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Mitigation of environmental degradation through improving air quality

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ABSTRACT

- poor air quality, high-rise buildings, central Mechanical Ventilation & Air-conditioning system (MVAC)
- HKEPD: about 32% office buildings, 75% restaurants, 37% shopping malls, 60% cinemas classified as "Sick Building"
- leads to headaches, nausea, dizziness, sore throats, sinus congestion, nose irritation etc.
- this research to identify the principal causes, design, construction, users' habitual modes & measures to resolve potential IAQ problems
- action research be applied in 2 case studies of a learning centre & a Grade A commercial building
- by means of preliminary investigation, analyzing collected air samples, obtaining occupiers' feedback through questionnaires (pre and post IAQ improvement works), and identifying long term mgt. measures

INTRODUCTION

- ASHRAE Standard 62(2001) - "Acceptable IAQ" is "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities & with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."
- World Health Organization (WHO, 1986) describes the same as "The physical & chemical nature of indoor air, as delivered to the breathing zone of building occupants, which produces a complete state of mental, physical and social well-being of the occupants, and not merely the absence of disease or infirmity."
- Growing concern in past decade over complaints attributed to IAQ. HK people spent about 85% of their time indoors (Chau, Tu, Chan, & Burnett, 2002).
- Canada, Japan, Korea, Singapore, Sweden, UK and USA conducted IAQ studies for setting standards and guidelines for a long time (Crandall & Sieber, 1996; Malkin, Wilcox, & Sicber, 1996; Mclius, Wallingford, Kccnlyside, & Carpenter, 1984; Scitz, 1990; Sieber, et al, 1996; USEPA, 1991).
- HKEPD (2003) - poor IAQ bring forth ill health, discomfort (e.g. itchy, headache, eyes, skin irritation, respiratory difficulties, fatigue, nausea) and absenteeism/lower productivity in workplace.
- Youngsters, aged and people with respiratory or heart disease further affected by poor IAQ. Good IAQ helps occupants in enhancing good health, effectiveness, productivity, efficiency and production.

- Land supply in HK is scarce, developers construct high-rise buildings equipped with central MVAC system esp. commercial use. Rental value of HK is high, space design/allowance for each personnel tend to be optimal and unevenly distributed.
- When occupiers complaint of headaches, nausea, dizziness, sore throats, sinus congestion, nose irritation or excessive fatigue, the building becomes sickening or possesses sick building syndrome.
- Indoor air pollution can be serious when ventilation rates are insufficient to dilute airborne contaminants; as a direct result of insufficient air exchange rates.
- Different criteria, regulations, guidelines in different places (Environment Australia, 2001; Health Canada, 1987; HKEPD, 1997; HKEPD, 2003; IAQMG, 1999; WHO, 2005; Womble et al., 1995).
- HKSAR (2003) set 12 parameters to self-regulate for air-conditioned buildings - carbon dioxide (C[O.sub.2]), carbon monoxide (CO), respirable suspended particulates (RSP), nitrogen dioxide (N[O.sub.2]), ozone ([O.sub.3]), formaldehyde (HCHO), total volatile organic compounds (TVOC), radon (Rn), airborne bacteria count (ABC), temperature (T), relative humidity (RH) & air velocity (V)
- Workstations usually crowded together, ventilation greatly reduced; VOC emissions from building materials/office furnishings/materials tend to be higher initially at higher air exchange rates

- MVAC system transports micro-organisms from locus of contamination to occupants in building (Law, Chau, & Chan, 2001; Seino, Takano, Nakamura, & Watanabe, 2005).
- Poor maintenance of A/C systems lead to Legionnaire disease from Legionella bacteria on drip pans in airconditioning ducts. Inefficient filtering due to poor fitting or overloaded filter caused poor IAQ.
- Maintenance include waterproofing, sealing effect of windows & doors and any infiltration through basement structure. Water leakage causes microbial growth and discomfort, allergic or toxigenic reactions
- Regular cleaning of carpets to remove accumulated dust, adsorbed organic, moulds, spores and other pests.
- C[O.sub.2] concentration significantly contributes to indoor air pollution - a surrogate indicator for assessing IAQ (ASHRAE, 2004; CEN, 1999; Persily, 1997).
- An Airborne Bacteria Count (ABC) - a good indicator of cleanliness of MVAC system.
- Energy crisis in 1970s, buildings "sealed" for energy conservation. MVAC systems installed with less outdoor air makeup.

- Modern buildings "tighter" and less infiltration of outdoor air & ex-filtration of indoor air.
- Photocopying machine, computer workstations, electro-photographic color reproduction equipment, and high speed printers, massively introduced into offices - induce IAQ problems
  - Increased health problems e.g. cough, eve irritation, headache, and allergic reactions,
  - Reduced productivity due to discomfort
  - Increased absenteeism
  - Strained relations between landlord and tenants

- WHO (2000) estimated 30% commercial buildings suffer from sub-standard indoor environments - reduction in productivity

- Common features of sick buildings:
  - often have forced ventilation
  - often of light construction.
  - Indoor surfaces often covered in textiles.
  - energy efficient, relatively warm/thermal environment.
  - airtight, i.e. windows cannot be opened.
  - occupants complain of acute discomfort, e.g. headache, eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentration; fatigue and sensitivity to odors.
  - complainants report relief soon after leaving building.

- WHO identifies indicators of building related illness (BRI):
  - occupants complain cough; chest tightness; fever, chills and muscle aches.
  - symptoms clinically defined, clearly identifiable causes.
  - complainants require prolonged recovery times
- USEPA and NIOSH (1991) state that poor air quality result in:
  - increasing health problems e.g. cough, eye irritation, headache and allergic.
  - legionnaire's disease, carbon monoxide poisoning
  - reducing productivity due to discomfort or increased absenteeism.
  - accelerating deterioration of furnishings and equipment.
  - straining relations between landlords and tenants, employers and employees.
  - creating negative publicity
  - insurance policies tend to exclude pollution-related claims

MAJOR FACTORS AFFECTING IAQ

- ***Physical factors***
  - building design, age, location, floor level and occupation density, affect the pollution load.
  - air tightness, energy conservation, little natural ventilation
  - synthetic materials emit pollutants.
  - industrialised, prime commercial area with heavy traffic.

- ***MVAC system***
  - system not well functioning
  - design fail to meet occupancy density and floor layout.
  - occupants generate pollutants e.g. carbon dioxide and water vapour.
  - density and distribution of occupants, furniture layouts
  - blockage of proper air circulation by furniture and fixtures
  - insufficient fresh air input and air changes causing carbon dioxide, heat and odour
  - insufficient outdoor air, poor distribution of supply air,
  - poor setting of air distribution devices, improper pressure

- ***External factors***
  - outdoor air quality and cross contamination.
  - industrial emissions and vehicular emissions.
  - pollutants from outside: particulate, SO_2, NO_2, CO and VOCs.
  - radon enters by "stack effect", when indoor air is warmer than outdoor air - creating a difference between indoor and outdoor air pressure - Infiltration occurs through gaps & openings
  - entry rate depends upon soil permeability, meteorology, structural, geological factors
  - pesticides and fertilisers sprayed outside buildings can enter

- ***Factors other than air pollutants***
  - temperature, humidity, lighting and noise.
  - 20-27°C is considered acceptable thermal comfort, beyond this range may increase emission of Volatile Organic Compounds
  - VOCs from materials, 40%-70% RH recommended by HKSAR (2003), above this range plus high temperature are uncomfortable - facilitate growth of micro-bacteria & fungi.
  - dehumidification device required, HK's RH 90% in summer

- ***Materials and equipment affecting IAQ***
  - photocopying machine, laser printer, adhesive tape, glue, correction fluid; and building materials e.g. wallpaper, paints, tiles, caulking compounds, carpet, mineral products emit VOCs, ozone and particulate.
  - extent depends on type of equipment, processes, intensity of use

SOURCES OF IA POLLUTION

- ***Environmental Tobacco Smoke (ETS)***
  - largest contributor to IA air particulate concentrations where cigarette smoking occurs.
  - accounts for most of odour and irritation.
  - particulate phase adsorb to surfaces and emit more irritating & odorous gaseous components an hour after emiting smoke (Clausen et. al., 1987).
  - workplace exposure to nicotine to 2.3 µg/m3 for 40 years presents a risk of obvious concern.
  - US OSHA considers workplace exposure to more then 6.8 µg/m3 as a significant risk.
  - a study of 25 work-sites in Massachusetts shows that smoking permitted area increase nicotine concentrations (9.1µg/m3) than smoking restricted area (1.3 µm/m3).
  - particles in tobacco smoke attract radon decay products.
  - 17% of lung cancers among non smokers can be attributed to high levels of exposure to ETS during childhood and adolescence (Clausen et. al., 87)
  - USEPA (1999) - ETS is causally associated with lung cancer in non-smoking adults and considered a "Group A" carcinogen, 3800 lung cancer deaths per year among non-smokers
- ***Formaldehyde Emission***
  - from Resin Urea Formaldehyde used in furniture to glue wood products
  - emission is highest when product is new, enough ventilation be provided
  - no regulation governing

- ***Ozone***
- ozone (O3) - an atmospheric oxidant formed through photochemical reactions of volatile organic compounds and nitrogen oxides.
- an irritant to the pulmonary system.
- affects mucous membranes and lung tissues,
- at low levels (60-120 ppb), cause cough, inflammation associated with biochemical changes and increased sensitivity to allergens (Boeniger, 1995).
- with ultra violet (UV) from photocopiers - an indoor pollutant.

