 million Committed**













Green Building Masterplans

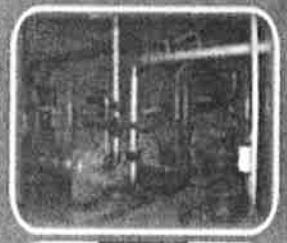
Legislating the minimum Green Mark standards

Building Control (Environmental Sustainability) Regulations 2008



Min. Green Mark standards for new buildings

Environmental Sustainability Measures for Existing Buildings 2013



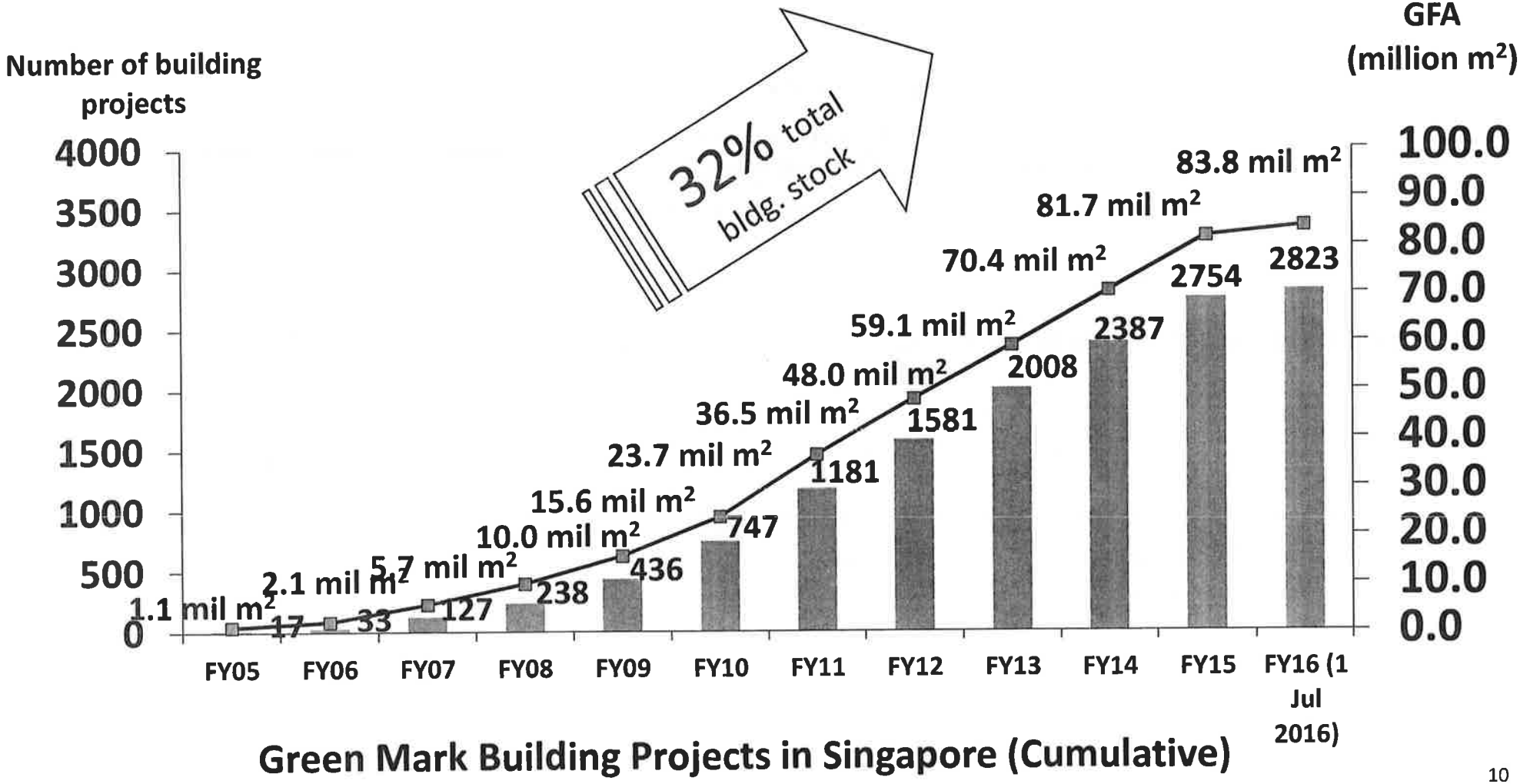


Min. Green Mark standards for existing buildings

Three-yearly energy audit on cooling system and compliance of design system efficiency

Annual submission of building information & energy consumption data

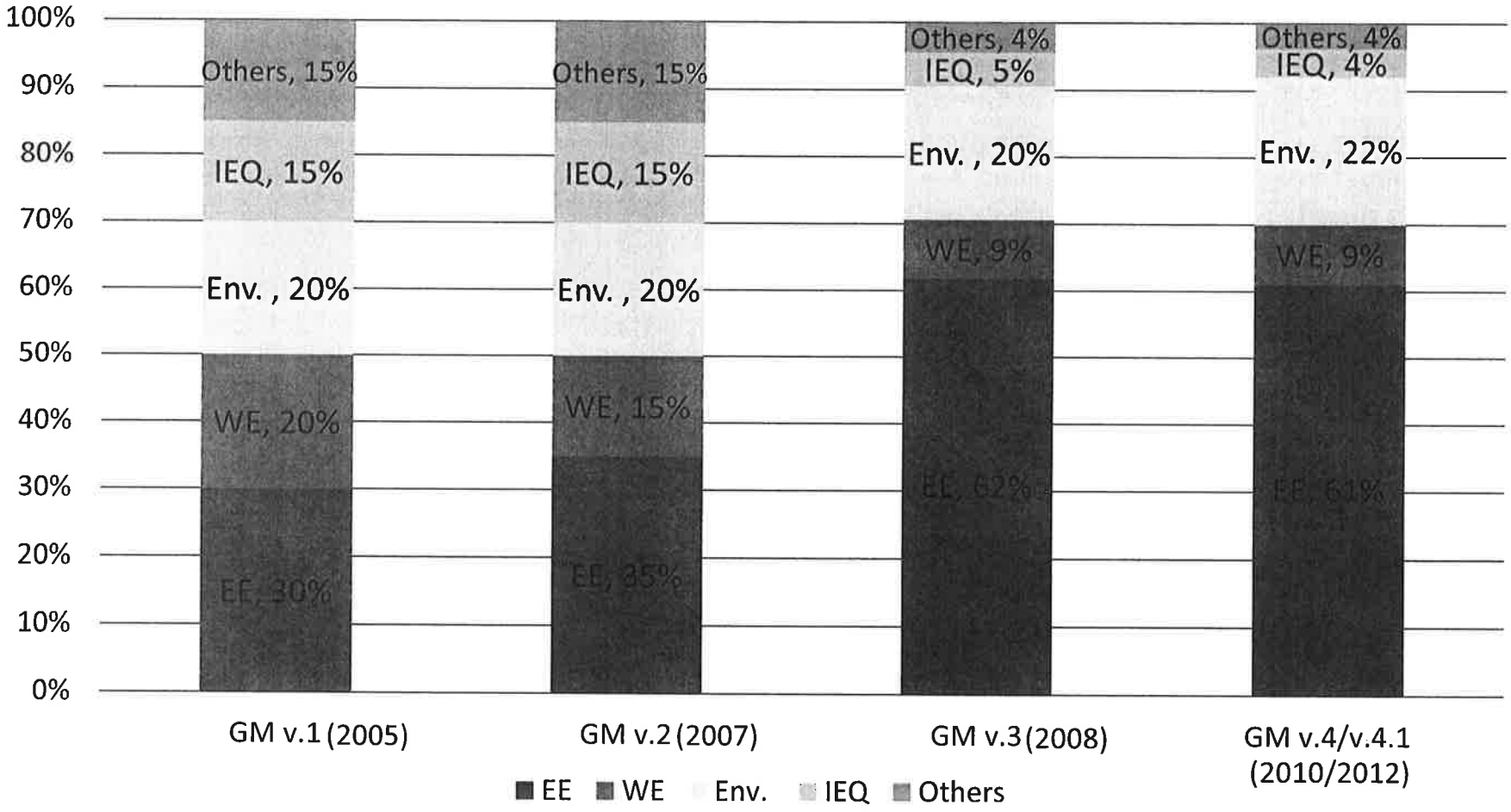
Green Building Masterplans



Green Mark Building Projects in Singapore (Cumulative)

Energy Focused Rating System

Stringent prerequisites & high point weightage on Energy Efficiency

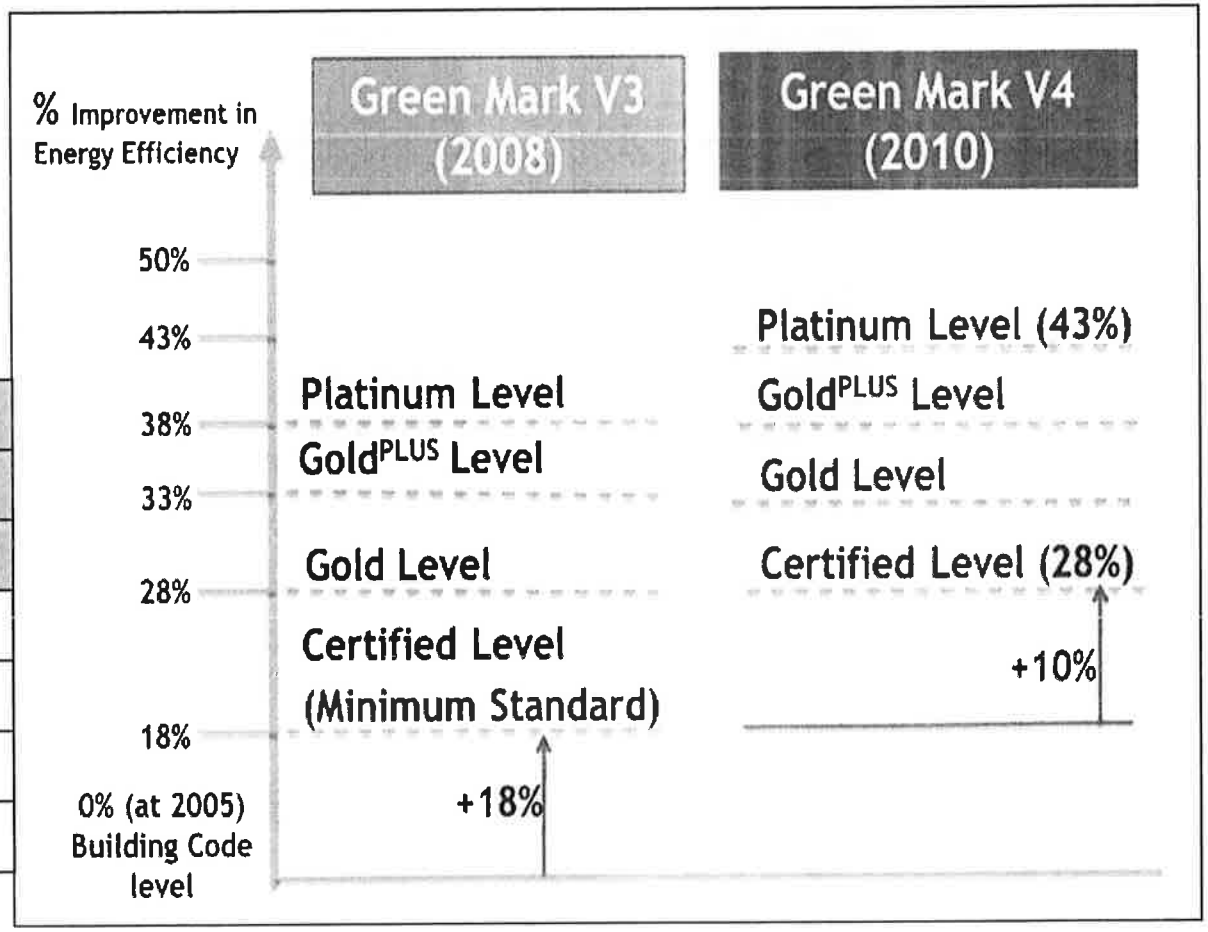


Energy Focused Rating System

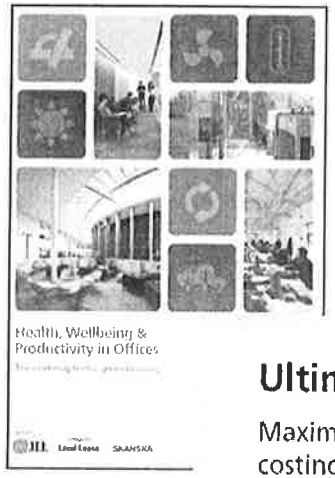
Stringent pre-requisites on Energy Efficiency

- Façade performance
- Energy modelling
- Air-con system efficiency
- Permanent Measurement &Verification system

Green Mark Rating	Building Cooling Load (RT)	
	< 500	≥ 500
	Air-con Efficiency (kW/RT)	
Certified	0.80	0.70
Gold	0.80	0.70
Gold^{Plus}	0.70	0.65
Platinum	0.70	0.65



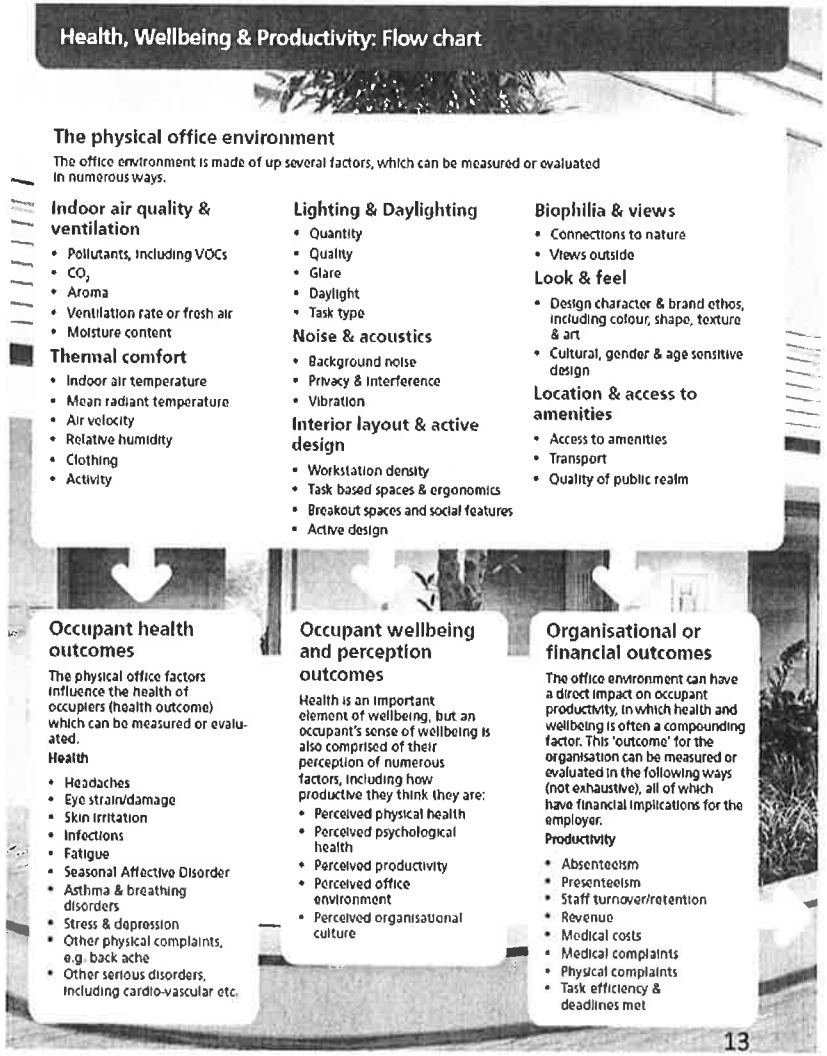
IAQ's Impact on Health and Productivity



Ultimate aims

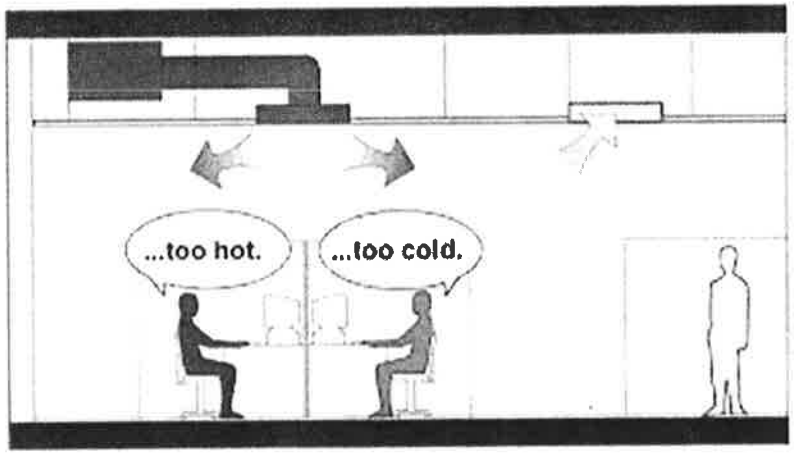
Maximised Return on Investment (financial evaluation based on life cycle costing – capital & operational) for all strategies designed to benefit occupants and improve productivity:

- 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 feed-back systems, leading to reduced costs
- Increased company revenue



IAQ's Impact on Health and Productivity

- The primary function of a building is to increase occupant satisfaction, reduce environmental impacts and improve productivity levels
- Small improvements in IAQ have been shown repeatedly to increase occupant productivity levels and yield big benefits

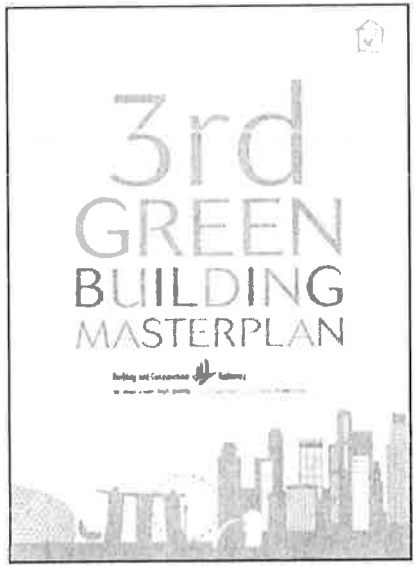


IAQ's Impact on Health and Productivity

- 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

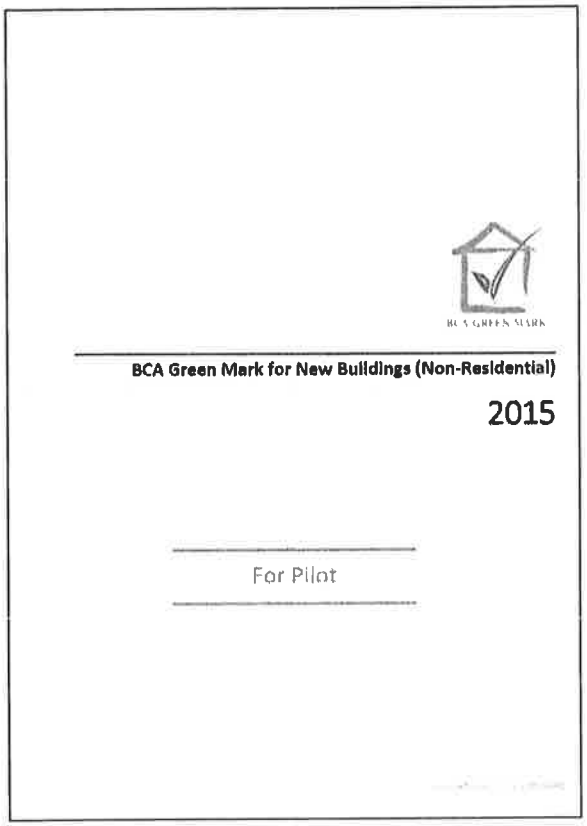


The 3rd GBMP & GM NRB 2015



Greater emphasis on occupants and their well-being.

