Mitigation of Environmental Degradation through Improving Air Quality

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ABSTRACT

Poor air quality has been a serious problem in most countries, especially in the high-rise buildings equipped with central Mechanical Ventilation & Airconditioning system (MVAC). According to the Hong Kong Environmental Protection Department (HKEPD, 2003), about 32% of office buildings, 75% of restaurants, 37% of shopping malls and 60% of cinemas have been classified as "Sick Building" that leads to headaches, nausea, dizziness, sore throats, sinus congestion, nose irritation etc. In this research, we'll identify the principal causes, design, construction, users' habitual modes and measures to resolve the potential indoor air quality problems. Action research will be applied in two case studies of a learning centre and 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 management measures; as a holistic approach to resolve the IAQ problems.

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1. INTRODUCTION

ASHRAE Standard 62-2001 (2001) contends that "Acceptable IAQ" is "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." World Health Organization (WHO, 1986) describes the same as "The physical and 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."

There was growing concern in the past decade over complaints attributed to IAQ. A survey showed that people in Hong Kong spent about 85% of their time indoors (Chau, Tu, Chan, & Burnett, 2002). Some countries including Canada, Japan, Korea, Singapore, Sweden, UK and USA conducted IAQ studies for the aim of 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) states that poor IAQ would 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 are further affected by poor IAQ. Good IAQ helps occupants in enhancing good health, effectiveness, productivity, efficiency and production. As land supply in Hong Kong is scarce, developers will construct high-rise buildings equipped with central MVAC system especially for commercial use. The rental value of Hong Kong is one of the highest in the world, 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 were set in the form of regulations or guidelines in different places (Environment Australia, 2001; Health Canada, 1987; HKEPD, 1997; HKEPD, 2003; IAQMG, 1999; WHO, 2005; Womble et al., 1995).

HKSAR (2003) has set twelve parameters to self-regulate for mechanically ventilated air-conditioned buildings, which are 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) and air velocity (V).

Workstations are usually crowded together. The effectiveness of ventilation in these areas would be greatly reduced. However, VOC emissions from building materials/office furnishings/materials tend to be higher initially at higher air exchange rates, but this causes the source to be depleted more quickly. MVAC system is also responsible for providing a path to transport micro-organisms from the locus of contamination to occupants in the vicinity of the building (Law, Chau, & Chan, 2001; Seino, Takano, Nakamura, & Watanabe, 2005).

Poor maintenance of the airconditioning systems would lead to outbreak of Legionnaire's disease due to the growth of the Legionella bacteria on the drip pans in airconditioning ducts. Inefficient filtering due to poor fitting or overloaded filter have also caused poor indoor air quality. The maintenance works should include water proofing, sealing effect of windows and doors and any infiltration through basement structure. Moisture accumulation due to water leakage and seepage causes microbial growth and would cause discomfort or even allergic or toxigenic reactions in the occupants. Regular cleaning of soft furnishing including carpets is important to remove accumulated dust, adsorbed organic, moulds, spores and other pests. These agents were found to be culprits in causing building related discomforts and illnesses.

C[O.sub.2] concentration significantly contributes to indoor air pollution of a typical air-conditioned environment and thus could be selected as a surrogate indicator for assessing the IAQ (ASHRAE, 2004; CEN, 1999; Persily, 1997). An Airborne Bacteria Count (ABC) in an indoor environment is a good indicator of the cleanliness of the MVAC system and one of the important parameters to evaluate IAQ.

As a consequence of the energy crisis in the early 1970s, buildings were "sealed" for the purpose of energy conservation. MVAC systems were designed and installed with less outdoor air makeup. Modern buildings are much "tighter" and less infiltration of outdoor air and ex-filtration of indoor air. New technologies, including photocopying machine, computer workstations, electro-photographic color reproduction equipment, and high speed printers, were massively introduced into offices. When installed without adequate ventilation, these equipment can induce IAQ problems and harm the building occupants.

