Abstract of thesis entitled:

Investigation of Indoor and Outdoor Air Quality at Classrooms in Hong Kong

submitted by

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ABSTRACT

An investigation of the indoor and outdoor air qualities at classrooms in Hong Kong was carried out. Classrooms chosen were located in industrial, residential, urban, and rural areas. Pollutants and parameters studied were temperature, relative humidity, carbon dioxide (CO_2), sulfur dioxide, nitrogen oxides, volatile organic compounds, particulate matter with diameter less than 10 microns (PM_{10}), particulate matter with diameter less than 2.5 microns ($PM_{2.5}$), formaldehyde, carbon monoxide, and bacteria. The effect of ventilation rate on pollutant concentration was also investigated. Indoor and outdoor PM_{10} concentrations were high mainly due to vehicle exhaust emissions and construction activities. High PM_{10} concentrations (200 $\mu g/m^3$) were observed during classroom cleaning because sweeping of the floor re-suspended particulate matters settled on the ground into the air. Higher CO_2 concentrations, with averages over 1000 ppm, were found at classrooms with mechanical ventilation than those classrooms with natural ventilation. All of the maximum CO_2 concentrations in the classrooms were higher than the American Society for Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) standard of 1000 ppm due to very high occupancy (over 60 person/100 m^2) and inadequate ventilation. Maximum CO_2 level of 5900 ppm measured at an air-conditioned classroom because the door and windows were closed and ventilation was shut off. Ventilation rates measured at the naturally ventilated classroom and the air-conditioned classroom were 0.937 air changes per hour (ACH) and 0.217 ACH respectively. The ventilation rates were below the ASHRAE Standard 62-1989 of 7.5 l/s. Results from the control study agreed with those in the previous studies that pollutants with outdoor sources had lower indoor concentrations than the outdoors in an air-conditioned classroom. The air-conditioners, though not providing

enough fresh air, could be barriers for outdoor pollutants. Therefore air-conditioning in classrooms can provide a quiet learning environment for children, and also provide a thermally comfortable environment, and lower concentrations of pollutants but not adversely affecting indoor air quality. Improvements in air exchange rates with installation of air cleaning devices can provide a more comfortable learning environment for students.

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DECLARATION

I hereby declare that this thesis entitled "Investigation of Indoor and Outdoor Air Quality at Classrooms in Hong Kong" has not been previously submitted to any other institution for a degree or other qualification, and contains no material previously published or written by another person, except where due reference is made in the text.

Maureen Chia Chi Chang

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1.0 INTRODUCTION

Indoor air quality in workplace and residential environments is of increasing concern since most people spend a lot of their times indoors. Air pollutants produced by indoor and outdoor sources directly affect the environment and our health. Indoor air quality at school is of special concern since children are more susceptible to poor air quality, moreover indoor air problems can be subtle and do not always produce easily recognisable impacts on health and well-being. Good indoor air quality at schools also favours children's learning ability, teacher and staff's productivity (USEPA 1996a). Failure to prevent indoor air pollution can increase the chance of long-term and short-term health problems for students and staff; reduce in productivity of teachers; degrade the student learning environment and comfort; and reduce the efficiency of the school physical plant and equipment. Investigation of air quality in classrooms can help us to characterise pollutant levels and to implement corrective measures for improvement if necessary.

A large number of schools in Hong Kong is located near the Kai Tak Airport (the airport terminal no longer in operation in July 1998) or heavy traffic roads and is adversely affected by traffic and aircraft noise. The 'Hong Kong Planning Standards and Guidelines' (Planning Department 1991) requires noise mitigation measures for schools with noise levels at building facades over 65 dB(A). The Environmental Protection Department (EPD) started a school insulation program in 1987 to provide a quiet learning environment for students. The first stage of the program aims to insulate classrooms from aircraft noise, the second stage is to benefit those affected by road traffic noise and lastly those affected by railroad and road traffic noise. Up to the year of 1997, the Hong Kong Government has already spent $563,000,000 HKD on

classroom insulation and 9,165 classrooms were benefited from this program (EPD 1998). With relocation of the airport from Kowloon City to Chek Lap Kok in 1998, the number of schools affected by aircraft noise has diminished greatly. Traffic is now the main contributor to school noise problems. The best practical mean to tackle aircraft and road traffic noise at classrooms determined by consultation studies is to provide double glazed windows and air-conditioning. In this confined and overcrowded environment air quality problems arise. Air-conditioned classrooms in Hong Kong have problems like higher prevalence of respiratory symptoms among students. Higher percentages of kindergarten children with lower respiratory tract symptoms, intestinal diseases, and skin irritation were found when compared to those before starting school. Types of classroom furnishings and ventilation system used could lead to very different indoor pollutant concentration and composition. Classrooms in Hong Kong are usually constructed with painted walls, ceramic tile covered floor with aluminium framed windows. Most are equipped with ceiling fans, and/or window type air-conditioners. Classrooms remote from traffic noise interferences are usually naturally ventilated and equipped with ceiling fans to remove heat during the summer seasons. Western countries have classrooms with wall-to-wall carpeting and various types of ventilation systems were used for both heating and cooling purposes. Most classroom air quality studies were carried out in the United States and European countries, similar studies in South East Asian countries having hot and humid climate are not well characterised.

2.0 OBJECTIVES

The change in design for improving environmental qualities at classrooms in Hong Kong also brought changes in the indoor air quality. The aim to reduce traffic and aircraft noise at classrooms forced them to be air-conditioned and equipped with double glazed windows. The objectives of this study are to study the indoor and outdoor pollutant concentrations and comfort parameters at five selected classrooms, to investigate the effect of ventilation rate on indoor pollutant concentrations, and lastly, to compare the concentration of pollutants in air-conditioned and naturally ventilated classrooms.

3.0 LITERATURE REVIEW

3.1 Indoor and Outdoor Air Quality Guidelines

Air quality guidelines and standards are established to protect human from exposure to high levels of health concerned pollutants. The Hong Kong EPD has established a set of air quality guidelines for both indoor and outdoor premises. The indoor guidelines were set based on several criterions. For non-carcinogenic pollutants, the concentrations should not be above odor thresholds or any health concerned concentration. For carcinogenic pollutants, the concentrations should not be higher than a level that would give a risk of 1×10^{-6}; and the standard should be comparable to the Technical Memorandum (for specifying Air Quality Objectives for Hong Kong) and/or standards established by the World Health Organization (WHO) and other advanced countries (Pang 1994). Table 3.1 shows the Hong Kong Air Quality Objectives (HKAQO) and the Interim Indoor Air Quality Guidelines for Hong Kong (HKIAQ). The HKAQO is a guideline for outdoor premises and HKIAQ is for indoor environments.

The Hong Kong Government has recently proposed a set of Indoor Air Quality Objectives (IAQO) for Office Buildings and Public Places in Hong Kong (Indoor Air Quality Management Group 1999). The classroom environment is classified as a public place and therefore the new set of Objectives will be applicable. Note that the Objectives are only applicable to indoor environments with mechanical ventilation, thus classrooms with natural ventilation are not governed by the Objectives. Tables 3.2 and 3.3 show the recommended contaminant levels.

Table 3.1 - *Summary of Indoor and Outdoor Air Quality Guidelines for Hong Kong*

Pollutants	**Interim Indoor Air Quality Guidelines for Hong Kong**	**Hong Kong Air Quality Objectives**
Sulfur Dioxide	800 $\mu g/m^3$ (1-hour average) 350 $\mu g/m^3$ (24-hour average) 80 $\mu g/m^3$ (Annual average)	800 $\mu g/m^3$ (1-hour average) 350 $\mu g/m^3$ (24-hour average) 80 $\mu g/m^3$ (Annual average)
Nitrogen Dioxide	300 $\mu g/m^3$ (1-hour average) 150 $\mu g/m^3$ (24-hour average) 80 $\mu g/m^3$ (Annual average)	300 $\mu g/m^3$ (1-hour average) 150 $\mu g/m^3$ (24-hour average) 80 $\mu g/m^3$ (Annual average)
Carbon Monoxide	30,000 $\mu g/m^3$ (1-hour average) 10,000 $\mu g/m^3$ (8-hour average)	30,000 $\mu g/m^3$ (1-hour average) 10,000 $\mu g/m^3$ (8-hour average)
Respirable Suspended Particulate	180 $\mu g/m^3$ (24-hour average) 55 $\mu g/m^3$ (Annual average)	180 $\mu g/m^3$ (24-hour average) 55 $\mu g/m^3$ (Annual average)
Lead	1.5 $\mu g/m^3$ (3-month average)	1.5 $\mu g/m^3$ (3-month average)
Photochemical Oxidants (as ozone)	-	240 $\mu g/m^3$ (1-hour average)
Formaldehyde	100 $\mu g/m^3$ (1-hour average)	-
Dichloromethane	300 $\mu g/m^3$ (1-hour average)	-
Trichloromethane	60 $\mu g/m^3$ (1-hour average)	-
Trichloroethylene	300 $\mu g/m^3$ (1-hour average)	-
Tetrachloroethylene	8,000 $\mu g/m^3$ (1-hour average)	-
1,4-Dichlorobenzene	730 $\mu g/m^3$ (1-hour average)	-
Benzene	110 $\mu g/m^3$ (1-hour average) 0.12 $\mu g/m^3$ (Annual average)	-
Toluene	600 $\mu g/m^3$ (1-hour average)	-
Benzo[a]pyrene	0.4 $\mu g/m^3$ (1-hour average)	-
Microbial/Biological Contaminants	1,000 Colony Forming Units/m^3 (1-hour average)	-
Radon	200 Bq/m^3 (Annual average)	-

Table 3.2 – *Recommended Indoor Air Quality Objectives for Office Buildings and Public Places in Hong Kong (Indoor Air Quality Management Group 1999)*

Parameter	**Unit**	**8-hour average**		
		Level 1	**Level 2**	**Level 3**
Carbon Dioxide	ppm	< 800	< 1000	< 5000
Carbon Monoxide	$\mu g/m^3$	< 2000	< 10000	< 29000
Respirable Suspended Particulate	$\mu g/m^3$	< 20	< 180	-
Nitrogen Dioxide	$\mu g/m^3$	< 40	< 150	< 5600
Ozone	$\mu g/m^3$	< 50	< 120	< 200
Formaldehyde	$\mu g/m^3$	< 30	< 100	370
Total Volatile Organic Compounds	$\mu g/m^3$	< 200	< 600	-
Radon	Bq/m^3	< 200	< 200	-
Airborne Bacteria	CFU/m^3	< 500	< 1000	-
Room Temperature	°C	20.0-25.5	< 25.5	-
Relative Humidity	%	40-70	< 70	-

There are three levels of the proposed IAQO to act as benchmark for evaluating and assessing IAQ. Classification of the three levels are: Level 1 – represents very good IAQ that a high-class and comfortable building should have; Level 2 – represents IAQ that provides protection to the public at large including the very young and aged; and Level 3 – represents IAQ that is required to protect workers and employees as enforced under the current occupational safety and health laws. At least Level 2 IAQO should be attained at classroom environments since it aims for protection of health of the general public. Note that the concentration levels stated in the Level 2 IAQO are very similar to those in the HKIAQ.

Table 3.3 – *Indoor Air Quality Objectives for Individual Volatile Organic Compounds (Indoor Air Quality Management Group 1999)*

Compound	**Levels 1 & 2**	**Level 3 (Occupational Exposure Limits)**
Benzene	16.1 $\mu g/m^3$	1600 $\mu g/m^3$
Formaldehyde	30, 100 $\mu g/m^3$	370 $\mu g/m^3$
Carbon Tetrachloride	103 $\mu g/m^3$	31000 $\mu g/m^3$
Trichloroethylene	770 $\mu g/m^3$	269000 $\mu g/m^3$
Tetrachloroethylene	250 $\mu g/m^3$	170000$\mu g/m^3$
Chloroform	163 $\mu g/m^3$	49000 $\mu g/m^3$
1,2 (1,3)-Dichlorobenzene	500 $\mu g/m^3$	150000 $\mu g/m^3$
1,4-Dichlorobenzene	200 $\mu g/m^3$	60000 $\mu g/m^3$
Ethylbenzene	1447 $\mu g/m^3$	434000 $\mu g/m^3$
Toluene	1092 $\mu g/m^3$	188000 $\mu g/m^3$
Xylenes	1447 $\mu g/m^3$	434000 $\mu g/m^3$

The Clean Air Act was last amended in 1990 that requires the United States Environmental Protection Agency (USEPA) to set National Ambient Air Quality Standards (NAAQS 1992) for pollutants considered harmful to public health and the environment. Primary standards are set to protect public health, including the health of 'sensitive' populations such as asthmatics, children, and the elderly. Secondary standards are set to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. The USEPA sets NAAQS for six principal pollutants, which are called 'criteria' pollutants and they are listed in Table 3.4. Units of measurement for the standards are in parts per

Table 3.4 – *Summary of United States National Ambient Air Quality Standards (NAAQS 1992)*

Pollutant	**Standard Value**	**Standard Type**
Carbon Monoxide (CO)	10 mg/m^3 (8-hour average) 40 mg/m^3 (1-hour average)	Primary Primary
Nitrogen Dioxide (NO_2)	100 $\mu g/m^3$ (Annual Arithmetic Mean)	Primary & Secondary
Ozone (O_3)	235 $\mu g/m^3$ (1-hour Average) 157 $\mu g/m^3$ (8-hour Average)	Primary & Secondary Primary & Secondary
Lead (Pb)	1.5 $\mu g/m^3$ (Quarterly Average)	Primary & Secondary
Particulate matter < 10 micrometers (PM_{10})	150 $\mu g/m^3$ (Annual Arithmetic Mean) 50 $\mu g/m^3$ (24-hour Average)	Primary & Secondary Primary & Secondary
Particulate matter < 2.5 micrometers ($PM_{2.5}$)	15 $\mu g/m^3$ (Annual Arithmetic Mean) 65 $\mu g/m^3$ (24-hour Average)	Primary & Secondary Primary & Secondary
Sulfur Dioxide (SO_2)	80 $\mu g/m^3$ (Annual Arithmetic Mean) 365 $\mu g/m^3$ (24-hour Average) 1,300 $\mu g/m^3$ (3-hour Average)	Primary Primary Secondary

million by volume (ppmv), milligrams per cubic meter of air (mg/m^3), and micrograms per cubic meter ($\mu g/m^3$) of air at 25°C.

Indoor air quality guidelines and standards in the United States are mainly established by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and the WHO. The ASHRAE Standard 62-1989 (ASHRAE 1989), "Ventilation for Acceptable Indoor Air Quality", states that there are two procedures to follow for achieving acceptable indoor air quality. The "Ventilation Rate Procedure" describes the amount and the rate of ventilation necessary to

achieve acceptable indoor air quality; and the "Indoor Air Quality Procedure" describes the control of known and specifiable contaminants to achieve acceptable IAQ. The ASHRAE Standard 55-1992 (ASHRAE 1992) describes requirements for mechanical ventilation to provide thermal comfort in human occupied indoor environments.

In the "Preliminary Draft: Conceptual Standardized EPA Protocol for Characterizing Indoor Air Quality in School Buildings", the USEPA recommended that to monitor indoor air in schools, study areas should be selected based on criteria for occupancy, air supply, and test space requirements. Rooms included in the survey requires at least 75% occupancy during the defined test period of 8 a.m. to 4 p.m. and a minimum occupant density of 5 people per 1000 square feet (~92.9 m^2) (USEPA 1996b).

3.2 Air Contaminants and Health Effects

There are a large variety of pollutants in the atmosphere. Different source strength and characteristics affect the differences in composition and characteristics of ambient and indoor pollutants. There are mainly two types of pollutants in indoor and outdoor air, namely, suspended particulate matter and gaseous pollutants. Exposure to a complex mixture of pollutants containing the two may result in acute or chronic diseases or symptoms.

The quality of indoor air can affect our health. More importantly a person's perception of the healthfulness of a certain environment can bring discomfort or ill-health when inside a building. Pollutant concentrations and other indoor environmental factors such as temperature and humidity affect our health differently. There are two

different types of indoor air quality problems, Sick Building Syndrome (SBS) and Building Related Illness (BRI). SBS is a term referring to a set of symptoms experienced by a significant number of occupants in certain buildings with no obvious caused or related clinical illness. The symptoms usually disappear when the individual is not occupying the building. Occupants usually experience irritation in eyes, nose and throat, dry skin, headaches, or excessive fatigue. BRI refers to well characterized human illnesses which are caused by adverse indoor environmental factors which complaints and health of occupants can be explained by pathophysiological principles. An example of BRI is Legoinnnaires' disease.

3.2.1 Suspended Particulate Matter

Suspended particulate matter can be segregated according to their sizes. Those inhalable can affect our health the most. Suspended particles with aerodynamic diameters of less than 10 microns are those that can penetrate into our lower respiratory tract. Particulate matter contains both biological and non-biological components. Biological components include bacteria, fungi, pollens, insect scales, and algae. Sources are from men, animals, pets, rodents, insects, plants, vegetables, fruits, fluids, and many materials providing conditions for growth. Cross infection could easily occur if the air is not suitably ventilated. Mould is a common problem in indoor premises in Hong Kong. The weather here is hot and humid which provides ideal condition for mould growth. Non-biological particulate matters are dusts, smoke and fibers. Airborne volatile compounds of metals can attach to the surfaces of particulate matters. Researchers have extensively investigated the sources and characteristics of trace elements present in particulate matters. Qin et al. (1997)

analyzed the chemical composition of respirable particulate matter measured at eleven air monitoring stations in Hong Kong. The concentrations of aerosols measured in Hong Kong were low compared with other Asian cities.

3.2.2 Gaseous Pollutants

Gaseous pollutants like sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x) (nitric oxide (NO) and nitrogen dioxide (NO_2)), ozone (O_3), and formaldehyde are commonly found in the ambient air. Sulfur dioxide is produced from combustion of sulfur containing fuel. Nitrogen oxides are products from high temperature combustion. Their health effects include lung irritation and even substantial change in pulmonary function if chronically exposed. Carbon monoxide results from incomplete combustion and has strong affinity to blood hemoglobin. It competes with oxygen molecules in combining with hemoglobin to form carboxyhemoglobin and affects the ability of red blood cells carrying oxygen to different parts of the body. Carbon dioxide (CO_2) though not considered as a pollutant can have adverse health effects on human being. Its concentration is commonly used as an indicator of how well the indoor environment is ventilated. Ozone is an oxidant formed from reactions between volatile organic compounds and nitrogen oxides under sunlight. It is an irritant to the pulmonary system and affects mucous membranes and lung tissues. Pressed wood products, containing urea-formaldehyde and phenol-formaldehyde release formaldehyde in the gaseous form. Formaldehyde causes irritation to mucous membrane of eyes and upper respiratory tract. At high levels it causes cardiovascular and pulmonary effects, neurological effects and cancer.

3.2.3 Volatile Organic Compounds

Volatile organic compounds (VOC) are a diverse group of carbon-containing compounds. They are a group of chemically diverse compounds differing in toxicity by more than four orders of magnitude (Rothweiler and Schlatter 1993). There are numerous indoor and outdoor sources of VOC such as evaporation from adhesives, cleaning agents, vehicle exhaust, solvents and even from humans. Molhave (1990) stated that total VOCs levels at 0.2 mg/m^3 had no long-term effect on health, but at levels between 0.2 to 3.0 mg/m^3 they might trigger headaches and irritations. Many indoor environments identified that vehicle exhaust has been the major contributor to indoor VOC levels. Daisy et al. (1994) found that motor vehicle emissions were the major source of VOCs (7 aromatic compounds and 5 alkanes) at a building and also leaky air-conditioning systems were the major source of indoor freon. Perry and Gee (1993) found that a larger percentage of indoor VOCs came from the outdoors in London. Indoor furnishing, especially those newly furbished, also contributes to VOC levels. Brown et al. (1994) found that new buildings had VOC concentrations an order of magnitude higher than older ones due to construction materials and building contents.

3.2.4 Comfort Parameters

Air pollutants affect our health and environmental parameters such as temperature, relative humidity, and air movements affect our comfort especially in indoor environments. Uniformity of temperature is an important factor for comfort. Environmental factors also affect pollutant concentrations, such as formaldehyde concentrations, and growth of bacteria. Goh et al. (1999) investigated the effect of

temperature and relative humidity on microorganism levels in a library. Bacteria levels measured in the library were higher than those measured outside, but in contrast the fungal levels were higher in the outdoors than in the indoors. Bayer and Downing (1992) related the effect of humidity level on indoor air quality in hot and humid places. They found that the lack in controlling humidity could result in significant microbial growth. Lowering of indoor temperatures was not a good way to control humidity since the number of complaints in respiratory problems by occupants was increased. Kwok (1998) investigated thermal comfort of students in tropical classrooms with and without mechanical ventilation. Majority of the classrooms did not meet requirements listed in the ASHRAE Standard 55-1992 though occupants were satisfied with the environment even though the standard was not met.

3.3 Sources of Indoor and Outdoor Air Pollutants

The cause of indoor air pollution is a combination effect of physical, chemical and biological factors, and adequacy of ventilation in the environment. Exposure to indoor air pollutants has increased due to construction of tight buildings for energy conservation, use of synthetic building materials and furnishings, use of personal care products, and use of chemical solvents for cleaning. Major indoor air pollution sources are from the outdoors, heating, ventilation, and air-conditioning (HVAC) and building equipment, furnishings, and human activities. Major outdoor air pollutant comes from traffic, industrial, construction, and combustion sources. Pollutants commonly found in the air and their origins are summarized in Table 3.5 (Yocom 1982).

Table 3.5 - *Air Pollutants by Source Locations (Yocom 1982)*

Pollutants	**Sources**
Group I – Sources Predominantly Outdoor:	
Sulfur oxides (gases, particles)	Fuel combustion, non-ferrous smelters
Ozone	Photochemical reactions
Lead, manganese	Automobiles
Calcium, chlorine, silicon, cadmium	Suspension of soils or industrial emissions
Organic substances	Petrochemical solvents, natural sources, vaporisation of unburned fuels
Group II – Sources Both Indoor and Outdoor:	
Nitric oxide, nitrogen dioxide	Fuel burning
Carbon monoxide	Fuel burning
Carbon dioxide	Metabolic activity, combustion
Particles	Re-suspension, condensation of vapours and combustion products
Water vapour	Biological activity, combustion, evaporation
Organic Substances	Volatilisation, combustion, paint, metabolic action, pesticides, insecticides, fungicides
Spores	Fungi, moulds
Group III – Sources Predominantly Indoor:	
Radon	Building construction materials (concrete, stone), water, soil
Formaldehyde	Particleboard, insulation, furnishings, tobacco smoke, gas stoves
Asbestos, mineral and synthetic fibres	Fire-retardant, acoustic, thermal or electric insulation
Organic substances	Adhesives, solvents, cooking, cosmetics
Ammonia	Metabolic activity, cleaning products
Polycyclic hydrocarbons, arsenic, nicotine, acrolein, etc.	Tobacco smoke
Mercury	Fungicides in paints, spills in dental care facilities or laboratories, thermometer breakage
Aerosols	Consumer products
Viable Organisms	Infections
Allergens	House dust, animal dander

3.4 Indoor Air Quality at Schools

Indoor air quality at residential (Lee et al. 1999a, Chao et al. 1998, Lee 1997, Drahonovska and Gajdos 1996, Montgomery and Kalman 1989), office premises (Chuah et al. 1997, Hill et al. 1992, Grot et al. 1991), restaurants (Benfenati et al. 1998), and aircraft (Lee et al. 1999b, Nagda et al. 1992, Nagda et al. 1991, Malmfors et al. 1989, Holcomb 1988) have been extensively studied by air quality experts. Classrooms are complex environments influenced by a lot of factors such as the number of occupants, building design, office equipment, cleaning agents, and school activities. Other typical indoor air pollutants may include VOC emissions from cleaners, copiers, art supplies, and consumer products as well as formaldehyde emission from sources such as new furniture and carpeting. Indoor air quality at schools in the United States and European countries has been a subject of interest for researchers, but IAQ in tropical classrooms are not thoroughly studied. The following is a summary of the findings of air quality problems at schools.

Researchers have thoroughly investigated the levels of carbon dioxide and VOCs in educational premises. Carbon dioxide, VOC measurements and a questionnaire survey were carried out in forty-eight schools and seventy-four kindergartens by Willers et al. (1996). Concentrations of total VOC were low (average = 145 $\mu g/m^3$) and within suggested guidelines. CO_2 levels (average = 1200 ppm) were higher than the guidelines in several cases. No relation was established between concentrations of total VOC and CO_2 with SBS symptoms. Awbi and Pay (1995) studied air quality in four naturally ventilated classrooms. The classrooms were studied under controlled and uncontrolled conditions. The results showed that the air quality were lower than the relevant guidelines and recommendations. They suggested that the

classroom CO_2 levels should determine the required ventilation rate instead of the reverse. Gusten and Strindehag (1995) carried out air quality measurements for CO_2 and total VOC at one hundred and eighty five schools in Sweden. The study revealed that outdoor contamination sources played a major role in affecting the IAQ. Cleaning products and floor polish also temporarily added to pollution contents in classrooms. Other factors influencing IAQ are the extent of human activities such as the number of students, length of lessons and breaks in the premises. The difference between the indoor air total VOC level and the supply air total VOC level, when correlated with CO_2 levels, showed that human activity was the major contributor of total VOC to the classrooms. Chan et al. (1993) investigated student's exposure to VOC in Taipei, Taiwan. Similar daily outdoor variation of VOC was observed, but the classroom VOC levels varied from day to day. The indoor VOC levels were five times lower than those measured on roads in the city. The authors concluded that vehicle emissions were an important source of VOC found in the classrooms in Taipei. Downing and Bayer (1993) investigated CO_2 and total VOC concentrations in elementary schools. CO_2 levels ranged from 600 to 2500 ppm and average total VOC concentrations exceeded 1 mg/m^3. The highest total VOC level recorded at one of the schools was 23 mg/m^3, which was from carpet adhesives. The CO_2 levels in ten kindergartens investigated by Pejtersen et al. (1991) ranged from 455 to 2130 ppm with an average of 963 ppm. Total VOC concentrations ranged from 0 to 5.18 ppm with an average of 1.56 ppm. The concentration of VOC, respirable dust, and personal factors on the prevalence of SBS in primary schools was investigated by Norback et al. (1990). The average indoor CO_2 concentration was 800 ppm indicated poor outdoor fresh air supply. Indoor VOC concentration was enhanced by elevated room temperature. The concentration of

respirable dust was higher when the ventilation rate was lowered and when the air had high moisture content. Cousins and Collett (1989) investigated CO_2 concentrations at twelve schools in Alberta, Canada. CO_2 concentrations ranged from 500 to 2800 ppm at old and newly renovated schools and also in portable classrooms. Berglund et al. (1982) investigated VOC levels in a newly built pre-school where symptoms of SBS were reported by staff and children. The indoor VOC concentrations were found to be greatly affected by building material emission and ventilation efficiency. Formaldehyde concentrations were found at low levels at about 110 $\mu g/m^3$.

Particulate matter is another important pollutant found in schools. Roorda-Knape et al. (1998) found that PM_{10} concentrations in classrooms had high variations and were much higher than those measured outdoors. The highest PM_{10} concentration was recorded during school hours, which was caused by re-suspension of particulate matters into the air originated from student activities. Janssen et al. (1997) also found significantly higher indoor PM_{10} concentrations than the outdoor concentrations. Scheff et al. (1999a) measured the baseline particulate matter and bacteria concentration at a school in the United States. Total particulate matter concentrations ranged from 29 to 177 $\mu g/m^3$. Respirable particle concentrations ranged from 13 to 38 $\mu g/m^3$ in the art room and lobby, respectively. The most abundant fungi identified were *Aspergillus, Cladosporium, Penicillium,* and Yeasts. Ransom and Pope III (1992) found a positive association between the concentration of PM_{10} with absenteeism in elementary school. The PM_{10} concentration averaged 50 $\mu g/m^3$ during the study period with the maximum 24-hour concentration at 365 $\mu g/m^3$. And the effect of high PM_{10} concentration persisted up to three or four weeks.