2014



2015

GM NRB 2015
Occupant Centric Criteria

- 6 / 15 Prerequisites for all ratings
- 4 / 13 Prerequisites for Goldplus & Platinum
- A quarter of the total score

Singapore Standard 554 Definitions

- 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.

Principles for Good IEQ & IAQ



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

GM NRB 2015 IAQ – Ventilation

Pre-requisite for all ratings

SS553 Table 1 Ventilation Rates

- To provide code-recommended ventilation rates according to the occupancy type
- Referenced to ASHRAE 62.1
- To address both human and material-generated pollutants

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
Restaurants	3.4	12.2	5.1	2
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
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
Hotel guest rooms	15.0 l/s per room	54.0 m^3 /h per room	5.5	1
Primary school and above	2.8	10.0	4.2	1
Childcare centres	2.8	10.0	8.4	1

SS553 Table 1 – Outdoor air supply requirement for comfort air-conditioning

GM NRB 2015 IAQ – Ventilation

- **Demand Control Ventilation**

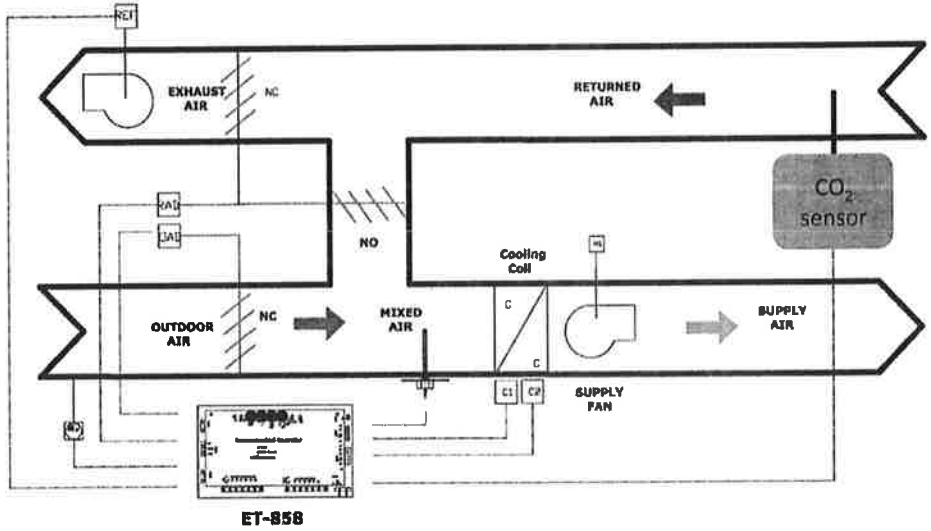
To regulate outdoor air quantity according to occupant density

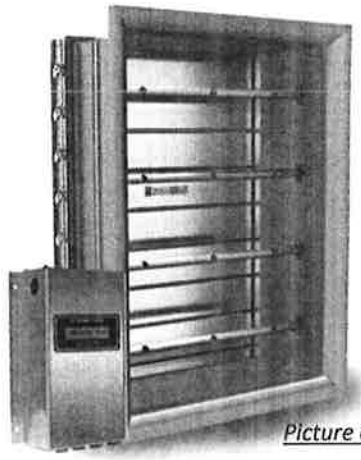
- **Air Purging system**

To flush out contaminated indoor air and replace it with outdoor fresh air

- **Permanent outdoor airflow measurement & monitoring system**

To ensure sufficient ventilation is provided to maintain good IAQ





Picture courtesy of Ebtron

Not use
Pitot tube

GM NRB 2015 IAQ – Filtration

Pre-requisite for all ratings

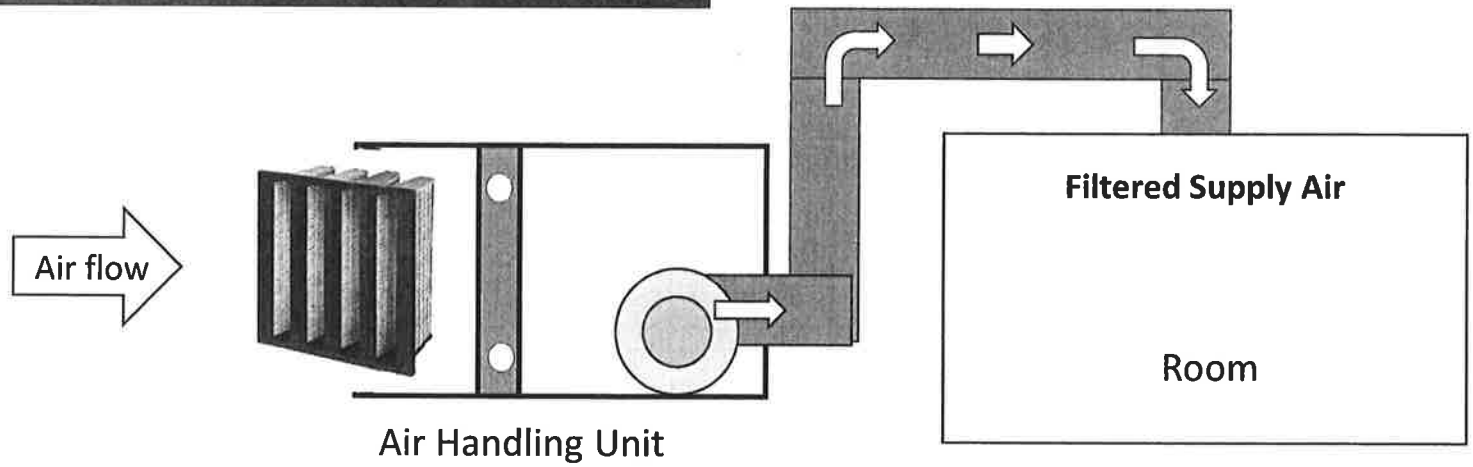
SS553

At least MERV 6 filter for outdoor air filtration

At least MERV 14 filter in times of pollution (PSI >100)

Pre-requisite for Goldplus and Platinum

At least MERV 14 filter for outdoor air filtration



GM NRB 2015 IAQ – Filtration

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		
10	F5	Remove coarse dust that cause plugging to the cooling coil
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

ASHRAE 52.2 MERV-A non charged.

ISO 16890 - 49 classifications

e.g. ePM2.5 80.... 95

GM NRB 2015 IAQ – Source Control

Pre-requisite for all ratings

Low VOC Paints

- Low Emitting Materials (VOCs)

To control VOC emissions at source

- Ultraviolet Germicidal Irradiation (UVGI)

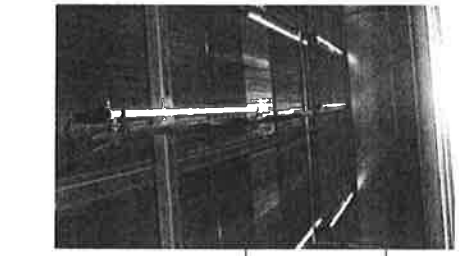
To effectively control airborne infective microorganisms

- Local Exhaust System

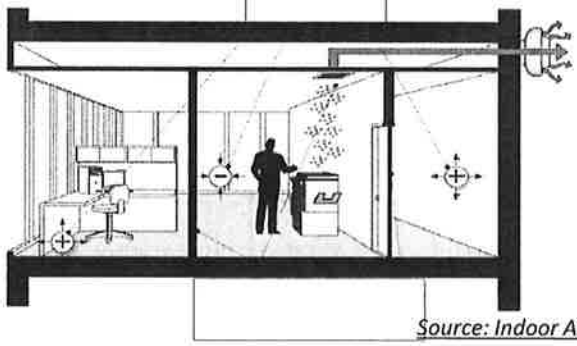
To isolate the contaminants and extract it out from the known source

Common Volatile Organic Compounds (VOCs)

- Paint, glue, cleaning detergent, aerosol spray, etc.



Picture courtesy of the NEWS

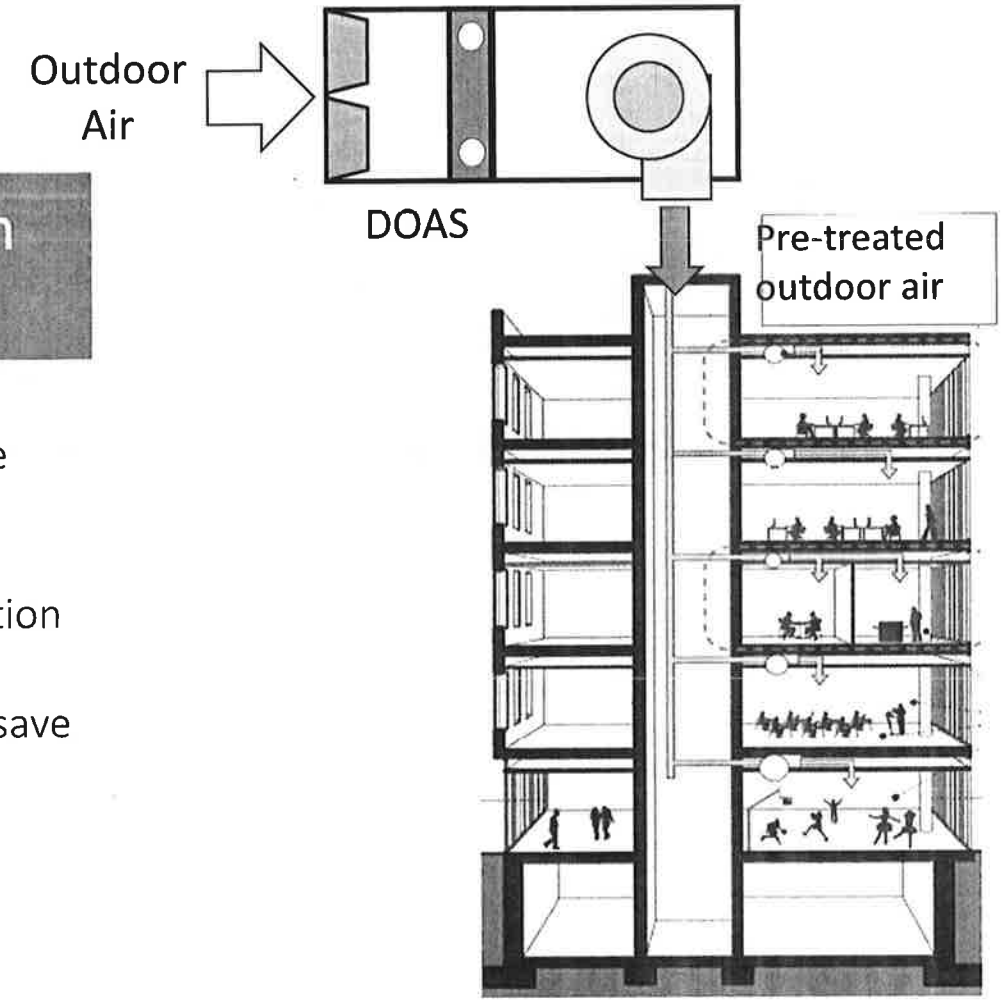


Source: Indoor Air Quality Guide, ASHRAE

GM NRB 2015 IAQ – Humidity Control

Dedicated Outdoor Air System (DOAS)

- Effective way of treating outdoor air for cooling and dehumidification to minimise microbial growth
- Centralised location for outdoor air filtration
- Combined with heat recovery system to save on cooling energy



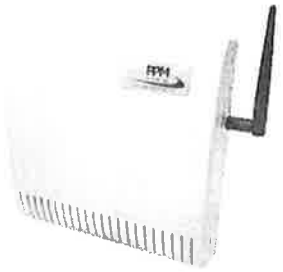
Source: Indoor Air Quality Guide, ASHRAE

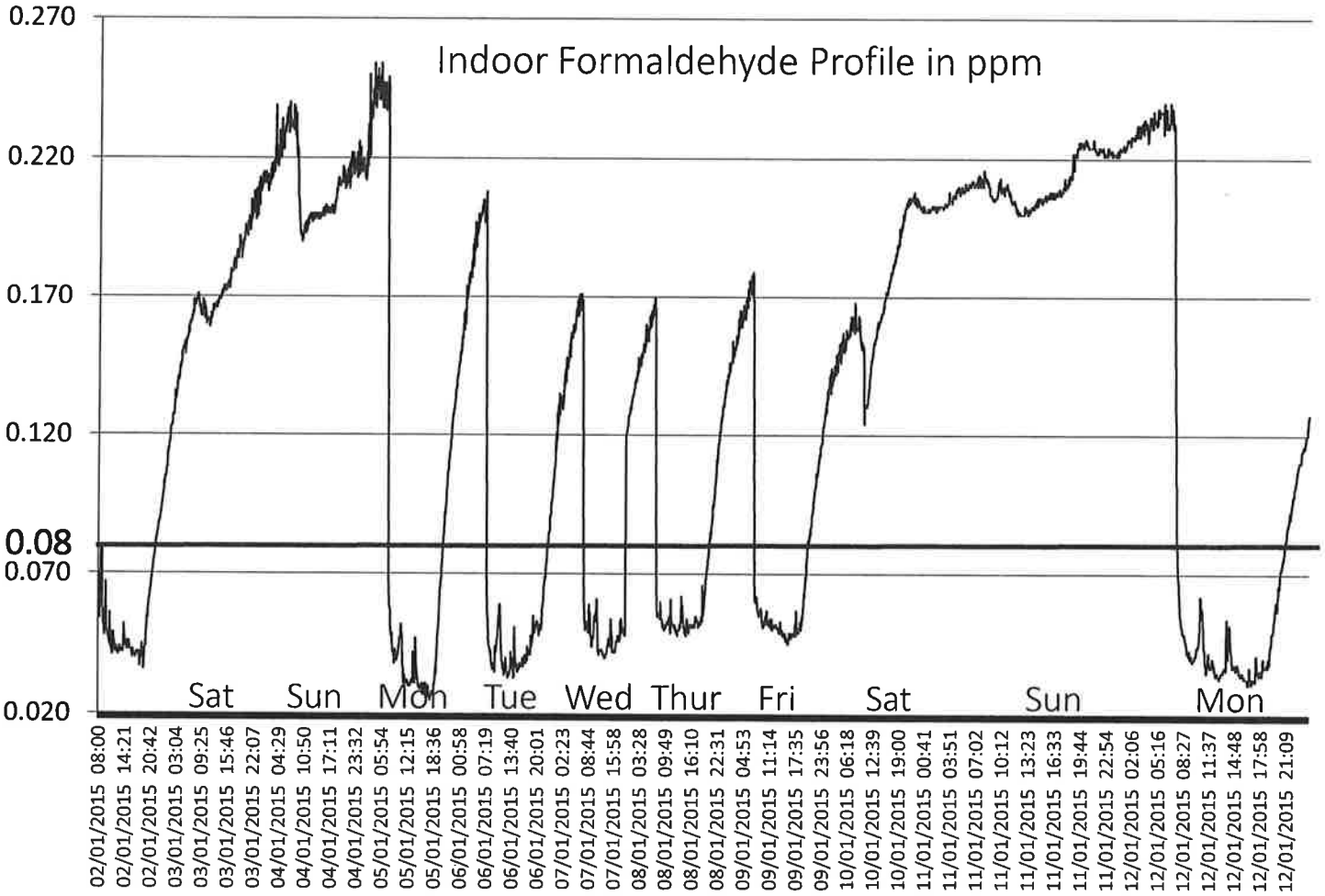
GM NRB 2015 IAQ – Demonstration

IAQ Monitoring & Display

To raise awareness on IAQ & To visualise the current IAQ condition and identify irregularities