When an IAQ problem does arise, it is important to respond with appropriate action. Failure in respond promptly would affect health and productivity and results in:

- Increased health problems such as cough, eve irritation, headache, and allergic reactions, and in some rare cases life-threatening conditions
- Reduced productivity due to discomfort
- Increased absenteeism
- Strained relations between landlord and tenants, employees potential liability problems

World Health Organization (WHO, 2000) has estimated that up to 30% of modern commercial buildings may suffer from sub-standard indoor environments due to a variety of reasons. The poor IAQ has led to a reduction in productivity as people at work suffer from sub-optimal health. WHO (2000) identifies the following common features of sick buildings:

- They often have forced ventilation (WHO does not specifically refer to air
- conditioning, even though it falls into this category).
- They are often of light construction.
- Indoor surfaces are often covered in textiles.
- They are energy efficient, kept relatively warm and have a homogenous thermal
- environment.
- They are airtight, i.e. windows cannot be opened.
- Building occupants complain of symptoms associated with 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.
- Some cause of symptoms is unknown.
- Most of the complainants report relief soon after leaving the building.

WHO also identifies some indicators of building related illness (BRI), as follows:

- Building occupants complain of symptoms such as cough; chest tightness; fever,
- chills and muscle aches.
- The symptoms can be clinically defined and have clearly identifiable causes.
- Complainants may require prolonged recovery times after leaving the building.

Other complaints may come from outside illness, acute sensitivity (e.g. allergies), job related stress or dissatisfaction and other psychosocial factors.

USEPA and NIOSH (1991) state that poor air quality would result in:

- Increasing health problems such as cough, eye irritation, headache and allergic.
- Reactions, and in some rare cases, resulting in life-threatening conditions (e.g.
- 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 that could put rental properties at a competitive
- disadvantage.
- Opening potential liability problems (insurance policies tend to exclude
- pollution-related claims).

2. MAJOR FACTORS AFFECTING IAQ

Physical factors

The physical conditions of the building include, for example: building design, age, location, floor level and occupation density, affect the pollution load. In the case of modern buildings, air tightness which is associated with energy conservation meant that little natural ventilation is available. On top of this is the increasing use of synthetic materials which may emit pollutants. Location is a significant factor because of air infiltration especially in areas with poor ambient air quality, such as established industrialised area or prime commercial area with heavy traffic.

MVAC system

This system is intended to provide thermal comfort, in particular temperature and humidity control and air distribution. Sometimes, the system may not be well functioning or its design may fall short of the requirement to meet the occupancy density and floor layout. Occupants will generate pollutants e.g. carbon dioxide and water vapour. In designing an effective ventilation system, the density and distribution of occupants, furniture layouts are crucial. Blockage of proper air circulation by furniture and fixtures will cause poor functioning of ventilation. In an area where occupants are sparsely distributed, there may be excessive cooling but at the same time there may be insufficient fresh air input and air changes causing carbon dioxide, heat and odour to accumulate.

Recent surveys of buildings with IAQ problems indicate that about half of the problems are caused by poor ventilation and the rest by a combination of contaminant sources. Some common IAQ problems may be due to insufficient outdoor air introduced to the system, poor distribution of supply air, poor setting of air distribution devices, improper pressure differences, too hot or too cold, too dry or too humid, poor filtration, poor maintenance on filters, etc.

External factors

The external factors include outdoor air quality and cross contamination. Outdoor pollution may come from industrial emissions and vehicular emissions. Outdoor air is drawn in as "fresh air" to dilute contaminants generated indoors. If the air drawn into the indoor premises is already burdened with pollutants, it will affect IAQ. These types of pollutants from outside sources are: particulate, SO2, NO2, CO and VOCs. Radon enters the buildings from air that is drawn from the underlying soil by the "stack effect" phenomenon. The stack effect is due to the tendency of air to rise whenever it is warmer than surrounding ambient air. When indoor air is warmer than outdoor air, air flows through the lower portions and out from the upper portions of the building outer envelope, creating a difference between indoor and outdoor air pressure. Infiltration occurs through gaps and openings present in the building envelope. Entry rate of radon depends upon soil permeability, meteorology, structural, and other geological factors. Pesticides and fertilisers sprayed into the soil outside buildings can also enter the building in the same way. Other typical sources of radon in indoor air are utility natural gas and water, and certain types of building materials. Pesticides and fertilizers sprayed into the soil from outside can also enter the building.

