A NEW ENGINEERING APPROACH

FOR

INDOOR AIR QUALITY MANAGEMENT IN BUILDING

WONG CHUN SING

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CERTIFICATE OF ORIGINALITY

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_______WONG Chun Sing_______ (Name of student)

Abstract

In November 1993, the Government of HKSAR issued '*A Green Challenge for the Community*', which was its second review of the 1989 White Paper. An Indoor Air Quality Management Group under the administration of the Environmental Protection Department was formed. It launched the 'Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places' (GN) together with 'A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places' in September 2003. Unfortunately, the response rate and the penetration rate have been low. Nevertheless, the specification of 'good' and 'excellent' IAQ criteria have been taken up as acceptable IAQ design and management criteria by building consultants and managers. Unfortunately, it confuses more the IAQ objectives rather than improving or enhancing it. Hence, much of the resources have been wrongly designated.

When the candidate was involved in the early work of the development of the GN, the candidate, together with the supervisor in various presentations, have shown that the GN was too comprehensive in soliciting social participation. On the other hand, the annual one day sampling was not adequate in sustaining acceptable IAQ throughout the year. In this respect, carried out in this study, a modified sampling protocol for indoor air quality has been developed, which can be shown to reduce resources requirements by at maximum of two-third without increasing the risk. It is therefore particularly suitable for periodically monitoring of the IAQ rendering a true protection of the health and sustaining comfort. The philosophy is based on the examination of outdoor air quality, pollutant sources and ventilating air distribution; and the distinguishment of the nature of the pollutants. The simplified version,

nonetheless, has influenced the annual comprehensive IAQ sampling into once in five years and that the further simplified version has been adopted in the GN for IAQ certification renewal purposes. The simplified protocol has also been adopted in the two Practice Notes for Managing Air Quality in Air-conditioned Public Transport Facilities. The usefulness of the verified version is validated through several thousands of the measurements of the pollutants in the Hong Kong offices.

In the IAQ design and management perspective, the 'good' and 'excellent' IAQ criteria approach triggers a follow suit as it is a rational performance specification. Sarcastically, design of ventilation rate continually calculated on a prescriptive approach. This does more harm to the IAQ management because one would take it as the IAQ is under control. The philosophy in this study is to formulate the deficiency in order to render the accomplishment of the intended objectives of the GN. Three main problem areas are identified: the lack of typical annual outdoor air quality profile, the difficulty in measuring pollutant emission rates and the undefined ventilation quality degradation.

Outdoor air quality is monitored at 14 locations in Hong Kong. This project takes tremendous effort in compiling over 8.9 millions of data into an analyzable format. Not only that the outdoor air quality in Hong Kong at these districts can be analyzed with respect to different air quality enhancement efforts, but also that an annual typical profile for each pollutant in each monitoring station is derived. It is the first of its kind. It has a great impact in a true ventilation design. To facilitate the ventilation calculation, a term 'pollutant inventory' in defined with a model on the evaluation of emission rates of pollutants with high precision. Finally, a four-tier scheme originally developed by the project supervisor is further elaborated into a pragmatic protocol for evaluation of ventilation quality degradation. This completes a protocol for ventilation management to determine optimum ventilation.

A total solution for IAQ is challenging because of its comprehensive work scope. Managing acceptable IAQ is even more demanding as management cannot be totally relied on computation nor design. Therefore, an electronic IAQ manager is established in this project which is comprised of an intelligent compilation of building information, an IAQ optimal calculator, a geographical tool of managing fresh air systems, vendor information, process information, key performance indices, emergency management and etc. It covers IAQ management to reduce risk of infectious communicable disease. This eIAQ manager is a novel development. It is welcome by the industry and is expected to innovate the IAQ management protocol.

Publications arising from the thesis

Chan D.W.T. and **Wong C.S.** *Conducting IAQ Surveys in Large Facilities*. Proceeding of International Symposium on Achieving Healthy and Productive Building. pp.77-84. (2003)

Wong C.S., Chan D.W.T. and Burnett J. *Effective Sampling Protocol for Managing Indoor Air Quality in Air-conditioned Buildings.* Proceeding of 7th International Conference Energy-Efficient Healthy Buildings. (2003)

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Wong, C.S., Chan, D.W.T. and Burnett, J. *HK-BEAM 5/04 'Existing Buildings': An Environmental Assessment for Existing Buildings, Version 5/04.* HK-BEAM Society. pp. 8-31~8-32 (2004)

Law L.K.C., Chan D.W.T. and **Wong C.S.** *Survey of Particulates Matter (PM10) Concentration in a University Campus.* Proceeding of 10th International Conference on Indoor Air Quality and Climate. (2005)

Mui H.K.W., **Wong C.S.**, Chan D.W.T. and Chan C.K. *Particulate Level in Residential Buildings – A Newly Developed Dust Collector.* Proceeding of 10th International Conference on Indoor Air Quality and Climate. (2005)

Wong C.S., Chan D.W.T. and Law L.K.C. *Indoor Air Pollutant Calibration in Buildings.* Proceeding of 10th International Conference on Indoor Air Quality and Climate. (2005)

Chan D.W.T., **Wong C.S.** and Tung T.C.W. *Using Rn-222 to Manage the Air Quality of Air Conditioned Buildings in Hong Kong.* Indoor and Built Environment 17; 5: 467-471 (2008).

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List of Abbreviations, Symbols and Nomenclatures

%	Percentage
$(A_k)_j$	Exposed area of material-*k* for pollutant-*j* (Rn-222; TVOC) [m^2]
$(C_j)_\infty$	Steady state concentration of pollutant-*j* (Rn-222; TVOC) [Bq/m^3; mg/m^3]
$(C_j)_i$	Initial concentration of pollutant-*j* (Rn-222; TVOC) [Bq/m^3; mg/m^3]
$(C_j)_o$	Outdoor concentration of pollutant-*j* (Rn-222; TVOC) [Bq/m^3; mg/m^3]
$(C_{Rn\text{-}222})_\infty$	Steady state concentration of Rn-222 [Bq/m^3]
$(C_{TVOC})_\infty$	Steady state concentration of TVOC [mg/m^3]
$(E_k)_j$	Emission rate of material-*k* for pollutant-*j* (Rn-222; TVOC) [$Bq/m^2/h$; $mg/m^2/h$]
$(L_j)_{RL}$	Resultant loss rate of pollutant-*j* (Rn-222; TVOC) [/h]
A/C	Air Conditioning
ACGIH	American Conference of Governmental Industrial Hygienists
ach	Air Change per Hour
AHU	Air Handling Unit
AIHA	American Industrial Hygiene Association
ALTER	Acceptable Long-Term Exposure Range
AQO	Air Quality Objectives
ASHRAE	American Soceity of Heating, Refrigerating and Air-Conditioning Engineers
ASTER	Acceptable Short-Term Exposure Range
ASTM	American Soceity for Testing and Materials
B(a)P	Benzo(a)pyrene
Bq/m^3	Bequerel per cubic metre
$Bq/m^3/h$	Bequerel per cubic metre per hour