Microorganism and relative humidity at high levels also poses health threat to

schoolchildren. Three case studies of contaminated indoor air in school buildings were studied by Godish (1996). One of the cases involved mould infestation of classroom furnishings and materials. Students and staff reported upper respiratory problems and asthma-like symptoms. Major mould types found were *Cladosporium, Penicillium, Epicoccum, Aspergillus.* In another case, elevated indoor levels of formaldehyde found were due to emissions from pressed wood desks and shelving units. The third case involved mould infestation of a high school building. The cause of the infestation was due to moisture. Abildgaard and Miljoteknik (1988) investigated the airborne microorganism concentration and airborne dust levels at Danish schools. A good correlation between the levels of dust and microorganisms was established. The authors concluded that dust particles might act as a carrier of bacteria.

Symington et al. (1991) investigated the formaldehyde concentration at schools near a foundry. Though the concentration of formaldehyde reached a very high level of 0.3 mg/m^3 over short periods of time, there was no evidence that formaldehyde emissions are related to children respiratory symptoms. Thorstensen et al. (1990) studied indoor air quality and pollution sources at school. The investigation included pollutant concentration measurements and a questionnaire survey. The results showed that pollutants from furnishings in the classrooms and the ventilation system varied considerably from school to school. The perceived air quality has good correlation with mucosal irritation and prevalence of general symptoms. Low ventilation rates and high pollution load in the schools were the reasons for high prevalence of symptoms.

Wang (1975) studied bioeffluent levels in a college auditorium. Organic compounds such as methanol, ethanol and acetone were found at high concentrations in the classroom. Carbon dioxide concentrations were 45% higher during examination

period than normal lecture. Indicating the amount of CO_2 released by students vary while performing different activities. Green (1975) identified a linear correlation between indoor relative humidity and absenteeism and colds in schools. Increasing the relative humidity from 22% to 35%, a 20% reduction in absenteeism was observed. This observation was also supported by similar studies at other schools in Canada.

3.5 Health Problems Related to Children

There are numerous studies on the effect of air pollution on health of children. Respiratory symptoms are commonly found among children living in highly polluted areas. Horstman et al. (1997) investigated the difference in pulmonary functions of two hundred and thirty five school children in a highly polluted district and a cleaner district in Northern Bohemia. The forced vital capacity of children living in the highly polluted area was significantly lower than those in the cleaner area. And the difference was not related to parental smoking habits, presence of pets, heating/cooking fuels, private home/apartment residency, or rural/urban residency. Tang et al. (1997) investigated the pulmonary function of elementary school children in an area of low air pollution. Indoor and outdoor air pollution parameters seemed to have no influence on the pulmonary function of children living in a low air pollution area. Oosterlee et al. (1996) found a higher prevalence of most respiratory symptoms with children living along busy streets than those living along quiet streets did. Risk ratios were higher for girls than boys. Cuijpers et al. (1994) studied respiratory health of children when exposed to summer smog. Prevalence of respiratory symptoms and forced expiratory volume were determined before and after the summer episode. The forced expiratory volume dropped slightly after the

episode but there was no increase in prevalence of acute respiratory symptoms. Lunn et al. (1967, 1970) found that air pollution levels were partly responsible for respiratory morbidity among children living in Sheffield.

Dockery et al. (1996) examined the respiratory health effects of exposure to acidic air pollution among children in the United States. Children living in area with the highest level of particle acidity were significantly more likely to report at least one episode of bronchitis when compared with those living at the cleanest area in the study. And fine particulate was related to higher reporting of bronchitis. Pope III (1991) found that hospital admission rates of children for acute respiratory disease were closely related to PM_{10} concentrations. Pandey et al. (1989) found that very high indoor particulate levels derived from biomass burning with inadequate ventilation could be the cause of the high death rates of children in the Third World.

Jedrychowski and Flak (1998) found that outdoor air pollution had a significant effect on the occurrence of allergy in children. Chronic phlegm was related to outdoor air pollution as well. Tri-Tugaswati and Yasuo (1996) found a significant relationship between NO_2 exposure and prevalence rates of cough, phlegm, and wheezing without cold. Romieu et al. (1992) related the level of ozone exposure to respiratory health related school absenteeism. Children exposed to high levels of ozone (0.120 ppm) for two consecutive days had a 20% increment in the risk of respiratory illness. This positive association was also suspected to have interactive effect with low temperature exposure.

3.6 Risk Assessment

Cancer is one of the most widespread diseases nowadays, it arises from exposure to a combination of pollutants in the environment. Risks of exposure to health concerned pollutants can be calculated through assessment from toxicological data. Risk assessment brought uncertainty since the measured pollutant concentrations usually have large variation. Exposure pathway and toxicology is not fully understood, the mathematical models might not be accurate or fully understood, different individual would exposed to different mix of pollutants, and there are a large number of ways to be exposed to pollutants (Anderson and Patrick 1999). The lifetime cancer risk, usually represented as a probability, can be calculated from multiplying the chronic daily intake (CDI) by a potency factor (PF) of a specific cancer causing substance (Anderson and Patrick 1999).

$$\text{Lifetime cancer risk} = \text{CDI} \times \text{PF}$$

CDI in mg/kg/day can be calculated according to the equation below:

$$\text{CDI} = \frac{\text{CA} \times \text{IR} \times \text{ED} \times \text{EF} \times \text{L}}{\text{BW} \times \text{AT} \times 365}$$

Where CA = contaminant concentration (mg/m^3)

IR = inhalation rate (m^3/hour)

ED = exposure duration (hours/week)

EF = exposure frequency (weeks/year)

L = length of exposure (years)

BW = body weight (kg)

AT = averaging time (period over which exposure is averaged – usually 70 years for carcinogens)

365 = days per year

Benzene is classified as a known carcinogen in the Risk Assessment Guidelines (USEPA 1998). There is strong and clear evidence that benzene is associated with acute non-lymphocytic leukemia and also for chronic non-lymphocytic leukemia. There are numerous epidemiological studies showing that a significant increase in risk of having leukemia has been reported with workers in benzene-exposed industries such as chemical factory, shoemaking, and oil refineries (ŪSEPA 1998). The risks for children are different from the rest of the population since they have a higher unit body weight exposure. Therefore a greater risk of children will result if exposed to the same concentration of benzene as an adult. The inhalation risk recently adopted from linear assumption at exposure to 1 ppm of benzene ranges from 7.1×10^{-3} to 2.5×10^{-2} (Bayliss et al. 1998).

3.7 Perceived Air Quality

Having low indoor pollutant concentrations do not mean that the indoor has good air quality or occupants are satisfied with the environment. Indoor comfort parameters such as temperature and relative humidity also affect how we interpret the indoor environment. Moreover, factors such as light intensity, air movement, noise level and psychosocial factors also affect us. Fang et al. (1998) observed the impact of temperature and humidity on perception of air quality. A strong

relationship was identified where the air was perceived as less acceptable with increasing temperature and humidity. Perceived air quality in relation to air pollutant levels at schools was investigated by Smedje et al. (1997). The young and people dissatisfied with their psychosocial work climate rated air quality the worst. In general, air quality was perceived as worse at high levels of VOCs, moulds, bacteria and respirable dust. Norback (1995) investigated the relationship between subjective IAQ and measured IAQ in six Swedish primary schools. The perception of high room temperature was related to a poor climate of co-operation, fleecy wall materials, and VOC (xylene, limonene and butanols) concentration. Perception of air-dryness was related to atopy, work stress, poor climate of cooperation, high room temperature, low air humidity, and high VOC (limonene and n-alkanes) concentration. Norback suggested that room temperature should be kept at 22°C, and exposure to fleecy materials and VOCs should be minimized.

3.8 Ventilation Effects

Ventilation rate affects the transport of pollutants in and out of an indoor environment. Rooms with air-conditioning systems are usually considered to have cleaner air than those without, but this is not necessarily true. If the indoor environment has sources of pollutants and the outdoor intake air is more polluted than the indoor air, then the indoor environment will be more polluted. The minimum classroom ventilation rate required in the United States was 15 l/s of outdoor air. Due to conservation of fuel during the oil crisis, it dropped to 5 l/s. The requirement has been raised to 7.5 l/s recently due to increased understanding of pollutant characteristics and their effect on human health.

Sheff et al. (1999b) used indoor CO_2 levels to calculate the ventilation rates at a school. A consistent relationship between hourly occupancy and CO_2 concentrations was observed. Measured ventilation rates at the art room, cafeteria and lobby were within specified ASHRAE guidelines. The science room, which relied on natural ventilation only, was not able to meet the ASHRAE guideline on one of the three days studied. Wheeler (1997) compared the ventilation rates at classrooms with different ventilation systems. Selection of ventilation systems used in classrooms is usually based on capital cost rather than on satisfying occupants with the classroom environment. Rather heating, ventilation and air-conditioning systems bear more significance on controlling the classroom humidity than the amount of outdoor air supply.

Rubino et al. (1998) found that the indoor pollutant variation pattern in rooms with mechanical ventilation was smoother than the outdoor variation. The outdoor variation pattern was transmitted to the indoors and attenuated in intensity and delayed in time. Berk et al. (1979) investigated the effect of reduced ventilation rate on pollutant concentration in classrooms. Carbon dioxide was the only pollutant found to increase drastically when the ventilation rate was lowered with the other pollutants kept at levels lower than relevant guidelines.

Koo et al. (1997) found that secondary school students in window type air conditioning classrooms in Hong Kong were 1.7 times more likely to have coughing than those in classrooms without air-conditioning. They believed that reduced ventilation in air-conditioned classroom increased cross-infections and discomfort associated with SBS. Vincent et al. (1997) related a slightly higher risk of non-specific symptoms to HVAC systems when compared with natural ventilation. Short term throat

irritation, work related nasal discharge, nasal blockage on awakening, migraine, and usual coughing was induced by cold air. Other researchers (Burge et al. 1993, Jaakola et al. 1993, Harrision et al. 1990) also found results supporting the fact that in air-conditioned environments diseases and symptoms are more frequently encountered by occupants.

To summarise, common classroom air quality problems were CO_2 levels found in classrooms were high, VOC levels at classrooms with carpeting were high and outdoor VOC sources mainly from vehicle exhaust emission, and high bacteria and fungi levels were mainly due to high relative humidity levels.

4.0 METHOD

This study was conducted in three parts. The first part, baseline study, involved sampling of indoor and outdoor air pollutants at five classrooms in schools located in different areas. Then two classrooms were chosen from the previously sampled schools for further investigation on the effect of air-conditioning on pollutant concentrations. The effectiveness of using air cleaner in classrooms to improve air quality was also investigated. Lastly, a set of control experiment was done in a classroom at the Hong Kong Polytechnic University to investigate the effect of air-conditioning on classroom air quality.

4.1 Site Description

Indoor and outdoor air samples were obtained from five schools located at different areas in Hong Kong. One classroom was chosen from each school and the five classrooms were TC, SF, MFS, MFC, and SJ. Figures 4.1 to 4.5 show pictures of the five classrooms. Selection of the schools was based on their location in different land-use areas such as residential, industrial and rural. A five-day sampling period was arranged for each school during November 1997, December 1997, and January 1998 for the first part of this study. TC is located in an urban area with major traffic roads surrounding the school building. The Hong Kong EPD reported an annual average PM_{10} level of 99 $\mu g/m^3$ outside TC in 1988,which is almost double of the level stated in the HKAQO. The heavy traffic surrounding TC was the main contributor of PM_{10}. Sampling equipment were placed inside a classroom on the fourth floor, while the outdoor measurement location at the balcony was just outside the classroom. The classroom had double glazed windows for excluding noise and was equipped with two

Table 4.1 – *Parameters for Classroom Used in the Baseline Study*

	TC	SF	MFS	MFC	SJ
Sampling Date	24/11/97-29/11/97	1/12/97-6/12/97	15/12/97-20/12/97	12/1/98-16/1/98	19/1/98-23/1/98
Floor Area (m^2)	60.8	46.9	48.3	83.7	52.5
Room Volume (m^3)	216	160	140	285	205
Indoor Sampling Floor	4	3	2	4	1
Outdoor Sampling Floor	4	6 (Roof)	2	4	Ground
Number of Students Occupying Classroom	~42	~40	~40	~38	~39
Approximate Number of Hours Occupied (hour)	~ 7	~ 7	~ 7	~ 5	~ 2
Number of Ceiling Fans	4	4	4	4	4
Mode of Ventilation	Window Type Air-Conditioning	Water Cooling Tower	Natural Ventilation	Natural Ventilation	Natural Ventilation
Location	Urban	Urban	Rural	Industrial	Residential
District Located	Sham Shui Po	Central	Shatin	Chaiwan	Tsing Yi

air-conditioners and five exhaust fans for ventilation purposes. SF is located in an urban residential area on Hong Kong Island. The classroom air was conditioned using a water cooling tower. Classrooms at MFS, MFC, and SJ were naturally ventilated, and the outdoor sampling sites were on the same floor as the indoor sites. MFS is located in a rural area with light industrial area nearby, MFC is located on a hillside near a light industrial area, and SJ is located in a residential area. The classroom floor area, classroom volume, the school location and other details of each sampling site are listed in Table 4.1. The aerial views of the classrooms (TC, SF, MFS, MFC, and SJ) used for investigation are shown in Appendices I-a to I-e.

Figure 4.1 – *Picture Showing TC*

Figure 4.2 – *Picture Showing SF*

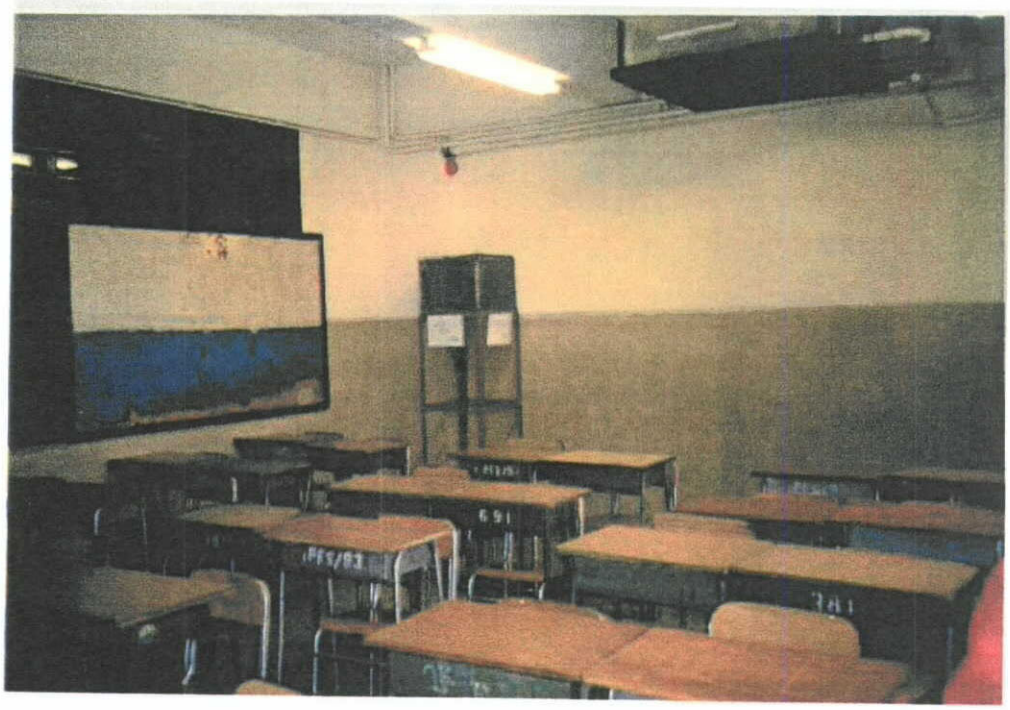


Figure 4.3 – *Picture Showing MFS*

Figure 4.4 – *Picture Showing MFC*

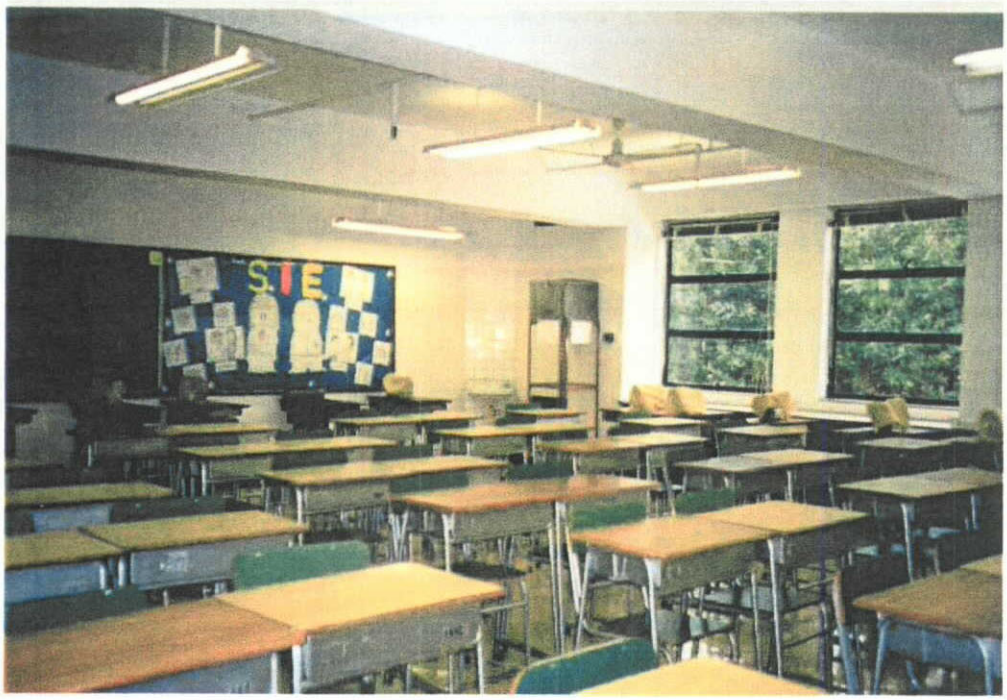


Figure 4.5 – *Picture Showing SJ*

The second part of this investigation includes ventilation rates study, and measurement of indoor and outdoor VOC, CO and $PM_{2.5}$ concentrations at two classrooms (MFSI and TC). Ventilation rates were measured following the Tracer Gas Technique where sulfur hexafluoride (SF_6) was used as the tracer gas. MFSI is naturally ventilated and TC is with air-conditioning. TC was the same classroom used in the Baseline Study and MFSI (Figure 4.6) is another classroom on the same floor as MFS. The classroom, MFS, was not available for use since it was converted into a student common room. The classroom parameters for MFSI are listed in Table 4.2 and the aerial view for MFSI is shown in Appendix I-b. Another room adjacent to MFSI was used to study the air cleaner effect on particulate matter concentrations. The room, MFSC, is located right next to MFSI and has exactly the same dimensions.

Figure 4.6 – *Picture Showing MFSI*

Table 4.2 – *Detail Parameters of MFSI*

	MFSI
Sampling Date	2-13 November 1998
Floor Area (m^2)	52
Room Volume (m^3)	162
Indoor Sampling Floor	1
Occupancy (Number of Students)	35
Approximate Number of Hours Occupied (hour)	7
Number of Ceiling Fans	4
Mode of Ventilation	Natural Ventilation

The control study was carried out in a classroom (PolyU) at the Hong Kong Polytechnic University (Figure 4.7). The purpose of this study was to minimise external factors which might affect the comparison between pollutant concentrations in a classroom with naturally ventilation and air-conditioning. The classroom chosen had two window type air conditioners and sampling was carried out when the classroom was unoccupied. The classroom (PolyU) parameters are shown in Table 4.3, and its aerial view is shown in Appendix I-c. The difference in contaminant levels of PM_{10}, $PM_{2.5}$, CO, relative humidity, VOC in a natural ventilated classroom and an air-conditioned classroom was compared, and ventilation rates were measured.

Figure 4.7 – *Picture Showing PolyU at the Hong Kong Polytechnic University*

Table 4.3 – *Detail Parameters of PolyU*

	PolyU
Sampling Date	8,9,12,13 July 1999
Floor Area (m^2)	58
Room Volume (m^3)	131
Indoor Sampling Floor	Ground level
Occupancy (Number of Students)	1-2
Approximate Number of Hours Occupied (hour)	8
Number of Ceiling Fans	Nil
Mode of Ventilation	Air-Conditioning/Natural Ventilation

4.2 Sampling and Analysis

4.2.1 Air Pollutants

Pollutants and parameters of interest for the Baseline Study were carbon dioxide (CO_2), temperature, relative humidity, formaldehyde, particulate matter with less than ten microns (PM_{10}), bacteria and primary air pollutants (sulfur dioxide (SO_2), ozone (O_3), nitric oxide (NO), and nitrogen dioxide (NO_2)). The second part concentrated on sampling individual target VOCs, carbon monoxide (CO), particulate matter with less than 2.5 microns ($PM_{2.5}$), and ventilation rate measurements. Air cleaner efficiencies at a classroom with windows opened and closed were also investigated. Sampling equipment were placed at 1.5 m above ground level at both indoor and outdoor locations. Indoor and outdoor monitoring of PM_{10}, CO_2, CO, $PM_{2.5}$, temperature, relative humidity were obtained simultaneously for 24 hour periods; while VOC, formaldehyde, gas bag sampling were obtained within five minutes apart. VOC samples were obtained within 10 minutes after school, formaldehyde samples were sampled for 24 hour; bacteria and gas bag samples were obtained before and after class. A Q-Trak IAQ Monitor (TSI Model 8551) was used for CO_2, temperature, and relative humidity measurements. The Q-Trak uses a non-dispersive infrared sensor for measuring CO_2 levels, a thermistor for temperature, and a thin-film capacitive sensor for relative humidity. A formaldehyde monitoring kit manufactured by SKC was used for 24-hour formaldehyde measurements. PM_{10} and $PM_{2.5}$ levels were measured using a Dust Trak Monitor (TSI Model 8520). MiniVol Sampler (AIRmetrics) was also used to measure particulate matter concentrations by gravimetric analysis. Whatman filter papers (QM/A 1861865) with diameter 47 mm were used together with the MiniVol

Sampler. A Portable Air Sampler for Agar Plates (Burkard) was used for bacteria sampling at 20 ml/min. Agar plates (Plate count agar) were incubated at 35°C for 48 hours with one field blank per batch of sample (Clescier et al. 1989). Tedlar air sampling bags and a portable sampling pump (Airchek sampler, Model 224-43XR) at 1 ml/min were used for grab air samples. The air bags were transferred to the laboratory for measurements. SO_2 were analyzed by a Thermo Electron Pulsed Fluorescence SO_2 Analyzer (Model 43B) while NO_x (NO and NO_2) were analyzed by a Thermo Electron Chemiluminescence NO_x Analyzer (Model 42). Ozone was analyzed by a Thermo Electron Instruments UV Photometric O_3 Analyzer (Model 49). Indoor and outdoor VOC samples were obtained at the end of the school day to minimize interference with school activities. SUMMA® polished canister (6 l) was evacuated to 29 inHg vacuum before sampling and automatically fills for 2 to 3 minutes to atmospheric pressure when it was opened. The SUMMA canisters are made of stainless steel and are not subject to permeation or photo-induced chemical effects. Samples were analyzed according to the USEPA TO-14 Method (USEPA 1988) with slight modification. Target VOCs in this study are listed in Table 4.3. The analytical system contains a Nutech Cryogenic Concentrator (Model 3550A), a Hewlett Packard (HP) Gas Chromatograph and Mass Selective Detector. A HP-5MS capillary column (30.0m × 250μm × 0.25μm) was used with the GC and helium was used as carrier gas at flow rate of 1 ml/min. All data are corrected with temperature and are presented in $\mu g/m^3$. Carbon monoxide concentration was monitored using an InterScan Electrochemical Voltametric Sensing Portable Continuous CO Monitor (Model 4148) with a Metrosonics datalogger (Model DC-714).

4.2.2 Ventilation Rate

The air change per hour (ACH) in each classroom was measured using SF_6 as the tracer gas according to the technique mentioned in "Measuring Ventilation Using Tracer-Gas" by Grieve (1991). SF_6 was released into the classroom and samples were obtained at different time intervals using 30 ml gas-tight plastic syringes. The samples were analyzed by passing through a HP Purge and Trap Concentrator followed by a Gas Chromatography (Model G 1530A) with Mass Selective Detector (Model 5973) (GC/MSD) for analysis. First order decay ($A = A_0e^{-ACHt}$) is assumed for SF_6 removal in the classroom. ACH was calculated by plotting the natural log of SF_6 concentration versus time in hours and the resultant slope is ACH in units of $hour^{-1}$.

Table 4.4 - *Target Volatile Organic Compounds*

Freon11	Carbon tetrachloride	Styrene
1,1-Dichloroethene	1,2-Dichloropropane	1,1,2,2-Tetrachloroethane
Dichloromethane	Trichloroethylene	o-Xylene
Freon113	cis-1,3-Dichloropropene	1,3,5-Trimethylbenzene
1,1-Dichloroethane	1,1,2-Trichloroethane	1,2,4-Trimethylbenzene
cis-1,2-Dichloroethene	Toluene	m-Dichlorobenzene
Chloroform	1,2-Dibromoethane	p-Dichlorobenzene
1,2-Dichloroethane	Tetrachloroethylene	o-Dichlorobenzene
1,1,1-Trichloroethane	Chlorobenzene	1,2,4-Trichlorobenzene
Benzene	Ethylbenzene	Hexachlorobutadiene
	m,p-Xylene	

Detection mechanisms and method detection limits for instruments used are listed in Table 4.5. Carbon dioxide, carbon monoxide, temperature, relative humidity, $PM_{2.5}$ and PM_{10} were continuously monitored while the classrooms were occupied. Formaldehyde was measured for 24-hour periods; air bag and bacteria samples were obtained before and after school hour to minimize interference with teaching. The 24-hour average indoor and outdoor pollutant levels for continuous monitored pollutants are also presented. Indoor to outdoor pollutant level ratios (I/O) were calculated by dividing the indoor pollutant concentration to its respective outdoor concentration. The average I/Os and standard deviation are presented in the next section for each pollutant.