Factors other than air pollutants

These factors include temperature, humidity, lighting and noise. In view of the potential impact of the outdoor air, all chemical measurements were also performed outdoor during on-site survey. In addition, weather conditions on the day of the survey were recorded.Temperature in the range of 20-27°C is considered an acceptable thermal comfort range. Beyond this range may increase the emission of Volatile Organic Compounds (VOCs) from materials. 40%-70% RH is acceptable as recommended by HKSAR (2003). Above this range, and associated with high temperature are uncomfortable, and facilitate the growth of micro-bacteria and fungi. Since the outdoor RH in the summer of Hong Kong will be on average 90%, dehumidification device is usually required in modern buildings to decrease the humidity level.

Materials and equipment affecting IAQ

Some office equipments e.g. photocopying machine, laser printer, adhesive tape, glue, correction fluid; and building materials e.g. wallpaper, paints, tiles, caulking compounds, carpet, mineral products tend to emit VOCs, ozone and particulate. The extent of these emissions depends on the type of equipment and processes involved, as well as the intensity of use of such equipment.

3. SOURCES OF INDOOR AIR POLLUTION

Environmental Tobacco Smoke (ETS)

It is the single largest contributor to indoor air particulate concentrations in office buildings where cigarette smoking occurs. The gaseous phase of ETS accounts for most of the odour and irritation. The particulate phase adsorb to surfaces and emit more irritating and odorous gaseous components an hour or so after emission of smoke (Clausen et. al., 1987). Workplace exposure to nicotine to 2.3 $\mu g/m^3$ for 40 years presents a risk of obvious concern. The US Occupational Safety and Health Administration considers workplace exposure to more then 6.8 $\mu g/m^3$ as a significant risk.

A study of 25 work-sites (including offices) in Massachusetts shows that smoking permitted area has a considerable effect on nicotine concentrations (9.1$\mu g/m^3$ in closed office of non-smoker) than smoking restricted area (1.3 $\mu m/m^3$). Particles in tobacco smoke are especially hazardous because they remain airborne for a prolonged period, and attract radon decay products. Despite the controversies of the early investigations to identify a cause-and-effect relationship between passive smoking and respiratory cancer, a recent study concludes that 17% of lung cancers among non smokers can be attributed to high levels of exposure to ETS during childhood and adolescence (Clausen et. al., 1987).

US Environmental Protection Agency (USEPA, 199) concluded that ETS is causally associated with lung cancer in non-smoking adults and considered a “Group A” carcinogen, and an estimated 3800 lung cancer deaths per year among non-smokers in the USA are due to ETS.

Formaldehyde Emission

This emission comes from the Resin Urea Formaldehyde used in furniture to glue the wood products together. The emission is highest when the product is new, thus adequate ventilation shall be provided for newel decorated premises. At present, there is no regulation on the use of this Resin Urea Formaldehyde.

Ozone

Ozone (O_3) is an atmospheric oxidant formed through photochemical reactions of volatile organic compounds and nitrogen oxides. Ozone is an irritant to the pulmonary system. It affects the mucous membranes and other lung tissues. It also affect respiratory function. At relatively low levels (60-120 ppb) which are more likely to occur in indoor premises, ozone may cause diminished lung function, cough, inflammation associated with biochemical changes and increased sensitivity to allergens (Boeniger, 1995). It may be generated by equipment with ultra violet (UV) sources such as photocopiers in the office and is therefore measured as an indoor pollutant.

Radon Emission

The main source of indoor radon is its immediate parent radium-226 in sites and building materials. Radium (a member of the uranium decay series) is present in various concentrations in all rocks and soils. Radium decays to radon enters into the air or dissolves in water. Radon has a short half-life of less than four days. Radon further decays into a series of short-lives isotopes, radon daughters that include 218Po, 214Pb, 214Bi and 214Po. This series of decay products terminate with 214Po, a stable radionuclide with a half-life of about 22 years. Radon daughters have half-lives ranging from 1 second to 27 minutes. Radon is the highest single source of background radiation; other sources include cosmic rays and other naturally occurring radioactive matter.

Epidemiological data is scarce and most risk assessments for low dose of indoor radon are based upon extrapolations of observations from among high exposure mining population. Thus, the exposure/dose relationship of radon is extremely complex. As the concrete used for buildings often contains granite which contains radium. The granite will emit radium when it disintegrates, and will form the decayed radioactive gas (radon). The radioactive gas and particles will increase the risk of lung cancer. However the average recorded levels of radon in Hong Kong are well and under the safety levels recommended by the World Health Organization (2000).