$C_{(t)}$	CO_2 concentration of space air at time t
C_1	Concentration of discharge of first tier / Concentration of air inlet to distribution duct
C_2	Concentration at discharge from the second tier / Concentration of air at inlet of distribution duct
C_3	Concentration at discharge from the third tier / Concentration of air at diffuser outlets of third tier
C_4	Concentration of air at the fourth tier
C_6H_6	Benzene
C_7H_8	Toluene
C_8H_{10}	Dimethybenzene
C_{Aroom}	Uniform room concentration of A
C_{Ain}	Concentration of A in the incoming air
CAV	Constant Air Volume
CB	Causeway Bay
C_{b1}	Concentration of by-passed air at first tier
C_{b2}	Concentration of by-passed air at second tier
C_{b3}	Concentration of by-passed air at third tier
C_{b4}	Concentration of by-passed air at fourth tier
C_{bn}	Concentration of by-passed air at that tier
CEN	European Committee for Standardization
cfu/m^3	Colony forming units per cubic metre
CIBSE	Chartered Institution of Building Services Engineers
C_j	Concentration of pollutant-*j* (Rn-222; TVOC) at time t [Bq/m^3; mg/m^3]
CL	Central
C_n	Concentration of air at that tier
C_{n-1}	Concentration of air at previous tier

CO	Carbon monoxide
C_o	Concentration of outdoor air
CO_2	Carbon dioxide
C_{OCO2}	CO_2 concentration of the outdoor air
conc.	concentration
COSHH	Control of Substances Hazardous to Health Regulations
C_{p1}	Concentration of pre-contaminated air at first tier
C_{p2}	Concentration of pre-contaminated air at second tier
C_{p3}	Concentration of pre-contaminated air at third tier
C_{p4}	Concentration of pre-contaminated air at fourth tier
C_{pn}	Concentration of pre-contaminated air at that tier
C_s	Space contaminant concentration
C_{s1}	Concentration of short-circuited air at first tier
C_{s2}	Concentration of short-circuited air at second tier
C_{s3}	Concentration of short-circuited air at third tier
C_{s4}	Concentration of short-circuited air at fourth tier
C_{sn}	Concentration of short-circuited air at that tier
CW	Central/Western
d	Margin of error
DAMA	Data Management Association
DCV	Demand Control Volume
D_{LTM}	Difference from the long term mean
DNPH	2,4-dinitrophenylhydrazine
EEGL	Emergency Exposure Guidance Levels
EEL	Emergency Exposure Limits
EN	Eastern
EPA	Environmental Protection Agency

EPD	Environmental Protection Department
Eq.	Equation
ETS	Environmental Tobacco Smoke
EU	European Union
E_v	System ventilation efficiency
FAF	Fresh Air Fan
FAS	Fresh Air System
FCU	Fan Coil Unit
FiSIAQ	Finnish Society of Indoor Air Quality and Climate
F_r	Flow reduction factor
FSP	Fine Suspended Particulates
G	Emission rate of the target pollutant
g/m^3	gram per cubic metre
G_A	Rate of generation
G_{CO2}	Instantaneous CO_2 generation rate of the occupants
GIS	Geographical Information System
GN	Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places
h	hour
H_0	Null hypothesis
h^{-1}	per hour
H_a	Alternative hypothesis
HCHO	Formaldehyde
HI	High
HK$	Hong Kong Dollar
HKS	Hong Kong South
HKSAR	Hong Kong Special Administrative Region

HSE	Health and Safety Commission
HVAC	Heating, Ventilation and Air Conditioning
I/O	Indoor / Outdoor
IAQ	Indoor Air Quality
IAQMG	Indoor Air Quality Management Group
IDLH	Immediately Dangerous to Life and Health
IEQ	Indoor Environmental Quality
j	Subscript of Rn-222 and TVOC
JB	Junk Bay
K	Kelvin
KC	Kwai Chung
kPa	kilopascal
K_{sink}	Rate constant for sink
KT	Kwun Tong
l/min	litre per minute
$L_{Rn\text{-}222}$	Resultant loss rate of Rn-222
m	metre
m/s	metre per second
m^2	square metre
m^3/s	cubic metre per second
MC6	Millennium City 6
MDL	Method detection limit
MED	Medium
MERV14	Minimum Efficiency Reporting Value 14
mg/m^3	milligram per cubic metre
$mg/m^3/h$	milligram per cubic metre per hour
MK	Mong Kok

MVAC	Mechanical Ventilation and Air Conditioning
n	Number of data points
N	Number of sampling points
N/A	Not applicable
N_2	Nitrogen gas
NAAQS	National Ambient Air Quality Standards
ng/m^3	nanogram per cubic metre
NH_3	Ammonia
NIOSH	National Institute for Occupational Safety and Health
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOHSC	National Occupational Health and Safety Commission
NO_x	Nitrogen oxides
NRC	National Research Council
N_y	Number of recorded year
O_3	Ozone
OAQ	Outdoor Air Quality
^oC	degree Celsius
OELs	Occupational Exposure Limits
OSHA	Occupational Safety and Health Administration
$\overline{p}(m, y)$	Mean pertinent outdoor air parameter for each month of every recorded year
PAN	Paroxyacetyl nitrate
PAU	Primary Air Unit
Pb	Lead
PD	Percentage of Dissatisfaction
PELs	Permissible Exposure Limits

pg I-TEQ/m^3	picogram of International Toxicity Equivalent per cubic metre
PM	Particulate matter
PM_{10}	Particulate matter with a diameter of 10 micrometres or less (Respirable suspended particulates)
$PM_{2.5}$	Particulate matter with a diameter of 2.5 micrometres or less (Fine suspended particulates)
ppbv	parts per billion by volume
ppm	parts per million
ppmv	parts per million by volume
q	Air flow across the sampled room [m^3/h]
Q	Volumetric flow rate
Q_1	Volumetric flow rate at discharge of first tier / Volumetric flow rate at inlet to distribution duct
Q_2	Volumetric flow rate at discharge of second tier / Volumetric flow rate at inlet to distribution duct
Q_3	Volumetric flow rate at supply to space at third tier / Volumetric flow rate at discharge from diffuser outlets of third tier
Q_4	Volumetric flow rate at space of fourth tier
Q_{b1}	Volumetric flow rate of by-passed air at first tier
Q_{b2}	Volumetric flow rate of by-passed air at second tier
Q_{b3}	Volumetric flow rate of by-passed air at third tier
Q_{b4}	Volumetric flow rate of by-passed air at fourth tier
Q_{bn}	Volumetric flow rate of by-passed air at that tier
Q_n	Volumetric flow rate at space of that tier
Q_{n-1}	Volumetric flow rate at discharge from previous tier
Q_o	Outdoor volume flow rate
Q_{OA}	outdoor air supply rate into the indoor space
Q_{p1}	Volumetric flow rate of pre-contaminated air at first tier