4.2.3 Air Cleaner

A Philips Air Clean System 120 (HR4385) was used at MFSI to investigate the effectiveness of air cleaners on reducing particulate matter concentration in classroom setups. The system includes a washable pre-filter, and filtrete filter, active carbon filter, and an ionizer (10 pin). The acetate pre-filter catches large dust particles, and the zig-zag filtrete filter (surface area 1835 cm^2) is a structure of electrostatically charged fibers which trap particles with diameters larger than 0.1 micron. Odorous organic molecules are removed by adsorption onto the active carbon filter. The active carbon structure is highly porous and has internal surface of about 840 cm^2 per gram. The ionizer traps very small particles passing through the three filters and negatively charged particles are subsequently attracted by surfaces such as walls and floors. The unit claims to be able to clean rooms with volumes up

Table 4.5 – *Detection Mechanisms and Detection Limits for Instruments Used*

Pollutant Analyzed	**Instrument**	**Detection Mechanism**	**Detection Limit**	**Response Time**
Particulate Matter	TSI Dust Trak	90° light scattering, laser diode	1 $\mu g/m^3$	na
Carbon Dioxide	TSI Q-Trak	Non-dispersive infrared	1 ppm	20 seconds
Temperature	TSI Q-Trak	Thermistor	0.1°C	120 seconds
Relative Humidity	TSI Q-Trak	Thin-film capacitive	0.1%	20 seconds
Formaldehyde	SKC Formaldehyde Monitoring Kit	Passive diffusion, then colormetric	0.002 ppm	na
Carbon Monoxide	InterScan Electrochemical Voltametric Sensing Portable Continuous CO Monitor	Electrochemical	0.1 ppm	na
Nitrogen Dioxide, Nitrous Oxide	Thermo Electron (Model 42) Chemiluminescence NO_x Analyzer	Chem-iluminscence	1 ppb	na
Sulfur Dioxide	Thermo Electron (model 43B) Pulsed Fluorescence SO_2 Analyzer	Pulse fluorescence	0.001 ppm	na
Ozone	Thermo Electron Instruments UV Photometric O_3 Analyzer	Ultra-violet	1 ppb	na
Total Bacteria	Burkard	Inertial impact onto agar plate followed by incubation	6 CFU/m^3	na

na – not applicable

to 120 m^3 or with floor surface of approximately 50 m^2, and the power consumption is 60W. The unit was placed at the rear corner of MFSI and TC and was in operation from 8:00 a.m. to 3:30 p.m. Particulate matter (PM_{10}) concentrations were compared with and without operation of the air cleaner, and with windows opened and closed during normal schools days. The rate of air displacement was set at the maximum position, 260 m^3/hour and a new filtrete filter was used at each classroom.

4.3 Quality Assurance and Quality Control

Duplicate sampling was done for formaldehyde and bacteria measurements. Field blanks of formaldehyde and bacteria samples were brought to the sampling sites to ensure there was no contamination during sample handling and transportation. Analytical instruments for measuring air bag samples were calibrated daily. Q-Trak and Dust Trak were calibrated according to manufacturer's manual (TSI 1997, TSI 1998). Tedlar air bags were flushed with zero air for at least five times before sampling to make sure that the bags are free of contaminants. They were transported to the laboratory in opaque plastic bags to prevent exposure to sunlight and were then analyzed within one hour after sampling to ensure sample integrity. Carbon monoxide monitors were calibrated daily before sampling using zero gas and a standard CO gas (7.9 ppm) for span check.

The Dust Trak was calibrated against an Andersen Hi-Vol Sampler and the Partisol^{TM} Model 2000 Air Sampler (Rupprecht & Patashnick Co, Inc.) for PM_{10} and $PM_{2.5}$ concentrations respectively. The results for Dust Trak measurements were converted to the respective gravimetric methods according to the regression curves as shown in Figures 4.8 and 4.9. Over estimation of the Dust Trak on particulate

measurements when compared with the Hi-Vol sampler was due to different techniques used. The Dust Trak measures particulate matter concentrations using light scattering technique (TSI, 1997). The air or sample was drawn into a chamber through a pump. The particulate matters scatter light from the laser beam and the scattered light are collected at 90°C to the laser source and was collected on a photodetector. Any substance that scatters light will give rise to a signal to the Dust Trak. Substance such as water vapor, smoke fumes affect the signal. Particle size will also affect the signal. The Hi-Vol sampler only measures particulate matter.

Canisters were flushed with zero air for at least five times and checked for contaminant levels before use. Target VOCs were quantified using a Toxi-Mat-14M Certified Standard (Matheson) TO-14 Standard Calibration Gas for each batch of samples. The calibration equations for the target VOCs are listed in Appendix II. Method detection limits (MDLs) were calculated by multiplying the relative standard deviation (RSD) for 10 runs of the standard VOC concentrations at 0.2 ppbv by 5. The MDLs for target VOCs are shown in Appendix III. Tune check of the GC/MSD was performed using 4-bromofluorobenzene daily before sample analysis. Duplicate samples were analysed for every batch of canister samples.

Figure 4.8 - *Calibration of Dust Trak with Hi-Vol Sampler for Particulate Matter with Less than Ten Microns*

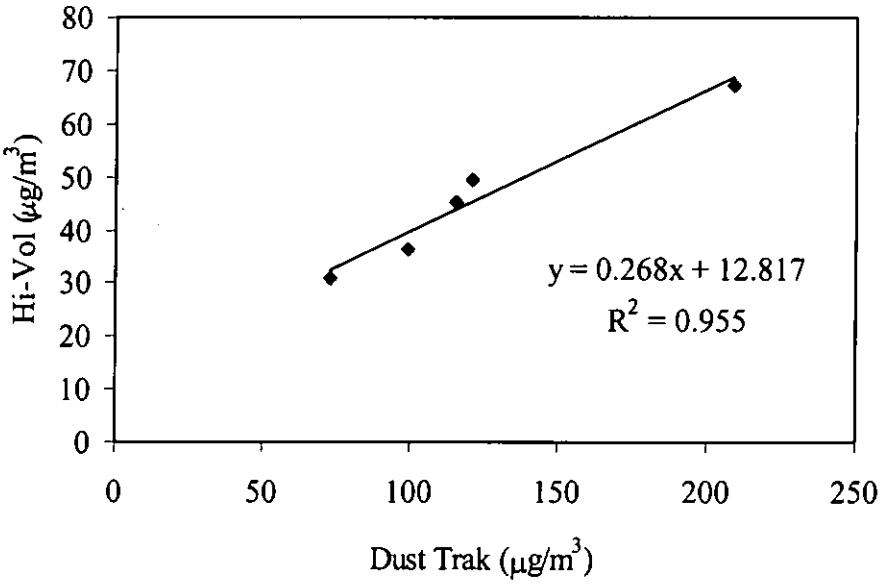
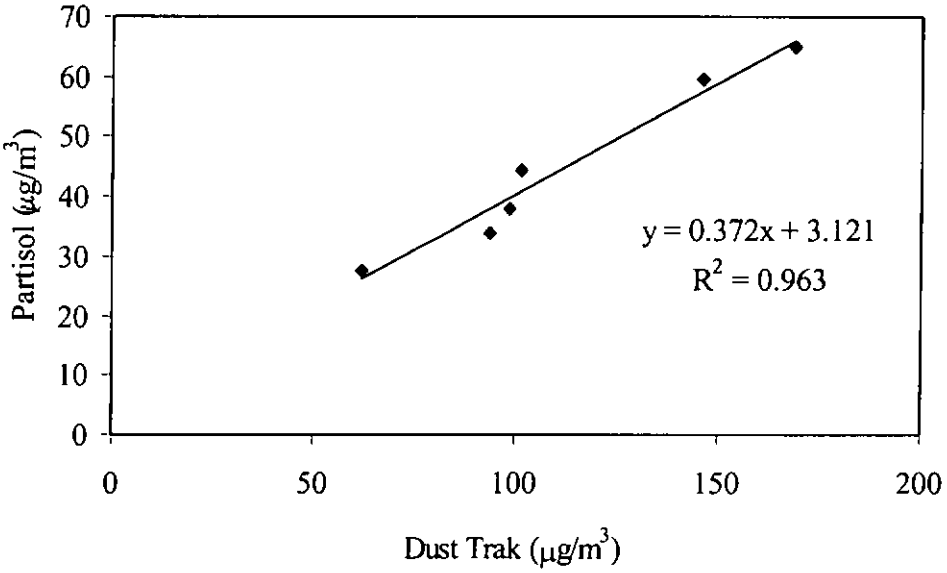


Figure 4.9 - *Calibration of Dust Trak with Partisol™ Sampler for Particulate Matter with Less than 2.5 Microns*



5.0 RESULTS AND DISCUSSION

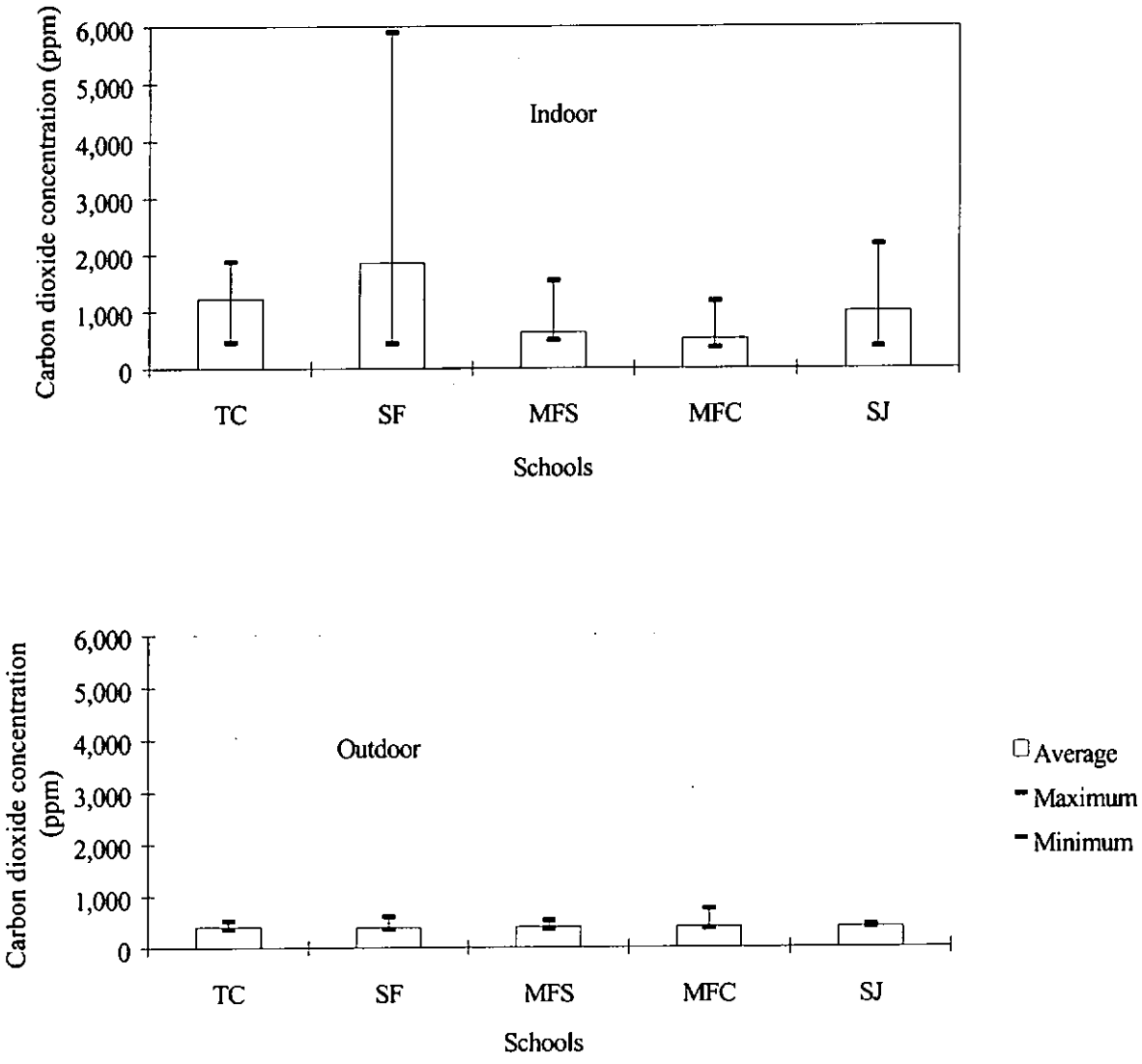
5.1 Baseline Study

5.1.1 Carbon Dioxide Concentrations

Averaged indoor CO_2 levels at TC and SF exceeded the ASHRAE CO_2 standard of 1000 ppm, but outdoor concentrations were within the standard (Figure 5.1). All maximum indoor CO_2 levels were above 1000 ppm at the five classrooms. The highest CO_2 concentration recorded at SF even reached 5900 ppm which approached the upper limit of measurement of the Q-Trak. This very high level of CO_2 at SF was recorded on a cold day and probably caused by closed windows and doors, and the ventilation system was not in operation. High occupancy further intensified the CO_2 level. The ASHRAE Standard 62-1989 stated that if CO_2 levels are above 1000 ppm at human occupied spaces, comfort criteria are unlikely satisfied. This implies that comfort criteria were probably not satisfied in the classrooms and ventilation was inadequate. Notice that those classrooms with air-conditioning had averaged CO_2 levels higher than the standard while those with natural ventilation had averaged levels below.

Figure 5.2 shows the variation of indoor and outdoor CO_2 concentrations on a typical sampling day at TC together with occupancy. The outdoor CO_2 level was relatively constant, while the indoor level was influenced by human occupancy and activity. Carbon dioxide concentration built-up began when students started occupying the classroom, and reached a maximum level of 1600 ppm at about 8:20 a.m. The CO_2 concentrations remained at the maximum until the morning break. CO_2 levels declined during the break and increased when the classroom was occupied again. A similar variation in CO_2 concentrations was observed during the lunch break, but a higher saturation level (1800 ppm) was observed. The higher CO_2 saturation level in the after-

Figure 5.1 – *Indoor and Outdoor Carbon Dioxide Concentrations at the Five Classrooms*



noon could be caused by higher CO_2 exhalation rate of students after doing vigorous activities during the lunch break. CO_2 production rate highly depends on the type of human activity and the type of diet ingested (ASHRAE 1989). The higher the activity more CO_2 will be produced. CO_2 concentrations at TC reached a saturation level within 40 minutes after it was occupied. This could be due to lower ventilation rate where the CO_2 produced were not transported out of the classroom quickly.

Figure 5.2 – *Typical Carbon Dioxide Variations with Occupancy at TC (Air-conditioning)*

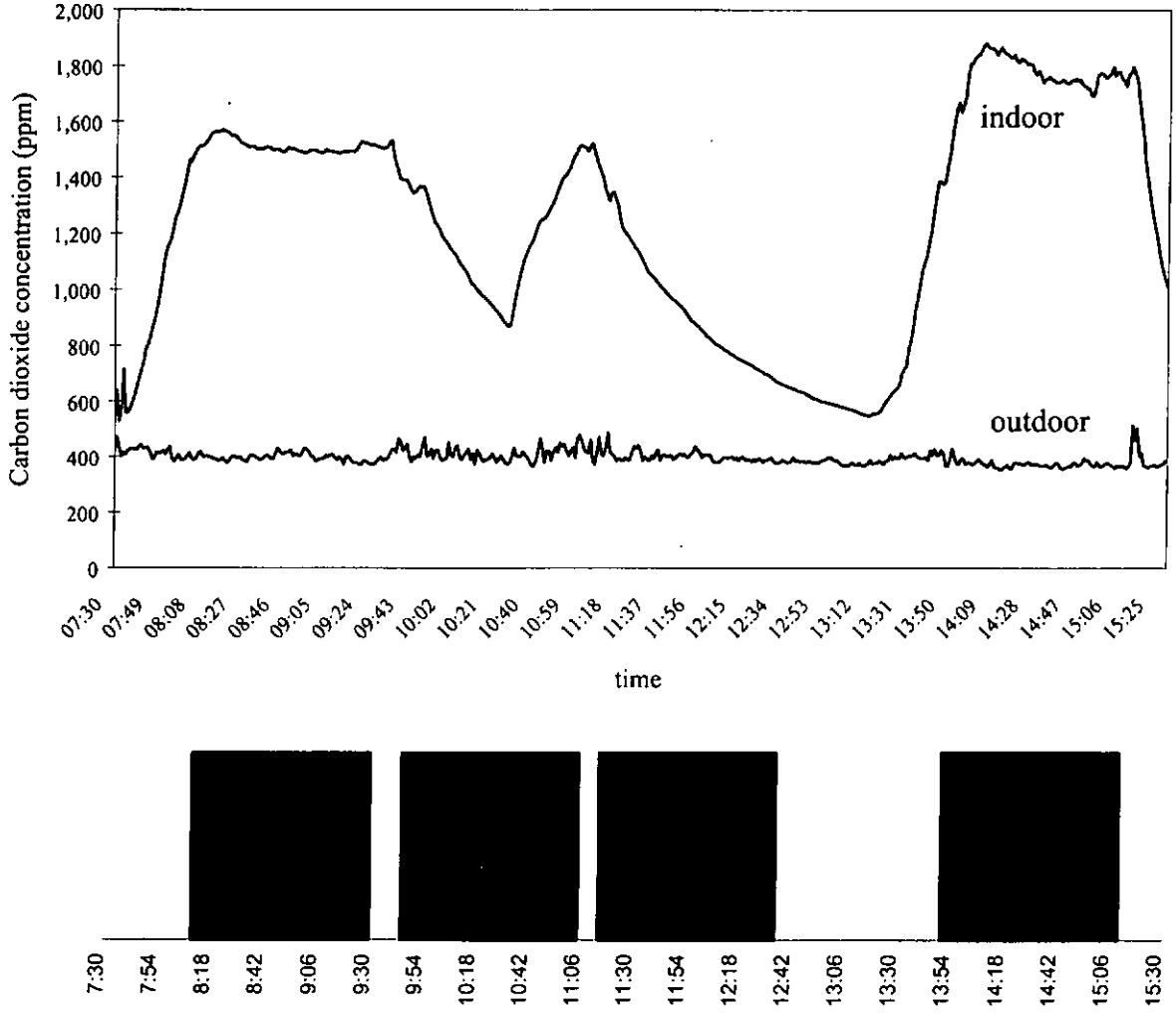


Figure 5.3 – *Typical Carbon Dioxide Variations with Occupancy at MFS (Natural Ventilation)*

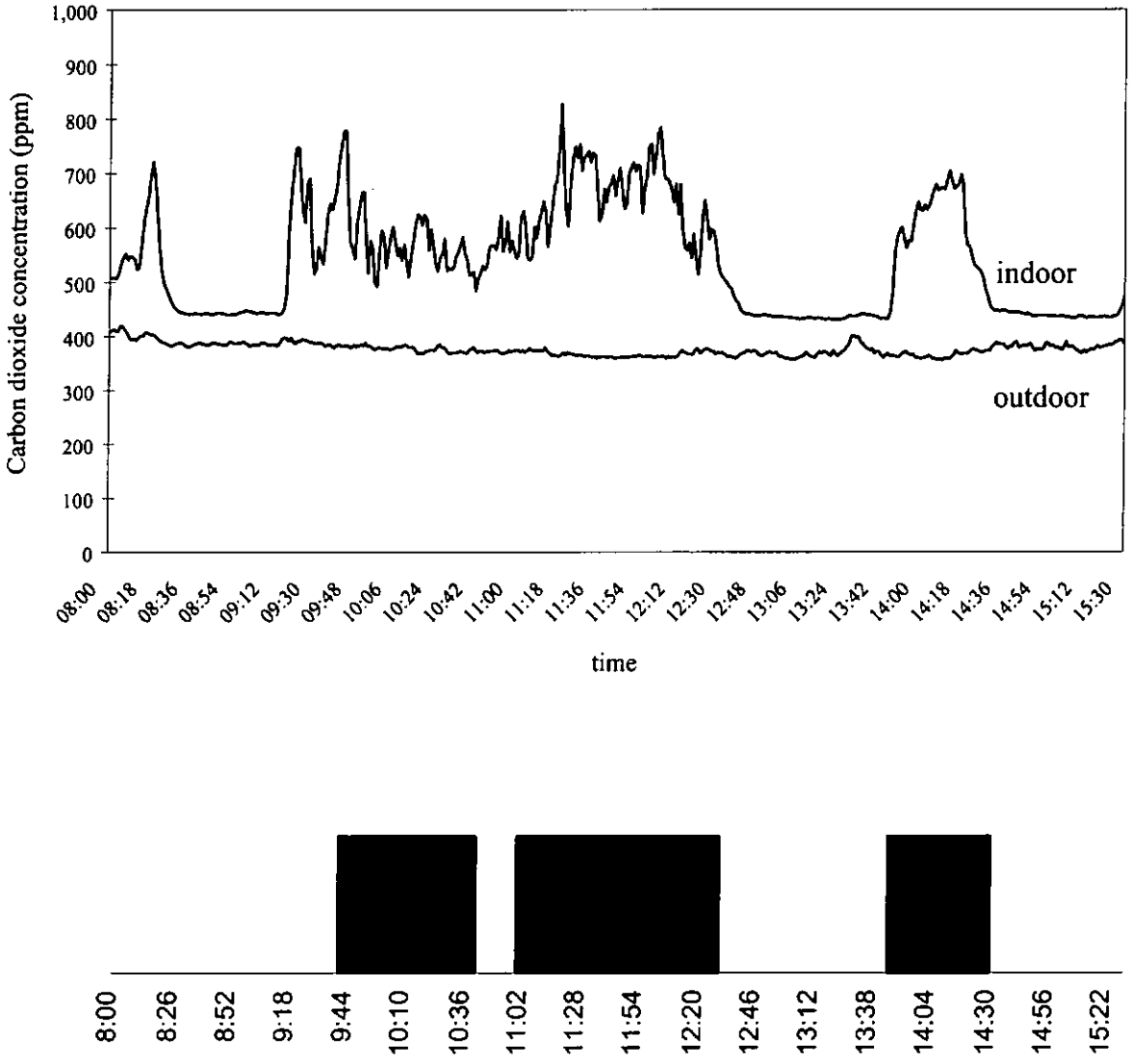


Figure 5.3 shows the indoor and outdoor CO_2 concentrations at MFS. The naturally ventilated classroom had CO_2 variations unlike TC. CO_2 concentrations did not reach a saturation level rather it fluctuated between 500 and 900 ppm. The concentrations remained low when the classroom was unoccupied during lunch break,

and after school hour. The morning CO_2 peak at about 8:20 a.m. corresponded to students entered the classroom prior to class. CO_2 concentrations did not reach a steady level as the CO_2 produced were transported out of the room quickly due to high air exchange rate.

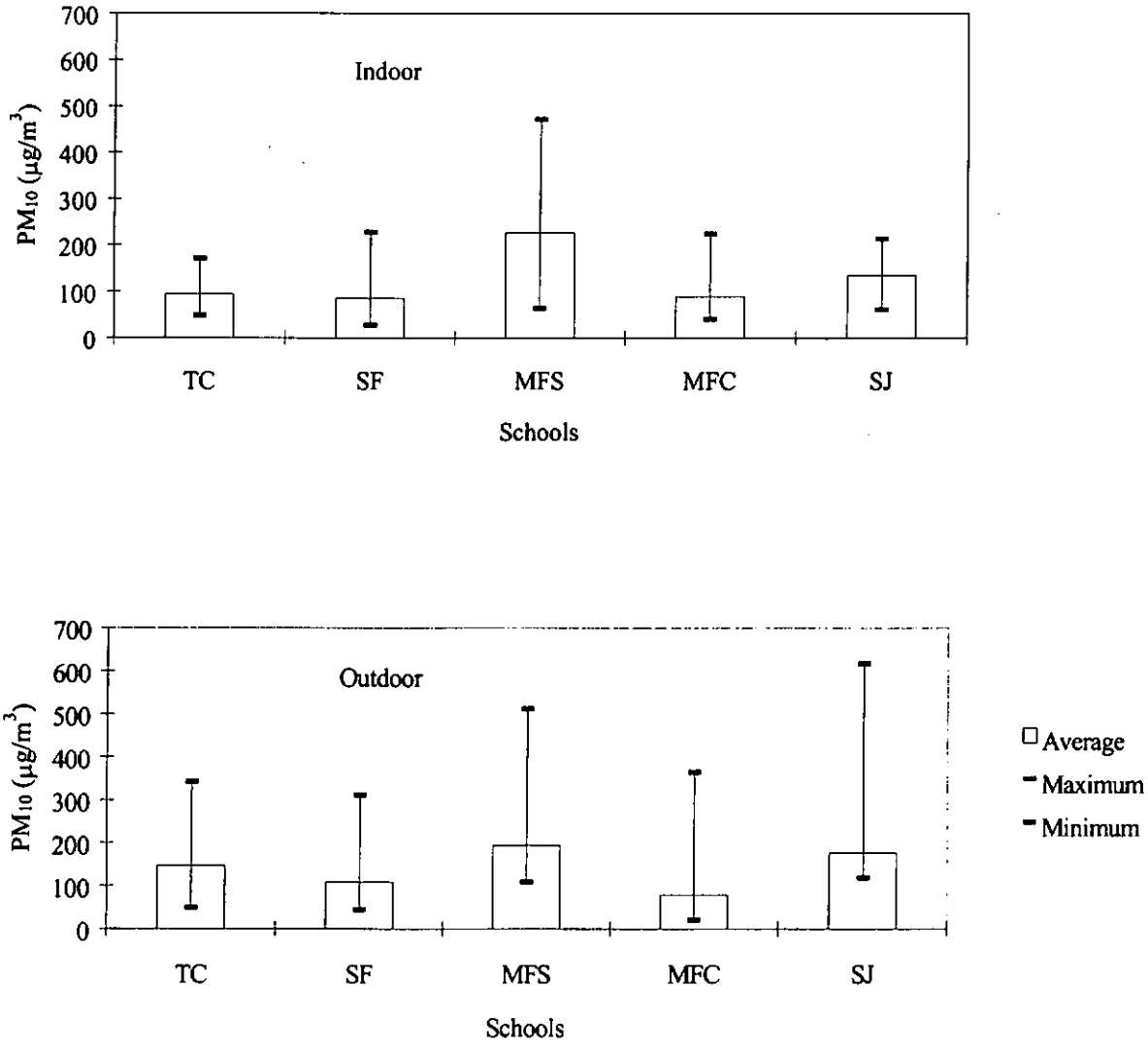
The indoor CO_2 concentrations at the five classrooms were always higher than the outdoor level even when the classrooms were not occupied. CO_2 molecules could be adsorbed onto furnishings and walls in the interior of the classrooms and released when CO_2 level is low in the air.

As mentioned in the Literature Review Section, CO_2 levels measured at other school locations often exceed the ASHRAE guideline. Similar in this study, CO_2 concentrations were above 1000 ppm at classrooms, especially those with air-conditioning. As the results from Willers et al. (1996), Downing and Bayer (1993), Pejtersen et al. (1991), and Cousins and Collett (1989), the CO_2 levels were above 1000 ppm at some occasions. Indicated that inadequate ventilation is not only a common problem at classrooms in Hong Kong, it actually is also a problem at classrooms in other countries. Variations in CO_2 level related to occupancy were also observed at other classrooms and might have correlation with pollutants such as VOCs. This problem needs to be recognised and mitigation measures should be applied. This is further discussed in the Ventilation Study Section where ventilation rates were quantified.

5.1.2 PM_{10} Concentrations

Particulate matter concentrations are affected by wind speed, wind direction, solar radiation, relative humidity, etc. Street level concentrations are affected by mechanical and thermal turbulence. Figure 5.4 shows the average, maximum, and minimum indoor and outdoor PM_{10} concentrations measured at the five classrooms. PM_{10} levels measured ranged from 21 to 617 $\mu g/m^3$. MFS had very high indoor and outdoor average PM_{10} concentrations and exceeded the 24-hour PM_{10} HKAQO. Very high PM_{10} concentrations were measured outside MFS since it was located near a highway with heavy traffic flow and construction activities near the school further enhanced the PM_{10} concentration. High PM_{10} concentrations observed inside MFS were due to transport of outdoor particulate matters into the indoors through opened windows and doors. Other school locations had average indoor and outdoor PM_{10} levels complied with the 24-hour HKAQO and HKIAQ guidelines. The extremely high maximum PM_{10} level (600 $\mu g/m^3$) outside SJ was due to construction of a new building within the campus. An increase in the outdoor PM_{10} level was observed during construction, but the indoor concentration was not affected since windows and doors were closed. Moreover, schoolchildren were not affected since construction was carried out after school hour when they had left the school.