Volatile Organic Compounds

In the past three decades, several hundreds different VOCs have been identified. USEPA (1989) identifies over 900 different VOCs in indoor environment. At least 250 of these compounds regularly occur at levels greater than 1 ppb, which are usually 2 to 20 times greater than outdoor concentrations and is about 50 $\mu g/m^3$ (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. (Table 0-1 and Table 0-2). These compounds are found in consumer products such as cosmetic, pesticides and cleaning agents. Paint is one of the products that contain the VOC and it is not easy to avoid contacting. Also there is no law against the use of these compounds, so adequate ventilation to a newly painted building shall be enforced. The VOC will cause irritation to the eyes and throat, particularly harmful to people with existing respiratory and heart problems.

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

Certain VOCs are given prominence because they are established or suspected carcinogens, e.g., benzene, formaldehyde and trichloroethylene.

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

Table 0-3 shows the specific VOCs and their health effects.

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

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

Carbon Dioxide

Carbon dioxide (CO_2) is a colourless gas, produced by combustion, unvented appliances and the normal metabolic activity of building occupants. Ambient concentrations of CO_2 tend to be fairly constant at 350-450 ppm. The concentration of CO_2 in exhaled human breath is typically around 3.8% (38,000 ppm). Indoor concentrations of CO_2 in occupied spaces typically range from 500 to 2,000 ppm. The difference between inside and outside concentrations in most non-industrial workplaces is primarily due to the CO_2 produced by building occupants. Carbon dioxide will increase when the occupancy inside the room increased. When there is insufficient intake of fresh air and the room is crowded with people, it will lead to high levels of CO2, which leads one sleepy, and serves as a good indicator of bad air quality.

Carbon Monoxide

Carbon monoxide (CO) is a colourless and odourless gas which may result from incomplete combustion of any carbon containing fuel. Natural background levels of CO range between 0.01 and 0.23 mg/m^3 (0.01 to 0.20 ppm). In the urban environment where traffic is heavy, the CO level is expected to be higher. The use of gas appliances can also result in an increase in the CO level. Another possible cause of a raise CO level is smoking. It tends to raise the mean CO concentration of indoor air significantly.

CO has a strong affinity with haemoglobin. It is about 200 times as effective as oxygen in combining with haemoglobin to form carboxyhaemoglobin (COHb). As such, it will affect the ability of the red blood cells in carrying oxygen to the body tissues. Carbon monoxide can have detrimental effects on the heart, lungs and nervous system. WHO indicated that at COHb levels 5 - 10%, neurobehavioural effects such as impaired co-ordination and cognitive performance may be noted. Intoxication from CO may be acute or chronic, depending upon concentration and duration of exposure.

Nitrogen Dioxide

Nitrogen dioxide (NO_2) comes from the oxidation of nitrogen in air under high temperature. In Hong Kong, the emission of nitrogen oxides is attributable to electricity generation. Indoor sources of NO2 may come from entrained exhaust. NO2 has significant health effects. It is a deep lung irritant which has been shown to result in biochemical alterations. Animal tests have demonstrated lung damage in laboratory animals as a result of both acute and chronic exposures.

For chronic exposures, substantial changes in pulmonary function can be demonstrated in normal, healthy adults at or above concentrations of 2 ppm (Manahan and Stanley, 1990). Asthmatics are likely to be the most sensitive subjects. The lowest reported effect on pulmonary function for mild asthmatics was an exposure of 30 minutes at concentration of 560 $\mu g/m^3$ (0.3 ppm) during intermittent exercise. These gases come from restaurants and home kitchens using gas stoves, car in the garages etc. High level of NO2 will be harmful to people with asthma while CO is highly poisonous and can kill people.

Sulphur Dioxide

Sulphur dioxide (SO2) is primarily resulted from the combustion of fuels containing sulphur. Local emission from industrial sources or traffic in the street may elevate the level of SO2 which may enter buildings by air infiltration. The concentration indoor is normally lower than outdoors (roughly half) because of adsorption or reaction. The inhalation of SO2 causes irritation of the respiratory tract, mucus secretion or increased airway resistance. Conditions such as respiratory weakness and sensitised asthmatics may be aggravated by exposure to SO. Since SO2 is not generated by indoor sources, it would not serve as a good indicator for IAQ.