Q_{p2}	Volumetric flow rate of pre-contaminated air at second tier
Q_{p3}	Volumetric flow rate of pre-contaminated air at third tier
Q_{p4}	Volumetric flow rate of pre-contaminated air at fourth tier
Q_{pn}	Volumetric flow rate of pre-contaminated air at that tier
Q_{s1}	Volumetric flow rate of short-circuited air at first tier
Q_{s2}	Volumetric flow rate of short-circuited air at second tier
Q_{s3}	Volumetric flow rate of short-circuited air at third tier
Q_{s4}	Volumetric flow rate of short-circuited air at fourth tier
Q_{sn}	Volumetric flow rate of short-circuited air at that tier
r	Correlation coefficient
Ra-226	Radium-226
RELs	Recommended Exposure Limits
RH	Relative humidity
R_j	Reaction loss of pollutant-*j* (Rn-222; TVOC) in space [/h]
Rn	Radon
Rn-222	Radon-222
$R_{Rn\text{-}222}$	Reaction loss of Rn-222 in space [/h]
RSP	Respirable suspended particulates
S	Standard deviation for the variable to be estimated
SBS	Sick Building Syndrome
SD	Standard deviation
SO_2	Sulphur dioxide
SPEGL	Shortterm Public Emergency Guidance Levels
SSP	Sham Shui Po
ST	Sha Tin
STEL	Short Term Exposure Limit
t	Time

$t_{0.025}$	Student's t-statistic for two-sided error of 2.5 percent (sums of 5 percent) [i.e. 95% confidence level]
TAPs	Toxic Air Pollutants
TC	Tung Chung
TCDD	Tetrachlorodibenzo-p-dioxin
TCDF	Tetrachlorodibenzofuran
TDC	Total dust collector
Temp	Temperature
TEOM	Tapered Element Oscillating Microbalance
TLV	Threshold Limit Value
TM	Tap Mun
TP	Tai Po
t_s	Number of standard deviations that account for the confidence level
TSP	Total suspended particulates
t_{st}	Test statistics
TST	Tsim Sha Tsui
TVOC	Total volatile organic compounds
TW	Tsuen Wan
TWA	Time weighted average
t_α	Critical values obtained from the Student t-distribution table
U.S.	United States
UK	United Kingdom
UV	Ultraviolet
V	Control volume of the sampled room [m^3]
VAV	Variable Air Volume
V_e	Effective volume of the space
V_o	Required outdoor air flow

VOCs	Volatile organic compounds
WELs	Workplace Exposure Limits
WHO	World Health Organization
x	Specific variable, x
$\bar{x}$	Arithmetic mean
Y	Specific variable, y
YL	Yuen Long
λ_j	Natural decay loss of pollutant-*j* (Rn-222; TVOC) [/h]
$\mu g/m^3$	microgram per cubic metre
μm	micrometre
ρ	Population correlation coefficient
$\sigma_p(m, y)$	Standard deviation of pertinent outdoor air parameter for each month of every recorded year
Φ_j	Specific production rate of pollutant-*j* (Rn-222; TVOC) [$Bq/m^3/h$; $mg/m^3/h$]
Φ_{Rn-222}	Specific production rate of Rn-222 [$Bq/m^3/h$]

CHAPTER 1 : INTRODUCTION

1.1 Live with Clean Air

1.1.1 Government Policy

Hong Kong's environmental problems are common to many developed countries. The rapid growth of its population together with of the prosperous commercial and industrial activities after the World War II, induce a serious built environmental degradation especially air pollution.

The Hong Kong Government policy with regard to environment protection first appeared in the White Paper, entitled '*Pollution in Hong Kong – A time to act*' on World Environment Day, the 5th of June in 1989. The White Paper placed considerable emphases on environmental planning. It states that 'serious environmental pollution is an unfortunate by-product of Hong Kong's economic success and population growth'. One of the Government's major priorities as stated was to halt the decline in environmental conditions and to do more to improve our environment. It laid down the framework for a comprehensive ten-year programme to tackle the pollution problems.

In November 1993, the Government issued '*A Green Challenge for the Community*', which was its second review of the 1989 White Paper. Besides to stress the need for public awareness and participation to improve the environment, the Government recognized the existence of potential health risks and problems associated with indoor air pollution.

The Government's initiative to improve indoor air quality (IAQ) in Hong Kong buildings has been ascertained by the inter-departmental Indoor Air Quality Management Group chaired by the Environment, Transport and Works Bureau (formerly the Environment and Food Bureau). The main functions of the Group, which has been set up since 1998, are to improve the IAQ in office buildings and public places and to monitor the implementation of an IAQ programme. In November 1999, the Group proposed an "IAQ Management Programme" to improve IAQ in buildings and public places for public consultation. The Programme has been launched in October 2000, which comprises the following:

- launching a public education and publicity campaign to promote public awareness of IAQ;
- setting up an IAQ Information Centre to disseminate information and reference materials related to IAQ;
- adopting a set of IAQ Objectives as a common benchmark for evaluating and assessing IAQ;
- publishing a set of Guidance Notes for the better management of IAQ in offices and public places;
- promulgating a voluntary IAQ certification scheme and invite owners and management of premises including the government buildings to participate in the scheme;
- conducting a review of legislative framework for the control of IAQ in parallel with the implementation of the voluntary IAQ certification scheme; and
- publishing a set of professional practice notes for public transport facilities.

To reinforce the Government's determination to improve Hong Kong's air quality, Mr. Donald Tsang, the Chief Executive of HKSAR officially launched the 'Action Blue Sky Campaign' on the 25th of July in 2006. The Campaign aims to encourage every citizen in Hong Kong to participate in protection acceptable air quality. In addition, indoor area of public place have become designated to 'no smoking' areas under the amended Smoking (Public Health) Ordinance (Cap. 371) since the 1st of January in 2007.

1.1.2 IAQ Survey by the Government

In October 1995 Environmental Protection Department (EPD) commissioned a consultancy study on Indoor Air Pollution in Offices and Public Places in Hong Kong. In 1997 the consultancy report concluded that the air quality in about one-third of the office buildings was perceived as unsatisfactory by the occupants. Other major findings in the study are summarized as below:-

(a) According to a questionnaire of telephone survey on 2,000 respondents and on-site survey on 1,183 occupants of 40 selected office premises, the survey found that some 32% of the respondents were dissatisfied with the IAQ of their workplace.

(b) In the field measurement in 40 offices between March and October 1996,

- 37.5% of offices had, over an 8-hour period, a mean carbon dioxide level exceeding 1,000 ppm;

- 90% of the office buildings were ventilated at a rate well below the minimum requirement of 7.5 litres per second per occupant specified by the revised ASHRAE Standard 62-1989R of the American Standard for Heating, Refrigeration and Air-conditioning Engineering;
- 20% of the offices had bacteria count in terms of "colony forming units per cubic meter" (cfu/m^3) were higher than the recommended level of 1,000 cfu/m^3; 32.5% of the offices were found with formaldehyde levels above the WHO guideline of 100 µg/ m^3;
- high levels of organic compounds were present at where redecoration was taking place.