- ***Radon Emission***
- immediate parent radium-226 in sites and building materials.
- radium decays to radon, enters into air or dissolves in water.
- radon has a short half-life of less than 4 days.
- radon further decays into short-lives isotopes, radon daughters that include 218Po, 214Pb, 214Bi and 214Po - terminate with 214Po, a stable radionuclide with a half-life of about 22 years.
- radon daughters have half-lives from 1 second to 27 minutes, highest background radiation;
- cosmic rays, natural radioactive matter.
- epidemiological issues, exposure/dose relationship of radon is extremely complex.
- granite emit radium, form decayed radioactive gas (radon).
- radioactive gas and particles increase risk of lung cancer.

- ***Volatile Organic Compounds***
- USEPA (1989) identifies over 900 different VOCs in indoor environment.
- at least 250 occur at levels greater than 1 ppb - 2 to 20 times greater than outdoor concentrations, about 50 µg/m3 (Black and Bayer, 1986).
- Burton (1993) and Tucker (1986) contend that building materials for structural and decoration e.g. wall, floor, ceiling coverings and coatings emit VOCs.
- cosmetic, pesticides, cleaning agents, paint
- VOC cause irritation to eyes and throat
- suspected carcinogens, e.g., benzene, formaldehyde and trichloroethylene.

Table 0-1 Emission Factors of Various Building Materials (Burton, 1993)

Materials	Emission Factors (mg/m^3-hr)	VOC	Time of Test
Medium Density Fibreboard	0.7-2.3	HCHO	higher values are for newer materials
Hardwood plywood panelling	0.06-1.4	HCHO	
Particleboard	0.08-2.0	HCHO	
Urea-formaldehyde foam insulation	0.05-0.8	HCHO	
Softwood plywood	0.01-0.03	HCHO	
Paper products	0.01-0.03	HCHO	
Plywood	1.0	HCHO	"new"
Silicone Caulk	13	TVOC	<10 hrs
	<2	TVOC	10-100 hrs
Floor adhesive	220	TVOC	<10 hrs
	<5	TVOC	10-100 hrs
Floor wax	80	TVOC	<10 hrs
	<5	TVOC	10-100 hrs
Wood stain	10	TVOC	<10 hrs
	<0.1	TVOC	10-100 hrs
Polyurethane wood finish	9	TVOC	<10 hrs
	<0.1	TVOC	10-100 hrs
Floor varnish or lacquer	1	TVOC	<10 hrs
Particle board	0.2	TVOC	2 years old
Chipboard	0.1	TVOC	unknown
Gypsum board	0.03	TVOC	unknown
Wallpaper	0.1	TVOC	unknown

Table 0-2 Indoor VOCs in Wall and Ceiling Materials (Tucker, 1986)

Compound	Formula	Substantiated Sources	Potential Sources
Formaldehyde	CH_2O	Plywood, particleboard, panelling, ceiling panels, urea foam insulation, wallpaper, caulking compounds, jointing compound, adhesive, fibreboard, chipboard, calcium silicate sheet, gypsum board	---
Benzene	C_6H_6	Adhesives, paint remover, particleboard	---
Trichloroethylene	C_2HCl_3	---	Solvent for paints and varnishes
Ethylbenzene	C_8H_{10}	Wall covering, insulation foam, chipboard, caulking compounds, jointing compound, fibreboard, calcium silicate sheet, adhesives	---
Toluene	C_7H_8	Solvent-based adhesive, water-based adhesive, edge sealing, moulding tape, wallpaper, jointing compound, calcium silicate sheet, vinyl coated wallpaper, caulking compounds, paint, chipboard	---
Xylenes	C_8H_{10}	Adhesives, jointing compound, wallpaper, caulking compounds, varnish	---
a = Source types for which quantitative data on emissions have been obtained in chamber tests, or for which quantitative data are available (e.g. from headspace testing).			
b = Source types known to contain the compound. Not all products of the source type will necessarily contain the compound			

Table 0-3 VOC Emissions From Furnishings with A Number of Health Problems (USEPA, 1991)

VOC	Emission Sources	Health Effects
Benzene	Paints, stains, and varnishes used in furnishings	Respiratory tract irritation
Xylenes	Varnish and solvents for resins and enamels	Narcotic and irritant that can affect the heart, liver, kidney, and nervous system
Toluene	Chipboard	Narcotic and may cause anaemia
Trichloroethylene	Furniture varnishes	affect the central nervous system
Methylene chloride	Acoustical office partitions	A narcotic that can affect the central nervous system
2-Butanone	Fibreboard and particleboard	An irritant and central nervous system depressant
Tetrochloroethylene	Dry-cleaned fabrics and draperies	An irritant to the skin and eyes, and can induce central nervous system depression

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- ***Carbon Dioxide (CO2)***
  - a colourless gas, ambient concentrations of CO2 tend to be fairly constant at 350-450 ppm.
  - CO2 in exhaled human breath around 3.8% (38,000 ppm), indoor concentrations of CO2 - 500 to 2,000 ppm.
  - increase when occupancy inside the room increased.
  - leads one sleepy, a good indicator of bad air quality.

- ***Carbon Monoxide*** (CO)
  - a colourless and odourless gas, incomplete combustion of any carbon containing fuel.
  - between 0.01 and 0.23 mg/m3 (0.01 to 0.20 ppm). -where traffic is heavy, CO level is higher. smoking increase CO level
  - CO has a strong affinity with haemoglobin.
  - 200 times as effective as oxygen to form carboxyhaemoglobin (COHb).
  - affect the ability of red blood cells in carrying oxygen to body tissues.
  - detrimental effects on heart, lungs and nervous system.
  - WHO indicated that at COHb levels 5 - 10%, neurobehavioural effects e.g. impaired co-ordination and cognitive performance
  - intoxication from CO may be acute or chronic

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- ***Nitrogen Dioxide*** (NO2)
  - from oxidation of nitrogen under high temperature.
  - in HK, from electricity generation.
  - indoor sources of NO2 come from entrained exhaust.
  - deep lung irritant, biochemical alterations,
  - pulmonary function at concentrations of 2 ppm (Manahan and Stanley, 1990).
  - pulmonary function for mild asthmatics, for 30 minutes at 560 µg/m3 (0.3 ppm) during intermittent exercise.
  - from restaurants and home kitchens using gas stoves, car in garages etc.
  - NO2 harmful to asthma people, while CO is highly poisonous

- ***Sulphur Dioxide*** (SO2)
  - from combustion of fuels containing sulphur.
  - from industrial sources or traffic
  - concentration indoor is lower than outdoors
  - causes irritation of respiratory tract, mucus secretion or increased airway resistance.
  - respiratory weakness and sensitised asthmatics may be aggravated
  - not generated by indoor sources, not a good indicator for IAQ.

- ***Respirable Suspended Particulate (PM10)***
  - suspended particles in air with a nominal aerodynamic diameter of 10 micrometres (µm).
  - released from indoor combustion sources, include polynuclear aromatic hydrocarbons (PAH) compounds, trace metals, nitrates, and sulphates.
  - PAH compounds – carcinogenic, can be inhaled into lungs.
  - depend on size, shape, density and reactivity of particulates, velocity of airway.
  - particles greater than 10 µm in diameter and about 60-80% of particles of 5-10 µm are trapped in the nasopharyngeal region.
  - 5% of particles smaller than 5 µm in diameter also trapped, leaving 95% RSP travel deeper into lungs.