Respirable Suspended Particulate (PM_{10})

RSP are suspended particles in air with a nominal aerodynamic diameter of 10 micrometres (µm). They are released from indoor combustion sources and may include polynuclear aromatic hydrocarbons (PAH) compounds, trace metals, nitrates, and sulphates. PAH compounds are of particular concern because of their carcinogenic potential. Its airborne substances can be absorbed into respirable sized particles and inhaled into the lungs.
The health effects of particulate will depend not only on the size, shape, density and reactivity of particulates, but also the velocity of the airway. These factors will determine how the particles will be deposited in the human respiratory tract. Particles greater than 10 µm in

diameter and about 60-80% of particles of 5-10 μm are trapped in the nasopharyngeal region. At the same time, another 5% of particles smaller than 5 μm in diameter are also trapped in this region, leaving the remaining (95%) of the RSP which travel deeper into the lungs. These particles may cause severe damage at the cellular level.

Biological Contaminants

Biological pollutants typically are brought into the building by ventilation systems or natural air exchange. Dirt and moisture that accumulate in MVAC systems provide a breeding ground for biological pollutants. In buildings, micro-organisms are generally found on surfaces (such as carpet, ceiling and tiles) or floating on dust/aerosol particles. Of the airborne bio-contaminants, the ones generally found in indoor environments are: viruses, bacteria (e.g. *Pseudomonas*, *Staphylococcus*), antinomycetes (e.g. *Mycobacterium*) and fungi (e.g. *Penicillium*, *Aspergillus*, *Cladosporium* and *Candida*).

Bio-contamination is common in MVAC system, particularly where stagnant water accumulates, such as humidifiers, drip pans and drain pans. Moisture accumulation on dusty units, induction units and cooling coils can turn these components into microbial reservoirs. Human have to contend with the vast number of microbes every day. However, the exposure to these microbes may not necessarily result in overt clinical manifestations because of the immune system. Yet, microbial contamination in air can cause illness through infection or allergic reaction. Common infections caused by airborne organisms include Legionnaire's disease, colds, and influenza. These contaminants also come from mould growth on damp surfaces, particularly in Hong Kong where the climate is excessively humid and warm. Special care shall be taken for those buildings using carpets as it is the main source of the contaminants for mould growth. Moreover, they can be found in those improperly maintained air ducts, air conditioners, air filters etc. When particles such as mould get into lungs, they can create chest problem finally.

4. IAQ IMPACTS TO HEALTH

As land in Hong Kong is very limited, it is a common practice for the developers to build high rise buildings equipped with central HVAC system for commercial use. When building occupants complain of headaches, nausea, dizziness, sore throats, sinus congestion, nose irritation or excessive fatigue, the building becomes sickening or having a sick building syndrome. World Health Organization (2000) estimated that about 30% of modern commercial buildings might suffer from sub-standard indoor environments. Poor IAQ in those buildings may cause low productivity to the people at work. Most Hong Kong people experience headache, itchy eyes, respiratory difficulties, skin irritation, nausea and fatigue in workplace. Godish (2004) states that pollutant effects are normally manifested in specific target organs e.g. pollutants in intimate contact with eye and respiratory irritation, pollutants enter bloodstream from lungs or gastrointestinal system by respiratory clearance. One may be affected anywhere within a poor IAQ workplace, as follows.

Eye Irritation

Eye irritation is one of the more prevalent manifestations of pollutant effects on human body. It is most often associated with exposure to aldehydes and photo-chemical oxidats. The threshold for eye irritation by oxidants is approximately 0.10 to 0.15 ppmv (reported as ozone). Oxidant levels are indicators of the eye irritation potential of photochemical pollutants such as per oxyacyl nitrate (PAN), acrolein, formaldehyde (HCHO), and other photochemically-produced compounds. However, no other physiological changes are detectable and eye irritation resolves quickly after exposure ceases. (Godish, 2004).

Effects on the Cardiovascular System.

Pollutant such as carbon momoxide and lead are absorbed into the bloodstream and may have both direct and indirect effects on the cardiovascular system. Cardiovascular disease may also result from the indirect effects of other air pollution-incited disease. For instance, some individuals die of corpulmonale, heart failure resulting from the stress of severe chronic respiratory disease. Recent epidemiological studies have shown that premature cardiovascular system-related mortality is strongly associated with exposures to small (less or equal than 2.5 um) particles. (Godish, 2004).