(c) In the statistical analysis, the results showed significant correlation between the occupants' perceptions and measured parameters of IAQ including temperature, humidity, air change per hour, and levels of carbon dioxide, carbon tetrachloride, dichlorobenzene, bacteria and fungal counts.

(d) For the IAQ in public places, only limited data of various premises (twenty restaurants, eight shopping malls, five cinemas, two wet markets and concourses/platforms of the Mass Transit Railway) were reported.

The consultant submitted a draft guidance note for managing IAQ that was later modified by the IAQ Management Group (IAQMG).

1.1.3 Guidance Notes

Under IAQ Management Programme, the first draft of the ‘Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places’ (GN) was released in November 1999 for public consultation. It received many responses from professional bodies, private companies and the general public. In general, the public welcomed the launch of a control measure in IAQ. Some respondents even requested control levels beyond that specified. On the other hand, building developers and system operators were very much concerned about the resources that would be required, for both the certification sampling and the mitigation measures if the IAQ was found unacceptable. Whilst responses supported the necessity of the GN, many building professions questioned the approach of controlling the tracers of air pollutants, and wondered at the feasibility and cost of carrying out detailed IAQ measurements. Moreover, there was a shortage of laboratories to support surveys for the many air-conditioned buildings in Hong Kong.

After the consultation period, an official and modified version of the GN together with ‘A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places’ were published in September 2003. The GN is established as an effective self-regulatory system for the maintenance of IAQ. It is not legally binding and could be treated as a voluntary guideline and sets of common IAQ objectives by the parties involved.

However, only the leading building developers are willing to spend money on certifying their buildings be ‘Excellent Class’ of IAQ in promoting their business image while the smaller scale developers and building owners remain speculative.

Up to now, the buildings or parts of buildings being certified are 275 premises (35 ‘Excellent Class’ and 240 ‘Good Class’) as shown in Appendix A while the building stock of air-conditioned buildings are shown in Table 1.1. The percentage of IAQ certified buildings is disappointing.

Table 1.1 Stock of Hong Kong Private Offices, Commercial Premises and Industrial/Office Buildings in 2006

	Stock [at year end of 2006] (m^2)
Private Offices - Grade A	5,799,200
Private Offices – Grade B	2,428,800
Private Offices – Grade C	1,584,800
Private Commercial Premises	10,395,500
Private Industrial / Office	612,800
Total Area :	20,821,100

In capitalism economy, statutory control through legislation of a business act should be the last resort to safeguard the health of indoor occupants. It might be effective to enforce participation in the programme. However, the administration and policing costs are tremendous. This project attempts to identify the factors vital to the success of a voluntary approach of sustaining acceptable IAQ and to provide a protocol not only in sampling, but also in continuous IAQ monitoring. It is the wish of the researcher that maintaining the ‘good’ or even ‘excellent’ IAQ sparkles from an ethical consideration rather than an act of compliance to law.

1.2 Benevolence or Devil?

The GN provides a specification for IAQ in terms of control levels of nine air parameters for which other than carbon dioxide, the rest are considered as gaseous pollutants. It specifies the measurement and sampling principles which are comprehensive even from a research perspective. It also includes an instructive management guidance. The control levels, especially for 'Excellent' level, are set with reference to the toughest standards of the developed countries. In real life, mandating the IAQ Scheme will require tremendous effort and resources. Its feasibility is doubtful. The high qualities of professionalism, instrumentation and laboratories discourage participation when the Certification Scheme is voluntary.

From a pragmatic perspective, an executable scheme would be one that the majority of building owners and operators will accept and the process is well supported by additional resources set up in the industry. There are several scenarios that could jeopardise the successful launch of the GN.

1.2.1 Cost to Building Owners

The GN specifies 12 IAQ parameters (9 airborne parameters and 3 thermal comfort parameters) for measurement at each sampling point for 8 hours time average or equivalent surrogate measurement (an intermittent measurement strategy based on the average of half-an-hour measurements conducted at four time-slots) (see Table 1.2). Each parameter requires a different measurement principle and therefore a different instrument.

The GN requires that the number of sampling points is based on the area of the premises (Table 1.3). A full certificate requires the sampling of the full set of 12 parameters and is valid for 5 years. In between, the certificate has to be renewed annually by ascertaining the compliance of two parameters, CO_2 and PM_{10}.

Table 1.2 Indoor Air Quality Objectives for Office Buildings and Public Places

Parameter	Unit	8-hour average	
		Excellent Class	Good Class
Room Temperature	^oC	20 to < 25.5	< 25.5
Relative Humidity	%	40 to < 70	< 70
Air Movement	m/s	< 0.2	< 0.3
Carbon Dioxide (CO_2)	ppmv	< 800	< 1,000
Carbon Monoxide (CO)	$\mu g/m^3$	< 2,000	< 10,000
	ppmv	< 1.7	< 8.7
Respirable Suspended Particulates (PM_{10})	$\mu g/m^3$	< 20	< 180
Nitrogen Dioxide (NO_2)	$\mu g/m^3$	< 40	< 150
	ppbv	< 21	< 80
Ozone (O_3)	$\mu g/m^3$	< 50	<120
	ppbv	< 25	< 61
Formaldehyde (HCHO)	$\mu g/m^3$	< 30	< 100
	ppbv	< 24	< 81
Total Volatile Organic Compounds (TVOC)	$\mu g/m^3$	< 200	< 600
	ppbv	< 87	< 261
Radon (Rn)	Bq/m^3	< 150	< 200
Airborne bacteria	cfu/m^3	< 500	< 1,000

Table 1.3 Guidelines for the Minimum Number of Sampling Points

Total floor area to be certified (served by MVAC system) (m^2)	Minimum number of sampling points
< 3,000	1 per $500m^2$
3,000 - < 5,000	8
5,000 - < 10,000	12
10,000 - < 15,000	15
15,000 - < 20,000	18
20,000 - < 30,000	21
≥ 30,000	1 per $1,200m^2$

The Hong Kong Guide appeals for participation to the scheme for around 2,000 air-conditioned high-rise office buildings. Each building requires around a minimum of 30 sampling points. A reasonable estimate of the cost for sampling one point, according to the market value is HK$4,000. Therefore, the total cost to building owners is HK$240 million. For ideal IAQ control compliance to the GN, the cost will be several folds higher. These costs will eventually be borne by the society at large. For many of these buildings, an additional cost is required to improve or enhance the air side system or even building tightness and layout before the IAQ can comply with the specified criteria. The improvement of the health of Hong Kong people consequential to better IAQ in working environment of white collars is paid by such cost. The Government can strike the balance by saving in medical cost, production cost saving in reducing sick leave and the cost of good will to the city. However, with an average of HK$120,000 on sampling for one building in the full certificate once in five years, and the cost of annual renewal of around HK$20,000, full participation under the voluntary scheme by all the expected buildings is doubtful. At the moment, based on the rate of participation, it is far from cost effective in the administration of the scheme and setting up of private laboratory facilities.