- ***Biological Contaminants***
  - via ventilation systems or natural air exchange.
  - dirt and moisture provide a breeding ground for biological pollutants.
  - micro-organisms found on carpet, ceiling, tiles or floating on dust/aerosol particles.
  - airborne bio-contaminants: viruses, bacteria (e.g. *Pseudomonas*, *Staphylococcus*), antinomycetes (e.g. *Mycobacterium*) and fungi (e.g. *Penicillium*, *Aspergillus*, *Cladosporium* and *Candida*).
  - bio-contamination via stagnant water, drip pans and drain pans.
  - moisture accumulation on dusty units, induction units and cooling coils
  - microbial contamination in air can cause illness through infection or allergic reaction.
  - legionnaire's disease, colds, and influenza.
  - mould growth on damp surfaces, esp. in Hong Kong
  - in air ducts, air conditioners, air filters etc.

IAQ IMPACTS TO HEALTH

- limited land in HK, central HVAC system,
- complaint of headaches, nausea, dizziness, sore throats, sinus congestion, nose irritation or excessive fatigue - sick building syndrome.
- WHO (2000) - Poor IAQ cause low productivity
- most HK people experience headache, itchy eyes, respiratory difficulties, skin irritation, nausea and fatigue
- Godish (2004) - pollutant effects manifested in specific target organs e.g. eye and respiratory irritation, pollutants enter bloodstream from lungs or gastrointestinal system.
- ***Eye Irritation***
  - prevalent manifestations of pollutant effects on human body.
  - exposure to aldehydes and photo-chemical oxidats.
  - threshold for eye irritation by oxidants is 0.10 to 0.15 ppmv (reported as ozone).
  - photochemical pollutants such as per oxyacyl nitrate (PAN), acrolein, formaldehyde (HCHO), and other photochemically-produced compounds.
  - eye irritation resolves quickly after exposure ceases. (Godish, 2004).

- ***Effects on the Cardiovascular System.***
  - may die of corpulmonale, heart failure from severe chronic respiratory disease.
  - premature cardiovascular system-related mortality strongly associated with small (less or equal than 2.5 um) particles. (Godish, 2004).

- ***Effects on the Respiratory System***
  - 3 major units of respiratory tract – the nasopharyngeal, tracheobronchial and pulmonary (Colls, 2002).
- ***Acute respiratory infection in children (ARI)***
  - pneumonia, a killer of children in developing countries.
  - 4 million deaths per year, exceeds deaths from diarrhea.
  - by exposures to air pollutants and indoor environment tobacco smoke (McGranahan, 2003).

ECONOMIC IMPACT FROM IAQ

- HKSAR (2003): cost of poor IAQ - direct medical costs and loss in productivity, as below.
- ***Direct Medical Costs***
  - USEPA (1991): US$1 billion spent annually on direct medical costs
  - allergies as occupational diseases
  - in HK, 48.8% of morbidity attributed to respiratory system
- ***Loss in Productivity***
  - HKSAR (2003): average sick leave rate about 1%, while workers' ill rate is 3-4%,
  - loss in productivity attributable to IAQ is 14 minutes per day, or 3% of total productivity.
  - HKCSD (1994): 10% of the economically active population have been ill in the past 14 days, only 3.5% took sick leave between 1/2 day to 4 days in the past 30 days preceding the survey.

SUGGESTIONS TO CONTROL IAQ

- Godish (2004) advocates source mgt.: source exclusion, removal/treatment, exposure control, contaminant control
- ***Source exclusion***
  - minimize by using low-emission products
  - low emissions of VOCs & odor-producing substance called 4 phenylcyclohexane (4-PC).
  - low formaldehyde emissions from pressed-wood products
  - avoiding HCHO-emitting products e.g. particle board, hardwood plywood paneling, medium-density fiberboard, and acid-cured finishes.
  - alternative products including softwood plywood, oriented-strand board, decorative gypsum board and hardboard panel
  - HCHO brings free varnishes and lacquers.
- ***Source removal***
  - to identify & remove the source
  - removal of minor source would not reduce HCHO levels.
- ***Source treatment***
  - modified to reduce contaminants emissions.
  - use encapsulants to prevent release of asbestos fibers from acoustical plaster.
- ***Exposure control***
  - all contaminant-producing activities be avoided
  - try to relocate susceptible individuals.

- ***Contaminant control***
  - reduced by diluting indoor air with less contaminated outdoor air, by infiltration or exfiltration, natural ventilation, mechanical ventilation (Godish, 2004).
  - non-specific symptoms including eye, nose, and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritation
  - "building related illness" (BRI) attributed directly due to airborne building contaminants.
  - Leslie and Lunau (1992) - discomfort associated with air pollutants, air temperature, mean radiant temperature, rate of air movement, relative humidity, insulation value of clothing worn, metabolic rate of task being performed.
  - well-planned maintenance program can prevent small deficiencies from blossoming into major, costly breakdowns, repairs and replacements.
  - routine oiling of bearings in a fan can prevent loss of make-up air

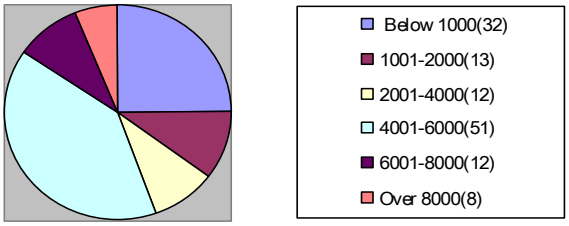
- Hansen (1999) supports preventive maintenance:
  - reduce unplanned services calls
  - reduce equipment breakdowns
  - cut down replacement materials and parts
  - reduce operating costs
  - create a more effective work environment for maintenance staff
  - lengthen equipment life
  - increasing energy savings

RESEARCH METHODOLOGY

- Action research applied in case studies of a local learning centre (Building A) and a commercial building (Building B), analyzing collected air samples, obtaining occupiers' feedback through questionnaires (pre and post IAQ improvement works), and
- Identifying IAQ long term mgt. measures, as a holistic approach to resolve IAQ problems.
- For Building A, IAQ problem areas be initially identified by recognized methods, obtain occupiers' comments via questionnaires, air samples be collected for analysis to ascertain future remedial actions e.g. source control, ventilation improvement, air cleaning, exposure control.
- For Building B, IAQ problem areas be identified by recognized methods, obtain occupiers' feedback via questionnaires from pre and post IAQ improvement works, identify specific long term mgt. measure e.g. source control, ventilation improvement, air cleaning, exposure control.
- **Building A – Findings/Analysis**
- Totally 128 out of 200 questionnaires (64% response rate) received

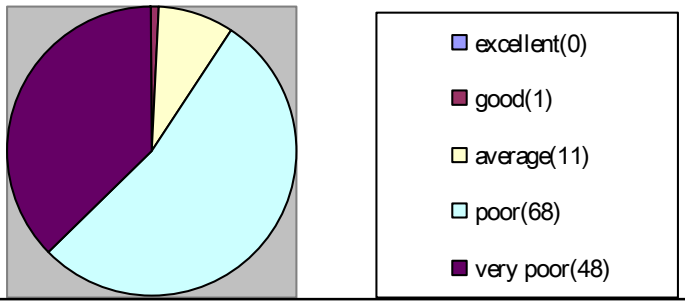
1) What is the size of your own working area (in sq.ft.)?

Size of working area (s.f.)	No.	Percentage
Below 1000	32	25
1001 – 2000	13	10.2
2001 - 4000	12	9.4
4001 – 6000	51	39.8
6001 – 8000	12	9.4
Over 8000	8	6.3
Total	128	100



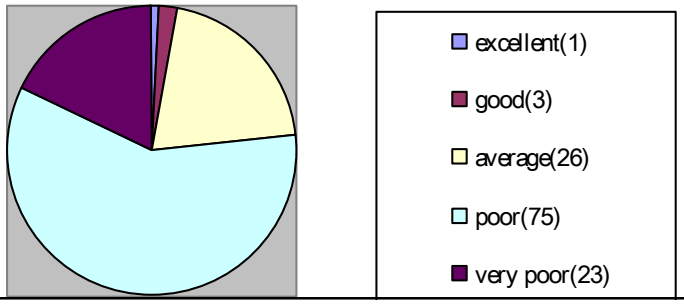
2) What is your comment on the air quality of this Building?