- Temperature & Relative Humidity
- Other pollutants such as Formaldehyde

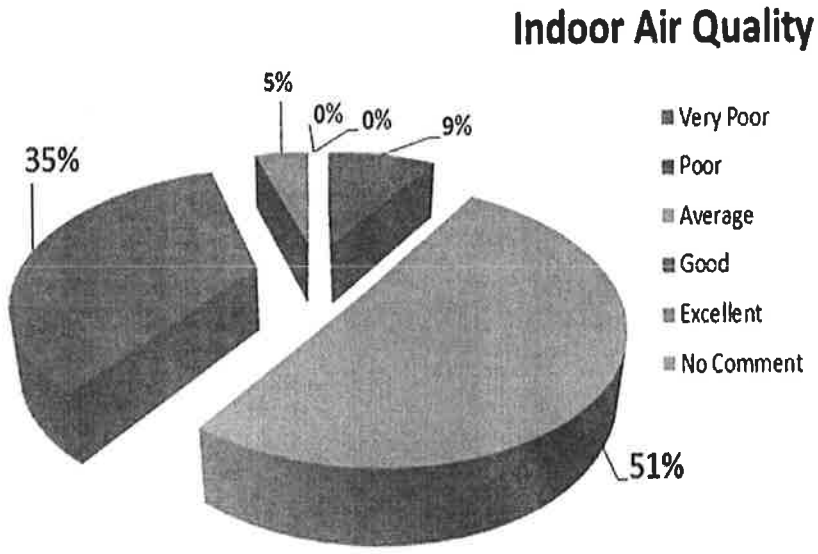




GM NRB 2015 IAQ – Demonstration

Post Occupancy Evaluation (POE)

To conduct a POE survey and take corrective actions accordingly within one year after occupancy



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
2.3 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? Centralized 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

GM NRB 2015 IAQ – Demonstration

IAQ Surveillance: Indicative methods

IAQ Audit: Reference methods

SS554 table 1

By SAC accredited laboratories within one year after occupancy

Parameter	Acceptable limit	Measurement method/ Analytical method
Air Temperature	23 – 25 °C	hot wire, thermistor or thermometer sling
Relative Humidity	≤ 65% for new ≤ 70% for old	thin film capacitor, hygrometer or thermometer sling
Air Movement	< 0.3 m/s	hot wire for linear air velocity or Kata thermometer for omni-directional air velocity
Carbon Dioxide	700 + outdoor ppm	real-time non-dispersive infra-red sensor
Carbon Monoxide	9 ppm	real-time electrochemical sensor
Formaldehyde	0.08 ppm	detection tubes or real-time electrochemical sensor **Reference method**: continuous air sampling with dinitrophenylhydrazine (DNPH) cartridges and analysis by High Performance Liquid Chromatography (HPLC)
TVOC	1 ppm	real-time photoionization detector (PID) **Reference method**: continuous air sampling with Tenax tube and subsequent analysis using gas chromatography and mass spectrometry (GCMS)
Respirable Suspended Particle (PM4)	50 $\mu g/m^3$	real-time optical scattering or piezoelectric monitoring **Reference method**: gravimetric analysis, beta-attenuation, tapered element oscillating microbalance (TEOM)
Particulate Matter 2.5 (PM2.5)	37.5 $\mu g/m^3$	
Total Bacteria Count	1,000 cfu/m^3 (colonial forming unit)	single-stage airborne microbial-viable impactor

GM NRB 2015 IAQ – Demonstration

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.

GM NRB 2015 IAQ – Demonstration

SS 554: Competency of IAQ Audit

Singapore Accreditation Council (SAC) accredited IAQ labs

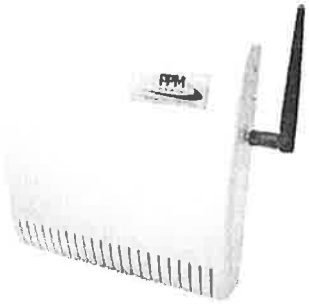
http://www.sac-accreditation.gov.sg/cab/acab/Pages/ACTL-Overview.aspx?f=LAF&a=LAF002

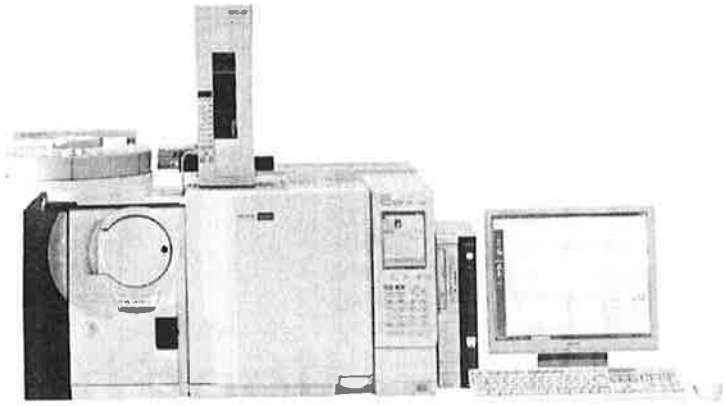
ALS Technichem (S) Pte Ltd	LA-2000-0178-F	Fountain and water feature water | Indoor Air Quality | Industrial Hygiene | Microbiological Tests in Water / Air | Soil | Stack/Source Emission | Swimming pool water | Trade Effluent | Waste/ Sludge | Water
Analytical Laboratories (S) Pte Ltd	LA-1999-0167-F	Fountain and water feature water | Indoor Air Quality | Industrial Hygiene | Stack/Source Emission | Swimming pool water | Trade Effluent | Waste/ Sludge | Water
ASTAR LABORATORY PTE. LTD.	LA-2014-0578-F	Fountain and water feature water | Indoor Air Quality | Industrial Hygiene | Microbiological Tests in Water / Air | Noise | Stack/Source Emission | Swimming pool water | Water
CAST Laboratories Pte Ltd	LA-2012-0516-F	Indoor Air Quality | Microbiological Tests in Water / Air
IAQ Consultants Pte Ltd	LA-2007-0377-F	Indoor Air Quality | Microbiological Tests in Water / Air
NUEVO LAB PTE. LTD.	LA-2014-0583-F	Indoor Air Quality
Setsco Services Pte Ltd	LA-2000-0181-F	Fountain and water feature water | Indoor Air Quality | Industrial Hygiene | Microbiological Tests in Water / Air | Soil | Stack/Source Emission | Swimming pool water | Trade Effluent | Waste/ Sludge | Water
Singapore Test Services Pte Ltd	LA-1999-0166-F	Fountain and water feature water | Indoor Air Quality | Industrial Hygiene | Microbiological Tests in Water / Air | Noise | Stack/Source Emission | Trade Effluent | Vehicle emission | Waste/ Sludge | Water
TUV SUD PSB Pte Ltd	LA-2007-0381-F	Indoor Air Quality | Microbiological Tests in Water / Air | Soil | Stack/Source Emission | Waste/ Sludge | Water

SS554 Measurement Methods

Indicative methods	Reference methods
• Handheld instruments • Instantaneous reading / trend logging • Simple and easy • Low resolution and accuracy • Reasonable measurement cost (~$50/point) • Affordable equipment cost (below $10k) • IAQ surveillance audits for commercial buildings in Singapore	• ISO, US EPA, NIOSH methods • Long sampling duration & lab analysis • Skills to handle & analyse data • High resolution and accuracy • Costly to measure (~$500/point) • Expensive equipment (above $100k) • MOM industrial workplace safety and health audits in Singapore • LEED, BREEAM IAQ testing







IAQ & IEQ Criteria in NRB v. 4.1 & 2015

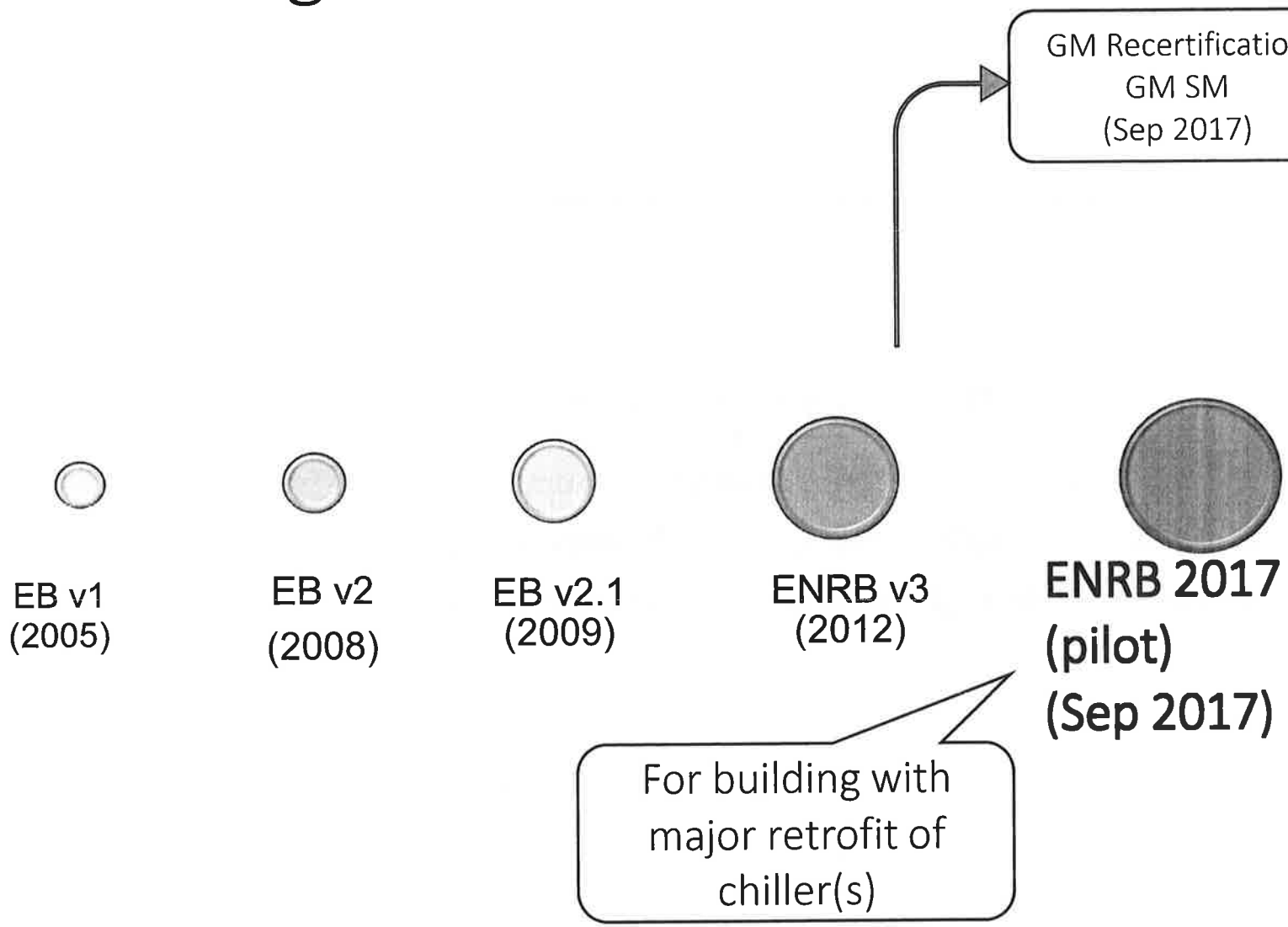
NRB V.4.1 IEQ criteria

1. Thermal Comfort
2. Noise Level
3. Indoor Air Pollutants
   - Low VOC paints
   - Adhesive with Green Labels
4. IAQ Management
   - MERV 13 filters
   - IAQ management plan
5. High Frequency Ballasts

NRB 2015 IEQ criteria (2015)

1. **Thermal Comfort** – Air temperature and Relative humidity
2. **Sound Performance** – Sound transmission, Reverberation, Sound level
3. **Visual Performance** – Daylight, Glare mitigation, CRI, Occupant control
4. **Wellbeing** – Biophilic design, Communal space, Universal design
5. **Indoor Air Quality (IAQ)**
   - IAQ Surveillance Audit
   - Post Occupancy Evaluation (POE)
   - IAQ Monitoring and Display
   - Ventilation Rates (VR)
   - Demand Control Ventilation
   - Permanent Outdoor Air Measurement & Monitoring System
   - High Performance Filtration (MERV 14 filters)
   - Low VOC paint
   - Low Emitting Materials
   - Local Exhaust System
   - Air Purging Systems
   - Ultraviolet Germicidal Irradiation (UVGI) System
   - Dedicated Outdoor Air System

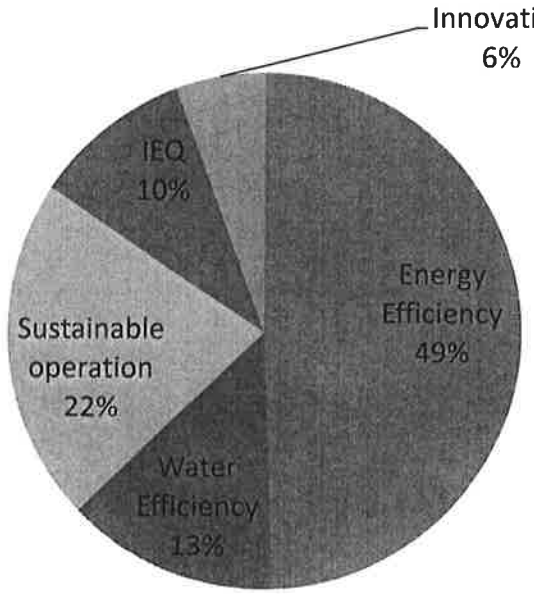
GM for Existing Non-Residential Buildings 2017



GM for Existing Non-Residential Buildings 2017

Review: GM EB v.3 IEQ components

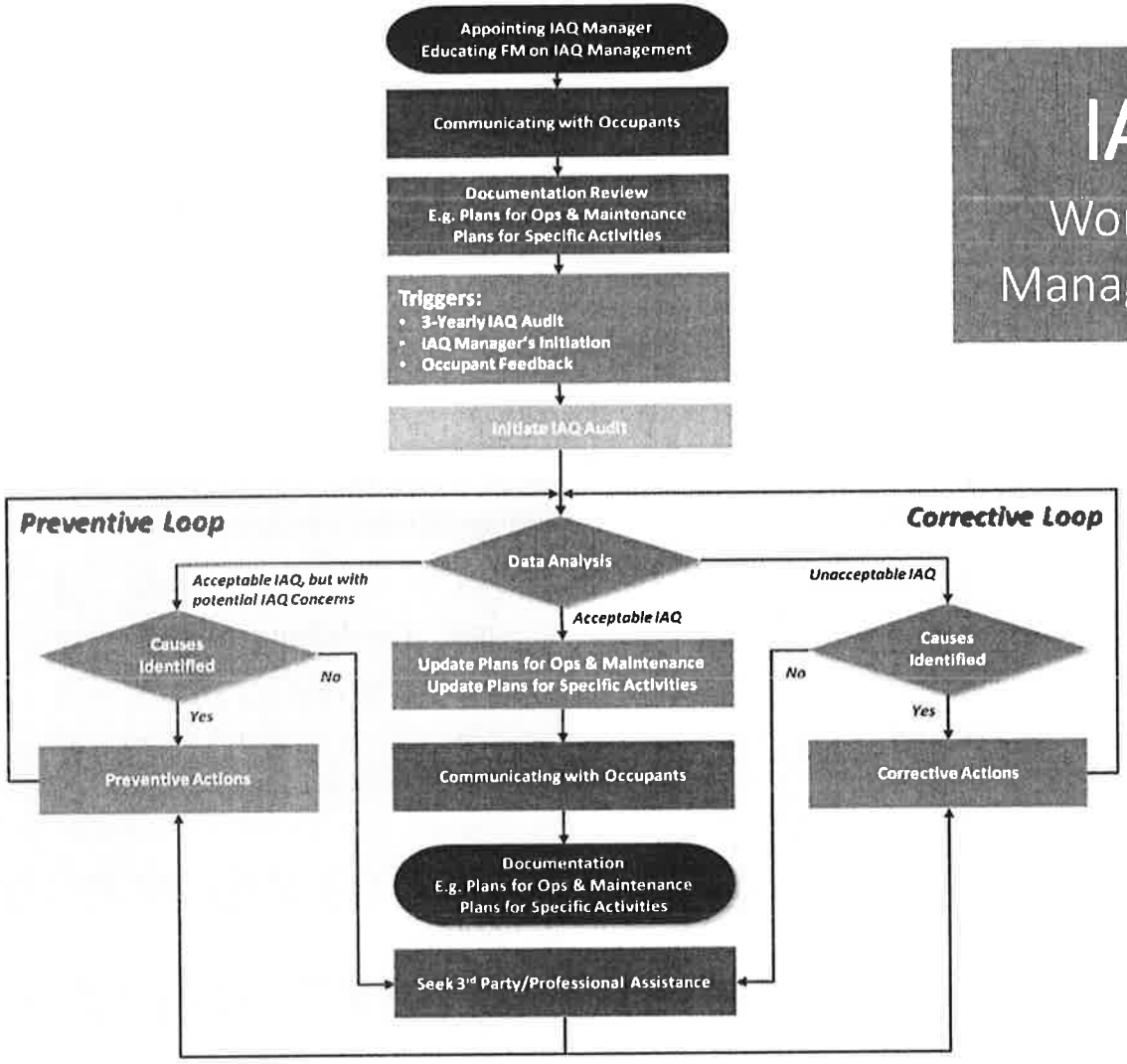
EB v.3	Part 4. IEQ criteria description	Points
1	Conduct IAQ audit	4
2	IAQ management plan	1
3	MERV 13 filter	1
4	Room temperature display	1
5	Carbon dioxide level display	1
6	Low VOC paints	1
7	Environmentally friendly adhesives	1
8	Lighting level	1
9	Lighting control & task light	2
10	High frequency ballast	2
11	Thermal Comfort (Temp, RH)	1
12	Temperature control	1
13	Internal Noise Level	1
	Total	**18**
	Part 4. IEQ	**10%**



GM EB v.3

1	CO2 sensor to regulate fresh air	1
2	Post Occupancy Evaluation (POE)	2
3	POE corrective actions	1
4	Sustainable Products	8
5	Green procurement policy	1
	Total	**31**
	Total IEQ	**17.2%**

GM for Existing Non-Residential Buildings 2017



IAQ Management Plan

Workplace Safety and Health Guidelines
Management of IAQ in air-coned workplaces

1. Appoint IAQ manager
2. Attend IAQ management courses – GMFP, NEA Sei, WDA modules etc.
3. Educate FM team on IAQ management
4. Follow WSH Guidelines on IAQ management



https://www.wshc.sg/files/wshc/upload/infostop/attachments/2016/IS20160322000000396/WSH_Guidelines_on_Management_of_IAQ.pdf

GM for Office Interior V.1.1 – IAQ Requirements

Part 4 – Indoor Environmental Quality

4-1 IAQ Performance

Encourage and recognize good indoor air quality (IAQ) to ensure the comfort and well-being of office occupants

(a) Conduct IAQ audit once every three years and ensure that the following recommended IAQ parameters are met

Note : IAQ parameter recommended by NEA's Guidelines for Good Indoor Air Quality in Office Premises or *Singapore Standard Code of Practice for "Indoor Air Quality for Air-conditioned Buildings"*

(b) Develop an active IAQ management programme

(c) CO2 monitoring to ensure delivery of sufficient/ minimum outside air requirements

4-2 Indoor Air Pollutants

Minimise airborne contaminants, mainly from inside sources to promote a healthy indoor environment.