Figure 5.4 – *Indoor and Outdoor PM_{10} Concentrations at the Five Classrooms*



An unusual high concentration of PM_{10} was observed during classroom cleaning at SJ. Amah used broom and dustpan to clean the floor, the sweeping action caused re-suspension of particulate matters settled on the floor into the air. Maximum PM_{10} level measured was even as high as 200 $\mu g/m^3$. The floor of TC was cleaned using mop with water and no notable increase in PM_{10} concentration was observed. Classroom cleaning practices highly affect the indoor PM_{10} concentration. Use of water and mop is suggested for classroom cleaning to reduce PM_{10} exposure of schoolchildren and amahs.

In contrast to findings by Roorda-Knape et al. (1998) and Janssen et al. (1997), the concentrations of particulate matters in this study were higher outdoors than indoors. They suggested that high indoor particulate levels were caused by student activities. Particulate matters in this study were mainly originated from the outdoors. PM_{10} concentrations measured in the present study were much higher than those measured by Scheff et al. (1999a) and were comparable with those measured by Ransom and Pope III (1992).

5.1.3 Gaseous and Other Pollutants

Table 5.1 shows the indoor and outdoor averages of pollutant concentrations measured before and after school hours. Indoor and outdoor SO_2 levels ranged from 5.2 to 15.7 $\mu g/m^3$ and the average SO_2 concentrations were similar at the five classrooms. Averaged NO and NO_2 concentrations varied from 20.9 to 132.8 $\mu g/m^3$ and 37.7 to 81.1 $\mu g/m^3$ respectively. Indoor and outdoor NO concentrations varied from 1.2 to 304.9 $\mu g/m^3$ and 1.2 to 422.9 $\mu g/m^3$ respectively while indoor and outdoor NO_2 levels varied from 15.1 to 213.0 $\mu g/m^3$ and 22.6 to 295.9 $\mu g/m^3$ respectively. Averaged NO_2 concentrations were below 80 $\mu g/m^3$ given by HKIAQ except for the MFS outdoor average (88.3 $\mu g/m^3$). Exceedance of the HKIAQ for NO_2 was observed on a few occasions and the outdoor concentration even reached 322.4 $\mu g/m^3$ at TC. This high NO_2 concentration was possibly caused by vehicular emissions near the school.

24-hour formaldehyde concentrations (Table 5.2) ranged from undetectable to 27.0 $\mu g/m^3$ and all measured concentrations were substantially lower than listed in the HKIAQ. This implied that the classroom furnishings had low emission of formaldehyde and no classroom renovations were done recently, resulted in low levels of formaldehyde. Average total bacteria counts (Table 5.2) were below the HKIAQ level of 1000 CFU/m^3, but some outdoor samples had total bacterial counts over 900 CFU/m^3. In general, bacteria concentrations inside the classrooms were lower than the outdoor samples.

Table 5.1 – *Indoor and Outdoor Pollutant Concentrations (Sulfur Dioxide, Nitric Oxide and Nitrogen Dioxide)*

Classroom	**Indoor**	**Outdoor**
Sulfur Dioxide ($\mu g/m^3$)		
TC	10.5 (7.9-15.7)	13.1 (10.5-15.7)
SF	10.5 (5.3-15.7)	10.5 (7.9-13.1)
MFS	10.5 (7.9-13.1)	10.5 (7.9-13.1)
MFC	7.9 (5.3-13.1)	10.5 (5.3-13.1)
SJ	10.5 (5.3-15.7)	10.5 (7.9-15.7)
Nitric Oxide ($\mu g/m^3$)		
TC	106.9 (46.7-185.7)	103.3 (19.7-274.2)
SF	95.9 (39.3-169.7)	72.5 (35.7-120.5)
MFS	77.5 (1.2-304.9)	132.8 (1.2-422.9)
MFC	20.9 (2.5-134.0)	28.3 (3.7-108.2)
SJ	54.1 (2.5-125.4)	65.2 (7.4-211.5)
Nitrogen Dioxide ($\mu g/m^3$)		
TC	56.6 (20.7-213.0)	69.8 (22.6-295.9)
SF	39.6 (20.7-75.4)	65.9 (30.2-107.5)
MFS	56.6 (20.7-115.0)	81.1 (32.0-160.2)
MFC	37.7 (15.1-64.0)	49.0 (32.0-62.2)
SJ	52.8 (22.6-90.5)	60.3 (32.0-139.5)

( ) - range

Table 5.2 – *Indoor and Outdoor Pollutant Concentrations (Formaldehyde and Bacteria)*

Classroom	Indoor	Outdoor
Formaldehyde ($\mu g/m^3$)		
TC	23.4 (19.7-27.0)	11.5 (8.6-24.6)
SF	23.4 (na)	3.7 (na)
MFS	17.2 (na)	18.4 (na)
MFC	nd (na)	18.4 (4.9-7.4)
SJ	12.3 (9.8-13.5)	22.1 (4.9-8.6)
Bacteria (CFU/m^3)		
TC	294 (175-480)	647 (506-983)
SF	283 (97-644)	451 (106-708)
MFS	209 (50-417)	360 (222-633)
MFC	47 (8-108)	115 (14-289)
SJ	108 (56-183)	430 (27-822)

nd – not detected
na – not applicable
( ) - range

Table 5.3 shows the I/O for the five classrooms. For SO_2, the I/O at TC and SF are smaller than one and at MFS, MFC, and SJ average I/Os are closer to unity. This implies that the two classrooms with air-conditioning had slightly lower indoor SO_2 levels than those with natural ventilation. Since there are no sources of SO_2, NO, and NO_2 originated inside the classrooms, pollutants found indoors were mainly derived from outdoor sources. Closing of doors and windows might help to prevent outdoor produced pollutants from entering the classrooms. I/Os for formaldehyde are greater

than one except for MFS and MFC. I/Os for formaldehyde ranged from 0.907 to 6.333. I/Os for bacteria are less than one, which showed that the main source of bacteria was from the outdoors.

Table 5.3 – *Indoor to Outdoor Pollutant Ratios (I/O)*

Classroom	Sulfur Dioxide	Nitric Oxide	Nitrogen Dioxide	Formaldehyde	Bacteria
TC	0.885	1.389	0.976	1.656	0.456
SF	0.948	1.544	0.608	7.440	0.942
MFS	1.093	0.576	0.711	0.907	0.642
MFC	0.992	0.778	0.745	na	0.655
SJ	0.975	1.053	0.885	1.947	0.965

na – not applicable

5.1.4 Thermal Comfort in Classrooms

The use of air-conditioning classrooms in Hong Kong is primary for traffic noise remediation rather than for providing thermal comfort. The Baseline Study was carried out during the winter months where temperature and relative humidity were measured inside and outside the classrooms. Temperatures in Hong Kong during the winter usually ranges from 13.6 to 27.9°C and during summer ranges from 20.2 to 31.5°C. The respective winter and summer average relative humidities range from 67% to 84% and range from 78% to 82%. The weather is very hot and humid in Hong Kong during the summer months. Indoor classroom environments without air-conditioning might not be able to provide thermal comfort to students working in them.

Table 5.4 shows the temperature and relative humidity measured at the five classrooms. Average indoor temperature ranged from 17.2 to 23.2°C while the outdoor

temperature ranged from 14.0 to 27.3°C. Indoor relative humidity varied between 55.5% and 75.1% and outdoor relative humidity varied between 53.5% and 83.6%. ASHRAE Standard 55-1992 has a psychrometric chart showing acceptable ranges of operative temperature and relative humidity for people in typical summer and winter clothing (ASHRAE 1992). Compared with the measured data, average temperatures were within the standard but minimum and maximum temperatures were out of the standard range. Maximum relative humidities measured were above the standard's relative humidity range. Better control of the classroom temperature and relative humidity in classrooms is required to provide a comfortable learning environment for students.

Table 5.4 – *Comfort Parameters Measured at the Classrooms*

Comfort Parameter	**TC**	**SF**	**MFS**	**MFC**	**SJ**
Temperature (°C)	24.1 (19.4-27.1)	22.1 (18.6-24.8)	22.5 (17.1-25.5)	20.7 (18.9-24.1)	16.3 (14.7-18.9)
Relative Humidity (%)	70.3 (49.0-78.5)	56.8 (41.1-81.0)	67.1 (56.9-77.4)	73.9 (50.1-93.7)	74.4 (58.8-92.5)

( ) – range

Temperature and relative humidity at the three naturally ventilated classrooms were highly affected by outdoor weather conditions. Figure 5.5 shows the temperature variation at MFS (natural ventilation) while Figure 5.6 shows the temperature variation at TC (air-conditioning). Indoor temperature at TC was lower than the outdoors and at MFS the indoor temperature was lower than the outdoors for most of the time. Both the air-conditioning at TC and the ceiling fans at MFS removed the heat from the air

therefore the temperatures were lowered. Relative humidity variations at MFS and TC are shown in Figures 5.7 and 5.8. The indoor and outdoor variations were similar to the MFS profile but the indoor relative humidity was lower than the outdoor at TC. The air-conditioning system removes moisture from the outside supply air before entering the indoor, therefore a lowering of the indoor humidity level was observed. As to provide thermal comfort for students, air-conditioned classrooms had an advantage over naturally ventilated classrooms.

Figure 5.5 – *Indoor and Outdoor Temperature Variation Profiles at MFS*

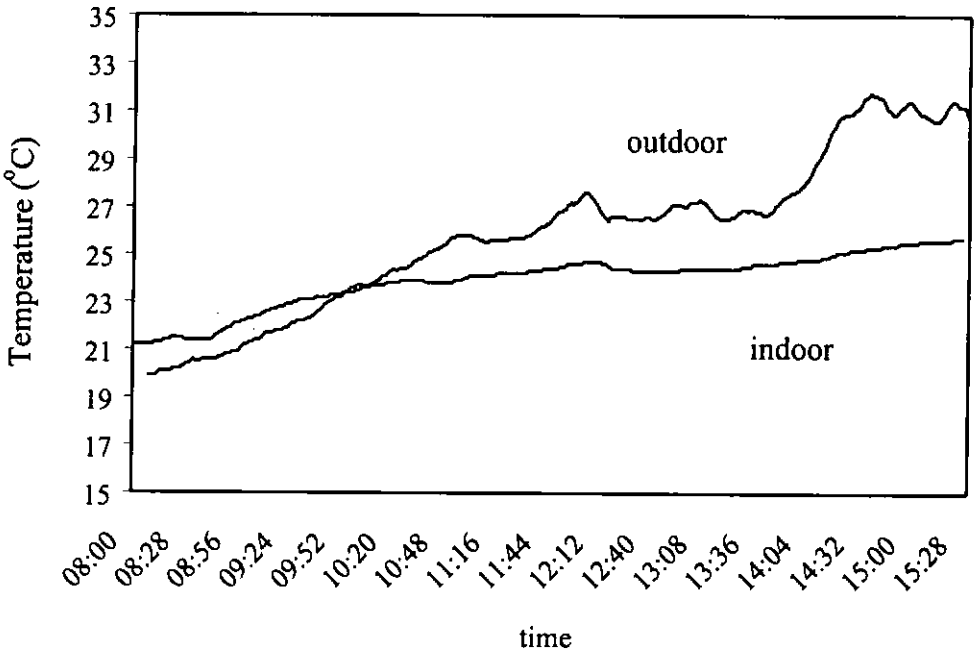


Figure 5.6 – *Indoor and Outdoor Temperature Variation Profiles at TC*

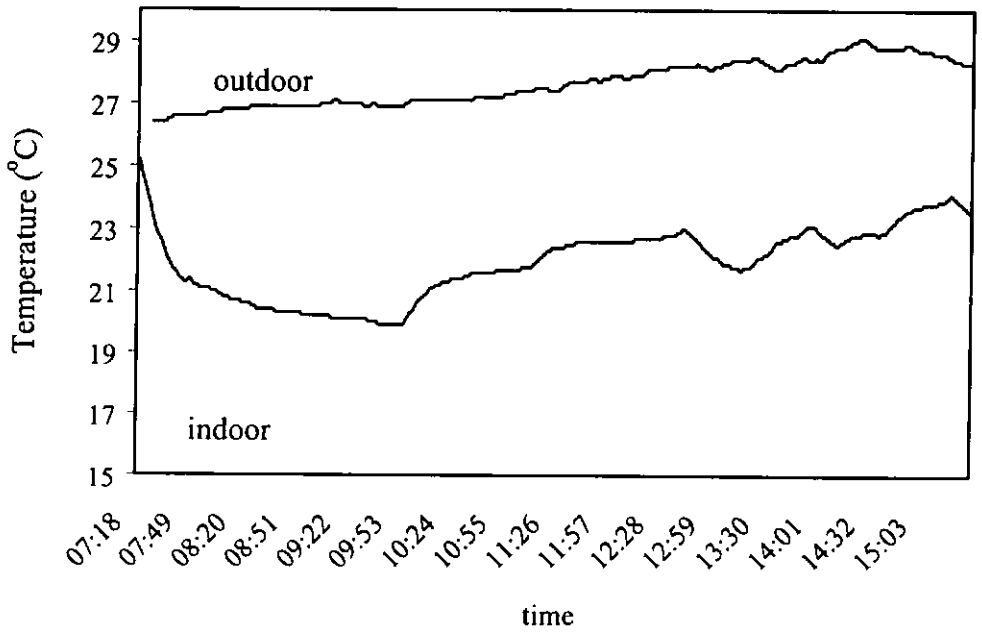


Figure 5.7 – *Indoor and Outdoor Relative Humidity Variation Profiles at MFS*

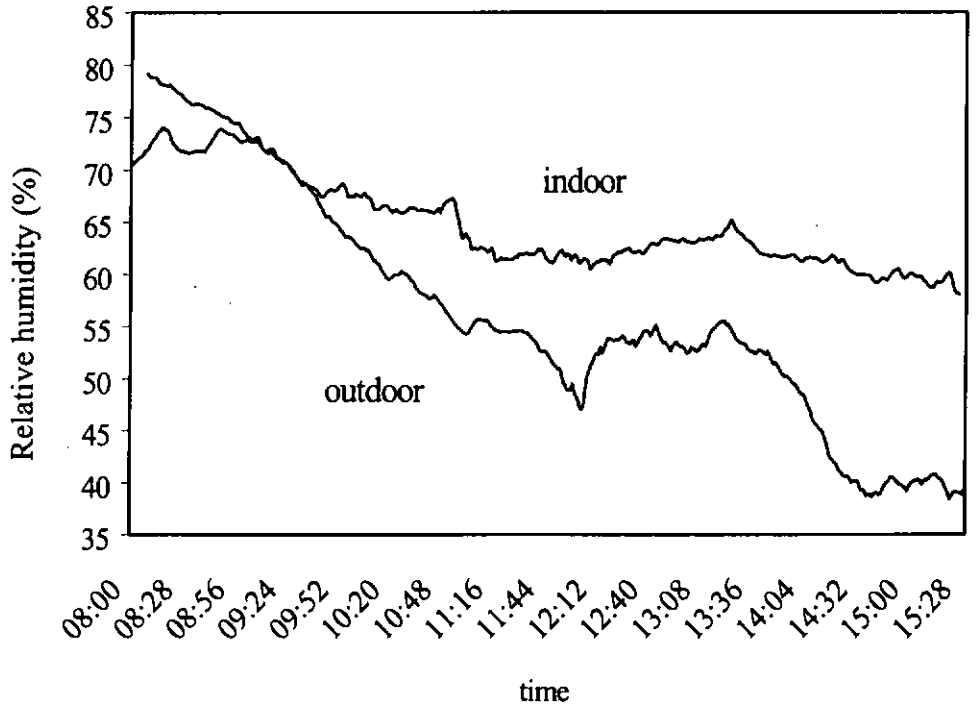
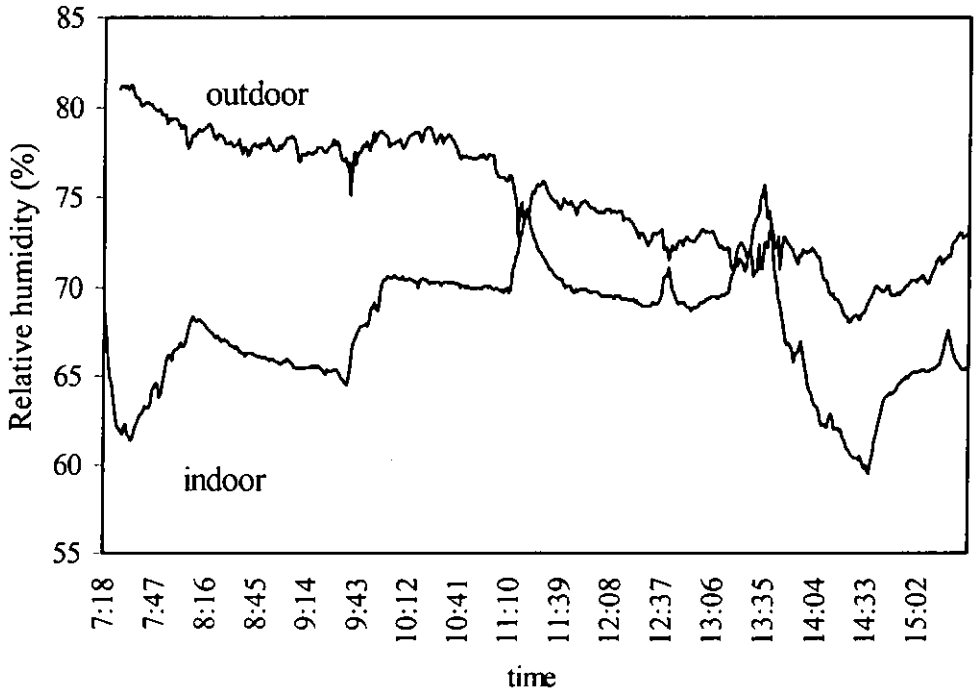


Figure 5.8 – *Indoor and Outdoor Relative Humidity Variation Profiles at TC*



5.2 Second Stage Study

Ventilation rate affects the speed of transport of pollutants into and out of an indoor environment. Rooms with air-conditioning are usually considered to have cleaner air than those without, but this might not be true. If the indoor environment has sources of pollutants and the outdoor intake air is more polluted, then the indoor environment is very likely to be more polluted. Carbon dioxide is a product from metabolic activities during human respiration. As shown in the first part of this study, CO_2 levels at classrooms were very high due to the high occupancy and inadequate ventilation. The ventilation rate was measured in this section using sulfur hexafluoride as a tracer gas at classrooms with and without air-conditioning to quantify the ventilation rate and the concentrations of $PM_{2.5}$, CO and target VOCs were measured. The effect of ventilation rate on pollutant concentrations was also investigated. And lastly, the effect of using air cleaners to reduce particulate matter concentrations was investigated.

5.2.1 Ventilation Rate

Ventilation rate was calculated according to the first order decay equation as mentioned in the Method Section. The slopes in Figures 5.9 and 5.10 correspond to the air change rate at MFSI and TC. MFSI, with windows half opened, had ventilation rate of 0.937 air change per hour (ACH); and TC, with air-conditioning and exhaust fans on, had ventilation rate of 0.217 ACH. Opened door and windows where outside air can enter and exit the room easily caused a higher ventilation rate at MFSI. An even higher ventilation rate would be expected if the ceiling fans were

on. The ventilation rate per occupant at MFSI was 1.205 l/s·person and for TC was 0.306 l/s·person. MFSI had ventilation rate per person almost four times of that at TC. ASHRAE Standard 62-1989 requires 15 cfm/person or 7.5 l/s·person for classroom premises and maximum occupancy of 50 person/100m^2 classroom environments. The occupancy at MFSI was 66 person/100m^2 and at TC was 69 person/100m^2. Both classrooms had occupancy exceeded the maximum value, and had ventilation rates per person not complied with the ASHRAE requirements. Low rate of ventilation might cause CO_2 and pollutants with indoor source accumulate, and students might feel stuffiness or even result with adverse health effects with prolonged time spent in the classrooms. The ventilation rates measured agreed with the results that very high CO_2 concentrations were found in inadequately ventilated classrooms in the previous section. Simply by increasing the ventilation rate so that the CO_2 or ventilation rate requirements are met might not be suitable, since other problems might arise. This problem needs to be recognized and mitigation measures should be applied.

Koo et al. (1997) reported higher prevalence of sore throats, sputum and fevers among children in air-conditioned schools than in naturally ventilated schools in Hong Kong. They suggested that reduced ventilation could cause higher rates of cross infections in highly crowded classrooms. Cross infection could be augmented in classrooms in Hong Kong since occupant density is very high. A suitable ventilation rate should be chosen to balance the effect. Lowering the occupancy is one of the methods to reduce indoor produced contaminants especially bacteria, but that might not be a feasible way to tackle the problem. With the increasing number of immigrants, there are not enough placements to meet their needs therefore to

lower the number of students in each class is impossible in the near future. Other ways are to increase the air exchange rate of the classroom, to implement more breaks between classes, to increase the frequency of HVAC system cleaning, or to install air-cleaning devices in classrooms.

Figure 5.9 – *Decay of Sulfur Hexafluoride at TC (Air-conditioning)*

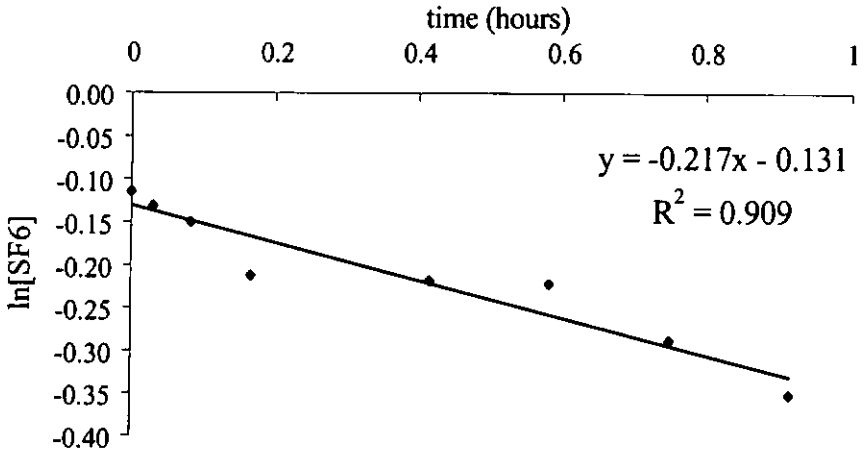
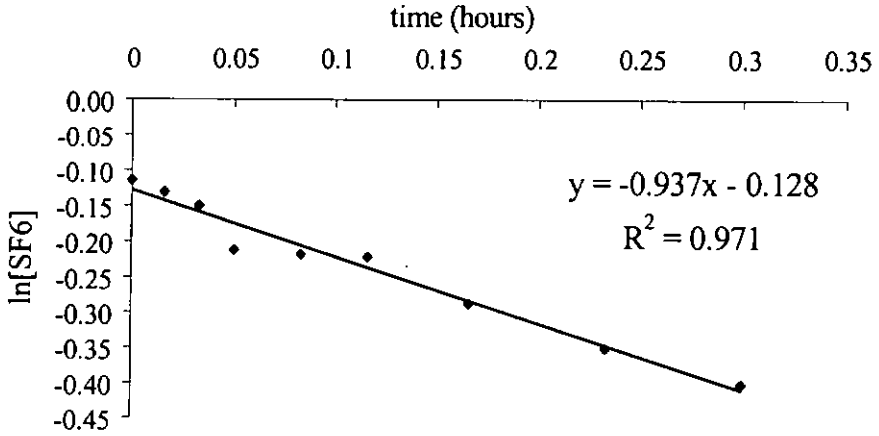


Figure 5.10 – *Decay of Sulfur Hexafluoride at MFSI (Natural Ventilation)*



5.2.2 Volatile Organic Compounds

Average concentrations of target VOCs at MFSI and TC are listed in Table 5.5. The outdoor VOC concentrations at TC were higher than at MFSI because TC is located in an urban area with higher traffic density. Vehicle exhaust emissions together with emissions from nearby shops and restaurants contributed to higher outdoor VOC levels. None of the indoor and outdoor VOC concentrations measured in this study exceeded levels in the HKIAQ. In fact, most target VOCs were found at very low levels and close to the detection limits of the GC/MSD. Most VOCs present in the outdoors were found indoors as well except for styrene and 1,2-dichlorobenzene.

Chan et al. (1993) measured VOC concentrations at classrooms in Taiwan. Averaged VOC concentrations measured at MFSI and TC were lower than those measured by Chan et al. Averaged benzene concentrations were almost ten times higher than at MFSI and TC and averaged toluene concentrations were five times higher. This could be due to the classrooms selected for measurements in Taiwan were in a very heavily trafficked area. Similar to Chan et al.'s findings, the source of VOC in this study was also highly related to vehicle exhaust emission. Compounds identified at MFSI and TC are those abundance in vehicle exhaust, for example, benzene, toluene, ethylbenzene, and *m,p,o*-xylenes. The daily indoor and outdoor variations of benzene and toluene during the five sampling days are shown in Figures 5.11 and 5.12. The indoor and outdoor variations of benzene and toluene at MFSI were similar, but the indoor VOC variations were not very similar to the outdoors at TC. The outdoor VOC concentrations at TC affected the indoor concentrations to a lesser extend. This could be due to a higher ventilation rate in the

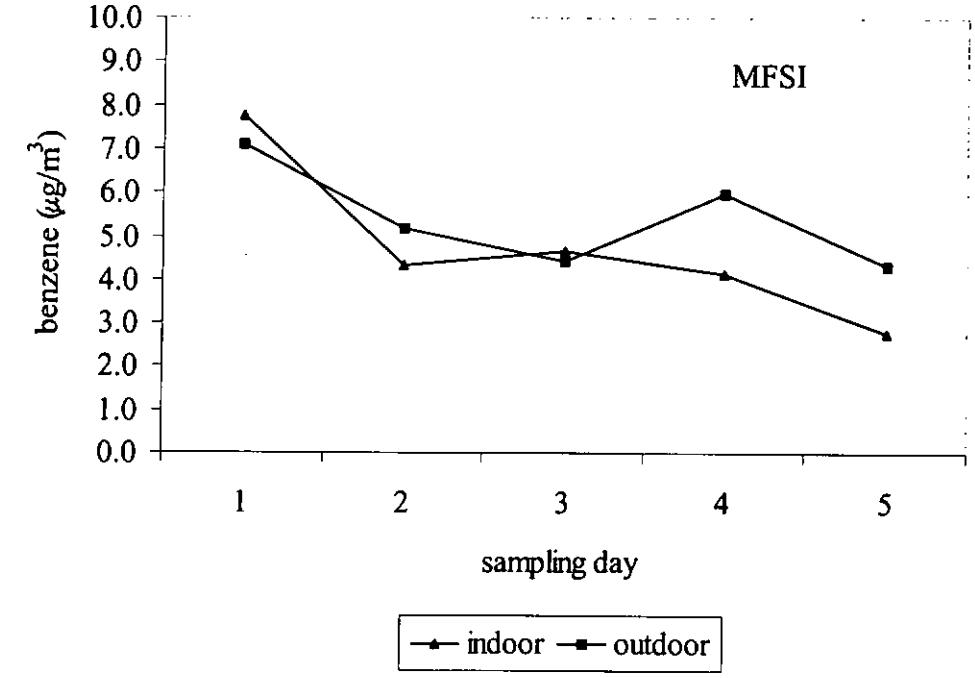
Table 5.5 – *Volatile Organic Compound Concentrations at MFSI and TC*

Volatile Organic Compound ($\mu g/m^3$)	**MFSI**		**TC**	
	Indoor	**Outdoor**	**Indoor**	**Outdoor**
Chloroform	<0.5	<0.5	0.6	0.7 (0.0)
1,1,1-Trichloroethane	1.8 (0.2)	1.6 (0.0)	<1.2	1.4
Benzene	4.7 (1.8)	5.4 (1.2)	4.9 (1.1)	7.4 (1.4)
Trichloroethene	2.0 (0.4)	1.8 (0.5)	1.6 (0.7)	1.9 (0.9)
Toluene	25.9 (14.1)	32.2 (17.6)	34.3 (11.4)	43.4 (8.7)
Tetrachloroethene	<1.5	<1.5	2.3 (1.2)	1.9 (0.9)
Ethylbenzene	2.5 (1.0)	2.6 (0.9)	3.3 (0.9)	5.0 (1.5)
m,p-Xylene	2.3 (0.8)	2.6 (0.6)	4.1 (1.0)	5.7 (2.1)
Styrene	<1.4	<1.4	<1.4	1.7
o-Xylene	1.8 (0.7)	1.8 (0.4)	3.2 (0.9)	4.8 (2.0)
1,3,5-Trimethylbenzene	1.4 (0.6)	1.6 (0.4)	<0.5	9.3 (12.0)
1,2,4-Trimethylbenzene	<0.5	1.3 (0.2)	0.8 (0.1)	1.2 (0.4)
1,4-Dichlorobenzene	0.3 (0.1)	1.1	0.9 (0.2)	1.9 (1.1)
1,2-Dichlorobenzene	<0.6	1.6	<0.6	<0.6

( ) – standard deviation

naturally ventilated classroom had a higher rate of indoor and outdoor air mixing which resulted in similar VOC compositions. On the other hand, the air-conditioning system at TC prohibited VOCs entering the classroom. The indoor benzene and toluene concentrations were lower at TC than the outdoors for most of the time while at MFSI the indoor and outdoor concentrations were very similar. Compared with indoor VOC levels measured at other places in Hong Kong (Ng and Lai 1997), VOC concentrations measured in classrooms were lower than those measured at shopping malls, restaurants and offices, but were comparable to those in cinemas.