Comment on air quality	No.	Percentage
Excellent	0	0
Good	1	0.8
Average	11	8.6
Poor	68	53.1
Very poor	48	37.5
Total	128	100



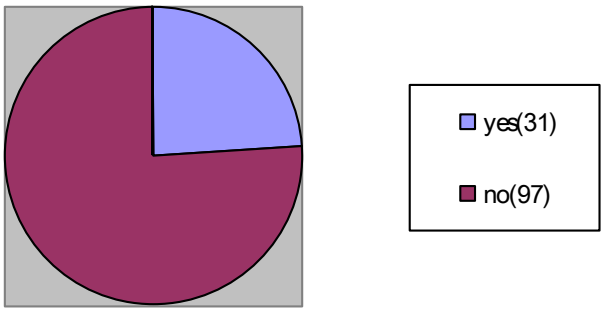
3) What do you think about the ventilation of this Building?

Comment on ventilation	No.	Percentage
Excellent	1	0.8
Good	3	2.3
Average	26	20.3
Poor	75	58.6
Very poor	23	18.0
Total	128	100



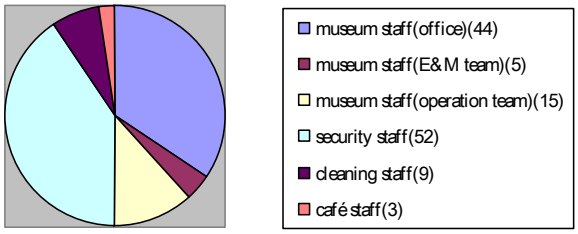
4) Are you a cigarette smoker?

Cigarette smoker	No.	Percentage
Yes	31	41.3
No	97	75.8
Total	128	100



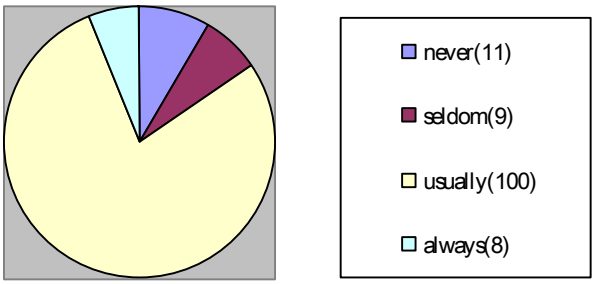
5) What is your nature of work in this Building?

Nature of work	No.	Percentage
Office staff	44	34.4
E&M staff	5	3.9
Operation staff	15	11.7
Security staff	52	40.6
Cleaning staff	9	7
Café staff	3	2.3
Total	128	100



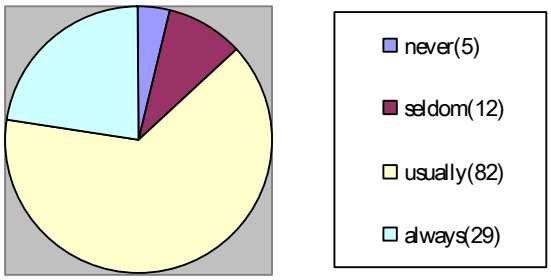
6) Do you find it difficult to breathe inside this Building?

Difficult to breathe inside this Building?	No.	Percentage
Never	11	8.6
Seldom	9	7
Usually	100	78.1
Always	8	6.3
Total	128	100



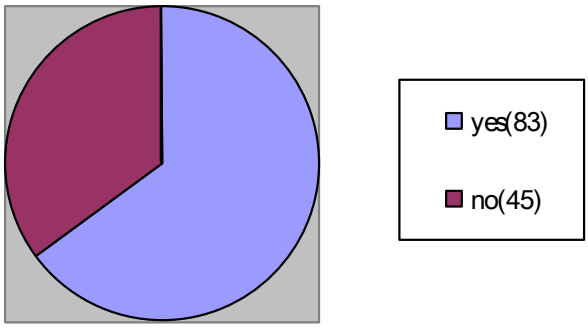
7) Have you ever suffered from headache or swoon inside this Building?

Suffered from headache or swoon inside this Building?	No.	Percentage
Never	5	3.9
Seldom	12	9.4
Usually	82	64.1
Always	29	22.7
Total	128	100



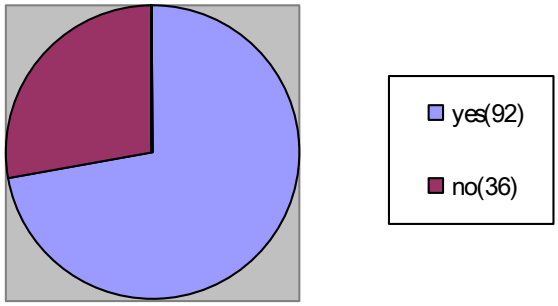
8) Does your respiratory system have any problem?

Any problem to respiratory system?	No.	Percentage
Yes	83	64.8
No	45	35.2
Total	128	100



9) Do you think the air quality needs to be improved?

Any needs to improve air quality?	No.	Percentage
Yes	92	71.9
No	36	28.1
Total	128	100



- Findings concurs with Hansen's (1999) argument - a building is defined as sick if 20% of the building's occupants exhibit such symptoms.
- A preliminary walkthrough inspection reveals following symptoms:
  - air grilles in air handling units filthy/dirty.
  - unused materials are piled in plant room.
  - inadequate air movement in customer service & resource center
  - in general office, drainpipes for fan coil units are clogged, causing overflow in drain pan.
- IAQ mgt. procedures developed by USEPA & NIOSH (1999) be adopted, using a checklist for diagnosing & mitigating IAQ problems, and finds out:
  - insufficient air movement identified after original sales shop modified to customer service & resources center.
  - mould, yeast & no cleaning found in air duct.



- intake air duct not fully covered with fresh air intake filter, fresh air not fully filtered before entering AHU
- return air grilles in AHUs dirty.
- unused materials stored inside plant rooms, where unwanted emissions/smell be distributed to occupiers through AHUs.
- filter indicator in plant rooms filthy/dirty, no replacement done.
- drainpipes clogged, causing condensed water to overflow from drain pan of FCUs, a major source of Legionnaire's disease.
- customer Services & Resources Centre, installed with FCUs without exhaust air duct to evacuate concentrated CO2 and respirable suspended particles (RSP)

To help further analysis, air samples are collected from:

- G/F Children zone
- 1/F Computer laboratory
- 2/F Science news corner
- 3/F Café

to identify for:

- Carbon Dioxide (CO2)
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO2)
- Respirable suspended particles (RSP)
- Total Bacterial Counts (TBC)
- Formaldehyde (HCHO)

and sent to accredited lab. to determine its concentration, results as follows:

Pollutants	Unit	G/F Childre n Zone	1/F Computer Laboratory	2/F Science News corner	3/F Cafe	HKEPD Objectives/ parameters
CO2	ppm	745	821	*1,020*	*1,653*	1,000
CO	µg/m³	10,000	10,500	15,000	21,000	30,000
NO2	µg/m³	94	90	96	100	200
RSP	µg/m³	94	130	160	*188*	180
TBC	cfu/m³	*1,800*	*2,000*	*2,200*	*1,700*	1,000
HCHO	µg/m³	30	26	27	31	100

Laboratory analysis results

Figures in *Italic* indicate that the values are higher than the objectives/parameters recommended by HKEPD (2003), as summarized below.

The results correlate with the preliminary site observations.

Location	Results
G/F Children Zone	TBC is 80% higher than HKEPD's objectives.
1/F Computer Laboratory	TBC is 100% higher than HKEPD's objectives.
2/F Science news corner	CO2 is slightly higher, and TBC is 120% higher than HKEPD's objectives.
3/F Café	CO2 is 65% higher and TBC is 70% higher than HKEPD's objectives.

Mitigating IAQ Problems

- USEPA & NIOSH's (1999) suggest following control strategies:
- ***Source Control***
  - insufficient air ventilation leads to high CO2, RSP and TBC content.
  - open kitchen in café further compounds the problem, changing to close kitchen be one solution.
  - adopting a stronger ventilation system, with –ve pressure be another way out.
- ***Ventilation***
  - problem in customer services & resources centre be resolved by installing additional return air duct (RAD)
  - ventilation rate at computer laboratory be increased.
- ***Air Cleaning***
  - TBC in all sample areas excessively high (70-120%), due to via mould/yeast/bacteria growth in air duct.
  - robotic air duct cleaning, an effective measure.
  - air cleaning device e.g. particulate filtration, electrostatic precipitation be used
  - particulate filtration removes suspended liquid or solid materials whose size, shape and mass remain airborne.
  - filters with higher efficiency could remove substantial particles.
  - electrostatic precipitation oppositely collect airborne particulates.
  - particles are charged by ionizing the air with an electric field.
  - charged particles are then collected by a strong electric field generated between oppositely-charged electrodes, provides high efficiency filtration of small respirable particles.