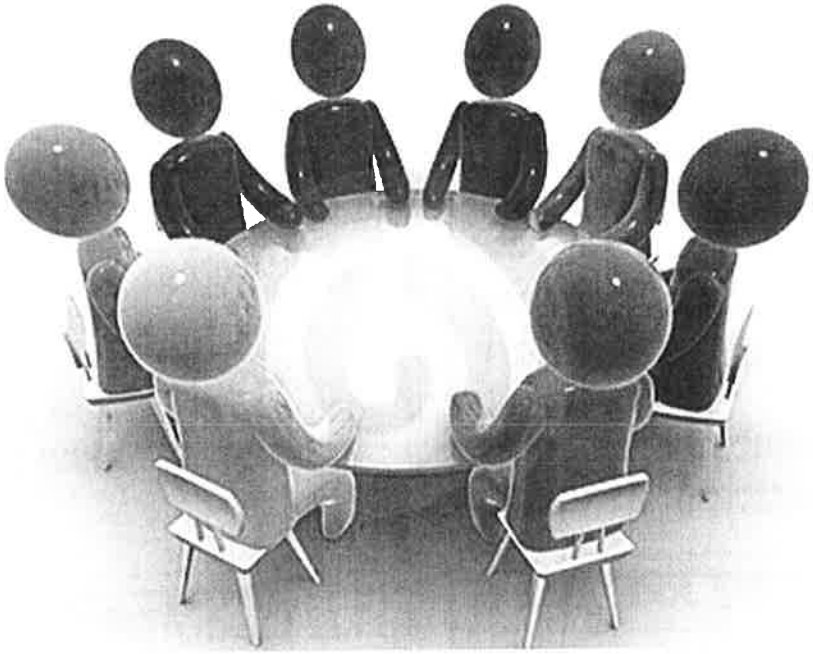
Use and purchase of sustainable and environmentally friendly products such as

- cleaning products recognised by approved local certification body or equivalent
- environmental -friendly janitorial paper products
- Office stationery

Setting of sustainable and environmentally friendly procurement and purchasing policy

Thank You

Q&A Discussions



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
2016

v2016.12



v2016.12



Topics

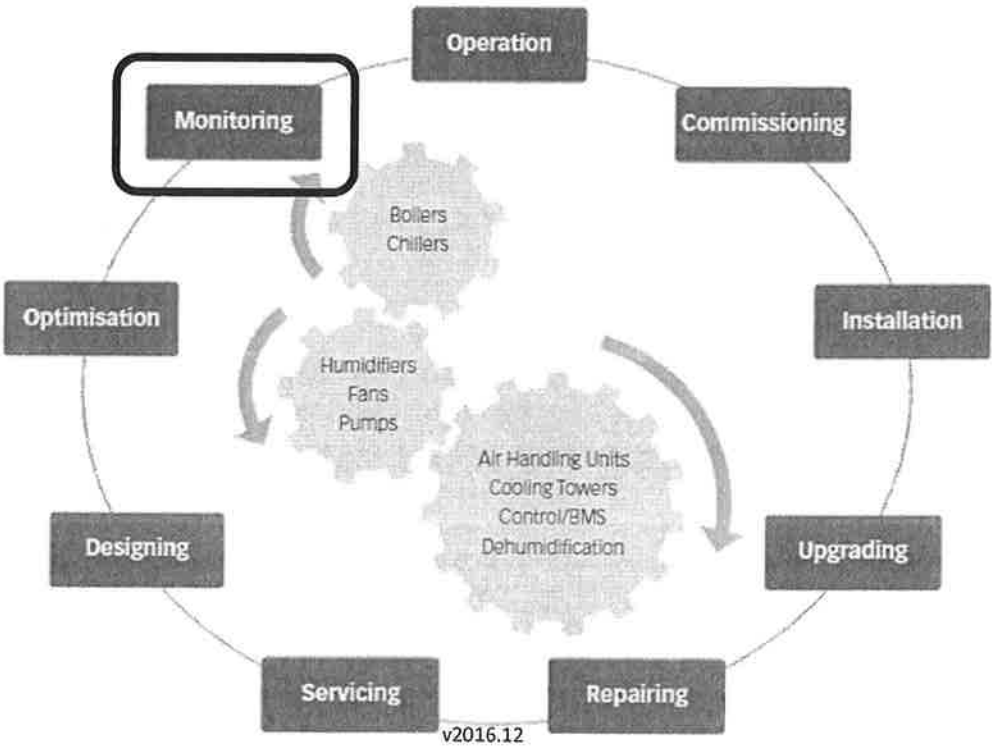
- Air Conditioning & Mechanical Ventilation (ACMV) for Good IAQ
  - **Inspection of ACMV System**
  - ACMV Operations and Maintenance
  - Ventilation and Filtration Systems
  - Causes of Poor IAQ in Tropical Climate
  - Energy Efficient Methods of Control
  - Relative Humidity to improve IAQ
- Measurement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

Reference Material

- SS553:2016: Singapore Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings
- SS554:2016: Code of Practice for Indoor Air Quality for Air-Conditioned Buildings

Updates on SS553:2016

The main changes made in this revision are as follows:

1) New outdoor air intake and purging of indoor air requirement for air handling systems.
2) New efficiency reporting method and equipment to improve air filtration standards in an air-conditioned space, in accordance with MOH guidelines.
3) Addition of equipment accuracy requirement for room temperature controls, modulating control valves and air temperature sensors.
4) Addition of chilled water temperature difference requirement for cooling coils of air handling units.
5) Raising full and part load fan power limitations for air handling units and car park fan systems, in accordance with ASHRAE Standard 90.1 : 2013.
6) Addition of location requirement for plants to provide ease of maintenance, replacement and specific functions unique to the plant equipment.
7) Raising motor power requirement for better control demand of pumping system.

Updates on SS554:2016

This code is a revision of SS 554: 2009. The key changes include:

a) Aligning acceptable limits of indoor air quality parameters to national and international standards.
b) Specifying the reference methods and indicative methods where relevant.
c) Enhancing the recommended filter ratings and providing information on filter use.
d) Specifying the number of sampling points according to floor sizes and ventilation types, in addition to number of floors.

Inspection of ACMV Systems

v2016.12

(informative)

Sample checklist for building inspection

NOTE – A walk-through inspection should include the premises, its air-conditioning system and any other ventilation installations. The purpose of the inspection is to identify irregularities. The following checklist is provided as a guide and is not meant to be exhaustive. Where necessary, assistance should be sought from the building manager.

1 Human exposure and comfort levels

1.1 Is the indoor temperature regulated by thermostats? Where are they located? Have they been correctly positioned following building alterations? Are they set to the correct temperature? Are they calibrated regularly?

1.2 Is there discomfort due to radiant heat from warm window surfaces? Or other heat sources?

1.3 Does air reach all parts of the office or are there dead spaces (use a smoke dete to test)?

1.4 Does the occupant sit directly under the air diffuser?

1.5 Is the building still used for the purpose it was intended? Have partitions/walls be or removed? Have occupancy levels changed?

1.6 Is there any twisted flexible duct?

2 Potential sources of contaminants

2.1 Is there any equipment which gives off gases or fumes? If so, is the equipment with separate exhaust ventilation? Does the exhaust convey air to the exter building or into corridors or into the air-conditioning system?

2.2 Are there furniture, furnishings, carpets, etc. that emit noticeable odours detergents, pesticides or other chemicals been used in the building?

2.3 Are renovation works being undertaken in any part of the building? Are they done during working hours? Are the air-conditioning ducts properly sealed to prevent infiltration to other units?

2.4 Is there a kitchen or pantry where cooking is done? Is exhaust ventilation provided there?

2.5 Is the building adequately cleaned? Is regular dusting of office furniture, ledges, shelves, etc. carried out to help keep dust to a minimum? Are the carpets vacuum-cleaned regularly?

3 Ventilation and air-conditioning

3.1 How many supply air and extract air vents are there in each room or area? Is there at least one each in every room?

3.2 Are vents located in positions that will permit the best air circulation?

3.3 Are supply air or extract air vents blocked in any way by partitions, files or other that obstruct air flow? Has dust collected around the air vents?

3.4 Is the air-conditioning system turned off any time during the day?

3.5 Is the system turned off after office hours? Are there still occupants in the building after office hours?

3.6 Where is the outdoor air intake duct located? Is it near the cooling tower in this building or near adjacent buildings? Is it near any kitchen exhaust? Is it at street level or near a car park? Is it blocked? Are heavy industries located nearby? Is there any construction work going on nearby? Does outdoor air enter the building?

3.7 Are filters being used? Are they adequate? Are they being bypassed? How often are they replaced?

3.8 Is there a regular schedule for cleaning and maintenance of the air-conditioning system in the building? Are all the components of the air-conditioning system regularly inspected for leaks, breaches, etc.?

Sample Inspection Checklist (Annex G)

Source: SS554:2016

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)

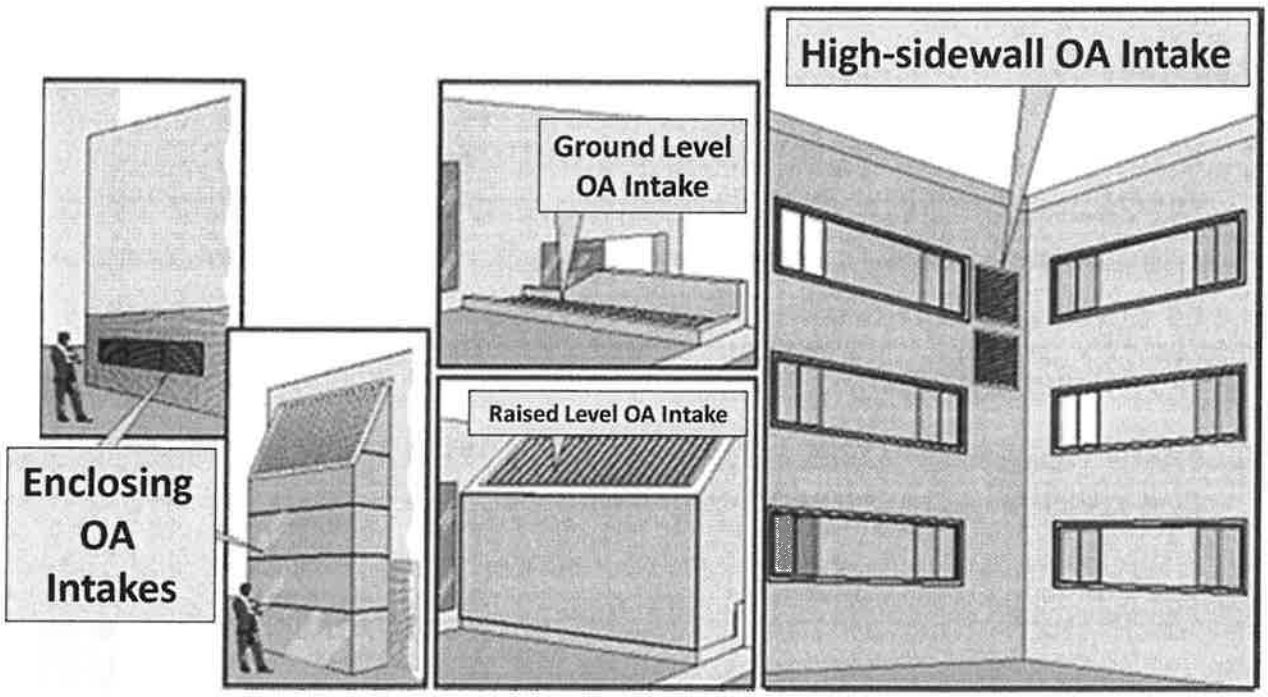
Poor Indoor Air Quality due to ACMV Systems (II)

- 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
101 - 200	Unhealthy
201 - 300	Very unhealthy
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.

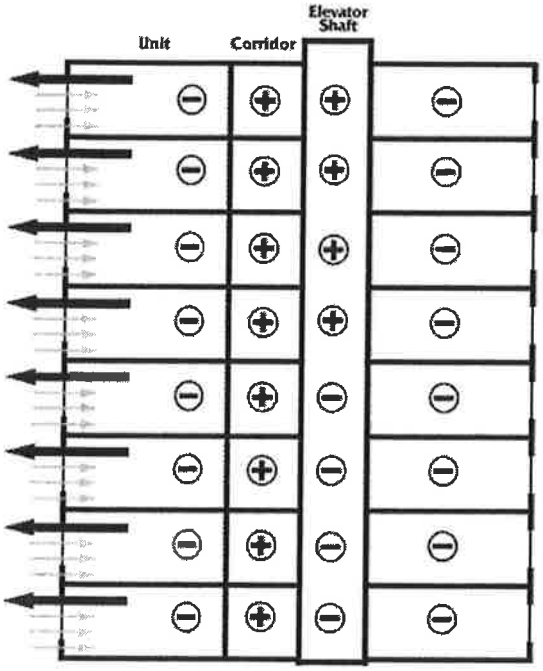
Relative pressurisation of isolation wards to corridors/adjacent rooms?

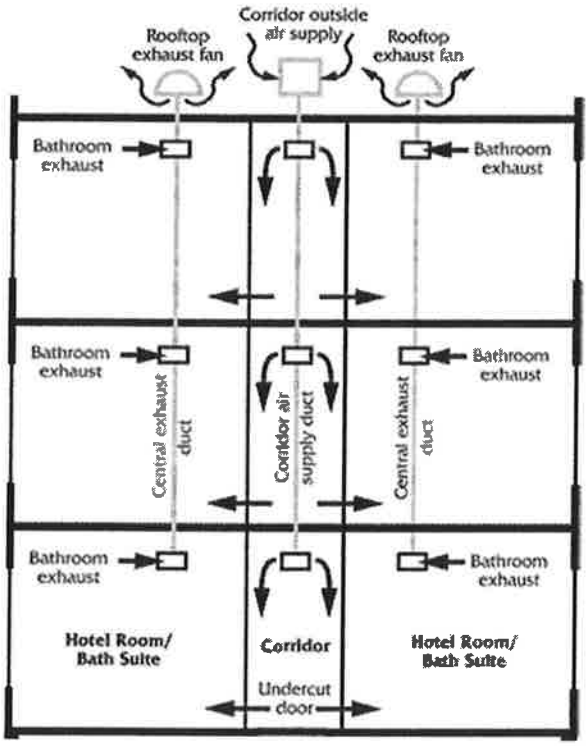
Relative pressurisation of operation theatres to corridors/adjacent rooms?