1.2.2 Resource Support

Taking the same basic reference number, there has to be adequate resources to sample 60,000 points, with 12 different types of instruments for each point. The measurements are conducted by qualified team and qualified laboratories. It should be adequate qualified engineers for pre-measurement inspection, post measurement data interpretation. It also requires qualified building services engineers for the upgrade of the services systems. The Government would also need to support a team for regulation of the laboratories and sampling processes, the campaign of the scheme, the monitoring and administration of the participate buildings.

The huge sum of money involved will surely stimulate new consultancy business for IAQ measurements. It seems inevitable that, with the overwhelming workload concerned, the quality of survey and assessment might run of control. The Indoor Air Quality Management Group (IAQMG) administered under the Environmental Protection Department, is then tightening up the quality of the 'authorized laboratories'. In fact, only HOLAS approved laboratories are qualified for the sampling processes starting from the 1st of February in 2008. The stringent requirement will deter the formation of investors. The consequence will further tighten up the available resources.

1.2.3 Rationale of the IAQ Class

The GN establishes a set of 2-level IAQ objectives (refer to Table 1.2) as the benchmark for evaluating and assessing IAQ:

"Excellent" Class – it represents an excellent IAQ that a high-class and comfortable building should have.

"Good" Class – it represents the IAQ that provides protection to the public at large including the young and the aged.

In general, Government regulations should only impose a minimum quality in order to safeguard the general public from hazardous conditions, like the Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment enforced through legislation. A voluntary scheme like the GN can encourage an 'excellent' level. The scenario is that private building owners who are willing to 'invest' would only prefer an 'Excellent' certificate or else they will be fall behind in competition of their quality of service provision. Or else, they prefer not to label their IAQ if they need to pay a fortune in the pursuance of the 'excellence'. On the other hand, EPD is seriously considering legislating the scheme. In the legal form, if the requirement is as stringent, it will violate the principle of 'Intervention to Trade with Minimum Requirement only'. This labelling actually imposes a difficulty in executing the scheme. In the voluntary approach, it only encourages 'excellent' achievement and hence it deters participation in the general sense.

1.2.4 Determining Factors for Acceptable IAQ

IAQ is a generic term and is often used implicitly for acceptable IAQ. The set of criteria in GN is therefore implicitly defined for acceptable IAQ. The philosophy for acceptance of IAQ will be elaborated further subsequent to a comprehensive review of the IAQ requirements in other countries outside Hong Kong in Chapter 2.

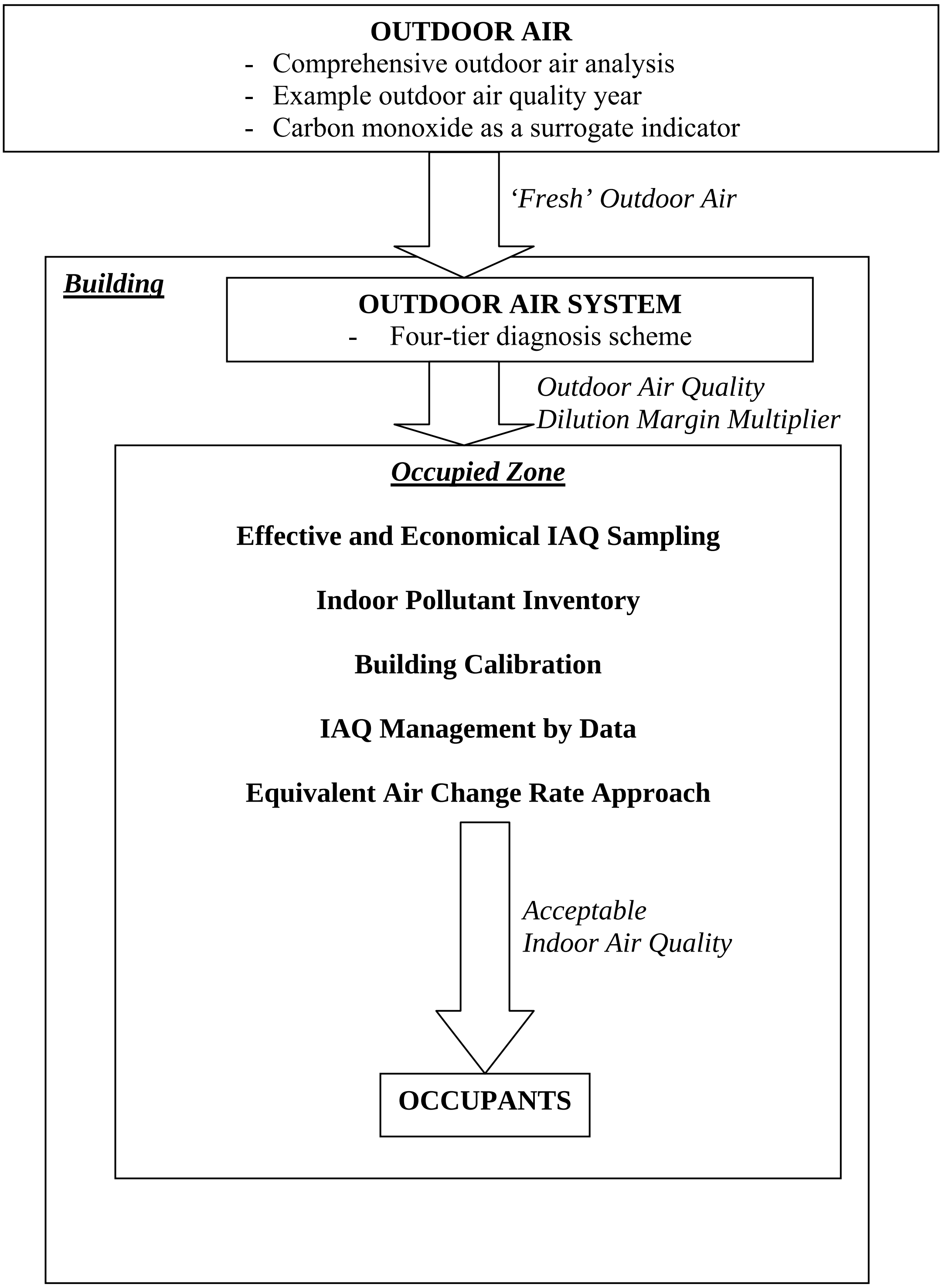
From a more pragmatic approach, the specification for IAQ criteria is performance based. The process to achieve this performance is left to the building managers and their technical teams. ASHRAE Standard 62, which has developed into the 2007 version provides two design procedures to achieve acceptable IAQ, namely, they are the Ventilation Rate Procedure and the IAQ Procedure. The former procedure is a prescriptive procedure and is therefore not suitable for IAQ management to meet the GN requirement. The IAQ procedure is based on the mass balance principle. It takes into account of the outdoor air quality which is used to dilute and exhaust the pollutants generated in indoor space. It considers the indoor pollutant production rates. The procedure calculates the maximum of the minimum ventilation rate for each of the pollutant under consideration. Therefore, the IAQ Procedure is an appropriate procedure to meet the GN requirement. Unfortunately, the outdoor air quality is not readily available and the indoor air pollutant emission rate is not easy to determine. Due to these difficulties, in all the ventilation design, it is almost overwhelmingly that the prescriptive Ventilation Rate Procedure is used in practice while there is a trend of specifying IAQ to the 'Excellent' or 'Good' level according to the GN. The GN, unexpectedly, brings about the contradicting specification and design procedure.