- ***Exposure Control***
  - an administrative approach that adopts behavioral methods e.g.:
  - scheduling contaminant-producing activities to avoid complaints
  - relocating susceptible individuals to control exposure

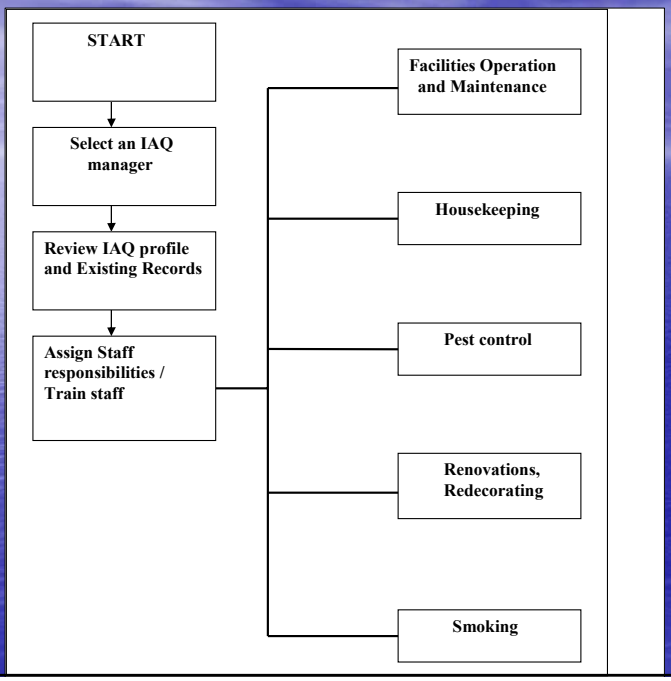
Location	Peak Hours
G/F Children Zone	10:00a.m.-12:00a.m. & 3:00p.m.-5:00p.m. daily (especially on holiday)
1/F Computer Laboratory	11:00a.m.-12:00a.m. & 4:00p.m.-5:00p.m. daily (especially on holiday)
2/F Science news corner	2:00p.m.-5:00p.m. daily (especially on holiday)
3/F Café	11:00a.m.-2:00p.m. & 6:00p.m.-8:00p.m. daily (especially on holiday)

- With the information provided from the assessment above, staffs and visitors exposure to those pollutants can be controlled as shown below:

Pollutant	Cause	Exposure control
CO2	Poor ventilation	Increase ventilation rate at peak hour
CO	Kitchen exhaust is not sufficient	Improve the exhaust system
RSP	Dust come from air ducts/grilles and dirty filters	Increase ventilation rate
TBC	Dirty air ducts/grilles and dirty filters	Perform air duct/grilles cleaning and replace air filter

- As an immediate measure, FM to check out/monitor the proper functioning of HVAC system/maintenance
- For a longer term, HKEPD (2003) objectives/precedures e.g. developing an IAQ Mgt. Plan and international standards be adopted.

IAQ Mgt. Plan



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Building B

- Building B - Grade A office building, completed 20 years, complaints poor IAQ, preliminary investigations & subsequent improvements done to cater for better IAQ, preliminary investigations are:
  - inactive air duct cleaning
  - over 20 years VAV boxes
  - no VOCs control within the buildings
  - allow smoking within the buildings
  - no regular IAQ monitoring

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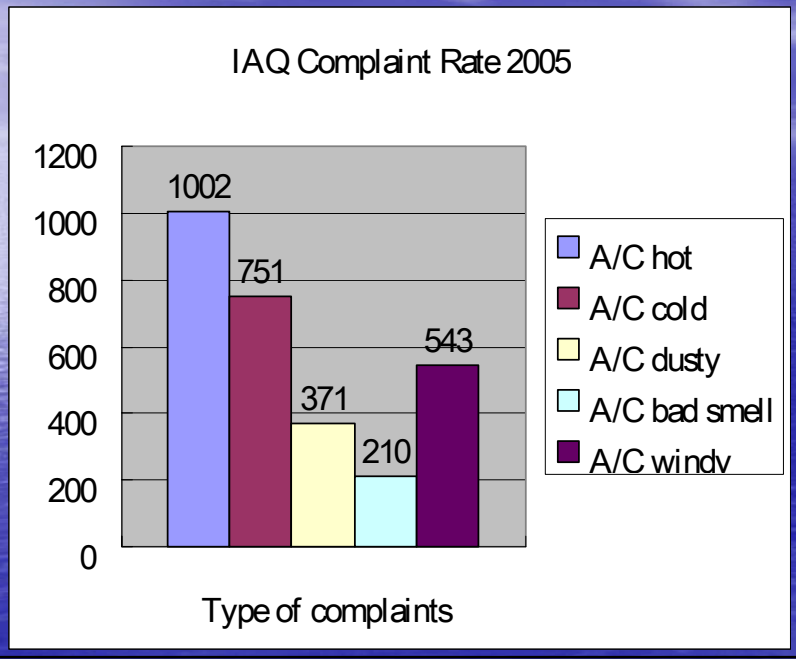
- Complaint rate before improvement works is:



- Among the 2877 complaints, 1002 (34.83%) opine A/C hot, 751 (26.1%) find A/C cold, 371 (12.90%) opine A/C dusty, 210 (7.30%) find A/C bad smell, 543 (18.87%) opine A/C windy.

Complaint	Complaint No.	Complaint %
A/C hot	1002	34.83%
A/C cold	751	26.1%
A/C dusty	371	12.90%
A/C bad smell	210	7.30%
A/C windy	543	18.87%
Total	2877	100%

- A questionnaire sent to solicit feedback from selected occupiers (Tower One 5-8/F, Tower Two 25/F, Tower Three 4/F) at pre and post IAQ improvements stages, criteria for selecting respondents are:
  - tenants with highest complaint rate from previous year
  - no air duct cleaning works done at these floors for over 5 years
  - ongoing fitting out works during project survey period
  - no VAV boxes replacement done

The IAQ improvement works are:

- ***Regular Air Duct cleaning***
  - air duct only be cleaned after substantial complaints received.
  - after proactive & extensive cleaning, tenants' complaint reduced which implied a significant improvement to IAQ, as revealed below.


- ***VAV upgrading***
  - aged VAV terminal units and pneumatic control system replaced.
  - fiber peeling inside VAV box expunched
  - new VAV box constructed with a clean perforated metal sheet lining,
  - reduces risk of fibre spreading within office.
  - all A/C flexible duct also replaced.
  - after upgrading, tenants enjoyed a better IAQ through a more precise/flexible control of VAV system


Old VAV boxes

- ***VOCs control within fitting out areas***
  - carbon-containing compounds that evaporate at room temperature and become airborne.
  - a dynamic class of indoor air contaminants.
  - some floor coverings, esp. carpets, act as sinks for pollutants, absorbing pollutants onto their surfaces/fibers, later releasing them into air.
  - fitting out tenants to abide:
    - not keep storage of offensive materials per regulations e.g. materials containing chlorofluorocarbons (CFC).
    - paints/coatings be low VOC type and suitable for use indoors in unventilated areas, all waste paints and other liquids be disposed of per regulations.
    - to provide all data on materials, chemicals and fluids used (safe use/disposal, safety data sheets)
    - all timber treatment works follow relevant codes/standards, any particleboard, fibreboard comply with BS 5669 or BS1142 to control formaldehyde emissions.
    - no alteration or repairs contain asbestos

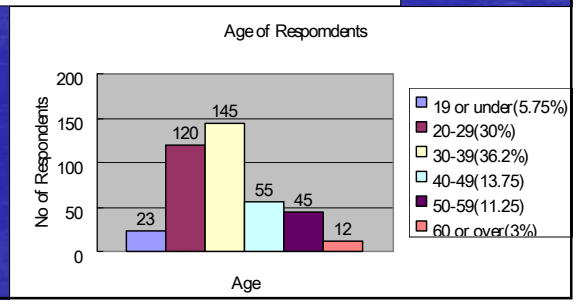
- ***Smoke free building***
  - environment Tobacco Smoke (ETS) is an aged, dilute mixture of side–stream and exhaled maintenance smoke from combustion of tobacco products such as cigarettes, cigars, etc.
  - single large contributor to indoor air particulate concentrations in office
  - contain a long list of potentially hazardous chemicals
  - this building was barred from smoking, as a “Smoke Free Building” from 1/9/2006.