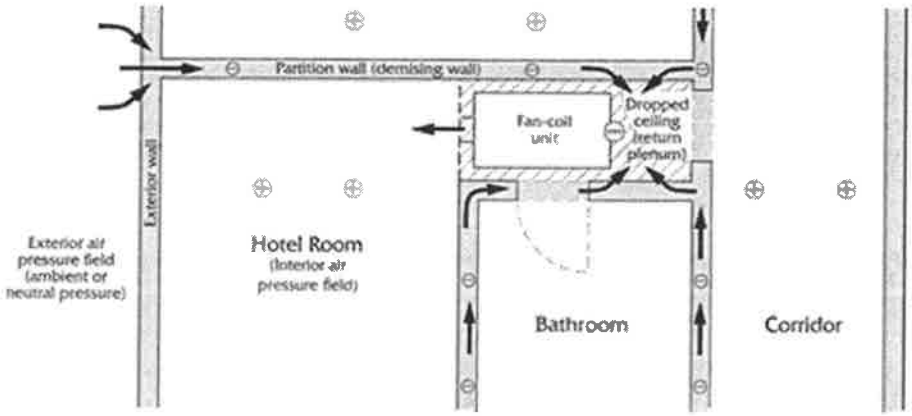
Relative pressurisation of bin centres to corridors/adjacent rooms?

Relative pressurisation of kitchen to corridors/adjacent rooms?

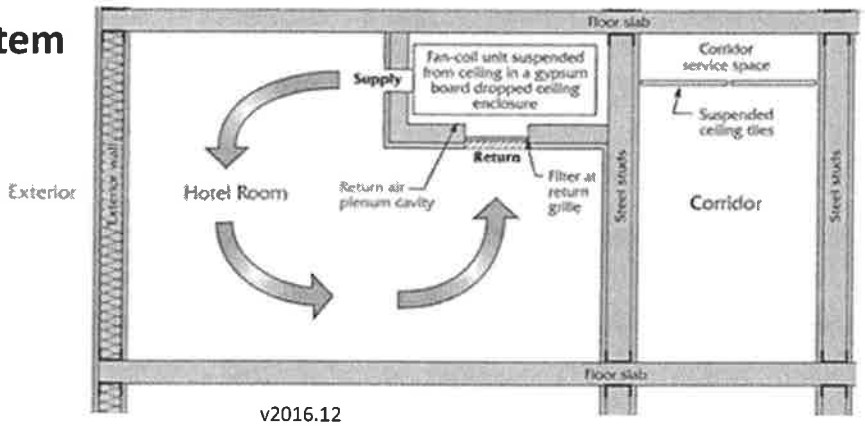
Relative pressurisation of toilets to corridors/adjacent rooms?



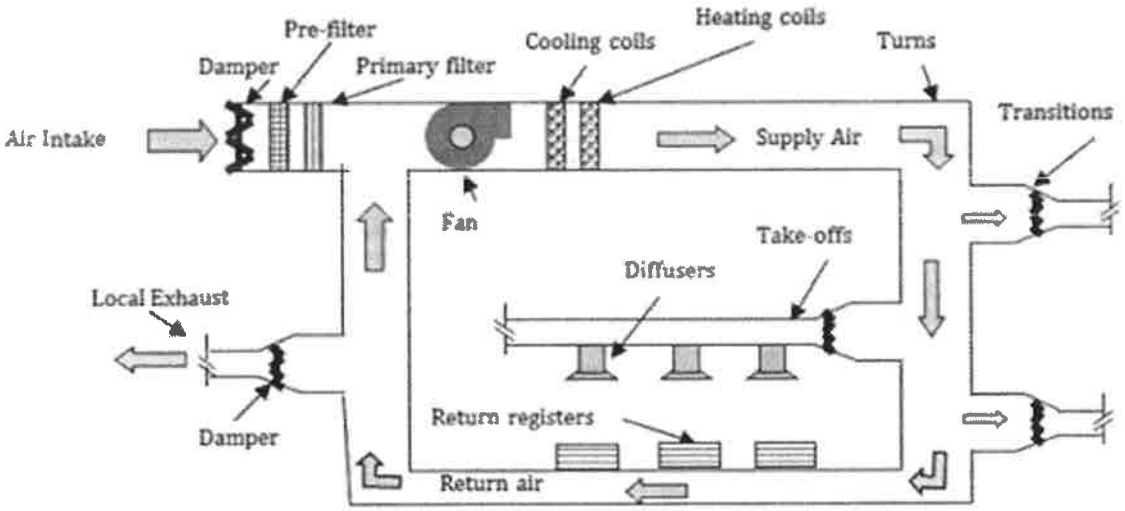




With Split AC System



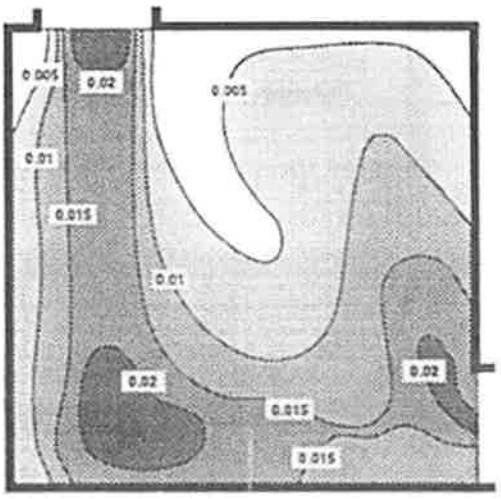
Typical System affecting Air Pressurisation



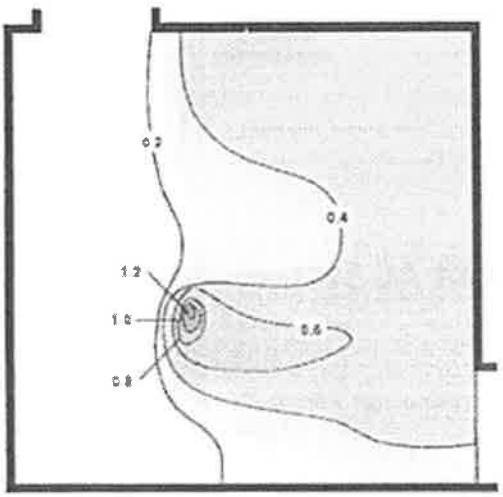
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Source: TSI

Design and Distribution of Air Flow



Turbulence Diffusion Profile



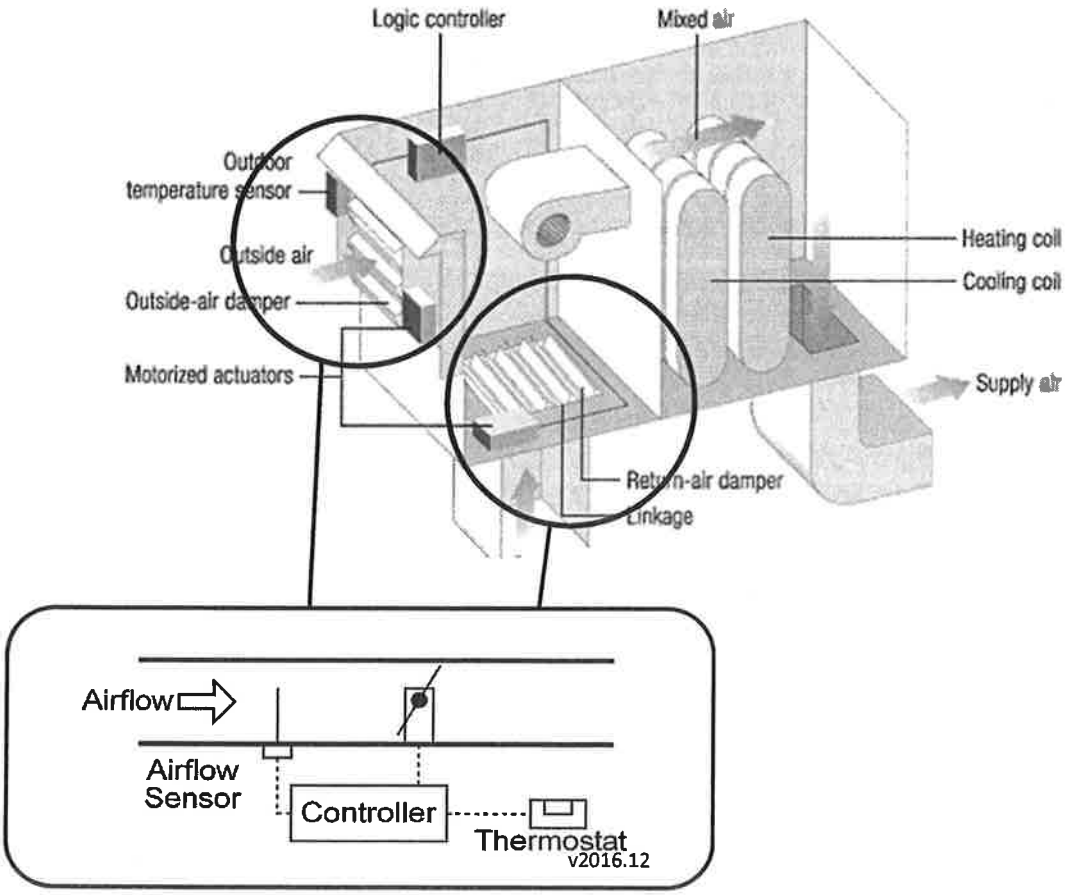
Air Pollutant Dispersion Profile

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Source: Yamamoto et. al.

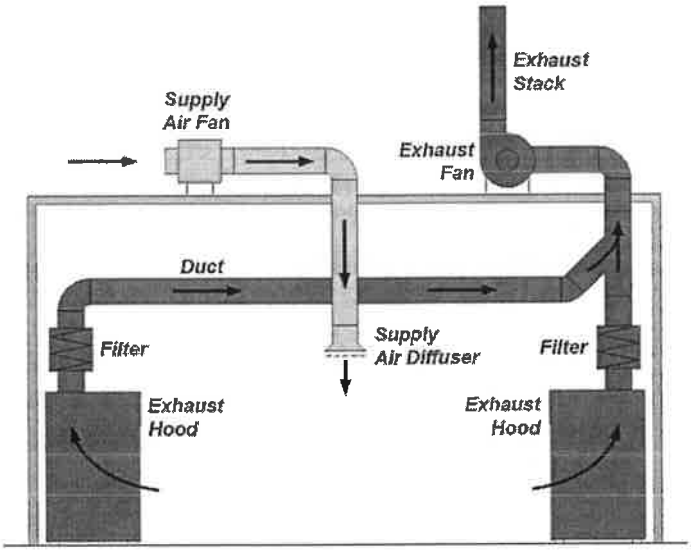
Position of Dampers

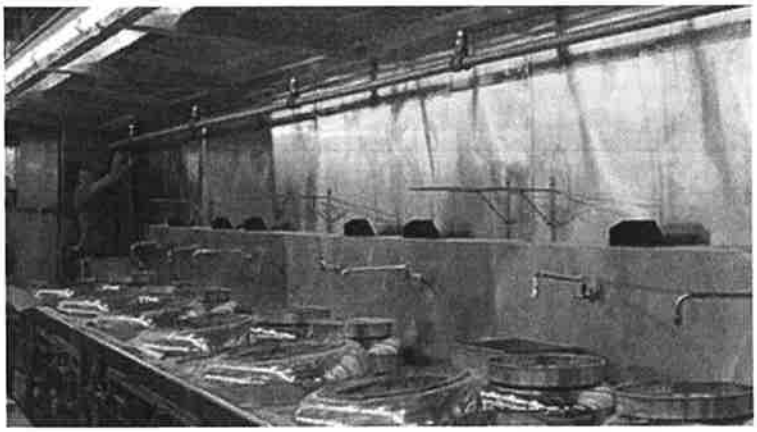
- Dampers are used **as controls to restrict airflow**. Damper positions may be relatively fixed (e.g., set manually during system testing and balancing) or may change in response to signals from the control system.
- The amount of outdoor air introduced in the occupied mode should be sufficient to meet 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)

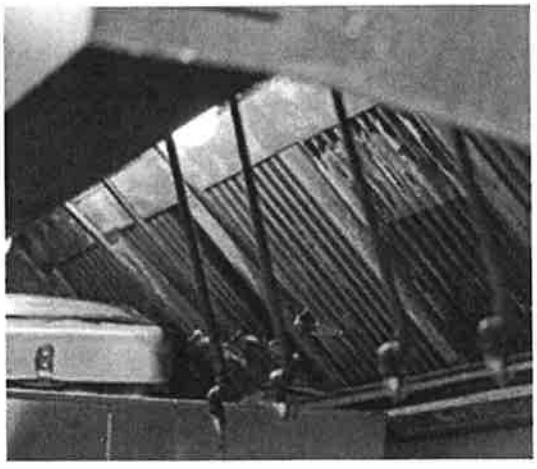
- Kitchens, laboratories, carparks, bin centres, toilet, and other specialised areas may be a source of pollutants when they lack adequate local exhaust ventilation.











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.

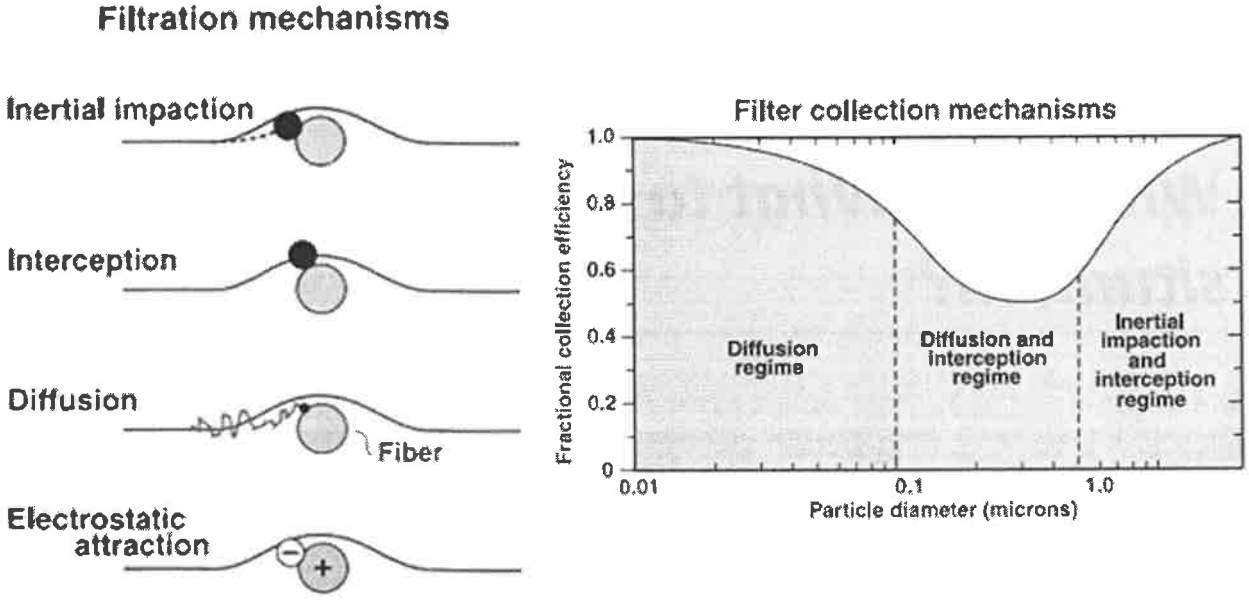
. Particulates (DUST)
· Gas & Vapour
· Microbial

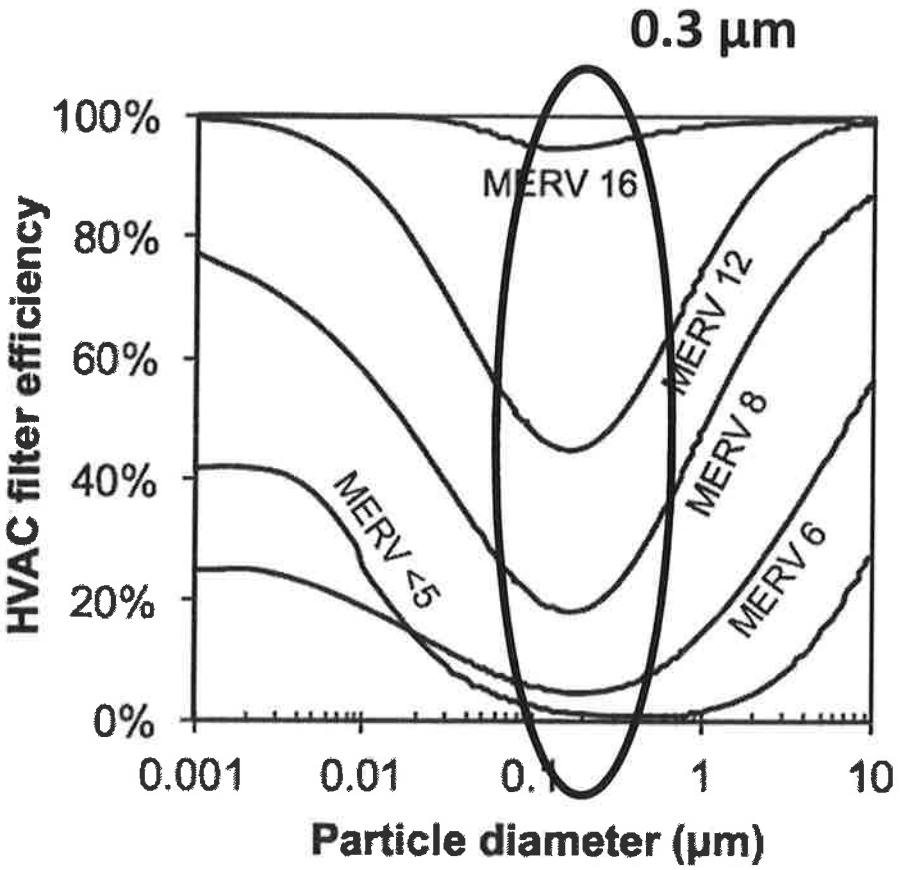
When and What to use for each situation?