1.3 Development of Pragmatic Protocol

From previous discussion, the Certificate Scheme emphasizes, or assumes that the sampled day represents the routine IAQ throughout the building at all time. Unfortunately, it does not provide guideline on how to take into account of the outdoor air quality and indoor pollutant emission. That makes the compliance to GN criteria very controversial and confusing. The key considerations in this study emphasize a pragmatic protocol which encourages concerns of the IAQ by the building owners, a more sensible IAQ sampling protocol and IAQ management procedures for running quality buildings at all time. This project aims to help building owners to optimize resources to obtain meaningful IAQ certification. The outputs from the research target to make the GN more executable and to render the objective of the GN to protect the public at large from over exposure to unacceptable IAQ possible.

Figure 1.1 summarizes the whole scene of pragmatic protocol on IAQ management for air-conditioned buildings. Managing indoor air quality in air-conditioned buildings has to be considered the full picture of outdoor air quality, outdoor air system, indoor air sampling, pollutant inventory in buildings, building calibration, indoor air quality management. This study helps to provide a comprehensive management protocol against the whole process on design, evaluation, operation and maintenance of indoor air quality in air-conditioned buildings.

Figure 1.1 Pragmatic Protocol on IAQ Management in Air-conditioned Buildings



1.4 Objectives of this Study

The objectives of this study are to:

(a) review all the relevant IAQ standards to justify a set of IAQ criteria;

(b) analyze outdoor air quality data in Hong Kong to develop typical outdoor air quality profile on designing outdoor air system for acceptable indoor air quality;

(c) develop an inspection protocol to diagnose IAQ problems arising from degradation of outdoor air system;

(d) develop a model of indoor pollutant inventory for IAQ management;

(e) establish a cost-effective protocol for IAQ sampling;

(f) develop an integrated and pragmatic web-based management platform for acceptable IAQ design, operation and maintenance.

1.5 Structure of the Thesis

This thesis is structured in Chapters in such a way that each chapter will bring out the outcome of the objectives stated in Section 1.4 supported with research results. Each chapter is briefed as below:

Chapter 1: Introduction

This chapter reviews the consequences of the GN of the IAQ Certification Scheme. It highlights the great financial impact to the good will of Hong Kong and the actual resources requirement. The chapter brings out the confusion of using GN as criteria for acceptable IAQ and the practice of using Ventilation Rate Procedure as a prescriptive design and management method. These facts set the scene for this research for a pragmatic management tool.

Chapter 2: Indoor Air Quality Definition

ASHRAE 62 defines acceptable IAQ from the physiological response perspective. GN defines IAQ quantitatively. Quantitative criteria may be a function of human races and culture. Chapter 2 is devoted to the review of various IAQ standards or legislations in places outside Hong Kong. It intends to give the GN a rational interpretation.

Chapter 3: Outdoor Air Quality in Hong Kong

As said earlier, outdoor air quality is an important issue in managing IAQ especially when sustainability is a design norm for today. Air quality monitoring data of total 23 years (from the years 1983 to 2005) collected by the Environmental Protection

Department’s fixed outdoor air monitoring network are summarized and analyzed. It involves the conversion of 8.9 millions data into an analyzable format.

Chapter 4: Application of Outdoor Air Data

Example outdoor air quality years as to facilitate outdoor air quality load calculation for outdoor air system design of buildings. Surrogate indicator for monitoring air quality at outdoor air intake is derived. Specifically, a typical year of outdoor air profile is derived based on a CIBSE (The Chartered Institution of Building Services Engineers) protocol in deriving typical annual temperature profiles.

Chapter 5: Four-Tier Diagnosis Scheme for Fresh Air System

Outdoor air when transporting into the indoor is subjected to various types of degradation. This chapter derives a scheme for compensating transportation degradation to maintain the indoor air quality.

Chapter 6: Indoor Pollutant Inventory

Indoor pollutant emission is the second important issue in managing acceptable IAQ. The concept of “indoor pollutant inventory” is introduced as a more appropriate assessment of indoor air pollutant ‘production’. It combines the technique of measurement and error analysis of the measurement results to give an accurate estimate of indoor pollutants. Hence, the outdoor air quantity is more accurately computed and the IAQ objectives can be more precisely controlled.

Chapter 7: Sampling Protocol on Indoor Air Quality Measurement

When the IAQ objectives are properly resolved, taking into account of the outdoor air quality and indoor pollutant emission, the study turns the focus to the proper sampling of the IAQ. Following the GN, this chapter will demonstrate the progressive difficulty in meeting the GN criteria. This chapter concludes with a much more cost effective and more representative sampling protocol. It intends to propose a more pragmatic and practical tool to be used by the industry to properly manage the IAQ in real life.

Chapter 8: Indoor Air Quality Management

IAQ is an integrated result of the environmental conditions both indoor and outdoor, and depends on the system design and operation modes. In this chapter, several IAQ management strategies on operation and maintenance are proposed. In addition, this chapter also develops a web based platform for a total solution. Using a web based environment, a platform integrated all the techniques developed in the study is used for the total management of IAQ.

Chapter 9: Conclusion

It draws the attention to the proper understanding of the basic philosophy of IAQ and its management. It concludes with the tool in Chapter 8 for a total solution.

CHAPTER 2 : INDOOR AIR QUALITY DEFINITION

2.1 Introduction

This chapter sets the scene of this research. The confusing notion of IAQ is the basic issue to be dealt with. This chapter dedicates to the review of IAQ criteria as set out in various codes of practices and the Guidance Notes of the Hong Kong Indoor Air Quality Management Group. The IAQ criteria as recommended in other countries is also discussed so that a worldwide view of the IAQ controlled levels can be compared. The ventilation by outdoor air used by design engineers in practice is important because this is the fundamental approach in managing IAQ. The project lays down the philosophy of managing IAQ by the formulation of a managing model backed up with analytic tools. It sets the basic consideration for the development of the management strategy including the sampling protocol. This chapter intends to resolve the ambiguity between the use of GN in generating the IAQ set points and the incompatible ventilation design procedures. The managing model is organized as three main sub-models for its basic composition and the alternative sampling protocol as an operative execution of ascertaining acceptable IAQ.