Figure 5.11 – *Indoor and Outdoor Variations of Benzene at MFSI and TC during the Five Sampling Days*



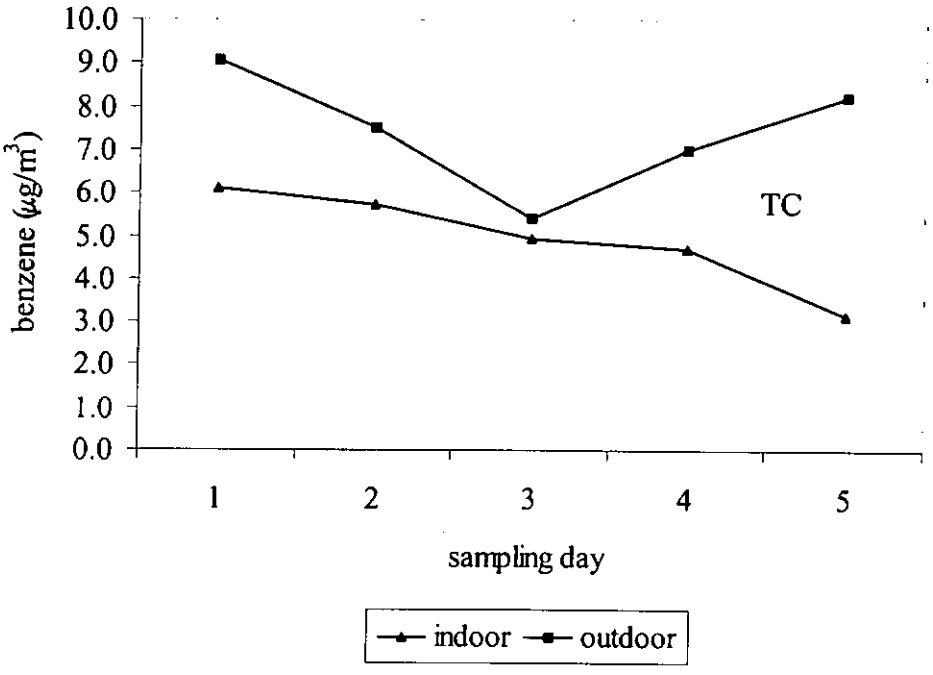
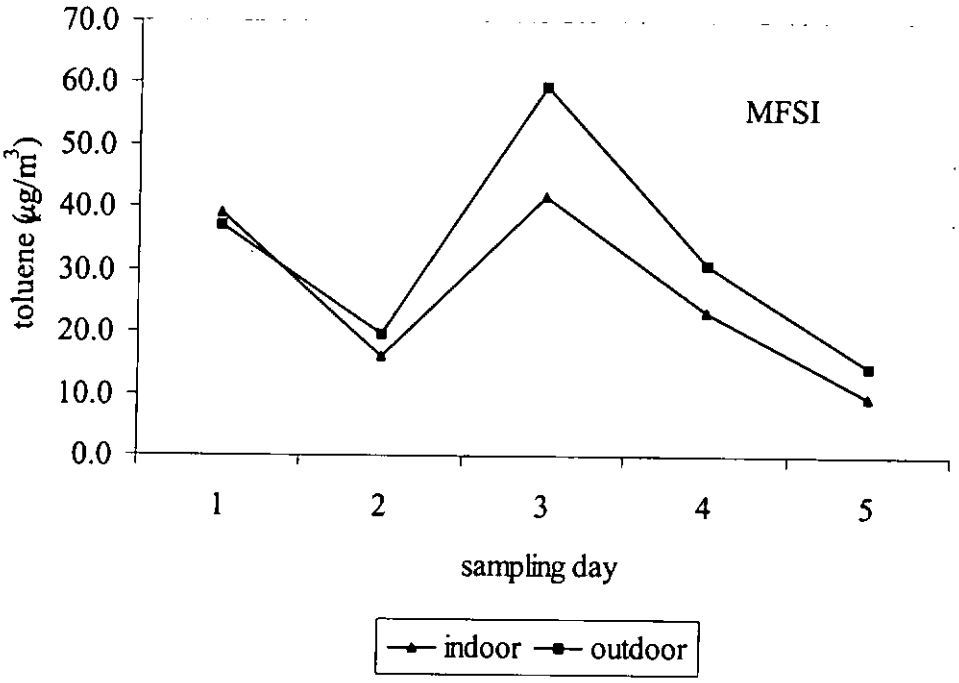
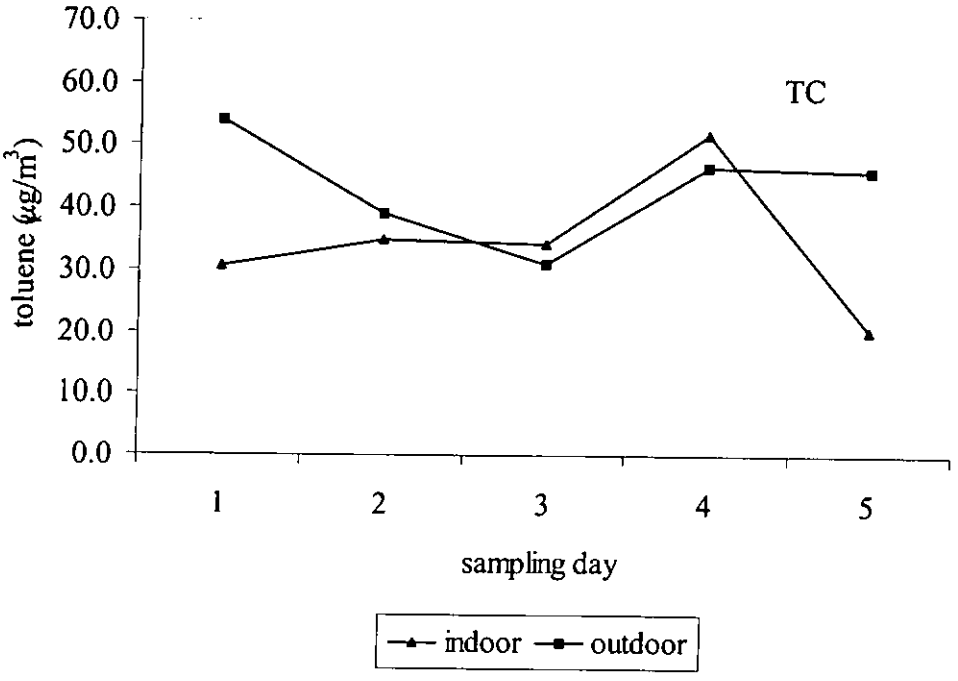


Figure 5.12 – *Indoor and Outdoor Variations of Toluene at MFSI and TC during the Five Sampling Days*





Though VOCs listed in the USEPA TO-14 Method were of interest in this project, VOCs such as aliphatic hydrocarbons, ketones and aldehydes are also commonly found in ambient air.

Since VOC concentrations inside TC seemed to be less affected by the outdoor levels, I suggest that air-conditioning not only mitigated traffic noise, but also prevent infiltration of VOCs. As from the ventilation rate measurements, air change rate measured at MFSI was higher than at TC. The air change per hour measured using tracer gas decay was 0.217 ACH at TC and 0.937 ACH at MFSI respectively. The reduced ventilation at TC lessened the exchange rate between indoor and outdoor air and prevented infiltration of the relatively higher outdoor VOC, but there are drawbacks from using air-conditioning in such crowded environments.

Indoor and outdoor pollutant ratios (I/O) of individual VOCs are listed in Table 5.6. I/O at MFSI are higher and closer to unity (I/O $\approx$ 1) than TC. This implies that indoor and outdoor VOC concentrations were similar at MFSI. The higher air exchange rate resulting from opened windows and doors was one of the reasons. The air-conditioning system at TC could act as a barrier to prevent outdoor pollutants from entering the classroom. I/Os at TC indicated a higher concentration of pollutants in the outdoors than indoors except for tetrachloroethylene. A high indoor concentration (3.2 $\mu g/m^3$) of tetrachloroethylene was found on one sampling day, and is suspected to be offgassed from dry cleaned clothing from the occupants. In general, the main sources of VOCs found in classrooms were from the outdoors.

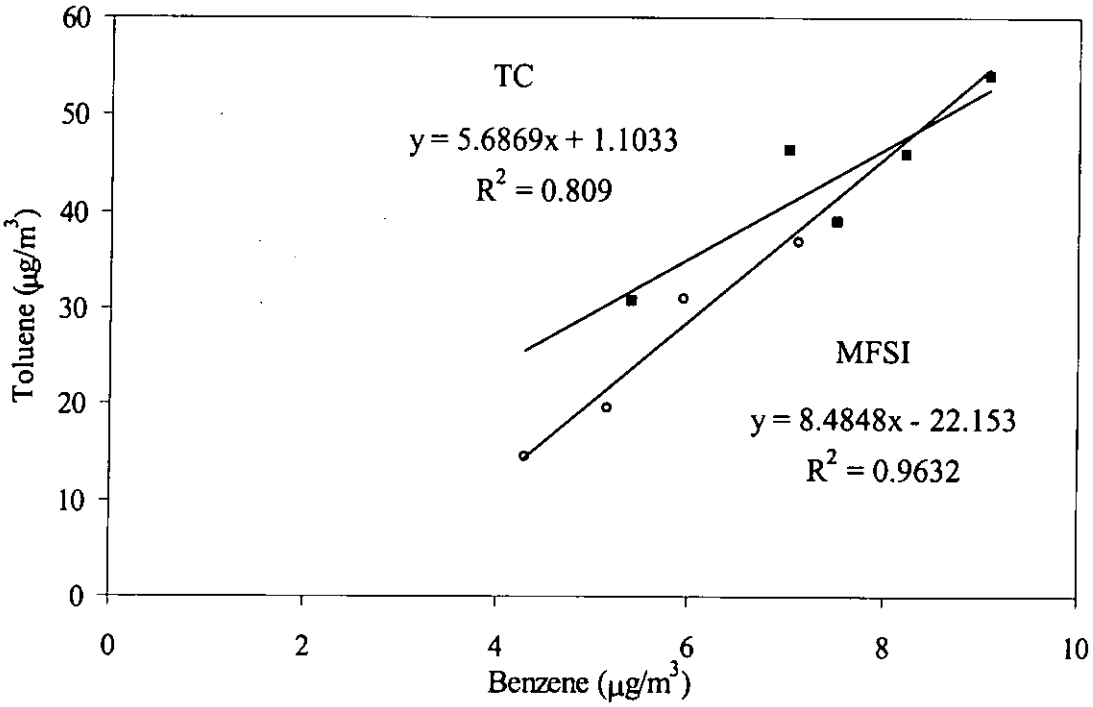
Table 5.6 – *Indoor to Outdoor Pollutant Ratios for Selected Volatile Organic Compounds at MFSI and TC*

Indoor to Outdoor Pollutant Ratio	**MFSI (without air conditioning)**	**TC (with air conditioning)**
1,1,1-Trichloroethane	1.1 (0.1)	na
Benzene	0.7 (0.2)	0.7 (0.2)
Trichloroethylene	1.0 (0.2)	0.8 (0.1)
Toluene	0.8 (0.2)	0.8 (0.3)
Tetrachloroethylene	na	9.6
Ethylbenzene	0.9 (1.0)	0.7 (0.2)
m,p-Xylene	0.9 (0.1)	0.8 (0.3)
o-Xylene	1.0 (0.3)	0.7 (0.4)
1,3,5-Trimethylbenzene	0.9 (0.3)	na
1,2,4-Trimethylbenzene	na	0.8 (0.4)
1,4-Dichlorobenzene	0.2	0.6 (0.3)

na – not applicable
( ) – standard deviation

The outdoor benzene to toluene concentration correlations at the two classroom locations are shown in Figure 5.13. The benzene and toluene concentrations were in good correlation, this is a strong evidence showing that the main source of VOC was from vehicle exhaust emission. Moreover, the VOC species found in this study (benzene, toluene, ethylbenzene, and xylenes) are those present in gasoline powered vehicle exhaust. Therefore vehicle exhaust emissions is an important outdoor pollutant source at school locations.

Figure 5.13 – *Correlation Between Benzene and Toluene Concentrations Outside MFSI and TC*



5.2.3 Particulate Matter with Diameter Less Than 2.5 Microns ($PM_{2.5}$)

Fine particles are a better surrogate for toxic compounds than other classes of particulate matter and since they can penetrate into the lower respiratory tract, they are more associated with health and mortality effects. Sources of fine particulates are mainly from diesel vehicle exhaust, secondary sulfate industry, paved road dust, and marine aerosol. The 24-hour averaged $PM_{2.5}$ concentration at MFSI was 48.8µg/m^3 (standard deviation 18.3µg/m^3) and at TC was 27.7µg/m^3 (standard deviation 7.1 µg/m^3). The 24-hour outdoor $PM_{2.5}$ concentrations at the two locations were also measured using MiniVol Samplers. The $PM_{2.5}$ concentration measured using the MiniVol Sampler was calibrated with Partisol™ Sampler as well and the calibration

curve obtained was $Mini_{2.5} = 0.9523 \times Partisol_{2.5} + 12.233$, $r^2 = 0.918$. $PM_{2.5}$ levels outside MFSI and TC were 61.7 $\mu g/m^3$ and 72.8 $\mu g/m^3$. There is no indoor requirement for $PM_{2.5}$ levels in Hong Kong at this moment, but the United States NAAQS $PM_{2.5}$ 24-hour average concentration of 65 $\mu g/m^3$ is under enforcement. The outdoor $PM_{2.5}$ at TC exceeded the NAAQS, and the level at MFSI was very close to the standard. The average indoor $PM_{2.5}$ level at MFSI was higher than at TC but both complied with the US standard. Indoor $PM_{2.5}$ level relative to the outdoors was 20.8% at MFSI and 61.9% at TC. Assuming that $PM_{2.5}$ generated indoors (human activities) and sink effects (deposition, adsorption) were similar, the concentrations were lower at the air-conditioning classroom. The lower ventilation rate in the air conditioning room is one of the reasons why TC had lower relative $PM_{2.5}$ levels. In addition, air-conditioner has filters to trap some of the fine particles present in the supply air. Comparison of PM_{10} and $PM_{2.5}$ concentrations was not made due to lack of equipment. The $PM_{2.5}$ to PM_{10} level correlation in Hong Kong was $PM_{2.5} = 0.67 \times PM_{10} + 10.4$ ($r^2 = 0.86$) (Lam et al. 1999).

5.2.4 Carbon Monoxide Variation

Carbon monoxide is produced from incomplete combustion and is one of the main components in vehicle exhaust. Variation in CO concentrations at MFSI and TC are shown in Figures 5.14 and 5.15 respectively. The indoor variation of CO at MFSI followed closely the outdoor variation, but the outdoor concentrations were higher than the indoor since the outdoor equipment were placed closer to the source. The outdoor equipment was quite far away from the indoor equipment due to limitation of available outdoor sampling locations. CO concentrations in the morning

were high since there was a lot of buses stopping near the school to drop off students. CO concentrations decreased with time due to no further production and dispersion of the CO. There are several parking spaces for heavy trucks near the front door of the school building. A higher CO concentration was observed at night due to heavy trucks drove near the school for parking that produced a large amount of vehicle exhaust that contains CO. The averaged CO concentration at MFSI was 1310 $\mu g/m^3$ and the averaged outdoor concentration was 2100 $\mu g/m^3$. The averaged indoor and outdoor CO concentrations at TC were 1130 $\mu g/m^3$ and 1250 $\mu g/m^3$, which were higher than those measured at MFSI. Since MFSI is located nearer to the ground level than TC and there was a lot of local traffic nearby, therefore a higher indoor and outdoor CO concentrations. There was a lot of traffic near TC throughout the day therefore the CO levels were high during school hours. From Figure 5.15, the outdoor CO concentration fluctuated highly and the indoor CO concentration had a smoother trend. Similar indoor and outdoor relationships between PM_{10} concentrations at TC were observed where the indoor variation is very similar to the outdoors but have a smoother trend.

Figure 5.14 – *Typical Indoor and Outdoor Carbon Monoxide Variation at MFSI*

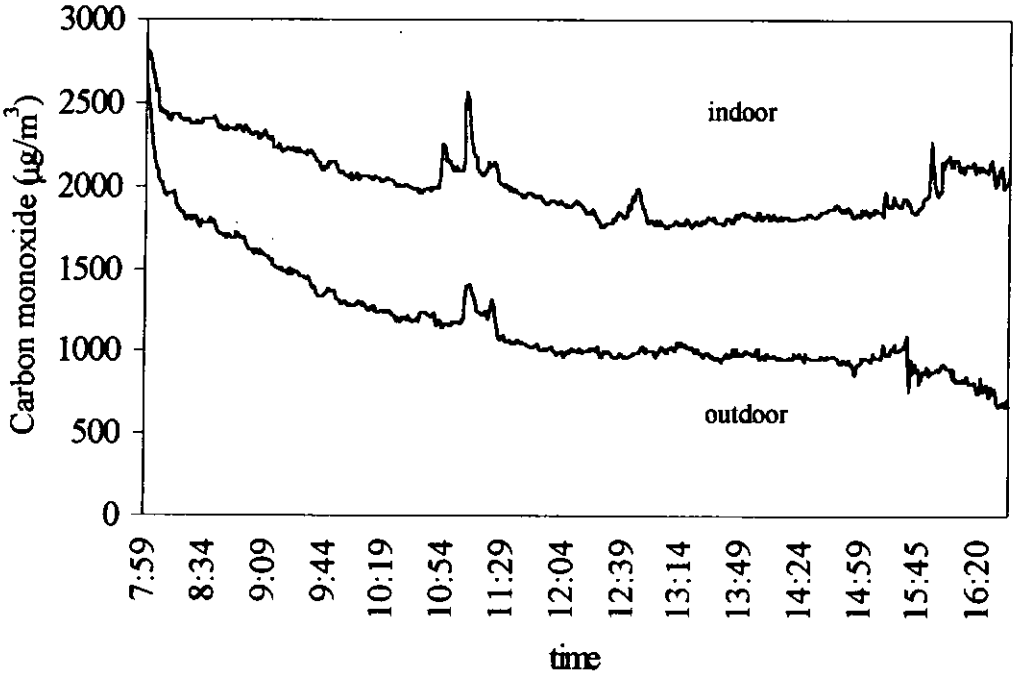
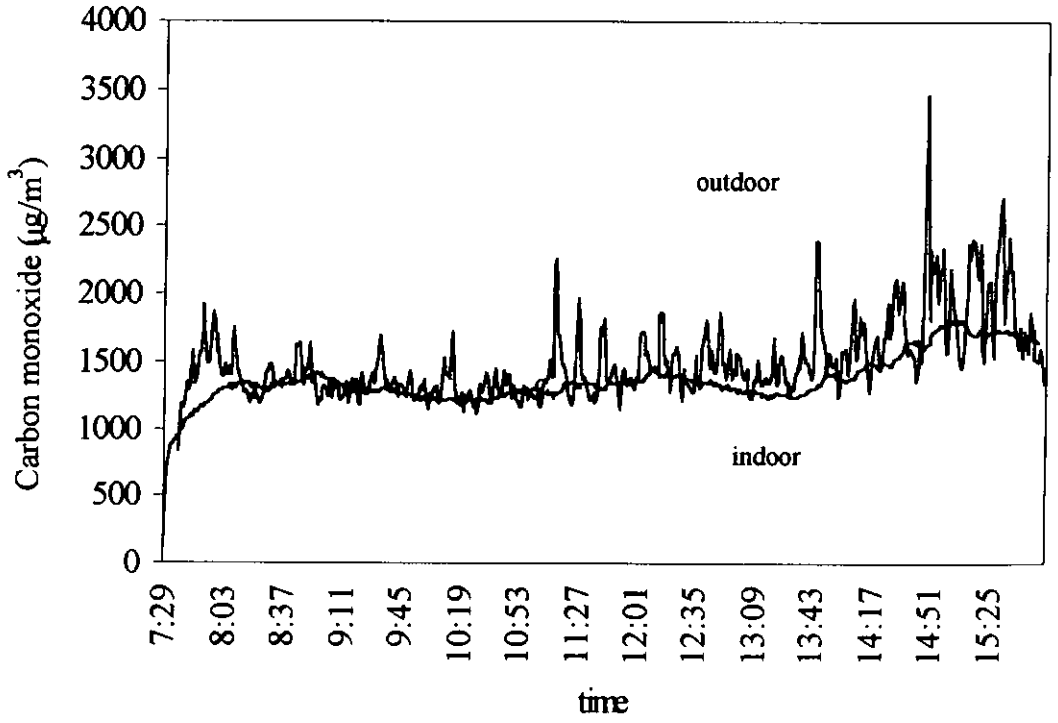


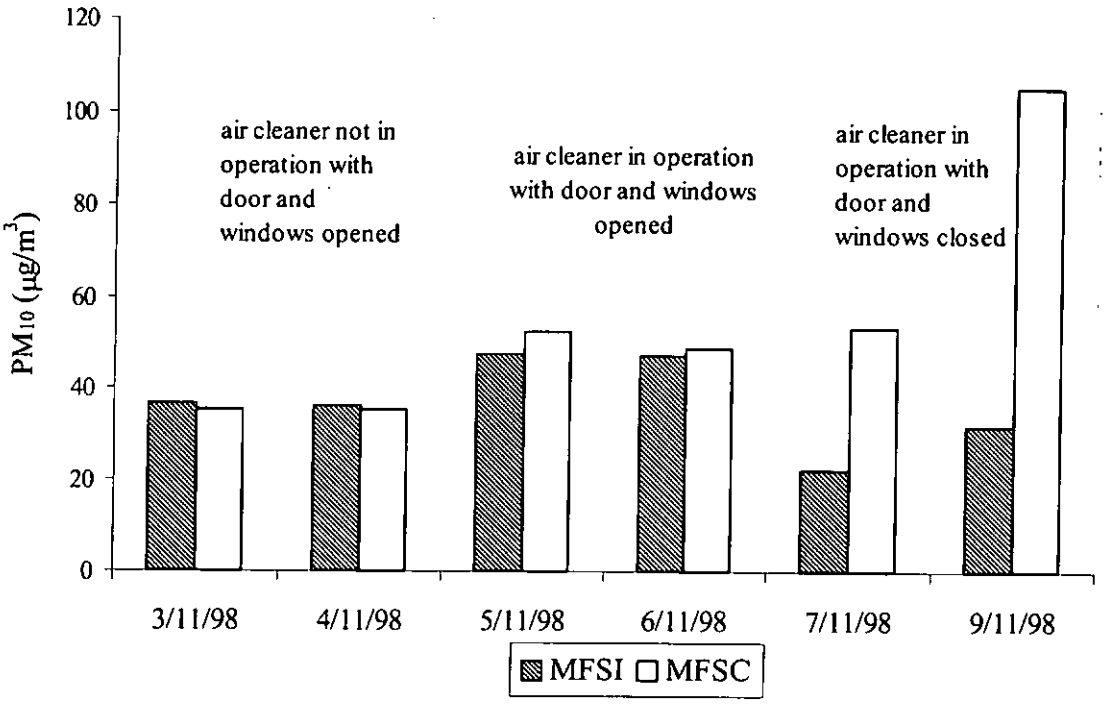
Figure 5.15 – *Typical Indoor and Outdoor Carbon Monoxide Variation at TC*



5.2.5 Effectiveness of Air Cleaner on Particulate Matter Concentration Reduction

The effectiveness of air cleaner on removing particulate matter (PM_{10}) inside a classroom was investigated at MFSI. Two adjacent classrooms both naturally ventilated and having the same size were used in this investigation. An air cleaner was placed at the back corner of one classroom (MFSI) while the other classroom (MFSC) had no air cleaner which served as the control for comparison. A six-day experiment was carried out at the two classrooms with two days occupied, with door and windows opened, and air cleaner not in operation; two days occupied, with door and windows opened and with air cleaner in operation, and two days unoccupied, with door and windows closed, and with air cleaner.

Figure 5.16 –*Effect of Air Cleaner on PM_{10} Concentrations*



As shown in Figure 5.16, the two classrooms had very similar PM_{10} concentrations when occupied and without air cleaner operation. The two set of bars in the middle of Figure 5.16 show the PM_{10} concentrations when both classrooms were occupied and air cleaner in operation. MFSI had PM_{10} concentration slightly lower than MFSC but concentrations were very similar. The effect of air cleaner on the PM_{10} concentration was also investigated when the classrooms were unoccupied, and door and windows were closed. The PM_{10} level at MFSI when unoccupied with air cleaner in operation was substantially lower than MFSC.

The results seem reasonable that the two classrooms, both without air cleaner has similar PM_{10} concentrations since they are adjacent to each other, therefore should be affected by outdoor particulate matter to a very similar extent. While the classrooms were occupied, the PM_{10} concentrations were similar since door, windows and ceiling fans were on, the high ventilation rate promoted mixing of the indoor and outdoor particulate matter, resulted in very similar PM_{10} concentrations at the indoors, outdoors and the adjacent classroom. When the door and windows were closed and fans were off, the mixing of indoor and outdoor PM_{10} was not good, the air cleaner removed the particulate matter in the classroom with air cleaner operating, and PM_{10} from the outdoors can not enter the room resulting in a much lower PM_{10} level. The use of air cleaner can remove particulate matter in classroom air, but was not effective enough if door and windows were opened and ceiling fans were on.