Particulate Air Filtration (I)

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

Primary Mechanical Filtration Mechanisms

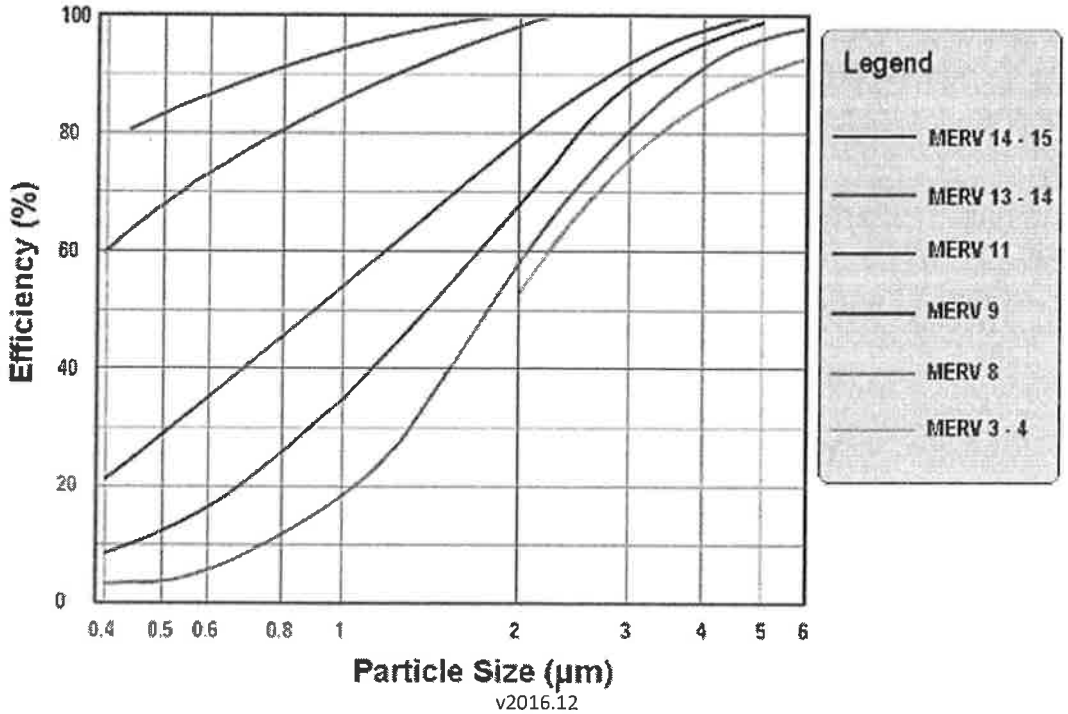




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3 to 5 months for filter cake to grow.

Initial Performance of Filters



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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.

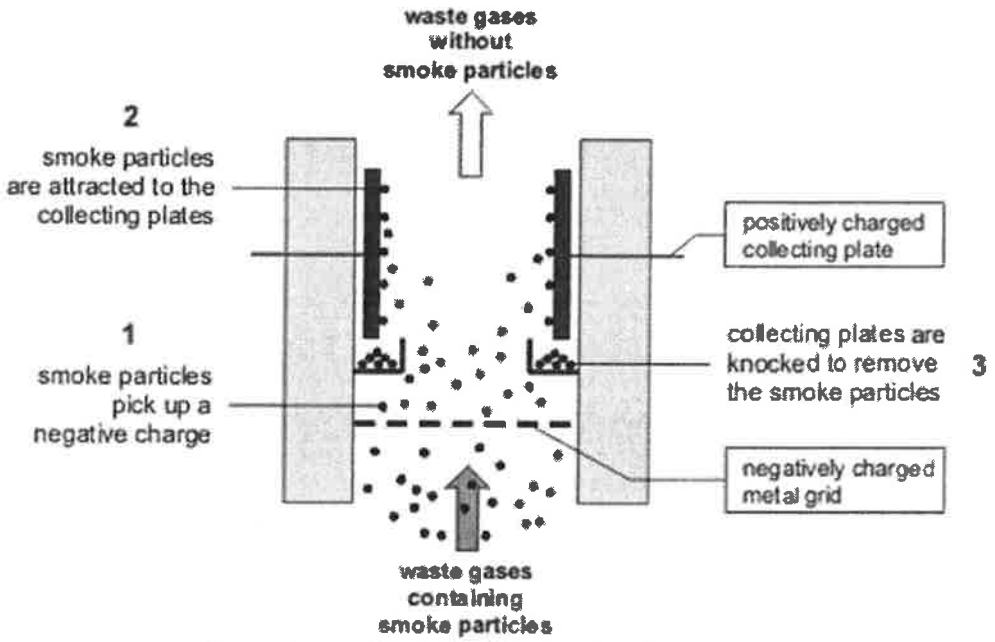
- Electrostatic filters, which are composed of polarized fibers, may lose their collection efficiency over time or when exposed to certain chemicals, aerosols, or high relative humidities.

Electrostatic Precipitator

- 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.



Electrostatic Precipitator

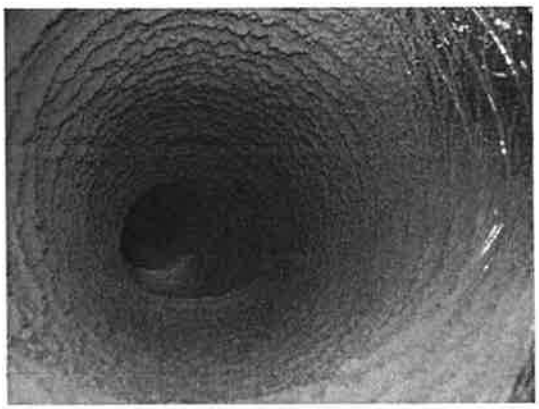
Gas-Phase Air Cleaning

- Sorbent filters 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.







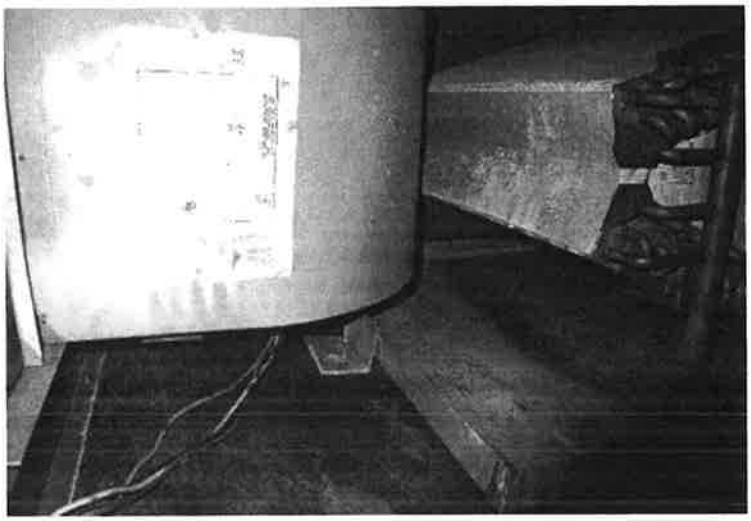


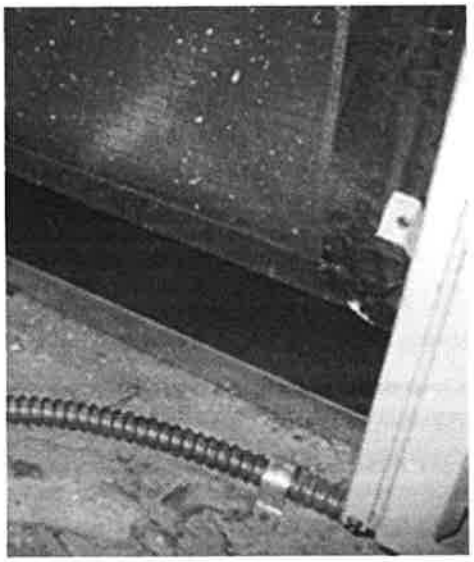
Duct Cleaning

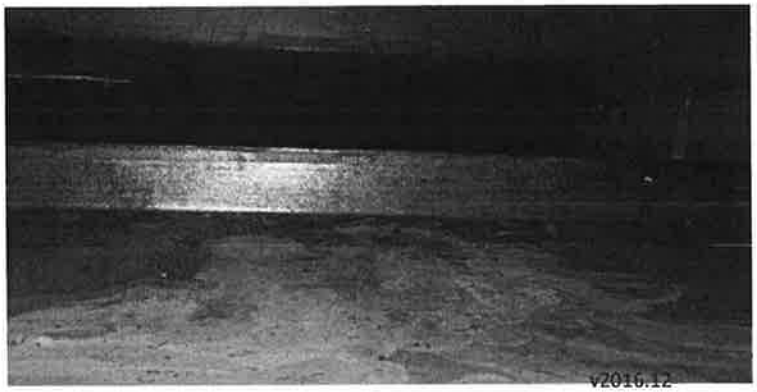
- Duct cleaning may be appropriate in the following circumstances:
  - Permanent or persistent water damage in ducts
  - Slime or microbial growth observed in ducts
  - Debris build-up in ducts that restricts airflow
  - Dust discharging from supply diffusers
  - Offensive odours originating in ductwork,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

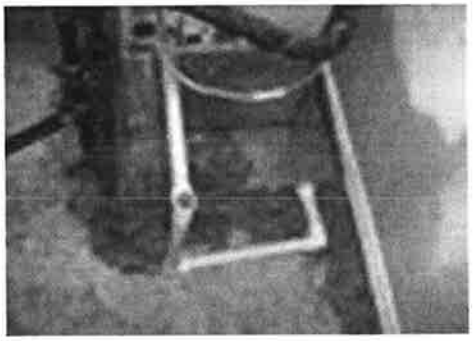
Presence of Water Leaks or Standing Water

- **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.









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US & Canada

Legionnaires' outbreak widens to 12 dead in New York

11 August 2015 | US & Canada

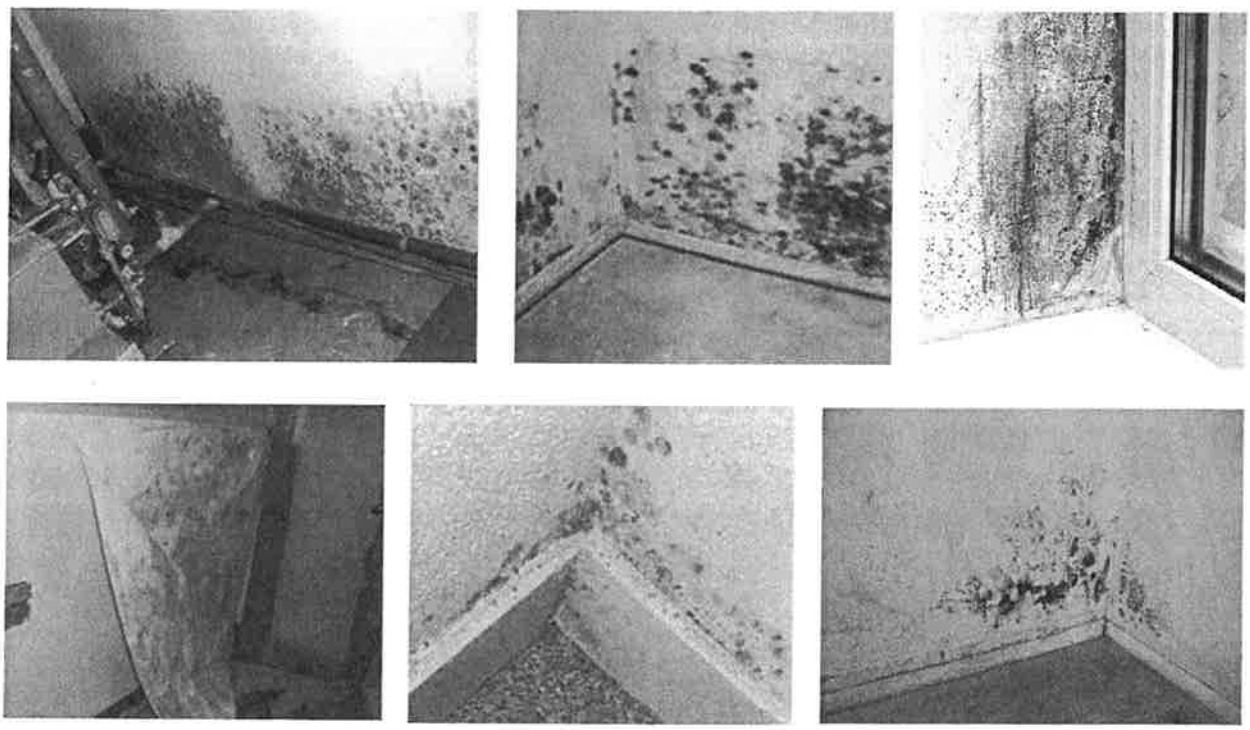


Water-Damaged Building Material

- 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
2016

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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)

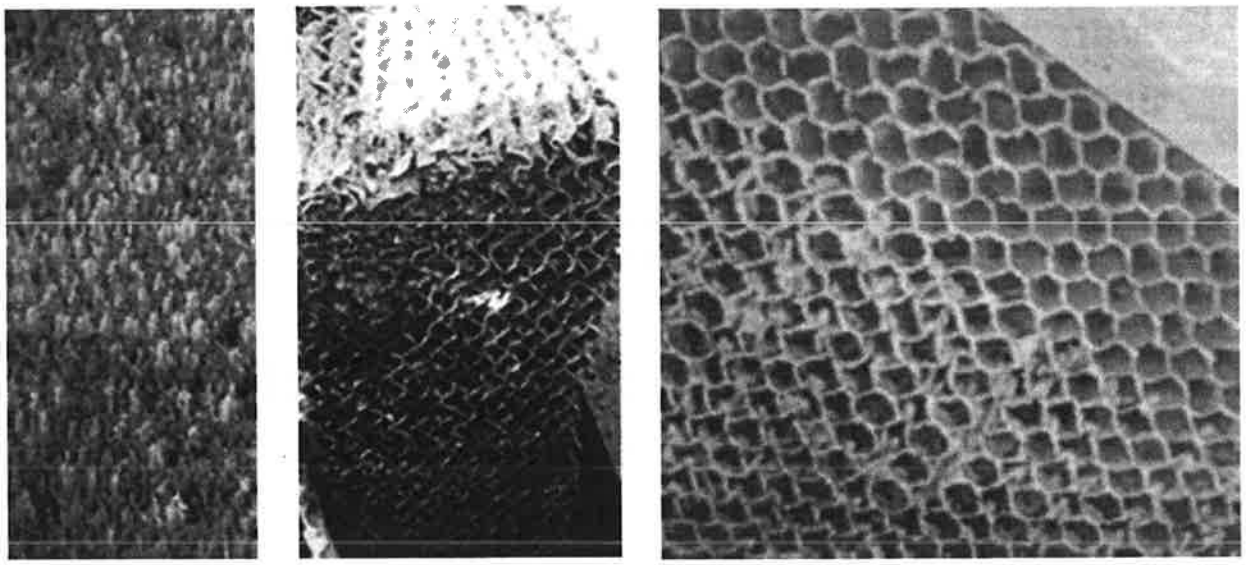
- Water leaks from pipes and faulty valves to be eliminated

- 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)

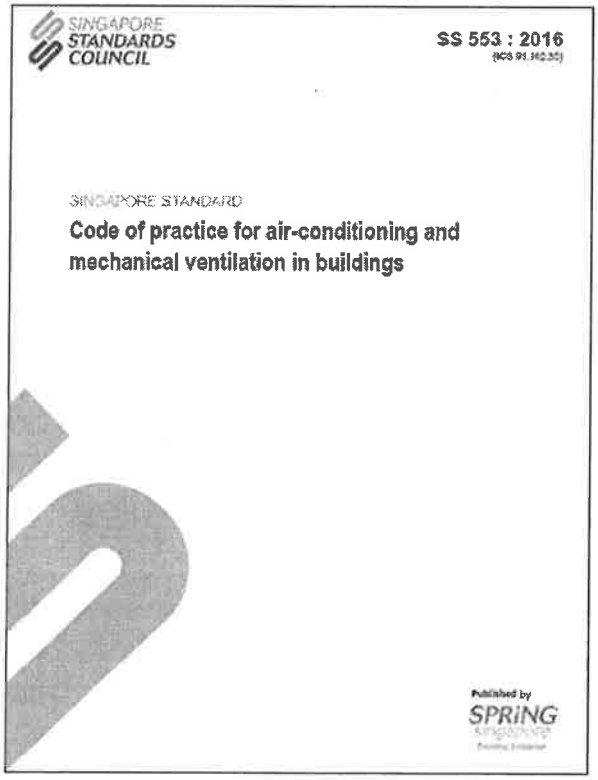
- Ensure control parameters such as temperature, RH and operating times are not wasteful.

- 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

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Ventilation and Filtration Systems



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."

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Source: SS553:2016

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

Return, Transfer or Exhaust

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: SS553:2016

Air Recirculation

Return, Transfer or Exhaust

Class 1 air may be recirculated or transferred to any space.

Class 2 air may be recirculated within the space of origin. It may be transferred to other Class 2 or Class 3 spaces utilised for the same or similar purpose involving the same or similar pollutant sources. It may also be recirculated or transferred to Class 4 spaces. Class 2 air shall not be recirculated or transferred to Class 1 spaces.

Class 3 air may be recirculated within the space of origin. Class 3 air shall not be recirculated or transferred to any other space.

Class 4 air shall not be recirculated or transferred to any space or recirculated within the space of origin.