Finding and Analysis of Questionnaires

- 400 out of 1000 questionnaires (40% response rate) received

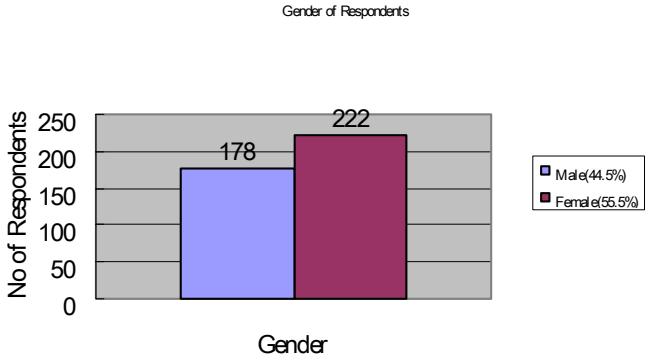
Q1. In what age group are you?

Age	Count	Percentage
19 and under	23	5.8
20-29	120	30
30-39	145	36.2
40-49	55	13.7
50-59	45	11.3
60 and over	12	3
Total	400	100



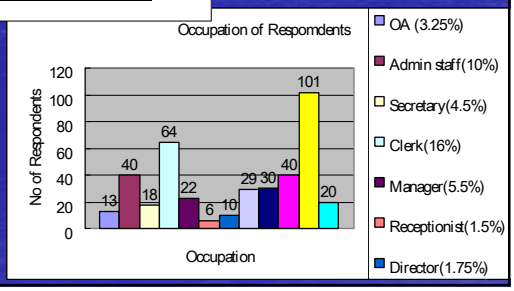
Q2. Gender

Sex	Count	Percentage
Male	178	44.5
Female	222	55.5
Total	400	100



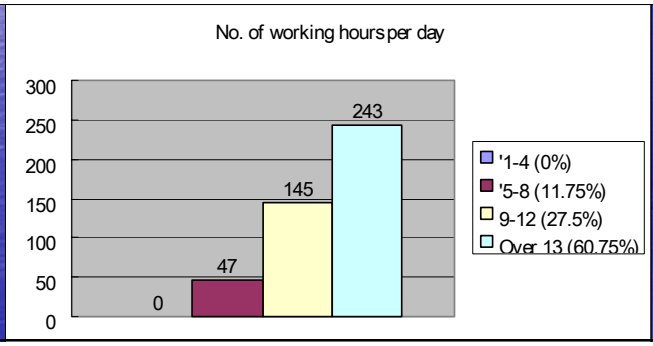
Q3. In terms of your current occupation, how would you characterize yourself?

Occupation	Count	Percentage
O. A.	13	3.3
Admin Staff	40	10
Secretary	18	4.5
Clerk	64	16
Manager	22	5.5
Receptionist	6	1.5
Driver	7	1.8
Director	10	2.5
Accountant	29	7.3
Technical staff	30	7.5
I.T.	40	10
Financial Adviser	101	25.3
Others	20	5
Total	400	100



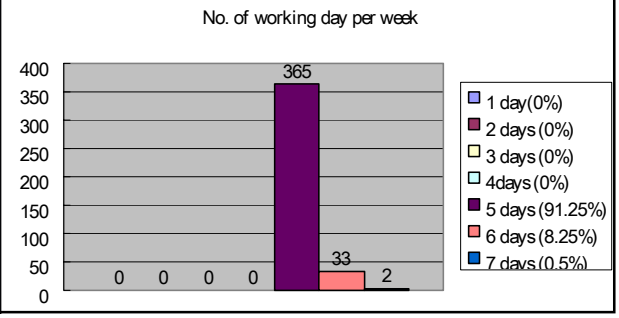
Q4. Numbers of working hours per day

Numbers of working hours per day	Count	Percentage
1-4	0	0
5-8	47	11.8
9-12	110	27.5
Over 13	243	60.8
Total	400	100



Q5. Numbers of working date per week

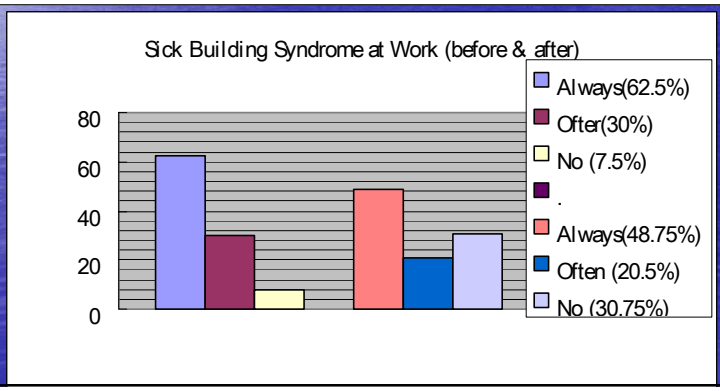
Numbers of working date per week	Count	Percentage
1	0	0
2	0	0
3	0	0
4	0	0
5	365	91.3
6	33	8.3
7	2	0.5
Total	400	100



Q6. Sick Building Syndrome Symptoms at work (before Sept 06):

(Eye Discomfort/Runny Nose/Sore/Dry Throat/Cough/Breathing Difficulty/ Headache/Dizziness/Dry/ Itchy Skin/Tiredness etc.

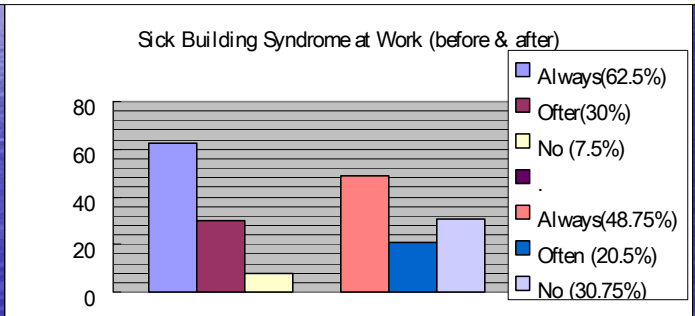
SBS at work	Count	Percentage
Always	250	62.5
Often	120	30
No	30	7.5
Total	400	100



Q7. Sick Building Syndrome Symptoms at work (recently, after Sept 06):

(Eye Discomfort/Runny Nose/Sore/Dry Throat/Cough/Breathing Difficulty/ Headache/Dizziness/Dry/ Itchy Skin/Tiredness etc.

SBS at work	Count	Percentage
Always	195	48.8
Often	82	20.5
No	123	30.8
Total	400	100



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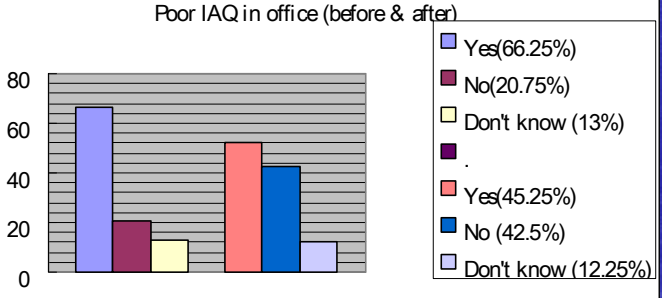
Q8. Poor IAQ in office (before Sept 06)

Poor IAQ	Count	Percentage
Yes	265	66.3
No	83	20.8
Don't know	52	13
Total	400	100



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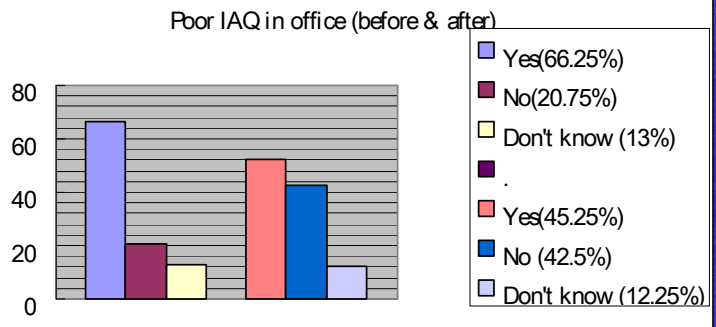
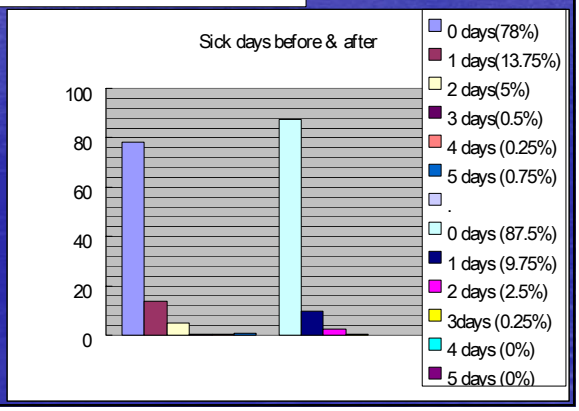
Q9. Poor IAQ in office (recently, after Sept 06)