Effects on the Respiratory System

The respiratory system is responsible for gas exchange and, therefore, receives direct exposure to air borne contaminants. Effects on the respiratory system are determined in great measure by its structural and functional anatomy as well as respiratory defense mechanisms. The principal function of the respiratory system is to supply the body with oxygen bloodstream and tissues. These functions are facilitated by the three major units of the respiratory tract – the nasopharyngeal, tracheobronchial and pulmonary (Colls, 2002).

Acute respiratory infection in children (ARI)

ARI, particularly as a acute lower respiratory infection (ALRI) suchas pneumonia, is one of the chief killers of children in developing countries. At about 4 million deaths per year, it now exceeds deaths from diarrhea. ARI is known to be enhanced by exposures to air pollutants and indoor environment tobacco smoke (McGranahan, 2003).

5. ECONOMIC IMPACT FROM IAQ

The Guidance Notes for the Management of IAQ in Offices and Public Places issued by the HKSAR (2003) states that the cost of poor IAQ is mainly clarified into direct medical costs and loss in productivity, as below.

Direct Medical Costs

As evident from this study (though not quantified), as well as from overseas studies, a certain percentage of the working population exposed to indoor air pollution may suffer from adverse health effects and require medical treatment of some sort, whether short term or long term. The USEPA (1991) submitted a draft report to Congress on Indoor Air Quality which included a rough estimate of US$1 billion spent annually on direct medical costs attributable to the health effects of indoor air pollution. In a report published by the Commission of European Communities, it lists allergies as occupational diseases where employees are working in buildings with air conditioning systems below standard; the medical costs for such diseases could be enormous but no figures were given.

In Hong Kong, the costs for medical treatment have not been categorised specifically to show the percentage of office workers suffering from indoor air pollution. A survey on prevalence of morbidity in Hong Kong from the statistics on visits to public clinics (Government general out-patient clinics) as well as the private sector clinics may help to shed light on the indoor air quality related sickness rate. It shows that 48.8% of the morbidity is attributed to respiratory system but there is no data on the prevalence of morbidity of the population.

Loss in Productivity

HKSAR (2003) contends that the average sick leave rate is about 1%, while the workers' ill rate is close to 3-4%, and the loss in productivity attributable to IAQ is about 14 minutes per day, or 3% of total productivity. HKCSD (1994) indicates that 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.

6. SUGGESTIONS TO CONTROL IAQ

Godish (2004) advocates source management (including source exclusion, removal and treatment), exposure control and contaminant control to control IAQ.

Source exclusion

In new building construction and remodeling, IAQ problems can be reduced or minimizes by us of low-emission products that are becoming increasingly available. Carpeting and mastic products are being producted and sold that have relatively low emissions of VOCs and the odor-producting substance called 4 phenylcyclohexane (4-PC). Formaldehyde emissions from pressed-wood products are much lower than they once were as lower-emission products have been developed. Low levels of HCHO can be attained and maintained by avoiding use of HCHO-emitting products such as particleboard, hardwood plywood paneling, medium-density fiberboard, and acid-cured finishes. Alternative products including softwood plywood, oriented-strand board, decorative gypsum board and hardboard panel and in the case of finishes, a variety of HCHO brings free varnishes and lacquers.

Source removal

The signal most effective measure to reduce contaminant levels is to identify and remove the source. In the case of HCHO control, its effectivebess depends on correct identification of the most potent source or sources in a multiple source environment. Because of interaction effects, HCHO levels are determined by the most potent source or sources present, removal of minor source would not resuce HCHO levels.

Source treatment

Source may be treated or modified to reduce contaminants emissions. One can, for example, use encapsulants to prevent release of asbestos fibers from acoustical plaster.

Exposure control

All contaminant-producing activities shall be avoided and try to relocate susceptible individuals.

Contaminant control

Contaminant levels in building space can be reduced by diluting indoor air with less contaminated outdoor air. Such dilution may occur in part or whole by infiltration or exfiltration, natural ventilation, and mechanical ventilation (Godish, 2004). Non-specific symptoms including eye, nose, and throat irritation, mental fatigue, headaches, nausea, dizziness and skin irritation, which seemed to be linked to the indoor climate . In contrast, the term “building related illness” (BRI) is used when symptoms of diagnosable illness are identified and can be attributed directly due to airborne building contaminants. WHO (2000) suggests that up to 30% of new and remodeled buildings worldwide may be subject of excessive and serious complaints related to IAQ.