2.2 Definition of Acceptable Indoor Air Quality

2.2.1 ASHRAE Standard

ASHRAE Standard 62.1-2007 Ventilation for Acceptable Indoor Air Quality defined acceptable indoor air quality as: air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

2.2.2 World Health Organization

The physical and chemical nature of indoor air, as delivered to the breathing zone of building occupants, which produces a complete state of mental, physical and social well-being of the occupants, and not merely the absence of disease or infirmity.

2.2.3 Discussion on Definition of Acceptable IAQ

It is obvious that IAQ concerns only constituents in air and IAQ in the general sense is often referred to ‘acceptable’ IAQ. This acceptance, according to the above cognizant authorities, complies with two types of performance – comfort as a sense of expressing satisfaction (very often expressed as PD, percentage of dissatisfaction) and a condition of healthiness (expressed as pollutant concentration controlled below a threshold). The former is a subjective response of human. The later pertains to the constituent state of the air. It is also important to realize that comfortable IAQ does not necessarily implies healthy IAQ. It will be elaborated further in later sections. However, it is this confusion that renders ventilation design erred.

Aiming at acceptable IAQ in combating communicable disease, another level of IAQ is necessary. ‘Safe’ IAQ is the level proposed in completing the range of IAQ acceptability. Intuitively, safe IAQ specifies the high limit of pathogenic species in air. The IAQ condition can then be used to calculate the infection risk. The later is beyond the scope of this study.

2.3 Review of IAQ Criteria in Hong Kong

The following sections describe the IAQ criteria adopted by Hong Kong and the related values of air quality objectives or guidance are shown in Appendix B.

2.3.1 Environmental Protection Department

The Government recognized the existence of potential health risk and problems associated with indoor air pollution from a second review of the 1989 White Paper that issued "A Green Challenge for the Community" in November 1993. This White Paper had an outline for a comprehensive ten-year plan to tackle the pollution problems. Based on this issue, the Environmental Protection Department has produced several practice notes on air pollution control in vehicle tunnels, car parks, semi-confined public transport interchanges and managing air quality in air-conditioned public transport facilities (buses and railways):

- Practice Note on Control of Air Pollution in Vehicle Tunnels [1995]
- Control of Air Pollution in Car Parks (ProPECC PN 2/96) [1996]
- Control of Air Pollution in Semi-Confined Public Transport Interchanges (ProPECC PN 1/98) [1998]
- Control of Radon Concentration in New Buildings (ProPECC PN 1/99) [1999]
- Practice Note for Managing Air Quality in Air-conditioned Public Transport Facilities - Buses (ProPECC PN 1/03) [2003]
- Practice Note for Managing Air Quality in Air-conditioned Public Transport Facilities - Railways (ProPECC PN 2/03) [2003]

In September 2003, “Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places” (GN) together with “A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places” have been launched by a cross-department Indoor Air Quality Management Group (IAQMG) under the chairmanship of the Environmental Protection Department (EPD) to apply for all buildings or totally enclosed areas served with mechanical ventilation and air conditioning (MVAC) system for human comfort except domestic buildings, medical buildings and industrial buildings.

2.3.2 Labour Department

The Occupational Safety and Health Ordinance (Chapter 509) provides for the safety and health protection to employees in workplaces, both industrial and non-industrial. This ordinance covers almost all workplaces - places where employees work. In addition to factories, construction sites and catering establishments, other places, such as offices, laboratories, shopping arcades, educational institutions also come under the ambit of the law.

“A Reference Note on Occupational Exposure Limits for Chemical Substances in the Work Environment”, latest edition of October 1998, provides a reference in the form of Occupational Exposure Limits (OELs) to assess the adequacy of the control measures taken for the chemical substances which are commonly found in local industry. These Occupational Exposure Limits represent airborne concentrations of individual chemical substance. Reference is made to the American Conference of Governmental Industrial Hygienists’ list of Threshold Limit Values and the standards of other overseas organizations in establishing the OELs.

2.3.3 Discussion on Implementation of IAQ Policy in Hong Kong

Encouragement in sustaining acceptable IAQ is a commendable movement of the Government in protecting the health of the citizen. It also reduces the indirectly loss of production due to sick leaves and deficiency in productivity. It conserves direct cost of communal medical care. It is the intention of the IAQ Guidance Notes of the IAQMG that the cost in improving and enhancement of ventilation and air cleaning systems, and the investment cost of laboratories and trained personnel would be far compensated by saving in expenses. However, if the campaign is not properly processed, the expected scenario, that is, healthier city and cost saving, cannot be achieved. This sets the background of developing an alternative sampling protocol in Chapter 7.

2.4 Review of IAQ Criteria Worldwide

The following sections describe the IAQ criteria adopted by worldwide and the related values of air quality objectives or guidance are also shown in Appendix B.

2.4.1 Australia

Interim National Indoor Air Quality Goals recommended by the National Health and Medical Research Council was published in 1996 but rescinded on 19 March 2002. It set ‘Goals for Maximum Permissible Levels of Pollutants in Indoor Air’ on pollutants of carbon monoxide, formaldehyde, lead, ozone, radon, sulfates, sulfur dioxide, total suspended particulates and TVOC. Worksafe Australia (National Occupational Health and Safety Commission) has also launched 'Exposure standards for atmospheric contaminants in the occupational environment' as a National Exposure Standards in early 1990s as guides to be used in the control of occupational health hazards.

2.4.2 Canada

The Federal-Provincial Advisory Committee on Environmental and Occupational Health has issued "Exposure Guidelines for Residential Indoor Air Quality" [April 1987; revised July 1989] with a primary objective "to develop guidelines for the concentrations of selected contaminants of residential indoor air, taking into account such factors as the sensitivity of groups at special risk and the sources and mechanisms of action of contaminants" and its second objective "to develop, where practicable, other guidelines or recommendations for measures that will preserve or improve air quality in domestic premises". The potential for adverse effects from long-term exposures and from shorter-term higher-level exposures has been considered. Two kinds of exposure limits are therefore specified:

Acceptable Long-Term Exposure Range (ALTER) – concentration range to which it is believed from existing information that a person may be exposed over a lifetime without undue risk to health;

Acceptable Short-Term Exposure Range (ASTER) – concentration range to which it is believed from existing information that a person may be exposed over the specified time period without undue risk to health.

2.4.3 China

National Standard (GB/T 18883-2002) entitled “Indoor Air Quality Standard” has been established by General Administration of Quality Supervision, Inspection and Quarantine, Ministry of Health and State Environmental Protection Administration of China in November 2002 with the aims of protecting human health, preventing and controlling the indoor air pollution. There are total 19 IAQ standard including 4 physical parameters (temperature, relative humidity, air velocity and outdoor air rate), 13 chemical parameters (SO_2, NO_2, CO, CO_2, NH_3, O_3, HCHO, C_6H_6, C_7H_8, C_8H_{10}, B(a)P, PM_{10} and TVOC), 1 biological parameter (total bacteria) and 1 radioactive parameter (radon).