Since the levels of PM_{10} were within the HKAQO and a consistently lower indoor PM_{10} level is observed at air-conditioned classrooms in this study,

investigation of the air cleaner effect in those classrooms was not carried out here. Further investigation is necessary and would give a better idea on whether air cleaners are effective in reduced ventilation environments.

5.3 Control Study

Indoor and outdoor pollutant concentrations were measured at classrooms located in different areas of Hong Kong in the first part of this study. Since there was no major indoor pollutant sources in the classroom, besides carbon dioxide, outdoor conditions play a major role in affecting the indoor pollutant levels. The aim of this section is to minimize the variables which could affect the indoor pollutant levels. Outdoor conditions were kept the same by using one classroom only. The same classroom, PolyU, was used for measurement of pollutants with and without air-conditioning. Measurements were taken when PolyU was unoccupied, therefore carbon dioxide levels were not considered here. PM_{10} and $PM_{2.5}$ concentrations are not compared since they were measured on separate days. The main difference between the classrooms used, previously, and PolyU is that PolyU is wall-to-wall carpeted. Carpet is known to act as a sink for VOCs which could affect the I/O of some VOCs.

The indoor and outdoor $PM_{2.5}$ concentration variations, with and without air-conditioning, at PolyU are shown in Figures 5.17 and 5.18. The indoor $PM_{2.5}$ concentrations were much lower than the outdoors when there was air-conditioning. The indoor $PM_{2.5}$ concentrations varied with the outdoor concentration closely when there was no air-conditioning, with doors and windows opened, but had a smoother trend. Similar results were obtained for PM_{10} concentrations. As shown in Figures 5.19 and 5.20, the indoor PM_{10} concentrations with air-conditioning were lower than that of the outdoors but the concentration varied similarly with the outdoors when there was no air-conditioning. These results agreed with particulate matter measurements at MFSI and outdoor and are similar to those of Rubino et al. (1998).

Figure 5.17 – *Variation of $PM_{2.5}$ Concentrations at PolyU with Air-conditioning*

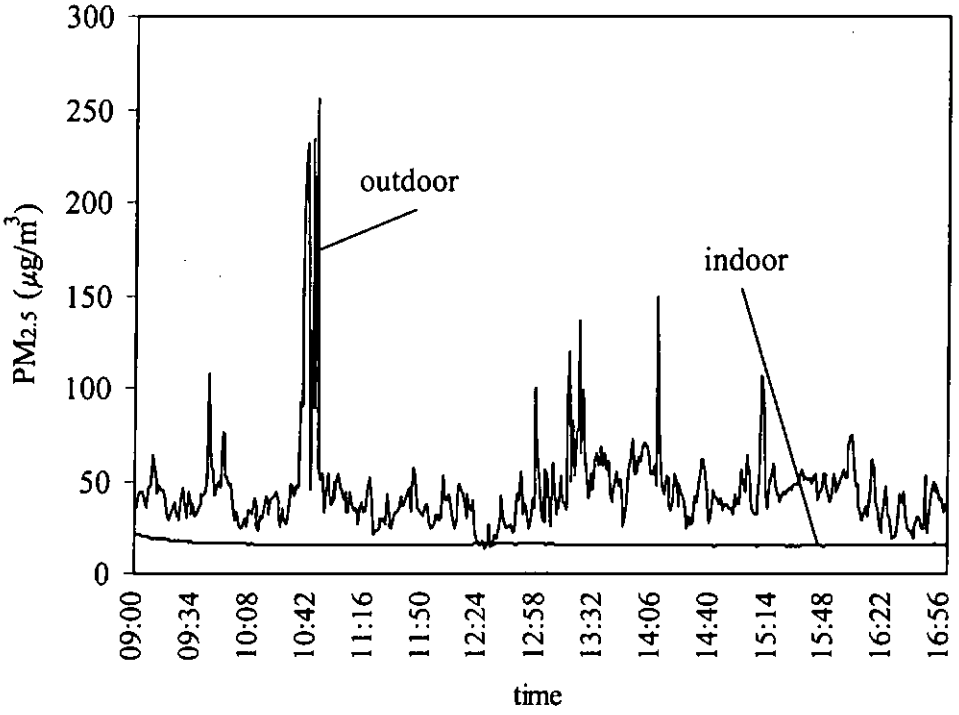


Figure 5.18 – *Variation of $PM_{2.5}$ Concentrations at PolyU without Air-conditioning*

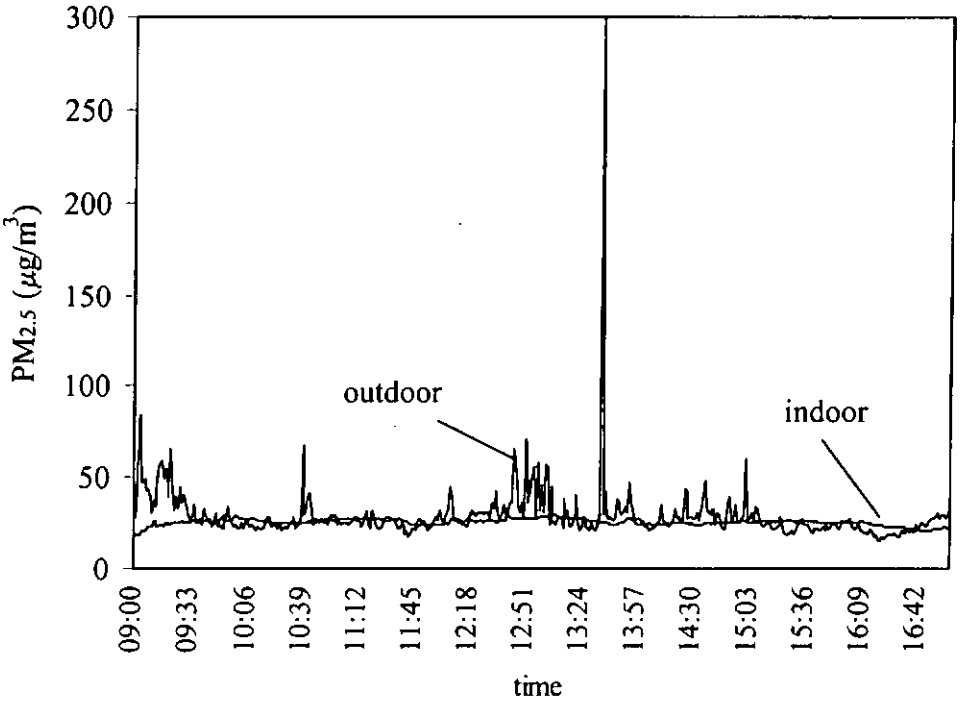


Figure 5.19 – *Variation of PM_{10} Concentrations at PolyU with Air-conditioning*

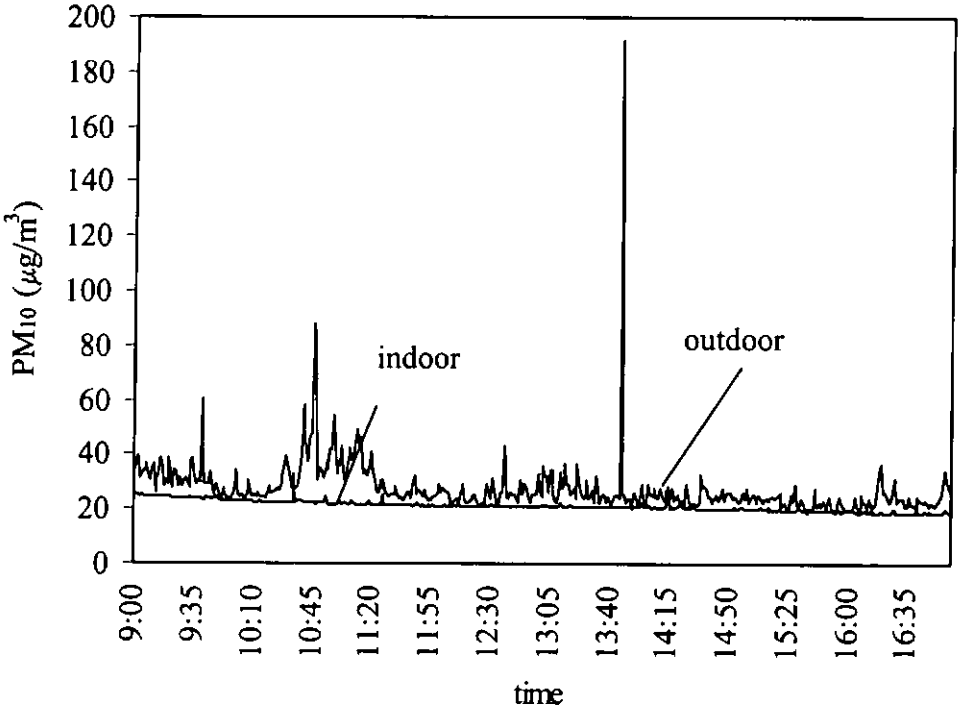
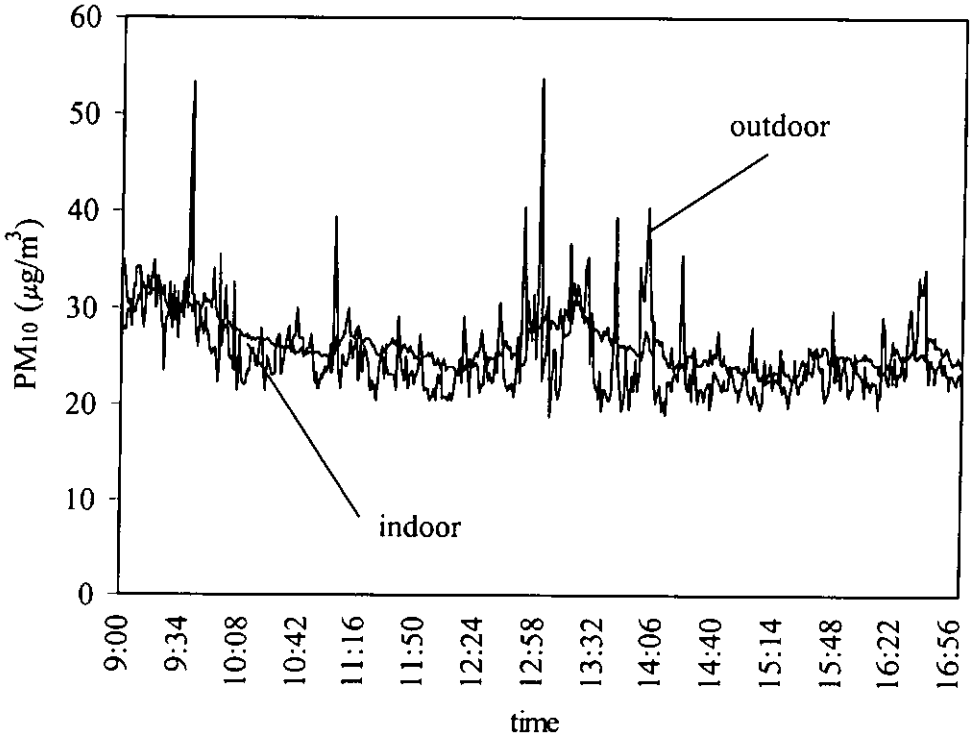


Figure 5.20 – *Variation of PM_{10} Concentrations at PolyU without Air-conditioning*



Ventilation rates at PolyU with and without air-conditioning were 0.259 ACH and 0.759 ACH respectively. The air exchange rate at PolyU with doors, windows opened and no mechanical ventilation was higher than with doors, windows closed and air-conditioning on. PolyU with air-conditioning had ventilation rate lower than with natural ventilation. This was similar at MFSI and TC where MFSI (natural ventilation) had ventilation rate lower than TC (air-conditioned) and therefore a comparison between the indoor and outdoor pollutant concentrations is possible.

Table 5.7 – *Indoor Pollutant Concentrations at PolyU With Air-conditioning and the Respective Outdoor Pollutant Concentrations*

Pollutant and Other Parameters	**Indoor**	**Outdoor**
Ventilation rate (ACH)	0.259	na
Particulate matter with diameter less than 10 micron ($\mu g/m^3$)*	21.2	27.7
Particulate matter with diameter less than 2.5 micron ($\mu g/m^3$)*	15.7	44.8
Benzene ($\mu g/m^3$)	8.2	3.6
Toluene ($\mu g/m^3$)	92.4	18.1
Ethylbenzene ($\mu g/m^3$)	9.4	3.7
Xylenes ($\mu g/m^3$)	14.0	13.5
Carbon monoxide (ppm)	1.1	1.2
Sulfur dioxide (ppm)	0.012	0.012
Nitric oxide (ppb)	92.6	86.5
Nitrogen dioxide (ppb)	11.3	28.5

na – not applicable

* PM_{10} and $PM_{2.5}$ monitoring were done on separate days

The average indoor and outdoor pollutant concentrations from 9 a.m. to 5 p.m. at PolyU, with and without air-conditioning, are listed in Tables 5.7 and 5.8. Averaged PM_{10} concentration at PolyU with air-conditioning was lower than the outdoor concentration; similarly, $PM_{2.5}$ concentrations were lower in the indoors than the outdoors. Concentrations of VOCs (benzene, toluene, ethylbenzene and xylenes) indoors were higher than the outdoors. The concentrations of CO and SO_2 had very similar indoor and outdoor concentrations. For nitrogen oxides, the concentration of NO was higher in the indoor than the outdoors and the concentration of NO_2 was higher in the outdoors than in the indoors. Assuming that particulate matter has outdoor sources only and when the air-conditioners were on, the smaller air exchange rate lowered the rate of indoor and outdoor mixing, and therefore lower indoor particulate concentrations were observed. For VOCs, since the indoor concentrations were much higher than the outdoors, I assumed that the carpet desorbed VOCs. The lower ventilation rate inhibited removal of VOCs from the room lead to a higher concentration in the indoors than the outdoors. A smaller variation in both temperature and relative humidity was observed when PolyU was air-conditioned than when it was naturally ventilated. A better control of the indoor temperature and relative humidity levels was observed with air-conditioners on.

When PolyU is naturally ventilated, the indoor PM_{10} concentrations were even higher than the outdoors. The $PM_{2.5}$ concentrations were lower but approached the outdoor concentrations. The concentrations of benzene, toluene, ethylbenzene, and xylenes were similar and lower than those measured when there was air-conditioning. This could be due to the offgassed VOCs were transported out of

PolyU at higher ventilation rates. Control of thermal comfort parameters in naturally ventilated PolyU was not good, the indoor temperature and relative humidity varied with the outdoors and the room was very hot and stuffy at midday.

Table 5.8 – *Indoor Pollutant Concentrations at PolyU Without Air-conditioning and the Respective Outdoor Pollutant Concentrations*

Pollutant and Other Parameters	**Indoor**	**Outdoor**
Ventilation rate (ACH)	0.785	na
Particulate matter with diameter less than 10 micron ($\mu g/m^3$)*	26.1	25.0
Particulate matter with diameter less than 2.5 micron ($\mu g/m^3$)*	25.4	28.8
Benzene ($\mu g/m^3$)	2.9	3.0
Toluene ($\mu g/m^3$)	44.1	37.4
Ethylbenzene ($\mu g/m^3$)	3.2	2.2
Xylenes ($\mu g/m^3$)	7.7	5.1
Carbon monoxide (ppm)	1.21	1.15
Sulfur dioxide (ppm)	0.011	0.011
Nitric oxide (ppb)	40.4	32.1
Nitrogen dioxide (ppb)	6.0	15.8

na – not applicable

* PM_{10} and $PM_{2.5}$ monitoring were done on separate days

5.4 Risk Assessment for Exposure to Carcinogen (Benzene) at Classrooms

The USEPA defined two categories for risk assessment, adult and child. Since the body weights defined were established for Americans, therefore, might not be applicable here. There is no information on body weight and air intake for local residents thus calculations for the two categories according to USEPA specifications are presented. Table 5.9 lists the air intake and body weight for a child and an adult.

Table 5.9 – *Body Weight and Air Intake for Child and Adult*

	Child	**Adult**
Body Weight (kg)	10	70
Air Intake (m^3/hour)	0.21	0.83

Assumptions made for calculation of daily intake are: exposure duration at school is 40 hours/week for 8 hours/day, 5 days/week; there are 90 days of school holiday per year and therefore the exposure frequency is 39 weeks/year ((365 days – 90 days) /7 days per week); and the length of exposure from primary to secondary school is 11 years (Primary 1 to 6 and Secondary 1 to 5). Among the target VOCs, benzene was the only carcinogenic compound detected at the two school locations. Indoor benzene concentrations used for calculation of the lifetime risks are 4.7 μg/m3 and 4.9 μg/m3 for MFSI and TC respectively. Overestimation of the risk could result due to benzene concentrations were measured using grab sampling method. The risks were calculated according to the equation listed in the Method Section. The PF for benzene is 2.9×10^{-2} $(mg/kg/day)^{-1}$ (USEPA 1998).

The lifetime cancer risks for child and adult at MFSI and TC are listed in

Table 5.10. The risks for children are almost double that of adults since they have higher unit body weight exposure. The risks calculated in this study were much lower than those in Chan et al. (1993), since benzene concentrations measured in this study were much lower. Significant risks were found in this study though not as high as those in Chan et al. Bear in mind that only exposure to benzene in the 11 years at primary and secondary school was considered in the risk calculation. The students are possibly exposed to a higher concentration and larger variety of carcinogens during commuting, at home, or at recreational places. The risks calculated do not comply with the HKIAQ which stipulates that pollutant concentrations should not induce a risk greater than 1.0×10^{-6}.

Table 5.10 – *Lifetime Cancer Risk Due to Benzene Exposure*

Cancer risk	**MFSI**	**TC**
Adult	1.09×10^{-6}	1.13×10^{-6}
Child	1.93×10^{-6}	2.00×10^{-6}

High risks were resulted from the above calculations infers that carcinogenic compounds are present in high concentrations in Hong Kong. Children have higher risk than adults therefore should be protected from exposure to such pollutants. By expressing pollutant concentrations in health risks could help students or citizen to understand more.

6.0 CONCLUSIONS

The indoor and outdoor air pollutant concentrations at classrooms in Hong Kong complied with the HKAQO and HKIAQ except for a few compounds. IAQ at classrooms with mechanical ventilation complied with the Level 2 IAQO except for CO_2 concentrations. The indoor CO_2 levels at the five classrooms often exceeded the ASHRAE requirement of 1000 ppm during class. Classrooms with air-conditioning exceeded the level to a more serious extend than those classrooms with natural ventilation, this was confirmed by the results from the ventilation study. A much lower ventilation rate was measured at the air-conditioned classroom (0.217 ACH) compared with the natural ventilated classroom (0.937 ACH). The classroom with air-conditioning had lower indoor and outdoor air mixing rate, therefore CO_2 produced by students were trapped inside. PM_{10} concentrations were also high in the classroom environment. High levels of suspended particulate matter are inevitably found in Hong Kong due to very high emissions from traffic and construction activities. High particulate matter concentrations were observed at classrooms located in high traffic density areas or with construction activities nearby. High dust levels were also observed inside the classroom when the amah was sweeping the floor. To avoid further exacerbate the situation, classroom cleaning should be done using water with mops. Fine particulate matters ($PM_{2.5}$) were found in high concentrations outside the classrooms, and one measurements was even above level suggested in the NAAQS. Exceedance of NO_2 concentrations above the HKAOQ was observed probably due to vehicle exhaust emissions. Carbon monoxide concentrations varied with activity of local traffics, the indoor trend was very similar to the outdoors but at a lower concentration with smaller variations. Volatile organic

compounds were found at low concentrations and were mainly from the outdoor sources such as vehicle exhaust emissions. Air-conditioned classrooms had ventilation rates lower than naturally ventilated classrooms hence resulted in a lower rate of mixing between indoor and outdoor air. Pollutants with high concentrations, outdoors, were prevented from entering the classrooms with air-conditioning. Both the control experiment and the on-site study confirmed that pollutants with outdoor sources had lower I/Os at the air-conditioned classroom. Since most of the classrooms had pollutants with outdoor sources (except for CO_2), air-conditioning is encouraged. The indoor air quality at classrooms was good at air-conditioned classrooms though the CO_2 levels were high. The pros of providing air-conditioning to classrooms are a quiet learning environment, a better control of comfort parameters such as temperature and relative humidity, and prevent unwanted pollutants from entering the indoors. Providing air-conditioning together with air cleaning devices could provide an environment that is quiet and has good air quality. The use of air cleaner in reduction of particulate matters with doors and windows opened showed little effectiveness since the mixing rate of indoor and outdoor air was very high, the capacity of the air cleaner to remove dust particles was not large enough. A simple cost analysis showed that to provide air-conditioning for classrooms at a typical school, the expenditure per school year is $65700. Since only five classroom locations were included in this IAQ study the results cannot represent other school IAQ conditions, further investigation should be carried out. Students should be aware of IAQ problems and help to improve IAQ at classrooms. The USEPA has brochures that suggest ways that teachers and student could participate and are attached in Appendix VII.

7.0 RECOMMENDATIONS

The following are a few suggestions for improvement that could be made in this project.

1. More schools should be included in this study since local environments could affect air quality at schools at different locations.
2. A larger number of classrooms should be surveyed at the same school and other special function rooms since other rooms could be affected by local pollutant sources.
3. Radon is a known human lung carcinogen and is present in building materials commonly used in Hong Kong. Exposure to high concentrations of radon is possible at indoor locations with reduced ventilation. Monitoring of radon concentrations can help to characterize exposure of schoolchildren to this important carcinogen.
4. Questionnaire survey should be carried out at the same time as air pollutant measurements to evaluate the effect of air pollution on schoolchildren's health. Many studies have related residential and office air quality to SBS. Other factors like psychosocial factor, pressure on schoolwork, noise, lighting could give rise to SBS should also be considered.
5. Integrated volatile organic compound samples should be taken instead of grab samples to improve the accuracy of measurements. An 8-hour measurement can give a better picture to exposure of schoolchildren to VOCs present in the classroom air.

6. To further study the reduction of PM_{10} concentrations using air cleaner at air-conditioning classrooms.
7. Simultaneous monitoring of student activity in the classrooms could help to further explain pollutant variations, for example, how opening of door and windows affect PM_{10} concentrations, occupancy in relation to CO_2 levels, or bacteria concentrations, outdoor activities exhaust emissions affecting indoor pollutant levels.
8. Exposure of school children to pollutants should be investigated using personal exposure monitoring badges.
9. Exposure risks should be calculated regarding to all pollutants measured.

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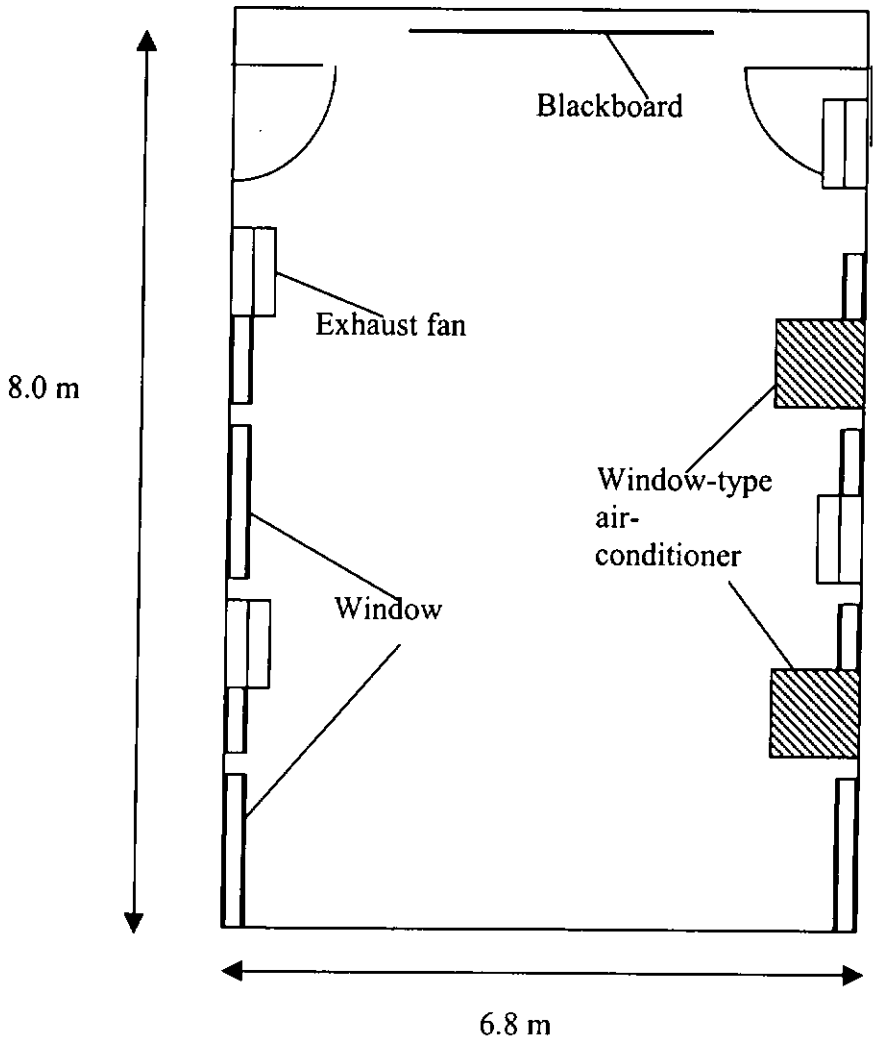
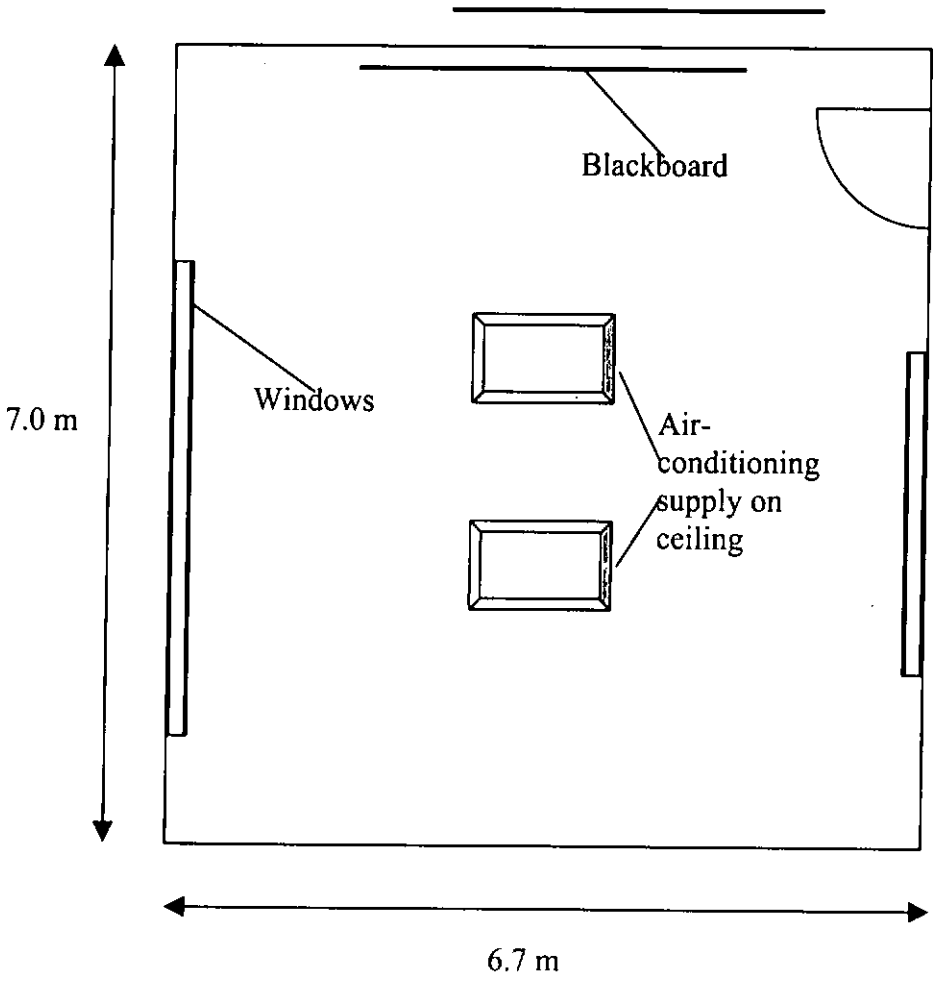
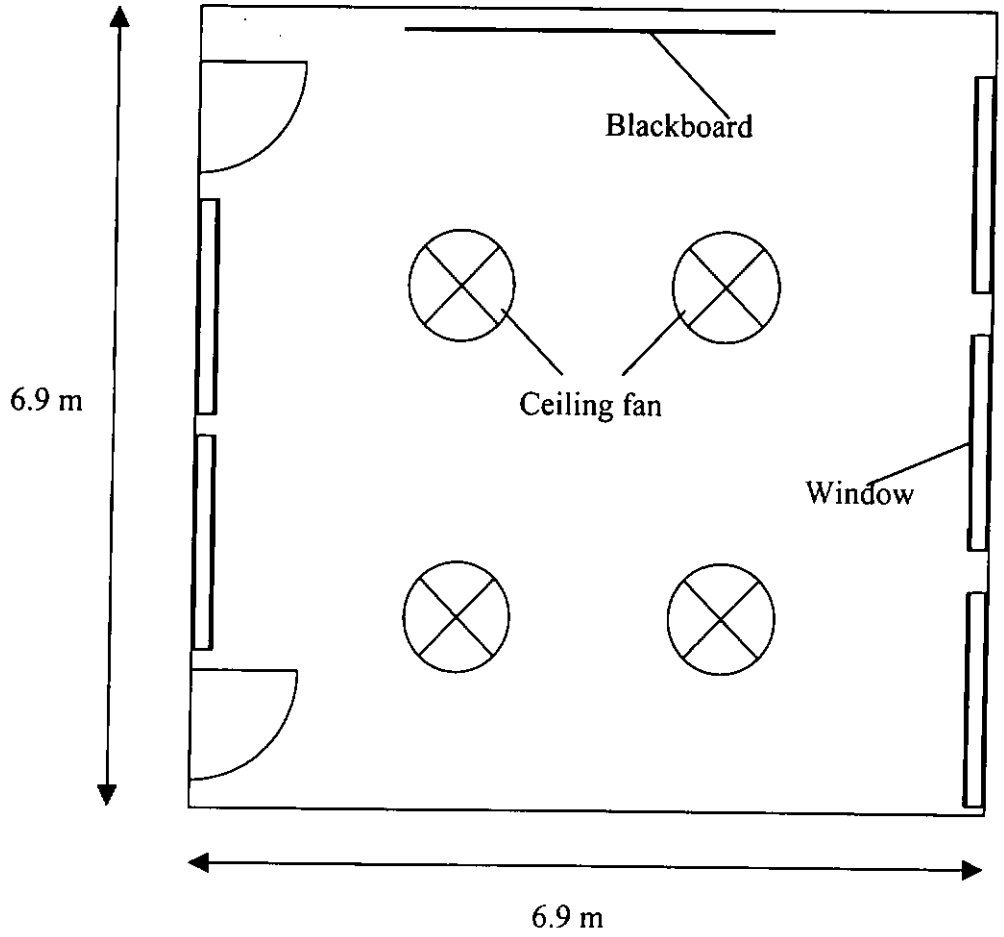
Appendix I-a1. Aerial View of TC