Poor IAQ	Count	Percentage
Yes	181	45.3
No	170	42.5
Don't know	49	12.3
Total	400	100



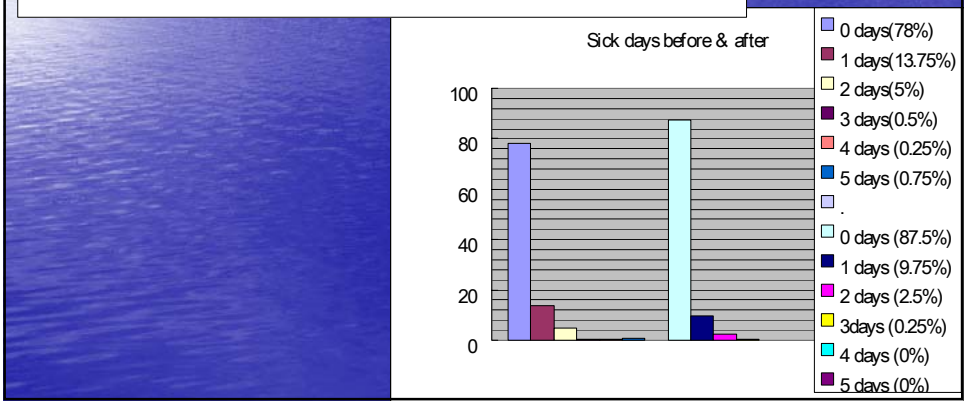
Q10. Sick Leave caused to SBS (01/01/06 - 30/8/06)

Sick day	Count	Percentage
0	312	79.4
1	55	14
2	20	5
3	2	0.5
4	1	0.3
5	3	0.8
Total	393	100



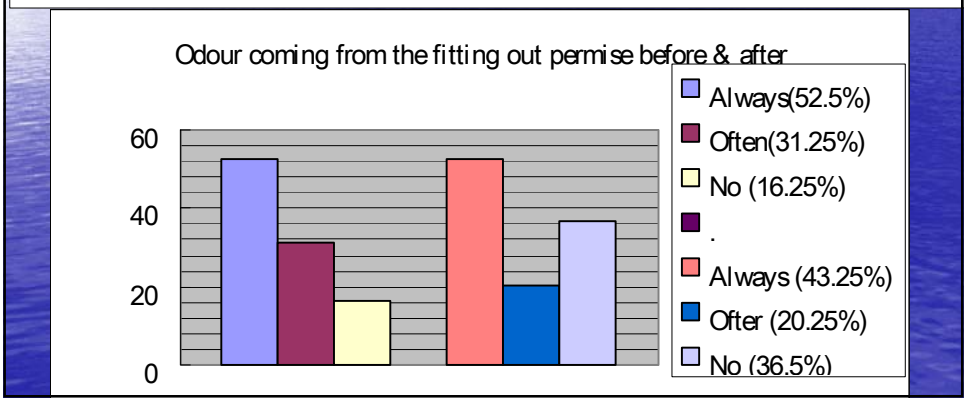
Q11. Sick Leave caused to SBS (01/09/06 - 1/4/07)

Sick day	Count	Percentage
0	350	87.5
1	39	9.8
2	10	2.5
3	1	0.2
4	0	0
5	0	0
Total	400	100



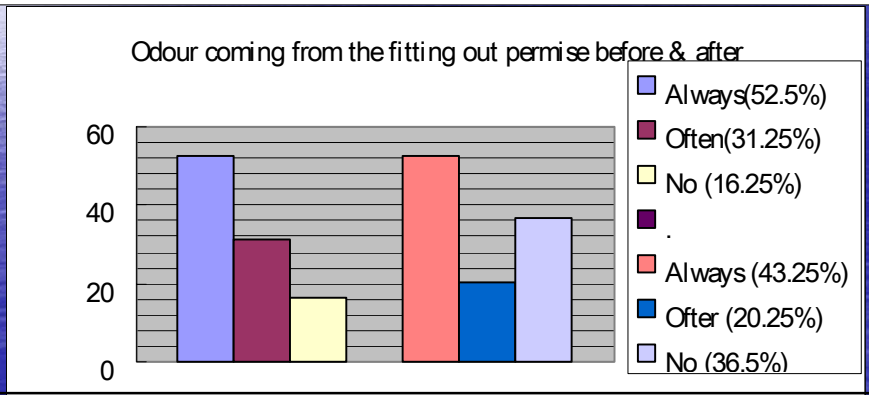
Q12. Odour coming from the fitting out/alteration premises (before Sept 06)

Odour	Count	Percentage
Always	210	52.5
Often	125	31.3
No	65	16.2
Total	400	100



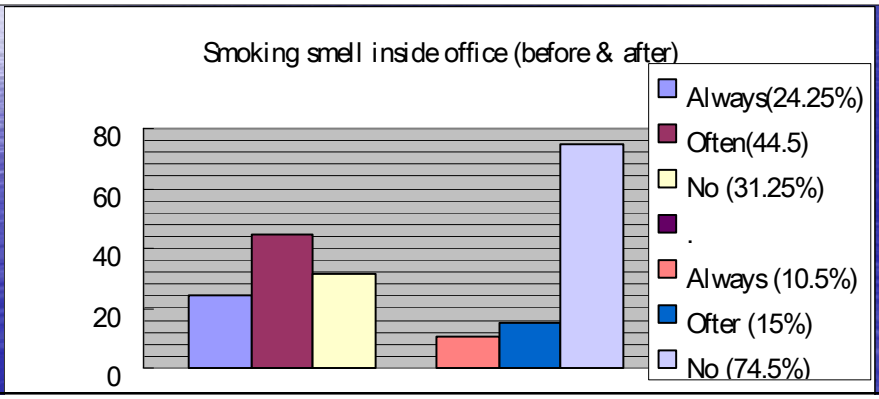
Q13. Odour coming from the fitting out/alteration premises (recently, after Sept 06)

Odour	Count	Percentage
Always	173	43.3
Often	81	20.2
No	146	36.5
Total	400	100



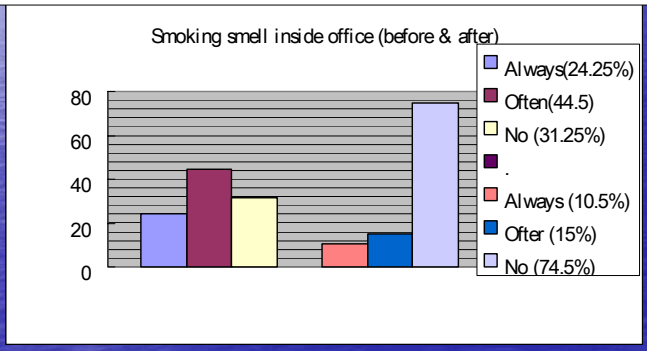
Q14. Smoking smell inside the office (before Sept 06)

Odour	Count	Percentage
Always	97	24.2
Often	178	44.5
No	125	31.3
Total	400	100



Q15. Smoking smell inside the office (recently, after Sept 06)

Odour	Count	Percentage
Always	42	10.5
Often	60	15
No	298	74.5
Total	400	100



- The analysis reveals that the IAQ improved e.g. respondents' sick leaves decreased, smoking/odour smell reduced.

CONCLUSION

- To tackle IAQ problems, a management strategy be specifically prepared for a building, including allocation of responsibility, preparation, review of work contracts & procedures, review of occupation contracts, communication, investigation of complaints, and record keeping.
- IAQ problems appear complex, integrated with technical, administrative, legal aspects and resources distribution.
- Self-regulation to safeguard occupiers' health for the time being before legislation is enforced.
- All major stakeholders e.g. owners, designers, facility managers, tenants, occupiers, users have to accomplish IAQ requirements/standards for better environment; and thus maintain a lasting sustainability for mankind.