Leslie and Lunau (1992) opine that most cases of dissatisfaction with the environment have an element of thermal discomfort associated with air pollutants, with other related factors e.g. air temperature, mean radiant temperature, rate of air movement, relative humidity, insulation value of clothing worn, metabolic rate of task being performed. They also reckon that “a well-planned maintenance program can prevent small deficiencies from blossoming into major, costly breakdowns, repairs and replacements. A simple thing like the routine oiling of bearings in a fan can prevent a loss of make-up air needed to assure quality indoor air.”

Hansen (1999) contends that preventive maintenance has always been economically defendable:

- Reduce unplanned services calls and the associated loss of man hours
- Reduce the number of equipment breakdowns
- Cut down the need for replacement materials and parts
- Reduce operating costs

- Create a more effective work environment for maintenance personnel
- Lengthen equipment life
- Increasing energy savings

7. RESEARCH METHODOLOGY

Action research will be applied in case studies of a local learning centre (Building A) and a commercial building (Building B), by means of analyzing collected air samples, obtaining occupiers' feedback through questionnaires (pre and post IAQ improvement works), and identifying IAQ long term management measures, as a holistic approach to resolve their IAQ problems.

For Building A, IAQ problem areas will be initially identified by recognized methods. Occupiers' comments through questionnaires to these identified problems areas will be obtained. Air samples will be collected for analysis at accredited laboratory to ascertain the future remedial actions e.g. source control, ventilation improvement, air cleaning and exposure control.

For Building B, IAQ problem areas will be identified by recognized methods. Occupiers' feedback through questionnaires from pre and post IAQ improvement works will be obtained to measure the results thereof, and identify specific long term management measure e.g. source control, ventilation improvement, air cleaning and exposure control.

Building A

Findings and Analysis

Totally 128 out of 200 questionnaires (64% response rate) have been received, with detailed analysis as below.

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	24.2
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

The above findings concurs with Hansen's (1999) argument that a building is generally defined as sick if 20% or more of the building's occupants exhibit such symptoms.

A preliminary walkthrough inspection reveals the following symptoms:

- Air grilles in the air handling units are filthy/dirty.
- Unused materials are piled in plant room.
- There is inadequate air movement in the customer service and resource center
- In the general office, drainpipes for fan coil units are clogged, causing overflow in drain pan.

As a step further, the IAQ management procedures developed by USEPA and NIOSH (1999) would be adopted, principally using a checklist for diagnosing and mitigating IAQ problems, and finds out:

- Insufficient air movement is identified after the original sales shop has been modified to customer service & resources center.
- Mould, yeast and no cleaning are found in the air duct.
- The intake air duct is not fully covered with fresh air intake filter, and thus fresh air was not fully filtered before entering the air handling units (AHU).
- The return air grilles in the AHUs are dirty.
- Unused materials are stored inside the plant rooms, where unwanted emissions/smell would be distributed to the occupiers through the AHUs.
- The filter indicator in the plant rooms are filthy/dirty, no replacement has been done.
- Drainpipes are clogged, causing condensed water to overflow from the drain pan of FCUs, which is a major source of Legionnaires's disease.
- Some areas like the Customer Services & Resources Centre, have just been installed with FCUs without exhaust air duct to provide sufficient air exchange, to evacuate the concentrated carbon dioxide (CO2) and respirable suspended particles (RSP) content, especially when user's numbers increase.

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 laboratory to determine its concentration, with results as follows:

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.

Laboratory analysis results

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

Pollutants	Unit	G/F Children 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

The above results correlate with the preliminary site observations.

Mitigating IAQ Problems

Following USEPA and NIOSH's (1999) control strategies, the following actions are suggested:

Source Control

Insufficient air ventilation would be one main reason leading to high CO2, RSP and TBC content. The open kitchen in the café further compounds the problem, and thus changing to close kitchen would be one solution. Adopting a stronger ventilation system for the kitchen, with negative pressure would be another way out.

Ventilation

This approach can be effective where buildings are under-ventilated or the contaminant source cannot be easily identified. The problem in customer services & resources centre can be resolved by installing additional return air duct (RAD), whereas the ventilation rate at computer laboratory can be increased.