Source: SS553:2016

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
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 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

**Gym: New in 2016 ed.*

Source: SS553:2016

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
(ii) Car parks	6
(iii) Toilets, bathrooms	10
(iii) Lobbies , concourse, corridors, staircases and exits	4
Kitchens (commercial, institutional and industrial)	(iv) 20

Source: SS553:2016

Air Filtration

Obsolete, 2009 edition

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

Obsolete, 2009 edition

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

Air Filtration

New Requirements in 2016 Edition

7.5.3 The Minimum Efficiency Reporting Value (MERV) for cleaning the air in all air-handling units shall be equivalent to MERV 6 or better, and MERV 14 when the outdoor pollution level is in the unhealthy range in accordance with MOH's guidelines. The MERV for cleaning outdoor air supplied to fan coil units shall be equivalent to MERV 6 or better, and MERV 14 when the outdoor pollution level is in the unhealthy range in accordance with MOH's guidelines. Fan motors shall be sized such that the required air flow rate can be maintained.

- Normal Outdoor Quality: MERV ≥ 6
- Unhealthy Range: MERV ≥ 14

Source: SS553:2016

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.

Hazy conditions may persist overnight due to Sumatra fires: NEA



Photo: Reuters

UPDATE: The 3-hr PSI reading is just under the unhealthy level of 100 at 6pm. 101-200 is considered unhealthy. At 5pm, the PSI level had hit 103.

v2016.12

Climate of Singapore

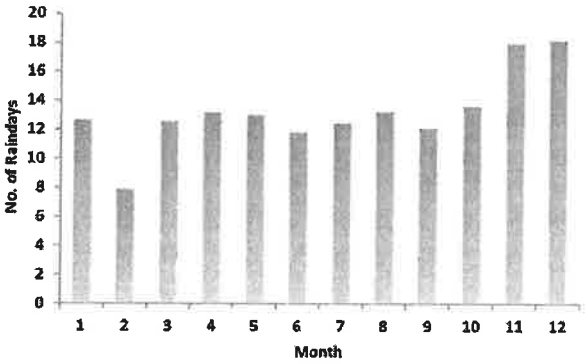
- Singapore is situated near the equator and has a typically tropical climate, with abundant rainfall, high and uniform temperatures, and high humidity all year round.

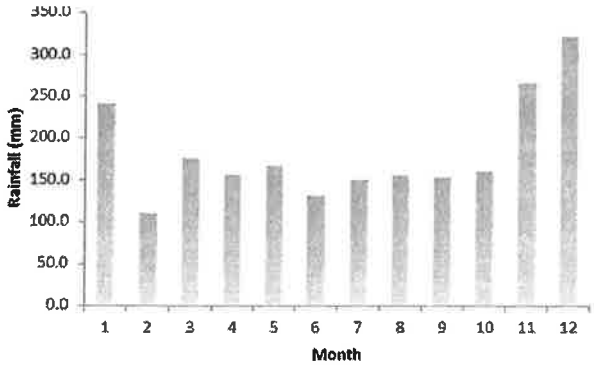
- Many of its climate variables, such as temperature and relative humidity, do not show large month-to-month variation. However, many variables exhibit prominent diurnal (or daily) variations from hour to hour, indicating the strong influence that solar heating has on the local climate.

Rainfall

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

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





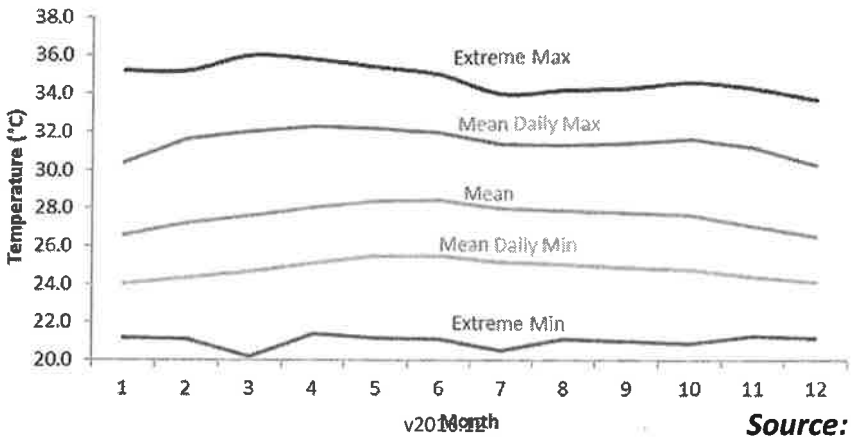
v2016.12

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).

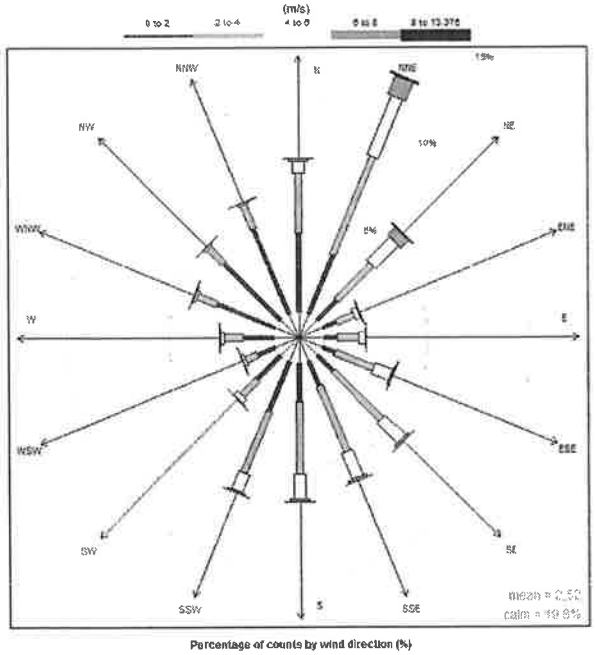


v2016.12

Source: weather.gov.sg

Surface Wind

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



Percentage of counts by wind direction (%)

- 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.

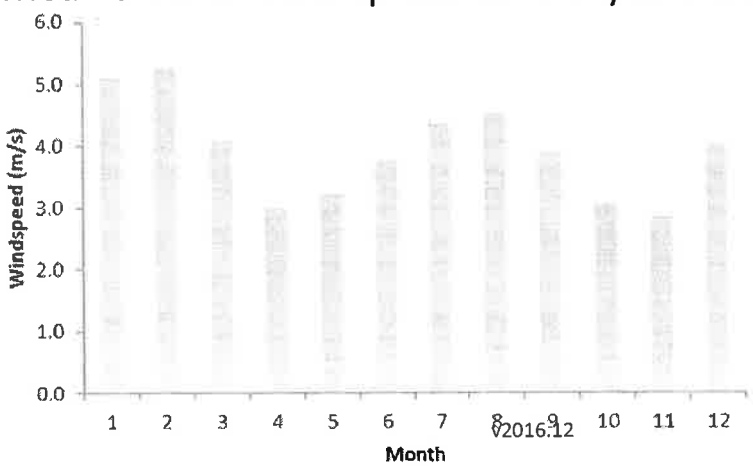
v2016.12

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.



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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.

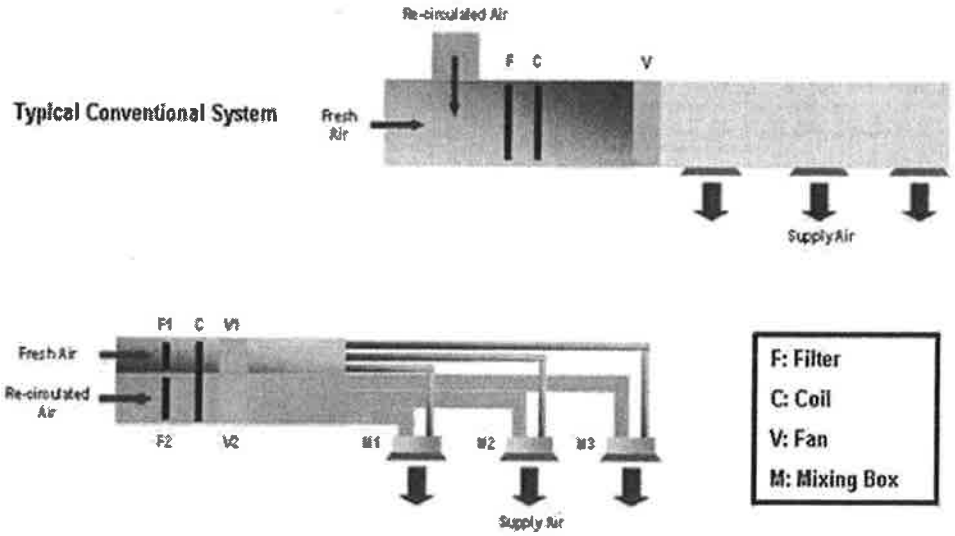
- **Chillers**: Chiller technology has maintained a steady state of advancement for many decades.

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

Single Coil Twin Fan System (I)



Single Coil Twin Fan System

v2016.12

Source: Tham et. al.

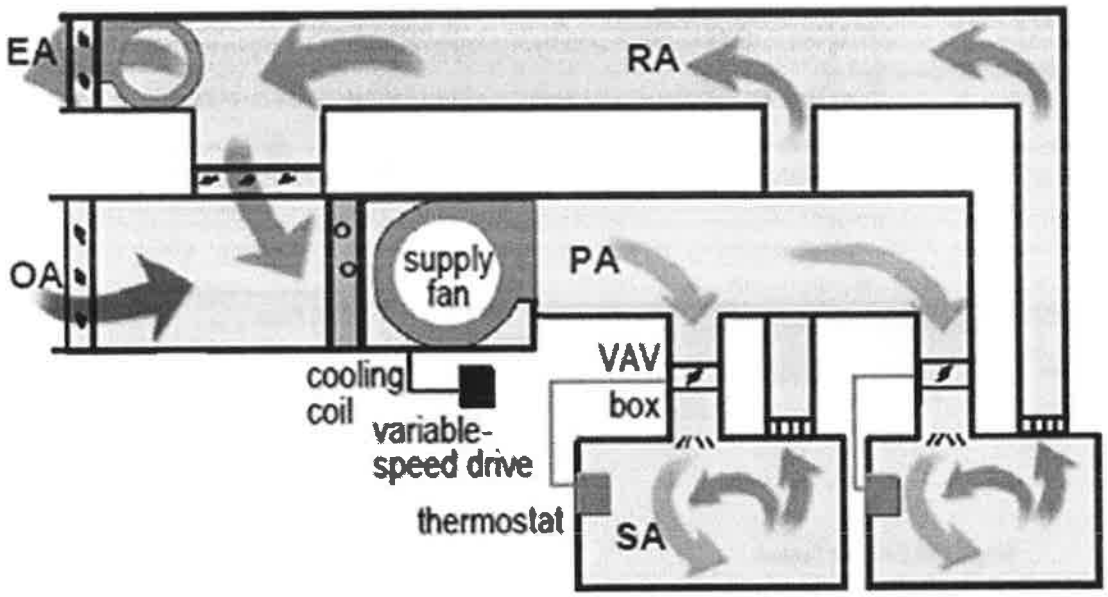
Single Coil Twin Fan System (II)

- The newly developed SCTF system with the compartmented coil conditions distributes air through the multiple zones of an air-conditioned building such that adequate ventilation, and consequently, acceptable Indoor Air Quality (IAQ) is ensured throughout the operating range of the air-conditioning system.
- The compartmented coil of the SCTF system has shown an energy saving potential of **12 %**.
- A basis is provided for an integrated design of the cooling and dehumidifying coil that derives the optimal energy efficiency of the coil while achieving the desired cooling and dehumidifying performance and is envisaged to be of immense benefit in maintaining good indoor air quality in tropical buildings.

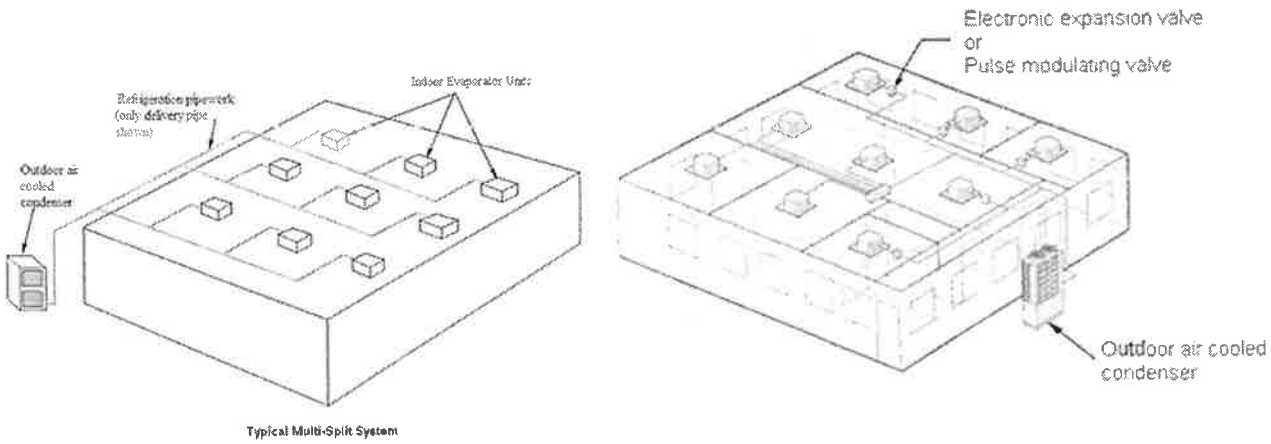
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Source: Tham et. al.

Variable Air Volume System



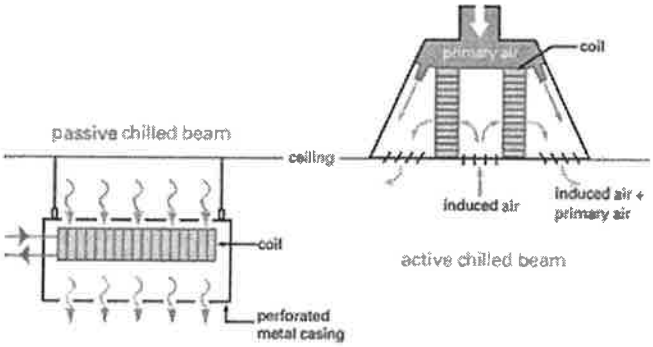
Variable Refrigerant Flow System

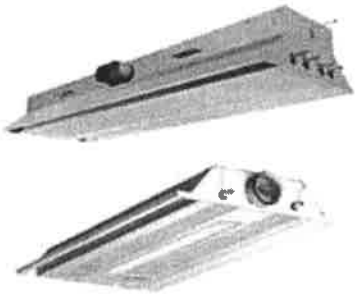


Typical Multi-Split System

VRV is a trademark of Daikin Industries, Ltd.

Chilled Beams





Relative Humidity to improve IAQ

Indoor Thermal Environment

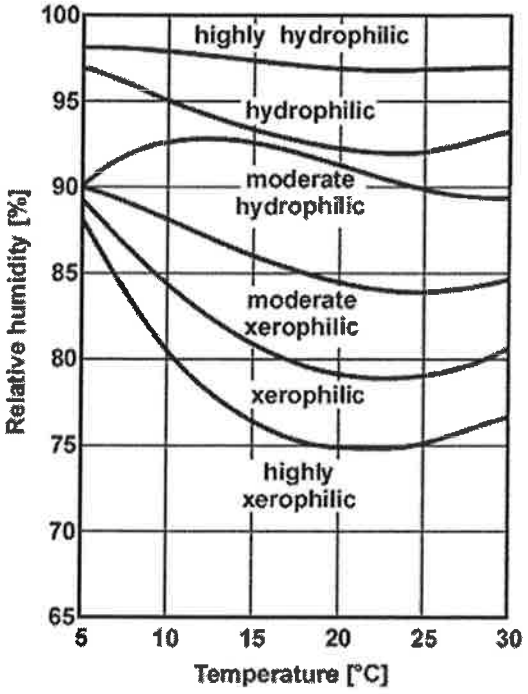
- When the air-conditioning system is in operation, the air temperature should be maintained within 24 to 26 °C, and the air movement should not exceed 0.30 m/s, and the average relative humidity should not exceed **65 % for buildings designed to SS553/SS554**, and **70 % for other buildings**.