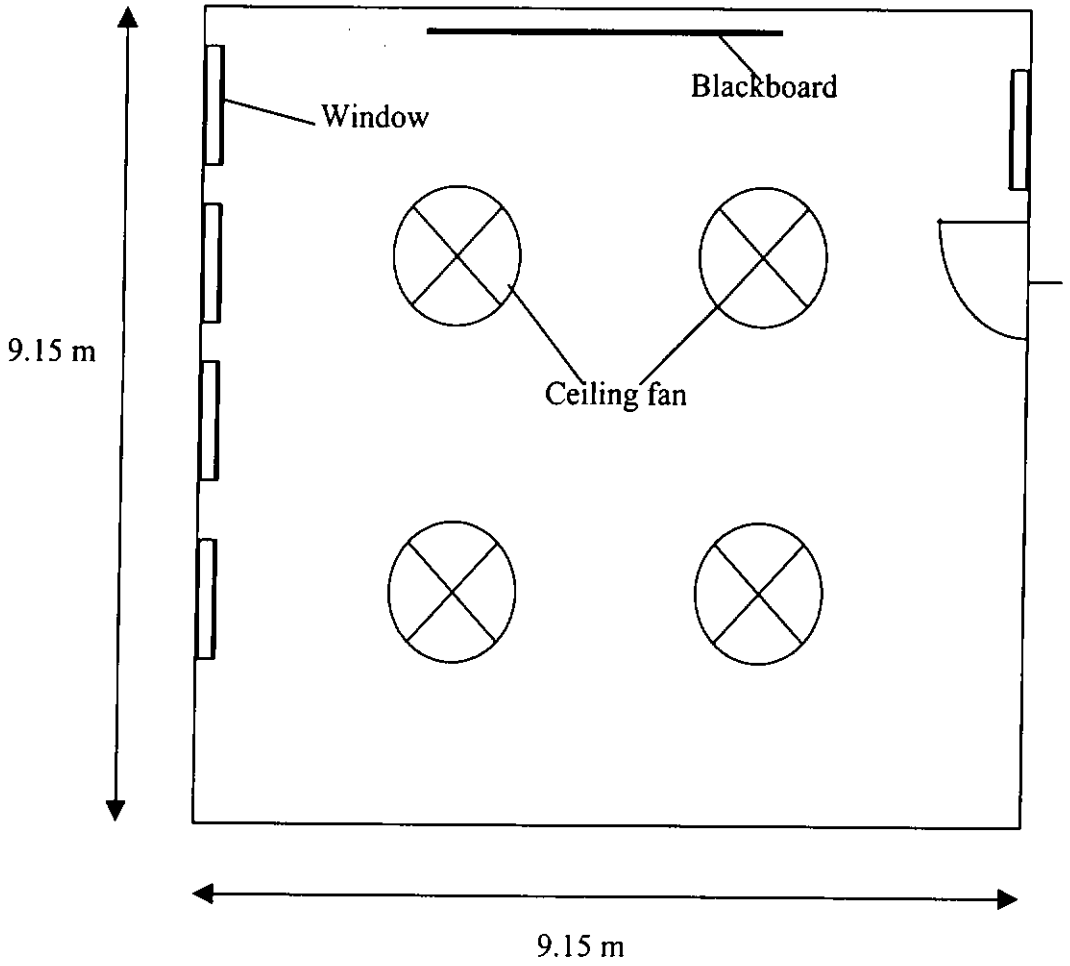
Appendix I-a2. Aerial View of SF



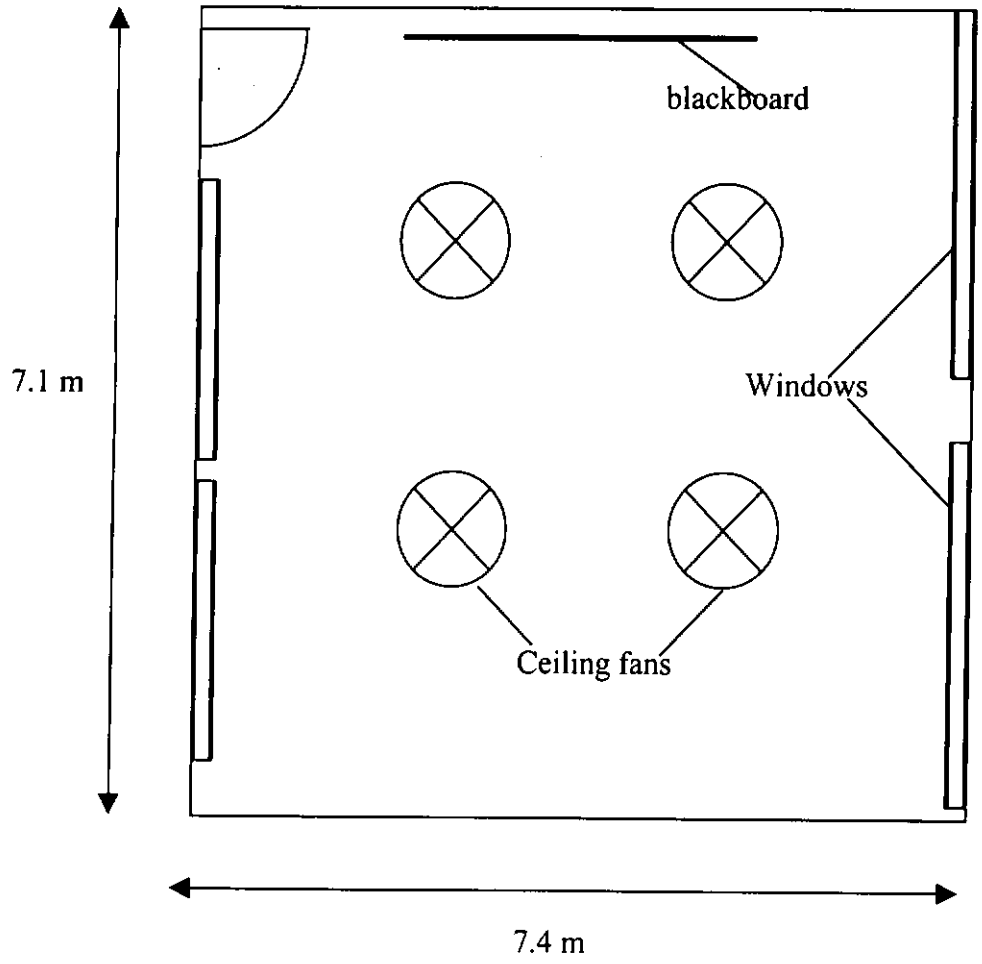
Appendix I-a3. Aerial View of MFS



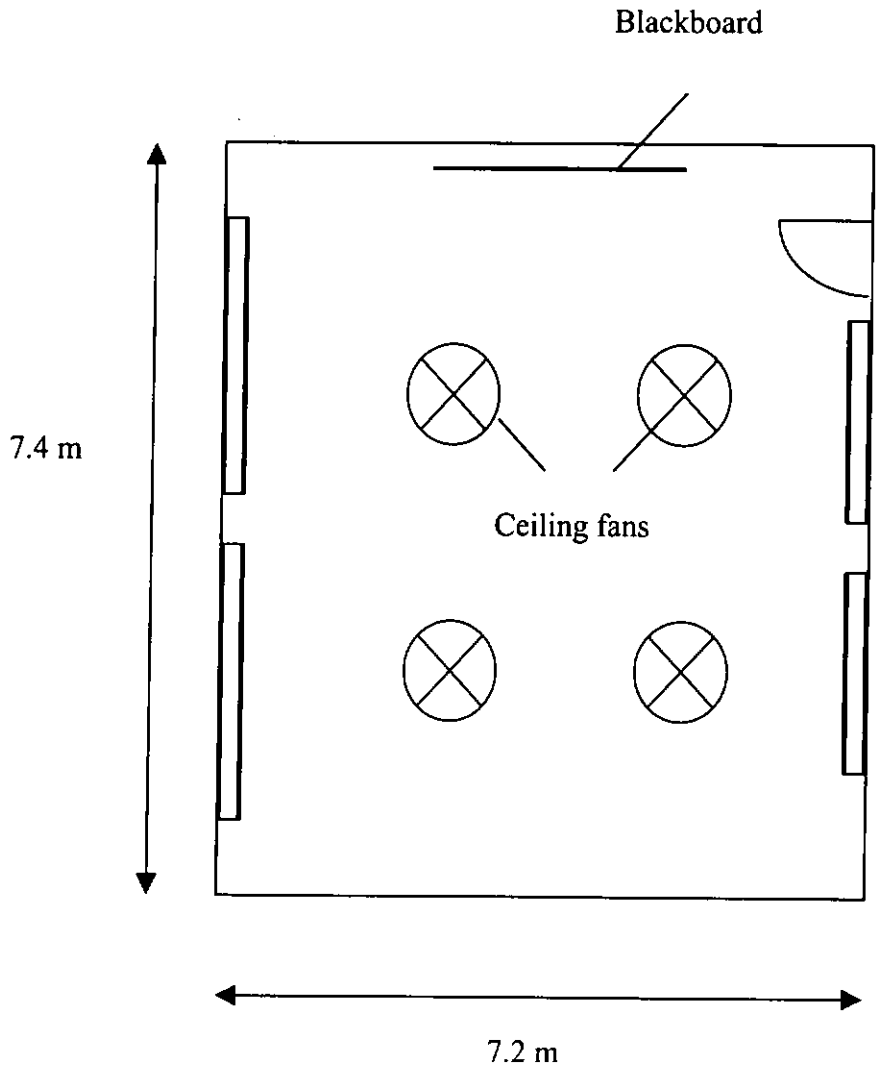
Appendix I-a4. Aerial View of MFC



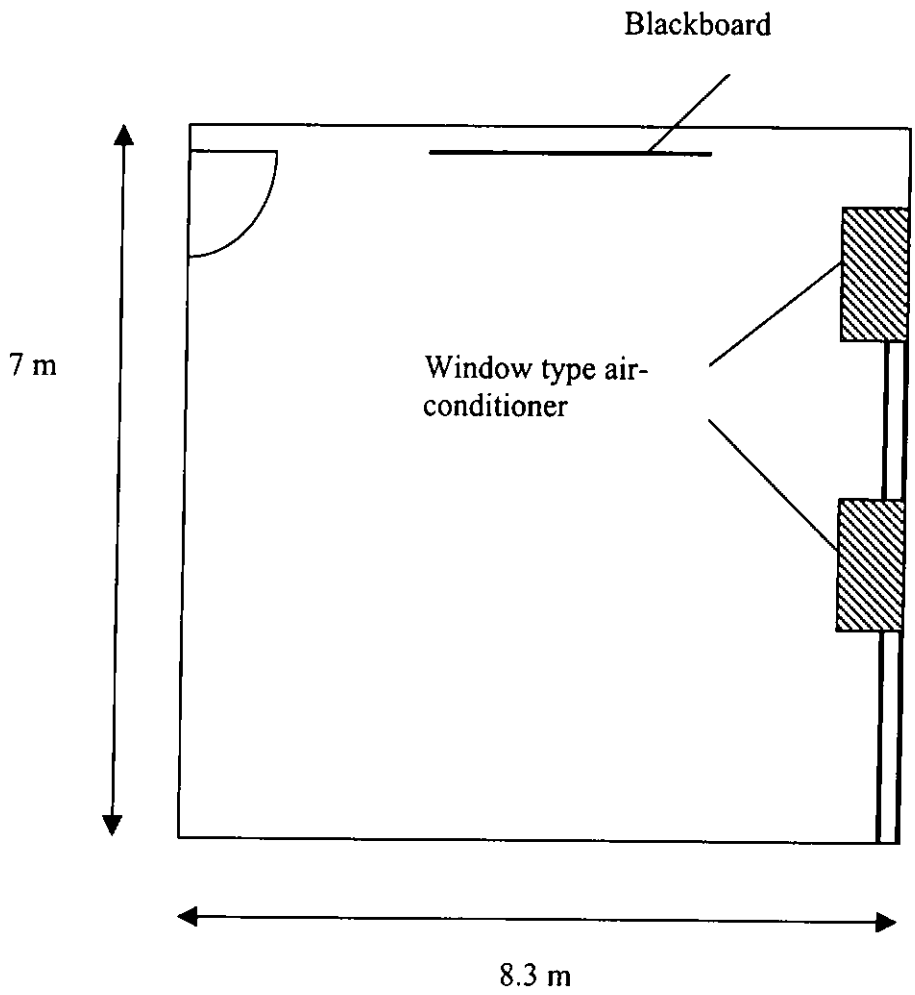
Appendix I-a5. Aerial View of SJ



Appendix I-b. Aerial View of MFSI



Appendix I-c. Aerial View of U



Appendix II. Calibration Equations for Target Volatile Organic Compounds

Compounds	Slope
Freon11	3278300
1,1-Dichloroethene	1930500
Dichloromethane	2257300
Freon113	1855000
1,1-Dichloroethane	1952300
cis-1,2-Dichloroethene	1555300
Chloroform	2288500
1,1,1-Trichloroethane	2198700
1,2-Dichloroethane	1765300
Benzene	2722800
Trichloroethylene	1343200
cis-1,3-Dichloropropene	481210
1,1,2-Trichloroethane	732930
Toluene	2609900
1,2-Dibromoethane	811190
Tetrachloroethylene	1165900
Chlorobenzene	1846000
Ethylbenzene	2939800
m,p-Xylene	4771600
Styrene	1218200
1,1,2,2-Tetrachloroethane	1160700
o-Xylene	2177600
1,3,5-Trimethylbenzene	19572000
1,2,4-Trimethylbenzene	1915700
m-Dichlorobenzene	1325500
p-Dichlorobenzene	1255400
o-Dichlorobenzene	537000
1,2,4-Trichlorobenzene	230450
Hexachlorobutadiene	293400

Appendix III. Method Detection Limits for Canister-Gas Chromatography/Mass Selection Detector.

	Method Detection Limit ($\mu g/m^3$)
Freon11	6.7
1,1-Dichloroethene	3.6
Dichloromethane	4.9
Freon113	8.4
1,1-Dichloroethane	0.4
cis-1,2-Dichloroethene	0.8
Chloroform	0.6
1,2-Dichloroethane	0.8
1,1,1-Trichloroethane	1.1
Benzene	0.6
Trichloroethylene	10.7
cis-1,3-Dichloropropene	0.9
1,1,2-Trichloroethane	1.1
Toluene	0.8
1,2-Dibromoethane	0.8
Tetrachloroethylene	1.4
Chlorobenzene	1.4
Ethylbenzene	0.9
m,p-Xylene	1.3
Styrene	1.3
1,1,2,2-Tetrachloroethane	1.4
o-Xylene	0.4
1,3,5-Trimethylbenzene	0.5
1,2,4-Trimethylbenzene	0.3
m-Dichlorobenzene	0.6
p-Dichlorobenzene	1.8
o-Dichlorobenzene	1.2
1,2,4-Trichlorobenzene	2.2
Hexachlorobutadiene	2.1

Appendix IV-a. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for TC*

Air Bag

Indoor (Morning)	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Sulfur Dioxide	0.005	0.003	0.004	0.003	0.004	0.003
Nitrous Oxide	143.2	77.8	101.6	99.8	97.0	166.1
Nitrogen Dioxide	50.3	26.0	11.0	13.6	18.1	25.4
Nitrogen Oxides	193.5	103.8	112.6	113.4	115.1	191.5
Carbon Monoxide	0.88	0.94	0.78	0.74	0.69	1.34
Ozone	67	48	45	44	46	46
TVOC	2.2	1.8	2.1	2.2	1.9	1.7

Air Bag

Outdoor (Morning)	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Sulfur Dioxide	0.005	0.004	0.004	0.004	0.004	0.003
Nitrous Oxide	132.4	223	62.2	76.0	74.0	80.9
Nitrogen Dioxide	51	38.8	11.9	11.6	15.8	12.5
Nitrogen Oxides	183.4	261.8	74.1	87.6	89.8	93.4
Carbon Monoxide	0.83	1.14	1.04	0.93	0.87	1.49
Ozone	79	51	69	63	60	46
TVOC	2.1	1.8	2.5	2.0	2.0	1.7

Air Bag

Indoor (Afternoon)	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Sulfur Dioxide	0.006	0.005	0.004	0.003	0.006	0.003
Nitrous Oxide	85.8	150.5	52.1	38.4	80.0	301
Nitrogen Dioxide	59.8	28.5	16.1	112.5	15.1	24.9
Nitrogen Oxides	145.6	179	68.2	150.9	95.1	325.9
Carbon Monoxide	0.84	1.20	0.72	0.82	0.78	1.40
Ozone	53	44	46	40	50	33
TVOC	2.1	2.2	2.0	2.2	2.3	2.9

Appendix IV-a. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for TC (continued)*

Air Bag

Outdoor (Afternoon)	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Sulphur Dioxide	0.006	0.006	0.004	0.004	0.006	0.003
Nitrous Oxide	152.8	86.6	33.1	16.1	98.8	312
Nitrogen Dioxide	58.6	28.1	13.5	156.6	15.6	46.5
Nitrogen Oxides	211.4	114.7	46.6	172.7	114.4	358.5
Carbon Monoxide	1.03	1.69	0.69	0.91	1.06	1.37
Ozone	63	69	60	54	76	40
TVOC	2.2	2.6	1.9	2.0	2.3	2.5

Formaldehyde

(ppm)	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Indoor	-	0.0215	-	0.0164	-	-
Outdoor	-	0.0196	-	0.0074	-	-

Bacteria

Morning	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Indoor (CFU/m^3)	220 217	-	350 217	283 442	-	-
Outdoor (CFU/m^3)	270 17	-	783 -	594 533	-	-

Bacteria

Afternoon	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
Indoor (CFU/m^3)	110 217	480 183	222 175	-	-	-
Outdoor (CFU/m^3)	160 350	560 983	506 567	-	-	-

MiniVol

	22 November 97	24 November 97	25 November 97	26 November 97	27 November 97	28 November 97
PM_{10} ($\mu g/m^3$)	196	126	100	74	96	99

Appendix IV-a. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for TC (continued)*

Particulate Matter (PM_{10}) Concentrations (mg/m^3) at TC Using Dust Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
22/11/97	0.466	0.108	0.250	0.114	22/11/97	0.835	0.131	0.352	0.190
24/11/97	0.171	0.092	0.126	0.015	24/11/97	0.353	0.054	0.148	0.065
25/11/97	0.075	0.053	0.063	0.006	25/11/97	0.171	0.047	0.082	0.020
26/11/97	0.104	0.049	0.066	0.011	26/11/97	0.224	0.034	0.083	0.030
27/11/97	0.106	0.054	0.086	0.009	27/11/97	0.329	0.049	0.124	0.031
28/11/97	0.183	0.075	0.128	0.031	28/11/97	0.307	0.05	0.118	0.040

Carbon Dioxide Levels (ppm) at TC Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
22/11/97	704	543	574	28	22/11/97	487	353	397	28
24/11/97	1790	535	855	427	24/11/97	564	344	394	27
25/11/97	1981	538	832	433	25/11/97	515	345	379	22
26/11/97	1817	531	841	430	26/11/97	492	349	381	20
27/11/97	1890	537	753	334	27/11/97	478	353	399	26
28/11/97	1176	543	686	146	28/11/97	715	353	402	28

Temperature (°C) at TC Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
22/11/97	27.1	25.8	26.3	0.2	22/11/97	27.9	24.8	26.0	1.0
24/11/97	25.2	20.6	23.7	1.4	24/11/97	27.2	24.1	25.8	0.5
25/11/97	27.1	19.6	24.2	2.1	25/11/97	28.4	26.2	27.0	0.5
26/11/97	26.2	19.9	24.5	2.1	26/11/97	29.1	26.4	27.5	0.6
27/11/97	27.3	21.5	24.8	1.8	27/11/97	29.3	25.9	27.5	1.2
28/11/97	26.1	21.4	24.2	1.7	28/11/97	29.4	25.4	27.0	1.2

Relative Humidity (%) at TC Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
22/11/97	71.1	65.3	67.2	0.8	22/11/97	70.9	61.6	66.7	2.7
24/11/97	74.1	48.3	66.3	6.3	24/11/97	78.8	64.9	74.4	2.5
25/11/97	77.8	48	71.0	8.0	25/11/97	80.6	67.8	75.6	3.4
26/11/97	76.3	59.5	72.4	4.3	26/11/97	81.3	68.1	74.6	2.5
27/11/97	74.1	56.4	68.6	6.1	27/11/97	75.8	61.9	70.2	4.1
28/11/97	76.3	54.5	67.5	8.2	28/11/97	76	59.1	69.6	4.3

SD – Standard Deviation

Appendix IV-b. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SF*

Air Bag

Indoor (Morning)	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Sulphur Dioxide	0.004	0.002	0.002	0.003	0.003
Nitrous Oxide	39.6	72.1	66.1	32.0	45.8
Nitrogen Dioxide	10.6	12.6	16.1	11.4	28.5
Nitrogen Oxides	50.2	84.7	82.2	43.4	74.3
Carbon Monoxide	1.27	0.92	0.97	1.04	1.25
Ozone	45	33	22	21	23
TVOC	2.0	2.0	2.1	2.3	2.1

Air Bag

Outdoor (Morning)	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Sulphur Dioxide	0.004	0.003	0.003	0.003	0.004
Nitrous Oxide	50.9	90.6	58.8	34.6	17.5
Nitrogen Dioxide	27.7	30.3	15.7	26.4	29.2
Nitrogen Oxides	78.6	120.9	74.5	61.0	46.7
Carbon Monoxide	1.26	1.07	1.01	0.92	0.77
Ozone	40	32	21	32	20
TVOC	2.1	2.0	2.0	2.2	2.1

Air Bag

Indoor (Afternoon)	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Sulphur Dioxide	0.005	0.006	0.004	0.005	0.003
Nitrous Oxide	85.8	112.2	137.8	74.2	82.1
Nitrogen Dioxide	39.2	39.6	19.0	17.7	39.3
Nitrogen Oxides	125.0	151.8	156.8	91.9	121.4
Carbon Monoxide	1.45	1.17	1.28	1.03	1.01
Ozone	38	30	23	23	25
TVOC	2.5	2.1	2.0	6.5	2.2

Appendix IV-b. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SF (continued)*

Air Bag

Outdoor (Afternoon)	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Sulphur Dioxide	0.004	0.005	0.005	0.005	0.003
Nitrous Oxide	28.8	97.8	81.9	25.4	18.8
Nitrogen Dioxide	57.4	38.6	42.4	39.2	34.3
Nitrogen Oxides	86.2	136.4	124.3	64.6	53.1
Carbon Monoxide	1.36	1.02	1.18	0.92	0.79
Ozone	44	29	23	25	26
TVOC	2.1	2.2	2.0	1.90	1.9

Formaldehyde

(ppm)	29 November 97	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Indoor	-	0.0186	-	-	-	0.0062
Outdoor	-	0.0025	-	-	-	0.0035

Bacteria

Morning	29 November 97	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Indoor (CFU/m^3)	-	-	239 97	-	-	144 -
Outdoor (CFU/m^3)	-	-	517 708	-	-	128 283

Bacteria

Afternoon	29 November 97	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
Indoor (CFU/m^3)	-	-	644 417	-	178 125	150 -
Outdoor (CFU/m^3)	-	-	472 -	-	106 -	156 -

MiniVol

	29 November 97	1 December 97	2 December 97	3 December 97	4 December 97	5 December 97
PM_{10} ($\mu g/m^3$)	44	49	56	78	25	25

Appendix IV-b. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SF (continued)*

Particulate Matter (PM10) Concentrations (mg/m3) at SF Using Dust Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
29/11/97	0.17	0.063	0.107	0.033	29/11/97	0.385	0.05	0.103	0.063
1/12/97	0.275	0.023	0.074	0.044	1/12/97	0.337	0.012	0.094	0.076
2/12/97	0.18	0.028	0.073	0.014	2/12/97	0.19	0.045	0.085	0.016
3/12/97	0.122	0.059	0.094	0.011	3/12/97	0.252	0.074	0.117	0.025
4/12/97	-	-	-	-	4/12/97	0.271	0.068	0.099	0.012
5/12/97	0.228	0.087	0.111	0.017	5/12/97	-	-	-	-