Reference

- ANSI/ASHRAE Standard 62.1-2004 (2004), *Ventilation for Acceptable Indoor Air Quality,* Publisher: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (2004), ANSI/ASHRAE 62-2004, Design for Acceptable Indoor Air Quality. GA: Atlanta American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Black, M.S., and Bayer, C.W., (1986), Formaldehyde and other VOC Exposures from Consumer Products, *Proceedings of ASHRAE IAQ '86 : Managing Indoor Air for Health and Energy Conservation*, pp. 454-68.
- Boeniger, M., (1995), Report : Ozone Generators Not Effective, Pose Added Health Risk, *Indoor Air Quality Update.* Vol. 8. No. 9. September 1995, pp. 1-3.
- Burton D.J. (1993), *IAQ and HVAC Workbook*, Utah, IVE, Inc.
- Chau, C.K., Tu, E.Y., Chan, D.W., & Burnett, J. (2002), Estimating the total exposure to air pollutants for different population age groups in Hong Kong. *Environmental International*, 27(8), 617-630.
- Clausen G.H., P.O. Fanger, W.S. Cain and B.P. Leader (1987), Stability of tobacco smoke odor in enclosed spaces. *Proceedings of Indoor Air '87* : 4th International Conference on Indoor Air Quality and Climate.
- Colls J. (2002), *Air pollution,* London ; New York : Spon Press, 2nd Ed., 2002.
- Committee of European Normalization (CEN) (1999), Ventilation for Buildings: Design Criteria for the Indoor Environment, *Brussels: Commission of the European Communities*, Directorate General for Science, Research and Development Joint Research Centre-Environment Institute, PD CR1752.

- Crandall, M., & Sieber, W. (1996), The National Institute for Occupational Safety and Health Indoor Environmental Evaluation Experience, Building environmental evaluations, *Applied Occupational Environmental Hygiene,* 11, 533-539.
- Environment Australia (2001), Parkes, NSW: Department of the Environment and Heritage, Australian Government.
- Godish T. (2004), *Air quality*, Boca Raton, Fla. ; London : Lewis Publishers, 4th ed., c2004.
- Hansen D. L., (1999), *Indoor air quality issues*, New York : Taylor & Francis.
- Health Canada (1995), *Indoor air quality in office buildings: A technical guide*, Health Canada, Ottawa.
- HKEPD (1997), Final report-Consultancy study of indoor air pollution in offices and public places in Hong Kong, Agreement No. CE 14/95.
- Hong Kong Special Administrative Region: Environmental Protection Department (2003), *Air Services Group,* HKEPD Indoor Air Quality Information Centre.
- HKCSD: Census and Statistics Department, Hong Kong (1994), *Special Topics Report No.10 and 11, Social Data Collected by the General Household Survey,* Social Analysis & Research Section of the Census and Statistics Department. Government Printer, H.K.
- Leslie G. B. and Lunau F. W. (1992), *Indoor Air Pollution: Problems and Priorities,* Cambridge University Press, Page 9-12.
- Hong Kong Special Administrative Region: Environmental Protection Department (2003), *Indoor Air Quality Certification Scheme for Offices and Public Places,* HKSAR, Indoor Air Quality Management Group (IAQMG).

- Hong Kong Special Administrative Region : Environmental Protection Department (2003), *Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places*, Hong Kong Special Administrative Region, Air Services Group.
- Law, A.K.Y., Chau, C.K., & Chan, G.Y.S. (2001), Characteristics of bioaerosol profile in office buildings in Hong Kong, *Building and Environment*, 36(4), 527-541.
- Malkin, R., Wilcox, T., & Sicber, W. (1996), The National Institute for Occupational Safety and Health indoor environmental evaluation experience: 2. Symptom prevalence, *Applied Occupational Environmental Hygiene*, 11, 540-545.
- Manahan S.E. (2005), *Environmental Chemistry,* 8th Ed., Boca Raton : CRC Press, c2005.
- McGranahan G. and Murray F. (2003), *Air pollution and health in rapidly developing countries,* edited by Gordon McGranahan and Frank Murray, London ; Sterling, VA : Earthscan, 2003.
- Mclius, J., Wallingford, K., Kccnlyside, R., & Carpenter, J. (1984), Indoor air quality: The NIOSH experience, *American Conference of Governmental Industrial Hygienists,* 10, 3-7.
- Persily, A. K. (1997), Evaluating building IAQ and ventilation with indoor carbon dioxide, *ASHRAE Transactions*, 103(2), 193-203.
- Scitz, TA. (1990), NIOSH indoor air quality investigations: 1971 through 1988, *Proceeding of the Indoor Air Quality International Symposium*, May 23, 1989. Cincinnati, OH: National Institute for Occupational Safety and Health, pp. 163-171.
- Seino, K., Takano, T., Nakamura, K., & Watanabe, M. (2005), An evidential example of airborne bacteria in a crowded, underground public concourse in Tokyo, *Atmospheric Environment*, 39(2), 337-341.

- Sieber, W., Stayner, L., Malkin, R., Petersen, M., Mendell, M., Wallingford, K., Crandall, M., Wilcox, T., and Reed, L. (1996), The National Institute for Occupational Safety and Health indoor environmental evaluation experience: 3, Associations between environmental factors and self-reported health conditions, *Applied Occupational Environmental Hygiene*, 11, 1387-1392.
- Tucker, W.G., (1986), Research Overview : Source of Indoor Air Pollutants, *Proceedings of IAQ '86 : Managing Indoor Air for Health and Energy Conservation*, pp. 395-404.
- United States Environmental Protection Agency (1989), *Report to Congress on Indoor Air Quality*, EPA Office of Air and Radiation/ Office of Research and Development (EPA/400/1-89/001).
- United States Environmental Protection Agency/ United States Public Health Service/ National Environmental Health Association (1991), *Introduction to Indoor Air Quality : A Reference Manual* , EPA/400/3-91/003, 297 pp.
- United States Environmental Protection Agency (1991), *Building air quality : a guide for building owners and facility managers*, Office of Air and Radiation, Office of Atmospheric and Indoor Air Programs, Indoor Air Division : U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, [Washington, D.C.] : 1991.
- Womble, S.E., Girman, J.R., Ronca, E.L., Axelrad, R., Brightman, H.S., and McCarthy, J.F. (1995), Developing baseline information on buildings and indoor air quality (BASE '94): Part I--Study design, building selection, and building descriptions. Healthy Buildings, September, 11-14.
- World Health Organization (2005), WHO Air Quality Guidelines Global Update, *Report on a Working Group Meeting*, Bonn, Germany, 18-20 October 2005.
- World Health Organization (1986), *EURO Reports and Studies 103: Indoor air quality research*, WHO, Regional Office for Europe, Copenhagen.
- World Health Organization (2000), Indoor Air Pollutants, Exposure and Health Effects, *EURO Reports and Studies,* 78, Copenhagen: World Health Organization.

- **Web site visited**
- Air Conditioning Contractors of America (ACCA) - US, http://www.acca.org/
- Air-Conditioning and Refrigeration Institute (ARI) - US, http://www.ari.org/
- Air Infiltration and Ventilation Centre (AIVC) - UK, http://www.aivc.org/
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) – US, http://www.ashrae.org/
- British Research Establishment - UK, http://www.bre.co.uk/
- Canada Mortgage and Housing Corporation (CMHC) – Canada, http://www.cmhc-schl.gc.ca/
- Carpet and Rug Institute - US, http://www.carpet-rug.com/
- Centre for Building Science (CBS) - US, http://eetd.lbl.gov/newsletter/CBS_NL/
- Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) - US, http://caddet-ee.org/
- Danish Indoor Climate Labelling, http://www.teknologisk.dk/byggeri/253
- Danish Society of Indoor Climate, http://www.dsic.org/dsic.htm
- Energy Efficiency and Renewable Energy - US, http://www.eere.energy.gov/
- Environmental Protection Agency (EPA) - US, http://www.epa.gov/iaq/
- Finnish Classification of Finishing Materials, http://www.rts.fi/english.htm
- Hong Kong Council on Smoking and Health (COSH), http://www.info.gov.hk/hkcosh/
- Indoor Air Quality Association (IAQA) - US, http://www.iaqa.org/
- Indoor Air Quality Information Centre - Hong Kong, http://www.iaq.gov.hk/
- International Society of Indoor Air Quality and Climate (ISIAQ), http://www.ie.dtu.dk/isiaq/
- National Air Duct Cleaners Association (NADCA) - US, http://www.nadca.com/
- National Institute of Occupational Safety and Health (NIOSH) - US, http://www.cdc.gov/niosh/homepage.html
- The Chartered Institution of Building Services Engineers - UK, http://www.cibse.org/
- World Health Organization, http://www.who.int/

Thank you

Q & A

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