Air Cleaning

The TBC in all these sample areas are excessively high (70-120%), as a result of mould/yeast/bacteria growth in the air duct. Robotic air duct cleaning woud an effective measure. To avoid outside pollutants from getting inside, air cleaning devices e.g. particulate filtration, electrostatic precipitation may be engaged. Particulate filtration removes suspended liquid or solid materials whose size, shape and mass would remain airborne at the air velocity conditions present. Filters with higher efficiency could remove a greater proportion of particles. Electrostatic precipitation uses the attraction of charged particles to oppositely collect airborne particulates. The particles are charged by ionizing the air with an electric field. The charged particles are then collected by a strong electric field generated between oppositely-charged electrodes. This provides relatively high efficiency filtration of small respirable particles.

Exposure Control

Exposure control is an administrative approach that adopts behavioral methods, such as:

- Scheduling contaminant-producing activities to avoid complaints, subject to the nature of the business.
- Relocating susceptible individuals to control exposure, which is least desirable and to be used only when all other strategies are ineffective.

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, the Facility Management has to devise an instant plan to check out/monitor the proper functioning of HVAC system/maintenance and associated operational control for the building. For a longer term, the HKEPD (2003) objectives/precedures e.g. developing an IAQ Management Plan and international standards shall be adopted.

Building B

Building B - a Grade A office building, has been completed and operated for more than 20 years. In recent years, there are complaints from tenants regarding the poor IAQ. Preliminary investigations and subsequent improvements are done to cater for better IAQ. Findings from the 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

Among the 2877 complaints in 2005, 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 survey is prepared 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. The criteria for selecting respondents are:

- Tenants with the highest complaint rate from the previous year
- No air duct cleaning works has been done at these floors for over 5 years
- There were fitting out works during the project survey period
- There has not been VAV boxes replacement

The IAQ improvement works are:

Regular Air Duct cleaning

In the past years, the air duct would only be cleaned after substantial complaints were received. After proactive and extensive cleaning, tenants' complaint reduced which implied a significant improvement to IAQ.

VAV upgrading

The aged VAV terminal units and associated pneumatic control system were replaced. By replacing the deteriorating VAV terminal units, the situation such as fiber peeling inside the VAV box will no longer exist, as revealed below. The new VAV box is constructed with a clean perforated metal sheet lining, and thus reduces the risk of fibre spreading within the office. All A/C flexible duct will be also replaced. After upgrading, the tenants enjoyed a better IAQ through a more precise/flexible control of VAV system via a new Building Management System.

VOCs control within fitting out areas

VOCs are diverse group of carbon-containing compounds that evaporate at room temperature and become airborne. They are also one of the most dynamic classes of indoor air contaminants. Floor covering are sources of a wide variety of indoor air contaminants such as, VOCs and fibers (including asbestos). Some floor coverings, especially carpets, also act as sinks for pollutants from other sources, absorbing the pollutants onto their surfaces or absorbing pollutants into their fibers and later releasing them into air. These dominate most IAQ complaints, as demonstrated in the survey. The following rules have to be abided by the fitting out tenants:

- The Tenant should not keep storage of offensive materials per local Government regulations and code of practices e.g. materials containing chlorofluorocarbons (CFC).
- Paints and coatings should be low VOC type and suitable for use indoors in unventilated areas. All waste paints and other liquids must be disposed of per Government regulations.
- The Tenant are required to provide all data on materials, chemicals and fluids used, including details on their safe use/disposal and safety data sheets.

- All timber treatment works will follow the relevant codes and standards. Any particleboard, fibreboard and similar composite boards used must comply with BS 5669 or BS1142 to control formaldehyde emissions.
- No alteration or repairs will contain asbestos or harmful materials.

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. It is the single large contributor to indoor air particulate concentrations in office buildings where cigarette smoking occurs; it also contain a long list of potentially hazardous chemicals but usually in very low concentrations. This building was barred from smoking, as a "Smoke Free Building" from 1/9/2006.

Finding and Analysis

Totally 400 out of 1000 questionnaires (40% response rate) are received, with results/analysis as shown below.

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

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

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 due 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 has been improved e.g. respondents' sick leaves decreased, smoking/odour smell reduced.

8. CONCLUSION

In order to tackle IAQ problems, a management strategy should be specifically prepared for a building, including allocation of responsibility, preparation, review of work contracts and 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 could be one way out to safeguard the 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 the IAQ requirements/standards for a better environment; and thus maintain a lasting sustainability for mankind.

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