Carbon Dioxide Levels (ppm) at SF Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
29/11/97	807	570	621	44	29/11/97	437	364	388	13
1/12/97	6000	555	1921	1731	1/12/97	590	357	390	32
2/12/97	5223	534	967	833	2/12/97	463	358	379	19
3/12/97	2460	533	756	345	3/12/97	433	357	379	14
4/12/97	6000	508	798	786	4/12/97	619	354	441	46
5/12/97	847	532	573	41	5/12/97	-	-	-	-

Temperature (°C) at SF Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
29/11/97	25.3	21.8	25.1	0.5	29/11/97	28.1	22	24.0	1.3
1/12/97	25	21.9	23.9	0.5	1/12/97	32.7	18.6	24.3	3.8
2/12/97	24.3	21.1	22.6	0.7	2/12/97	21.2	15.1	17.2	1.9
3/12/97	22.2	21.3	21.9	0.2	3/12/97	19.9	16.1	17.7	0.9
4/12/97	23	18.8	20.3	1.2	4/12/97	26.9	16.9	20.1	1.7
5/12/97	24.4	22.9	23.7	0.3	5/12/97	-	-	-	-

Relative Humidity (%) at SF Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
29/11/97	63.4	45.3	61.2	2.2	29/11/97	77.5	55.4	60.8	3.8
1/12/97	74.6	44.1	52.2	5.7	1/12/97	65.4	39.1	49.7	6.1
2/12/97	65.5	40.4	47.0	3.9	2/12/97	70.4	45.4	58.9	9.2
3/12/97	49.9	46.5	49.2	0.3	3/12/97	66.6	51.2	58.1	3.7
4/12/97	80.3	45.6	69.0	9.8	4/12/97	78	41.6	68.4	8.5
5/12/97	69.4	63.8	66.8	1.5	5/12/97	-	-	-	-

SD – Standard Deviation

Appendix IV-c. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFS*

Air Bag

Indoor (Morning)	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Sulphur Dioxide	0.003	0.003	0.004	0.005	0.004
Nitrous Oxide	122.6	83.8	248	142.5	4.3
Nitrogen Dioxide	23.8	28.7	23.5	19.4	27.7
Nitrogen Oxides	146.4	112.5	271.5	161.9	32.0
Carbon Monoxide	1.65	1.12	1.90	1.74	1.19
Ozone	23	22	21	24	21
TVOC	2.2	2.0	1.7	1.9	1.9

Air Bag

Outdoor (Morning)	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Sulphur Dioxide	0.003	0.003	0.005	0.005	0.003
Nitrous Oxide	208	140.5	344	252	10.6
Nitrogen Dioxide	26.4	44	57.9	48	33.9
Nitrogen Oxides	234.4	184.5	401.9	300	44.5
Carbon Monoxide	2.36	1.53	2.64	2.26	1.26
Ozone	24	24	23	22	19
TVOC	2.4	1.8	1.8	1.9	1.9

Air Bag

Indoor (Afternoon)	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Sulphur Dioxide	0.003	0.004	0.005	0.004	0.004
Nitrous Oxide	1.1	8.0	4.4	1.2	18.1
Nitrogen Dioxide	10.8	42.3	60.9	15.4	44.3
Nitrogen Oxides	11.9	50.3	65.3	16.6	62.4
Carbon Monoxide	0.88	0.97	1.19	1.04	1.19
Ozone	22	21	27	24	23
TVOC	2.6	1.8	1.9	1.8	1.8

Appendix IV-c. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFS (continued)*

Air Bag

Outdoor (Afternoon)	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Sulphur Dioxide	0.003	0.003	0.003	0.005	0.004
Nitrous Oxide	1.1	13.7	82.6	2.4	24.4
Nitrogen Dioxide	17.0	50.5	85.4	18.8	47.9
Nitrogen Oxides	18.1	64.2	168.0	21.2	72.3
Carbon Monoxide	0.92	1.01	1.32	1.10	1.3
Ozone	21	21	26	20	21
TVOC	2.6	1.6	2.0	1.7	1.8

Formaldehyde

(ppm)	13 December 97	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Indoor	-	0.0136	-	-	-	-
Outdoor	-	0.0150	-	-	-	-

Bacteria

Morning	13 December 97	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Indoor (CFU/m^3)	-	106 225	-	-	-	161 50
Outdoor (CFU/m^3)	-	433 633	-	-	-	222 375

Bacteria

Afternoon	13 December 97	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
Indoor (CFU/m^3)	-	206 417	-	-	-	278 225
Outdoor (CFU/m^3)	-	406 333	-	-	-	250 225

MiniVol

	13 December 97	15 December 97	16 December 97	17 December 97	18 December 97	19 December 97
PM_{10} ($\mu g/m^3$)	121	-	106	161	90	106

Appendix IV-c. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFS (continued)*

Particulate Matter (PM_{10}) Concentrations (mg/m^3) at MFS Using Dust Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
13/12/97	0.306	0.117	0.197	0.046	13/12/97	-	-	-	-
15/12/97	0.344	0.064	0.127	0.051	15/12/97	-	-	-	-
16/12/97	-	-	-	-	16/12/97	0.416	0.109	0.241	0.087
17/12/97	0.488	0.182	0.391	0.062	17/12/97	-	-	-	-
18/12/97	-	-	-	-	18/12/97	0.512	0.155	0.203	0.070
19/12/97	0.873	0.18	0.230	0.065	19/12/97	-	-	-	-

Carbon Dioxide Levels (ppm) at MFS Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
13/12/97	586	505	542	29	13/12/97	-	-	-	-
15/12/97	1637	508	625	191	15/12/97	451	357	402	22
16/12/97	927	531	599	65	16/12/97	492	356	422	38
17/12/97	1302	555	675	150	17/12/97	525	383	432	23
18/12/97	1293	530	601	143	18/12/97	491	363	387	23
19/12/97	1449	550	652	84	19/12/97	469	365	415	25

Temperature (°C) at MFS Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
13/12/97	17.6	16.4	16.9	0.3	13/12/97	-	-	-	-
15/12/97	22	17.3	20.3	0.9	15/12/97	27.7	18.3	19.8	2.2
16/12/97	23.4	20	21.9	0.8	16/12/97	32.5	17.6	21.7	3.6
17/12/97	25.7	21.2	23.7	0.9	17/12/97	31.8	18.7	22.8	3.6
18/12/97	24.6	22.4	23.4	0.5	18/12/97	27.9	19.3	22.2	2.1
19/12/97	25.6	22.8	24.3	0.6	19/12/97	34.2	19.1	22.8	3.3

Relative Humidity (%) at MFS Using Q Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
13/12/97	63.1	49.4	55.9	4.7	13/12/97	-	-	-	-
15/12/97	76.6	56.2	66.3	5.6	15/12/97	80.7	41.9	70.8	11.3
16/12/97	75.2	63.7	67.8	2.0	16/12/97	84.8	37.5	70.2	13.4
17/12/97	74	58	63.9	3.0	17/12/97	82.8	38.4	67.3	13.0
18/12/97	70.7	58.6	65.9	1.8	18/12/97	80.5	50.7	70.8	8.5
19/12/97	72.3	65.3	68.1	1.2	19/12/97	85.3	39.1	73.4	11.0

SD – Standard Deviation

Appendix IV-d. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFC*

Air Bag

Indoor (Morning)	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Sulphur Dioxide	0.002	0.003	0.004	0.003	0.003
Nitrous Oxide	8.8	1.6	4.0	7.4	3.4
Nitrogen Dioxide	8.2	9.1	7.3	17.1	13.4
Nitrogen Oxides	17.0	10.7	11.3	24.5	16.8
Carbon Monoxide	1.43	0.59	0.69	1.10	0.76
Ozone	38	29	31	19	17
TVOC	2.2	2.4	2.5	2.0	2.0

Air Bag

Outdoor (Morning)	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Sulphur Dioxide	0.003	0.002	0.004	0.004	0.003
Nitrous Oxide	18.4	3.1	88.0	13.5	12.6
Nitrogen Dioxide	21.1	16.5	26.6	20.0	24.6
Nitrogen Oxides	39.5	19.6	114.6	33.5	37.2
Carbon Monoxide	1.35	0.60	0.85	1.10	0.79
Ozone	28	26	29	18	16
TVOC	2.3	2.4	2.1	2.0	2.0

Air Bag

Indoor (Afternoon)	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Sulphur Dioxide	0.003	0.002	0.004	0.004	0.003
Nitrous Oxide	18.4	3.1	88.0	13.5	12.6
Nitrogen Dioxide	21.1	16.5	26.6	20.0	24.6
Nitrogen Oxides	39.5	19.6	114.6	33.5	37.2
Carbon Monoxide	1.35	0.60	0.85	1.10	0.79
Ozone	28	26	29	18	16
TVOC	2.3	2.4	2.1	2.0	2.0

Appendix IV-d. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFC (continued)*

Air Bag

Outdoor (Afternoon)	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Sulphur Dioxide	0.003	0.004	0.004	0.005	0.003
Nitrous Oxide	9.4	6.3	66.0	4.9	12.2
Nitrogen Dioxide	32.2	28.6	33.3	29.4	28.6
Nitrogen Oxides	41.6	34.9	99.3	34.3	40.8
Carbon Monoxide	1.36	0.80	-	0.99	0.69
Ozone	27	21	26	19	14
TVOC	2.2	3.6	1.8	1.9	2.6

Formaldehyde

(ppm)	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Indoor	n/d	-	-	n/d	-
Outdoor	0.004	-	-	0.006	-

Bacteria

Morning	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Indoor (CFU/m^3)	83 28	-	-	19 27	-
Outdoor (CFU/m^3)	256 289	-	-	90 64	-

Bacteria

Afternoon	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
Indoor (CFU/m^3)	108 88	-	-	8 16	-
Outdoor (CFU/m^3)	66 -	-	-	14 23	-

MiniVol

	10 January 98	12 January 98	13 January 98	14 January 98	15 January 98	16 January 98
PM_{10} ($\mu g/m^3$)	35	36	76	14	11	51

Appendix IV-d. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for MFC (continued)*

Particulate Matter (PM_{10}) Concentrations (mg/m^3) at MFC Using Dust Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
10/1/98	0.17	0.107	0.130	0.018	10/1/98	0.219	0.069	0.112	0.020
12/1/98	0.158	0.065	0.091	0.014	12/1/98	0.142	0.056	0.094	0.016
13/1/98	0.254	0.097	0.153	0.019	13/1/98	0.294	0.115	0.166	0.022
14/1/98	0.191	0.034	0.061	0.020	14/1/98	0.116	0.009	0.039	0.022
15/1/98	0.104	0.04	0.066	0.007	15/1/98	0.102	0.021	0.048	0.008
16/1/98	0.106	0.069	0.084	0.006	16/1/98	0.163	0.058	0.114	0.028

Carbon Dioxide Levels (ppm) at MFC Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
10/1/98	494	368	404	33	10/1/98	426	374	393	12
12/1/98	647	348	384	52	12/1/98	535	381	393	14
13/1/98	935	358	431	124	13/1/98	549	383	396	13
14/1/98	1174	351	416	74	14/1/98	430	364	387	11
15/1/98	773	350	395	81	15/1/98	431	373	385	11
16/1/98	713	352	465	120	16/1/98	456	381	392	9

Temperature (°C) at MFC Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
10/1/98	22.8	21.9	22.3	0.2	10/1/98	23.6	21.3	22.3	0.6
12/1/98	22.3	20.1	21.3	0.4	12/1/98	20	18	19.5	0.4
13/1/98	22.6	21.2	21.6	0.3	13/1/98	21.9	19.2	20.8	0.6
14/1/98	24.3	20.2	22.5	1.1	14/1/98	25.2	15.1	20.3	3.1
15/1/98	22.1	19.1	20.1	0.6	15/1/98	18.4	13.7	15.9	1.1
16/1/98	19.7	18.7	19.1	0.3	16/1/98	18.2	15.3	17.1	0.7

Relative Humidity (%) at MFC Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
10/1/98	82.6	80	81.8	0.7	10/1/98	93.4	82.9	89.1	3.3
12/1/98	80.2	62.5	74.3	4.5	12/1/98	89.8	69.2	82.9	6.8
13/1/98	87.1	77.1	82.6	1.6	13/1/98	95.3	84.8	90.2	2.1
14/1/98	93	62.3	78.6	9.2	14/1/98	92.6	75.3	84.7	4.0
15/1/98	66.5	49.4	57.8	3.2	15/1/98	82.7	59.1	68.5	5.0
16/1/98	80.7	60.6	73.1	4.7	16/1/98	95.6	76.5	90.8	3.4

SD – Standard Deviation

Appendix IV-e. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SJ*

Air Bag

Indoor (Morning)	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Sulphur Dioxide	0.002	0.003	0.005	0.004	0.004
Nitrous Oxide	9.4	2.0	101.3	57.9	9.6
Nitrogen Dioxide	16.4	11.8	20.8	19.8	12.9
Nitrogen Oxides	25.8	13.8	122.1	77.7	22.5
Carbon Monoxide	0.83	0.83	1.12	0.84	1.18
Ozone	16	13	12	14	15
TVOC	1.6	1.6	1.8	2.0	1.9

Air Bag

Outdoor (Morning)	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Sulphur Dioxide	0.004	0.003	0.004	0.004	0.004
Nitrous Oxide	50.1	6.4	111.3	57.9	13.9
Nitrogen Dioxide	28.9	21.9	19.8	19.8	16.5
Nitrogen Oxides	79.0	28.3	131.1	77.7	30.4
Carbon Monoxide	0.89	0.83	1.19	0.88	1.06
Ozone	16	14	13	13	15
TVOC	1.7	1.7	1.9	2.0	1.9

Air Bag

Indoor (Afternoon)	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Sulphur Dioxide	0.004	0.006	0.004	0.004	0.005
Nitrous Oxide	46.5	101.8	23.8	25.7	59.3
Nitrogen Dioxide	34.3	48.4	28.8	40.0	48.9
Nitrogen Oxides	80.8	150.2	52.6	65.7	108.2
Carbon Monoxide	0.90	1.32	0.91	0.83	1.04
Ozone	14	13	12	14	11
TVOC	2.0	1.8	1.8	1.9	1.8

Appendix IV-e. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SJ (continued)*

Air Bag

Outdoor (Afternoon)	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Sulphur Dioxide	0.004	0.006	0.004	0.004	0.005
Nitrous Oxide	20.6	171.8	23.8	52.4	19.2
Nitrogen Dioxide	30.1	73.9	31.0	42.0	39.5
Nitrogen Oxides	50.7	245.7	54.8	94.4	58.7
Carbon Monoxide	0.90	1.45	0.94	0.82	0.99
Ozone	13	15	12	15	11
TVOC	1.80	1.9	1.8	2.0	1.8

Formaldehyde

(ppm)	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Indoor	0.008	-	-	0.011	-
Outdoor	0.007	-	-	0.004	-

Bacteria

Morning	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Indoor (CFU/m^3)	72 94	-	-	56 122	-
Outdoor (CFU/m^3)	27 -	-	-	72 406	-

Bacteria

Afternoon	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
Indoor (CFU/m^3)	83 139	-	-	117 183	-
Outdoor (CFU/m^3)	689 822	-	-	- 561	-

MiniVol

	17 January 98	19 January 98	20 January 98	21 January 98	22 January 98	23 January 98
PM_{10} ($\mu g/m^3$)	19	60	92	-	131	28

Appendix IV-e. *Results for Analysis of Air Bags, and Concentrations of Formaldehyde, and Bacteria for SJ (continued)*

Particulate Matter (PM_{10}) Concentrations (mg/m^3) at SJ Using Dust Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
17/1/98	0.142	0.054	0.074	0.022	17/1/98	0.664	0.029	0.081	0.042
19/1/98	2.052	0.126	0.182	0.126	19/1/98	5.767	0.119	0.260	0.387
20/1/98	1.287	0.129	0.304	0.133	20/1/98	2.534	0.139	0.286	0.133
21/1/98	0.48	0.093	0.121	0.032	21/1/98	0.679	0.063	0.137	0.045
22/1/98	0.543	0.073	0.242	0.120	22/1/98	0.603	0.045	0.262	0.133
23/1/98	0.143	0.053	0.080	0.018	23/1/98	0.228	0.005	0.049	0.019

Carbon Dioxide Levels (ppm) at SJ Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
17/1/98	409	339	349	12	17/1/98	465	370	386	9
19/1/98	1022	339	429	175	19/1/98	739	381	414	49
20/1/98	1090	353	409	125	20/1/98	546	382	398	12
21/1/98	2173	347	491	373	21/1/98	752	391	406	18
22/1/98	1282	357	424	158	22/1/98	518	389	427	24
23/1/98	1088	334	391	146	23/1/98	497	362	385	12

Temperature (°C) at SJ Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
17/1/98	19.5	16.6	18.3	0.9	17/1/98	18.4	11.9	15.4	2.0
19/1/98	17.3	15.2	16.0	0.4	19/1/98	13.3	11.8	12.6	0.4
20/1/98	17.5	14.9	15.7	0.5	20/1/98	14.9	12.1	13.3	0.8
21/1/98	17.4	15.3	16.1	0.4	21/1/98	17.2	12.8	15.6	1.1
22/1/98	19.1	16.5	18.0	0.6	22/1/98	20	13	17.5	2.0
23/1/98	18.3	15.3	16.7	0.6	23/1/98	15.5	10.3	14.0	1.5

Relative Humidity (%) at SJ Using Q-Trak for Measurement

Indoor	Maximum	Minimum	Average	SD	Outdoor	Maximum	Minimum	Average	SD
17/1/98	69.5	52.6	61.2	5.2	17/1/98	75.3	65.5	70.5	2.0
19/1/98	67.9	58.1	62.7	2.6	19/1/98	76.5	69.1	71.5	1.4
20/1/98	79.7	67.4	72.0	2.3	20/1/98	86.7	77.7	83.7	2.0
21/1/98	84.9	70.4	80.8	2.0	21/1/98	95.5	86.2	91.3	1.9
22/1/98	91.8	75.8	87.1	3.8	22/1/98	93.5	84.2	89.6	2.0
23/1/98	75.7	61	65.7	2.9	23/1/98	84.7	64.4	72.2	5.4

SD – Standard Deviation

Appendix V. Registration Records of Energy Efficiency Labeling Scheme for Window Type Room Coolers

Registration No.	Brand	Model	Cooling Capacity (kW)	Energy Efficiency Grade	Annual Energy Consumption (kWh/Yr)
C96-0002	General	AKG 7A	1.93	2	944
C96-0003	General	AKG 9A	2.43	2	1,212
C96-0006	LG	LW-B0760CL	2.11	1	931
C96-0008	MD	KC-32/Y	3.2	1	1,416
C96-0009	MD	KC-32	3.2	1	1,415
C96-0010	Hitachi	RA-10AF1	2.5	2	1,119
C96-0011	Sharp	AF-A1288	3.52	1	1,582
C96-0012	Sharp	AF-A988	2.64	1	1,177
C96-0013	Sharp	AF-W988	2.64	1	1,177
C96-0014	Sharp	AF-A788	2.05	1	912
C96-0015	Sharp	AF-W788	2.05	1	912
C96-0016	Sharp	AF-A1888	5.0	2	2,492
C96-0017	LG	LW-B0762CL	2.02	1	852
C96-0018	LG	LW-B0962CL	2.51	2	1,140
C96-0019	LG	LW-C1266CL	3.45	1	1,500
C96-0020	LG	LW-C1268CL	3.45	1	1,504
C96-0022	Sharp	AF-A798T	2.05	1	938
C96-0023	Fortress	FC-08CXA	2.0	1	881
C96-0024	Fortress	FC-10CXA	2.5	2	1,150
C96-0025	Fortress	FC-13CXA	3.5	2	1,666
C96-0031	National	CW-XC70TA	2.08	1	908
C96-0032	National	CW-C70TA	2.08	1	904
C96-0033	National	CW-PC71TA	2.08	1	904
C96-0034	National	CW-XC90TA	2.56	1	1122
C96-0035	National	CW-C90TA	2.57	1	1118
C96-0036	National	CW-PC91TA	2.57	1	1118
C96-0037	National	CW-C120FA	3.35	2	1580
C96-0038	National	CW-PC121FA	3.35	2	1580
C96-0041	Rasonic	RC-XC70T	2.08	1	908
C96-0042	Rasonic	RC-C70T	2.08	1	904
C96-0043	Rasonic	RC-PC71T	2.08	1	904
C96-0044	Rasonic	RC-XC90T	2.56	1	1122
C96-0045	Rasonic	RC-C90T	2.57	1	1118
C96-0046	Rasonic	RC-PC91T	2.57	1	1118
C96-0047	Rasonic	RC-C120J	3.35	2	1580
C96-0048	Rasonic	RC-PC121F	3.35	2	1580
C96-0051	Toshiba	RAC-09L4X	2.67	1	1195
C96-0052	Toshiba	RAC-07L4X	2.05	1	886
C96-0053	LG	GA-0761GC	1.88	2	864
C96-0054	LG	LWB0960ACG	2.55	1	1140
C96-0055	LG	LWC1260BCG	3.46	1	1506
C96-0056	LG	LWM1860BCG	5.08	2	2520
C96-0057	NEC	RC-7090AE	1.88	2	864
C96-0058	NEC	RC-9090AE	2.55	1	1140
C96-0059	NEC	RC-1290AE	3.46	1	1506
C96-0060	NEC	RC-1890AE	5.08	2	2520
C96-0061	Philco	GPA-2078	1.88	2	864
C96-0062	Philco	GPA-2098	2.55	1	1140
C96-0063	Philco	GPA-2128	3.46	1	1506
C96-0064	Philco	GPA-2188	5.08	2	2520
C96-0065	Fortress	FC-08CCA	1.88	2	864

Registration Records of Energy Efficiency Labeling Scheme for Window Type Room Coolers (continued)

Registration No.	Brand	Model	Cooling Capacity (kW)	Energy Efficiency Grade	Annual Energy Consumption (kWh/Yr)
C96-0066	Fortress	FC-10CCA	2.55	1	1140
C96-0067	Fortress	FC-13CCA	3.46	1	1506
C96-0068	Fortress	FC-19CCA	5.08	2	2520
C96-0069	General	AKG 7AP	2.14	1	924
C96-0070	Toshiba	RAC-13L4X	3.53	2	1728
C96-0071	Hitachi	RA-08CF (K)	2.1	1	946
C96-0072	Hitachi	RA-08CDF (K)	2.1	1	947
C96-0073	Hitachi	RA-10CF (K)	2.5	1	1126
C96-0074	Hitachi	RA-10CDF (K)	2.5	1	1126
C96-0075	Hitachi	RA-13CF (K)	3.75	1	1689
C96-0076	Hitachi	RA-13CDF (K)	3.75	1	1689
C96-0077	Mitsubishi Electric	MW-07RV	2.0	1	912
C96-0078	Mitsubishi Electric	MWD-07RV	2.0	1	912
C96-0079	Mitsubishi Electric	MW-09RV	2.6	1	1159
C96-0080	Mitsubishi Electric	MWD-09RV	2.6	1	1159
C96-0085	SANYO	SA-79GD/H	2.15	1	936
C96-0086	SANYO	SA-79G/H	2.13	1	930
C96-0087	SANYO	SA-128S4/H	3.43	2	1680
C96-0088	Carrier	51S7	2.03	1	891
C96-0092	Carrier	51DS7	1.964	1	870
C96-0094	Hitachi	RA-18CF	4.87	2	2153
C96-0095	Hitachi	RA-18C(D)F	4.87	2	2153

From Electrical and Mechanical Services Department, Hong Kong Government
www.info.gov.hk/emsd/english/energy/registers/rmcool.html

Appendix VI. Cost Analysis for Use of Air-conditioning at Schools

As from the results of previous sections, use of air-conditioning not only can reduce environmental noise and provide thermal comfort to schoolchildren; it can also prevent pollutants from entering the classrooms. The indoor air quality was not adversely affected by reduced ventilation since most of the pollutants have outdoor sources. Due to limited budgets, it is very expensive to provide air-conditioning for the entire school. A cost analysis for a typical secondary school is provided below.

Assuming there are two air-conditioners in each classroom and they operate eight hours a day. There are 90 days of school holidays for each academic year as predetermined by the Hong Kong Education Department. Therefore the number of school days, excluding Saturdays and Sundays, per year is approximately 196 days ((365 days per year – 90 days per year) × 5 school days per week /7days per week). The secondary school structure in Hong Kong consists of 5 years of secondary and 2 years of matriculation education. The number of classes in each grade is usually 6664422 or 5554422, with six classes in the first three years, four classes in the senior years and two classes each at matriculation level. Thus, the numbers of classes for a typical school, from Secondary One to Seven, are in the range of 27 to 30. I assumed the number of classroom is 30 to include other special function rooms.

The total number of hours of air-conditioning operating in each classroom is:

Number of operating hours per day per air-conditioner

= 8 hours per day

Number of hours per year = 8 hours per day × 196 days per year

= 1568 hours per year

Number of hours of air-conditioner operation per school per year

= 1568 hours per year × 2 units per classroom × 30 classrooms per school

= 94080 hours

According to the Hong Kong Electrical and Mechanical Services Department (EMSD) Energy Efficiency Labeling Scheme, the annual energy consumption for window type air-conditioners ranged from 852 to 2520 kWh/year operating 8 hours a day. Therefore energy consumption per hour is 0.292 kWh or 0.863 kWh ((852 to 2520 kWh/year)/ (365 days/year × 8 hours/day).

The total electricity consumption per year for each school is:

Total kWh per year = 0.863 kWh/hour × 94080 hours

$= 81.2 \times 10^3$ kWh

Electricity Tariff from 1 May 1999 for the China Light and Power Company Limited as listed in its website (www.chinalightandpower.com.hk). General Service Tariff is applied for customers with electricity consumption not solely for domestic use. The monthly basic charge for the first 5000 units is 97.4 cents/unit and for each subsequent unit is 96.4 cents.

For maximum energy consumption, and to keep it simple, consumption per month is:

81.2×10^3 kWh/year ÷ 12 month/year

$$= 6767 \text{ kWh per month}$$

The cost per month is

$$5000 \text{ unit} \times 97.4 \text{ cents/unit} + 1767 \text{ units} \times 96.4 \text{ cents/unit}$$

$$= 657 \times 10^3 \text{ cents}$$

$$= \$\ 65700$$

The cost for air-conditioning classrooms is

$$\$\ 65700 \times 12 \text{ month/year}$$

$$= \$\ 788400$$

The cost per year required for air-conditioning is $ 788400. Note that this is just an approximation of the cost since the energy consumption could vary. Due to tight budgets for subsidized school, to provide air-conditioning at classrooms could be very expensive.

Appendix VII. Teachers and Students Improving Indoor Air Quality at School

In order to protect the environment we live in, we must first know how to identify and recognize pollution and its sources. Then to diagnose the cause, apply practical actions to reduce emission and to remove pollutants from the air.

To further improve IAQ at schools, teachers and students can participate in helping to improve the indoor environment by:

- pick up trash
- make sure food ins not left in the classroom
- clean up spills or leaks
- if classroom contains animals, keep the animals in their cages and clean their cages regularly
- removing items that may sit in front of vents (to aviod blocking air flow of ventilation system)

The most important way is to educate students about indoor air pollution so that everyone will be aware of keeping the indoor environment healthy.