Source: SS553:2016



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
2016

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Topics

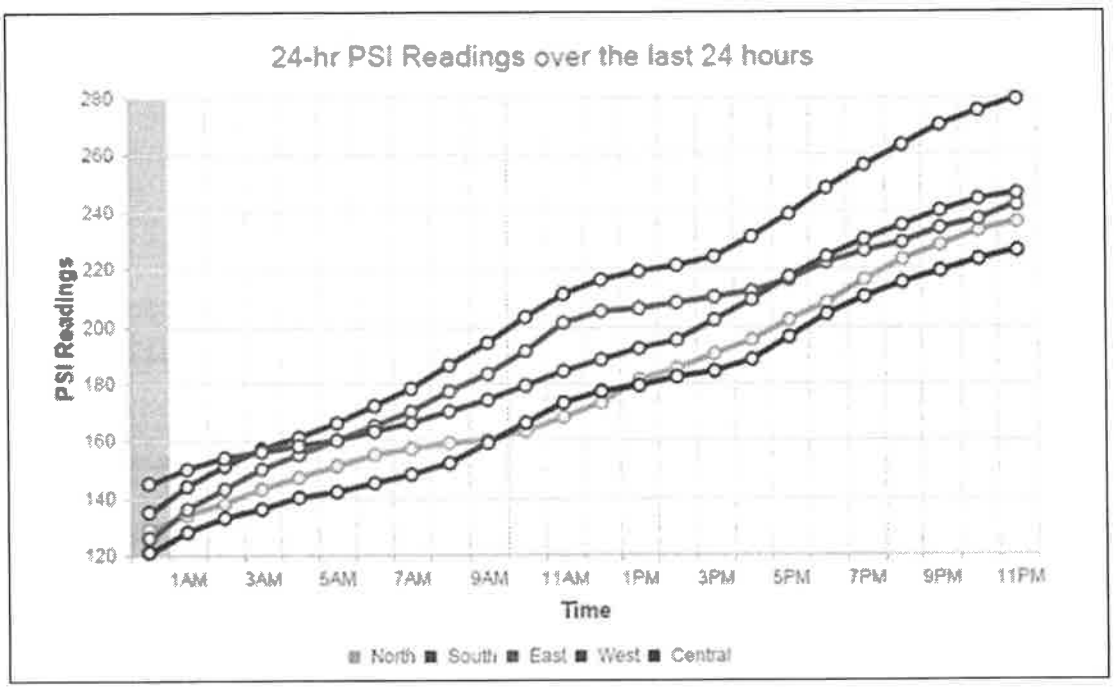
- Air Conditioning & Mechanical Ventilation (ACMV) for Good IAQ
  - Inspection of ACMV System
  - ACMV Operations and Maintenance
  - Ventilation and Filtration Systems
  - Causes of Poor IAQ in Tropical Climate
  - Energy Efficient Methods of Control
  - Relative Humidity to improve IAQ

- **Measurement and Instrumentation**

Pollutant Standard Index (PSI)

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PSI Readings: 24 September 2015



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Pollutant Standard Index (PSI)

- The PSI is based on **6 pollutants**:
  - PM_{10}
  - $PM_{2.5}$
  - SO_2
  - CO
  - O_3
  - NO_2

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

New Acceptable Limit Values
Recommended IAQ Parameters

Parameter	Acceptable Limit for 8 h
Temperature	23 ~~26 – 26~~ 24 °C
Relative Humidity	<65 % (designed to SS553/554); <70 % (others)
Air Movement	< 0.30 m/s
CO_2	700 ppm above outdoor
CO	9 ppm (8 h); 31 ppm (1 h)
HCHO	100 µg/m³ (30 min)
TVOC	1000 ppb
PM 4 RSP	50 µg/m³ (24 h)
$PM_{2.5}$	37.5 µg/m³ (24 h)
Total Viable Bacterial Count	~~500~~ 1000 cfu/m³

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Source: SS554:2016

New Acceptable Limit Values
Triggered by Sources

Parameter	Acceptable Limit for 8 h
NO_2	40 µg/m³
O_3	0.05 ppm
Radon	100 Bq/m³
Asbestos	0.01 fibre/cc
Nicotine	< 0.01 µg/m³
SVOC	PEL of Toxic Substances

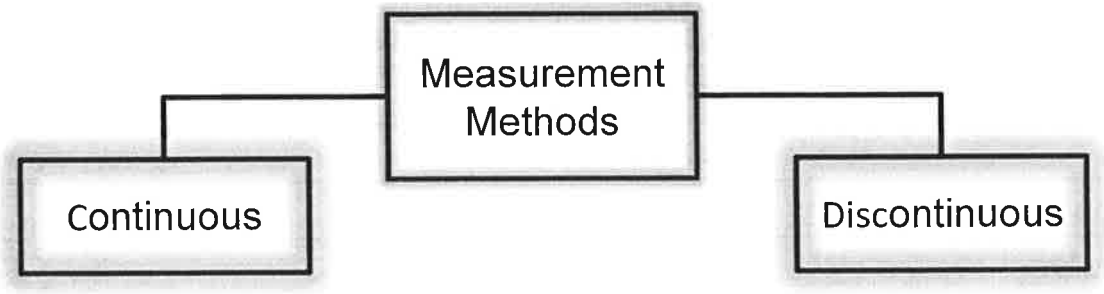
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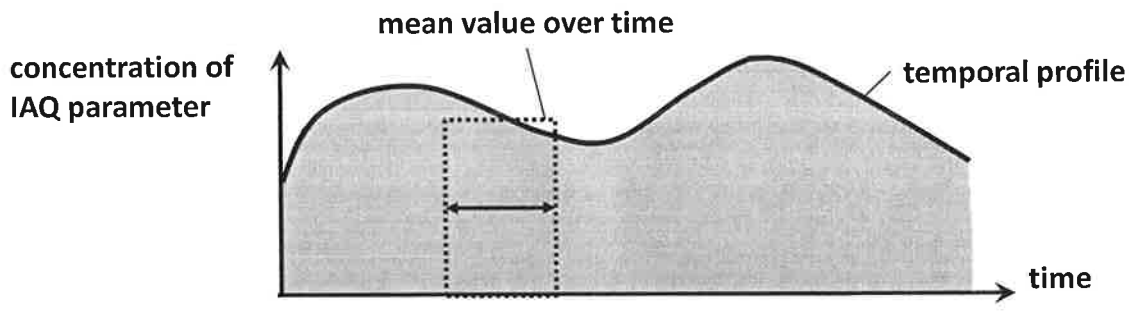
Source: SS554:2016

Measuring IAQ Parameters (I)

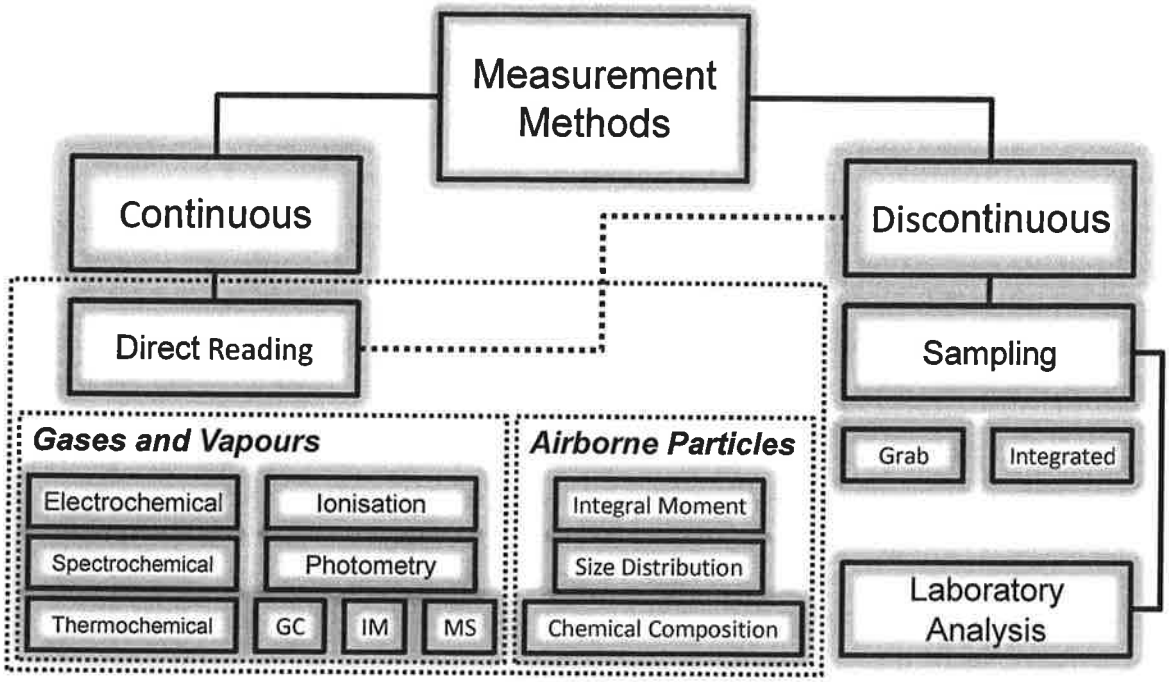
- Concept on reference method and indicative method introduced in SS554:2016.
- Indicative method may not be as accurate as reference method, but can be deployed as a **IAQ screening method** or **IAQ verification checks**.
- Reference and indicative methods can be either "continuous" or "discontinuous".

Measuring IAQ Parameters (II)





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

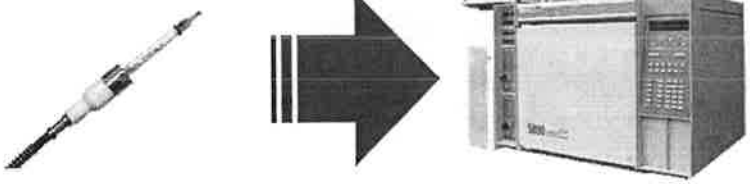
Direct Reading

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



v2016.12

Source: TSI; Agilent Technologies

Measurement Methods for Airborne Particles

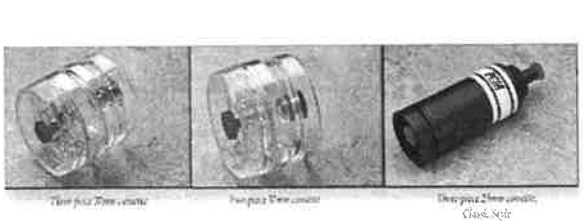
Direct Reading

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

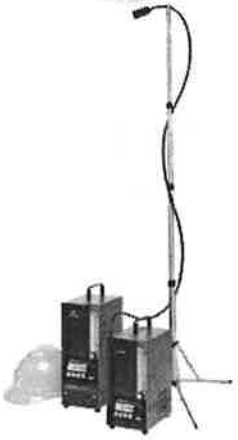


Sampling in Field/Analysis in Laboratory

Gravimetric method, counting method







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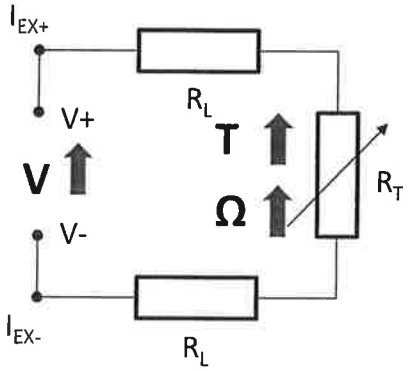
Source: TSI; Sensidyne

IAQ Screening Methods:
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

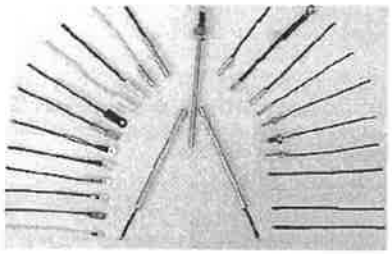
Measurement Method for Air Temperature



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 Radiant Heat

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

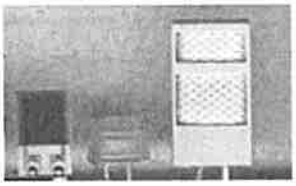
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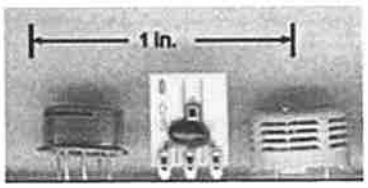
Source: Metrel

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:

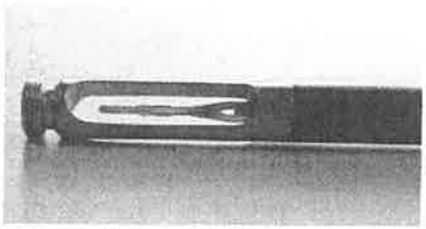
- Good recovery from condensation
- Reasonable resistance to chemical vapours
- Use up to ~ 200 ˚C
- Change in dielectric constant is nearly proportional to change in surrounding R.H

v2016.12

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

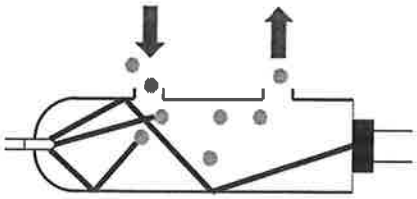
*Typical Characteristics:
- Accurate in low velocity region
- Accurate across a wide dynamic range

v2016.12

Source: Kanomax

Chemical Parameters

Measurement Method for Carbon Dioxide CO_2



IR Source IR Detector

Type: *Non-Dispersive IR

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

Unit of Measurement: ppm



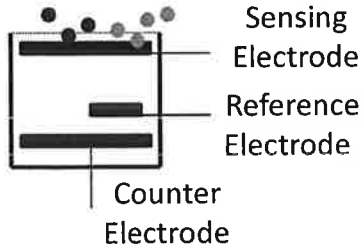
*Typical Characteristics:
- High sensitivity; very responsive to temperature changes
- Use up to ~ 300 ˚C
- Change in resistance is not linearly proportional to change in temperature

v2016.12

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

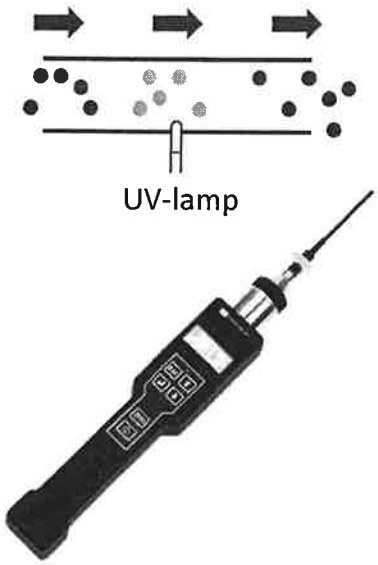
Unit of Measurement: $\mu g/m^3$, ppm

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

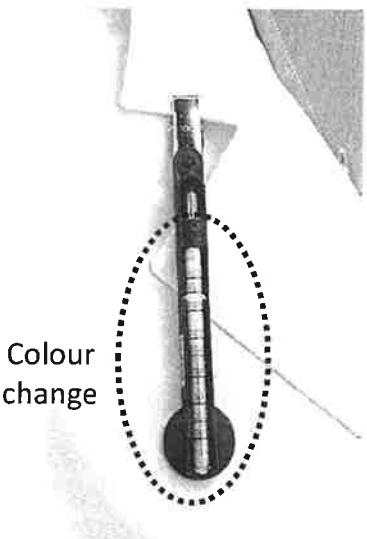
Typical Characteristics:
- Fast response
- Some VOCs have no response (e.g. HCHO, CH_4)
- Cannot determine the exact proportion of different HC within the TVOC stream

v2016.12

Source: Ion Science

Chemical Parameters

Measurement Method for Nitrogen Dioxide NO_2



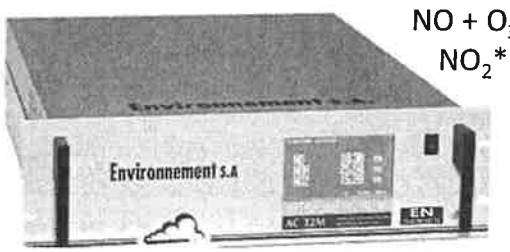
Type: Real-time chemiluminescence, diffusive tube passive samplers, chemical detector tubes

Measurement: µg/m³

Chemiluminescence Methodology Principle:

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

$NO_2^* \rightarrow NO_2 + hv$



v2016.12

Source: Draeger; Environnement S.A.

Chemical Parameters

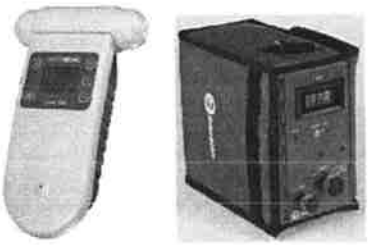
Measurement Method for Ozone O_3



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.

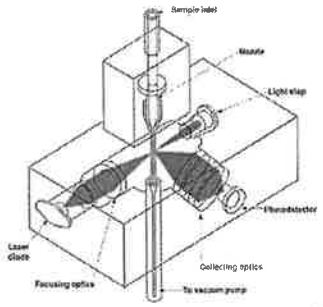
v2016.12

Source: Gastec; Aeroqual

Airborne Particles

Measurement Method for Particles (RSP and $PM_{2.5}$)

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 of SS554:2016

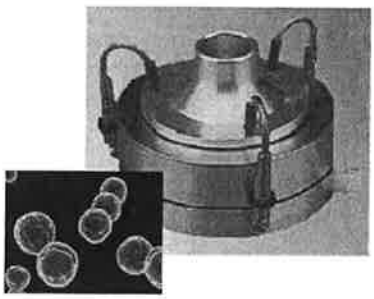
v2016.12

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

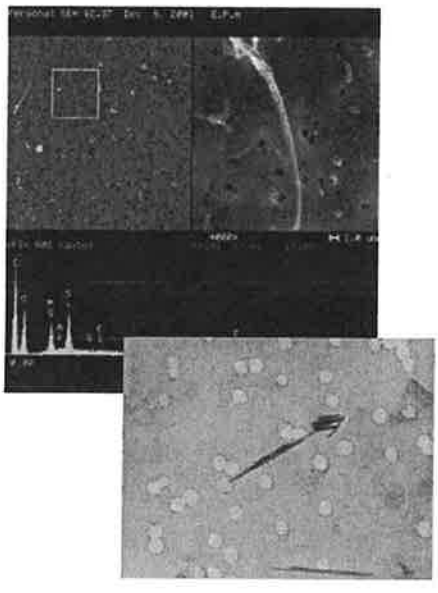
Unit of Measurement: cfu/m^3

v2016.12

Source: SKC; Thermo

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.

v2016.12

Source: RTI

How accurate are your measured results from screening? Representative?

How do you measure ODOUR?

(Dust, chemical vapours, or microbiological origin?)