2.4.4 Finland

Finnish Society of Indoor Air Quality and Climate (FiSIAQ) has published “Classification of Indoor Climate 2000. Target values, design guidance and product requirements” which is a document replacing the “Classification of Indoor Climate, Construction and Finishing Materials” published in 1995. It is intended to be used in the design and construction of healthier and more comfortable buildings and their mechanical systems. It also provides guidelines for manufacturers of air-handling equipment and building materials who wish to produce better building products.

The classification of indoor climate has three categories: category S1, S2 and S3. Category S1 corresponds to the best quality, meaning higher satisfaction with the indoor climate and smaller health risks. Category S3 corresponds to the requirements set by the Land Use and Building Act (1999) and the Health Protection Act (1994):

S1: Individual Indoor Climate – The indoor air quality of the space is very good and the thermal conditions are comfortable both in summer and winter. The user of the space may individually control the thermal conditions and improve the indoor air quality by increasing the ventilation when necessary. The thermal conditions and indoor air quality satisfy, as a general rule, the special requirements of the users (e.g. elderly people, people with allergies or respiratory illnesses, and others).

S2: Good Indoor Climate – The indoor air quality of the space is good and no draughts occur. The temperature may rise above comfortable level during the hottest days of the summer.

S3: Satisfactory Indoor Climate – The indoor air quality and the thermal conditions of the space fulfill the requirements set by the building codes. The indoor air may occasionally feel stuffy and draughts may occur. The temperature usually rises above comfort levels on hot summer days.

2.4.5 Japan

There is legislation which regulates temperature, relative humidity, air flow, and concentration of dusts, carbon dioxide and carbon monoxide in large buildings, in order to prevent diseases related to a poor indoor air environment and to ensure the comfort of workers. The Law for Maintenance of Sanitation in Buildings was introduced by the Ministry of Health and Welfare in 1970.

2.4.6 South Korea

Indoor Air Quality Management Act has been enacted by the Ministry of Environment in 2004. Under 'Indoor Air Quality Management in Public Facilities', the number of facilities subject to the Indoor Air Quality Management Act has been gradually expanded to 17 facilities whereas only subway stations and underground markets were subjected to the system under the previous Underground Air Quality Management Act of 1996. It enforces indoor air quality standards on PM_{10} (particulate matters), CO_2 (carbon dioxide), HCHO (formaldehyde), TBC (total bacteria counts), and CO (carbon monoxide) among others, with stringent control measures such as imposing charges to those who fail to comply with the standards. Also, indoor pollutants generated from outer sources or those with comparably less risk than the abovementioned pollutants, including NO_2 (nitrogen dioxide), Rn (radon), TVOC (toxic volatile organic compounds), asbestos and ozone are controlled voluntarily by the industries according to the suggested emission levels.

2.4.7 Singapore

In October 1996, the Institute of Environmental Epidemiology, Ministry of the Environment published a "Guidelines for Good Indoor Air Quality in Office Premises" providing general guidance on improving the indoor air quality of air-conditioned office premises and acceptable values for selected parameters. It also provides information on the potential health effects of indoor contaminants, and an action plan to achieve good IAQ. The Guidelines set out maximum concentrations for specific indoor air contaminants and values for specific physical parameters such as temperature, humidity and air movement.

2.4.8 United Kingdom

There is no specific legislation on IAQ standards in UK. Several pieces of legislation have a bearing on IAQ but this is not their main purpose. The legislation includes housing legislation, health legislation, building regulations, and restrictions on the manufacture, use and import of certain substances. The European Union (EU) plays a significant role in directing policy and planning in UK. Some European standards have been incorporated into the British Standards system which reflects the direction within the EU for greater harmonization of standard. The harmonization process may lead the UK to adopt European environmental legislation. Like other self-regulatory systems in the UK, IAQ standards and ventilation requirements are largely to be the responsibility of professional bodies who define guidelines which are voluntarily adopted by their members.

Under the Control of Substances Hazardous to Health Regulations 2002 (COSHH), the law requires employers to control exposure to hazardous substances to prevent ill health. Health and Safety Commission (HSE) has established Workplace Exposure Limits (WELs) for a number of substances hazardous to health. These are intended to prevent excessive exposure to specified hazardous substances by containing exposure below a set limit.

2.4.9 European Union

Under EU law a limit value is legally binding from the date it enters into force subject to any exceedences permitted by the legislation. A target value is to be attained as far as possible by the attainment date and so is less strict than a limit value.

European legislation on air quality is built on certain principles. The first of these is that the Member States divide their territory into a number of zones and agglomerations. In these zones and agglomerations, the Member States should undertake assessments of air pollution levels using measurements and modelling and other empirical techniques. Where levels are elevated, the Member States should prepare an air quality plan or programme to ensure compliance with the limit value before the date when the limit value formally enters into force. In addition, information on air quality should be disseminated to the public.

2.4.10 World Health Organization

The first edition of the WHO *Air quality guidelines for Europe* was published in 1987 that summarized scientific knowledge on the health hazards related to the 28 most common air pollutants and the second edition of these guidelines was published in 2000 that summarized risk characterization of 37 pollutants. The primary aim of these guidelines is to provide a basis for protecting public health from adverse effects of air pollution and for eliminating, or reducing to a minimum, those contaminants of air that are known or likely to be hazardous to human health and wellbeing. The guidelines are intended to provide background information and guidance to governments in making risk management decisions, particularly in setting standards, but their use is not restricted to this. When guideline values are indicated, this does not necessarily mean that they should be used as the starting point for producing general countrywide standards, monitored by a comprehensive network of control stations. In the case of some pollutants, guideline values may be of use mainly for carrying out local control measures around point sources. To aid in this process, information on major sources of pollutants has been provided.

The guidelines do not differentiate between indoor and outdoor exposure (with the exception of exposure to mercury) because, although the sites of exposure influence the type and concentration of air pollutants, they do not directly affect the basic exposure–effect relationships. Occupational exposure has been considered in the evaluation process, but it was not a main focus of attention as these guidelines relate to the general population.

Air Quality Guidelines Global Update 2005 – Particulate matter, ozone, nitrogen dioxide and sulfur dioxide, presents revised guideline values for these four most common air pollutants based on a recent review of the accumulated scientific evidence.

2.4.11 United States

The Occupational Safety and Health Act of 1970 created both the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA). OSHA is in the U.S. Department of Labor and is responsible for developing and enforcing workplace safety and health regulations. NIOSH is in the U.S. Department of Health and Human Services and is an agency established to help assure safe and healthful working conditions for working men and women by providing research, information, education, and training in the field of occupational safety and health.

The Environmental Protection Agency (EPA) regulates emissions from factories and automobiles that affect ambient air quality. The Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards for pollutants considered harmful to public health and the environment. The Clean Air Act established two types of national air quality standards. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings.

The American Conference of Governmental Industrial Hygienists (ACGIH) has been considered a well-respected organization by individuals in the industrial hygiene and occupational and environmental health and safety industry.

2.4.12 Discussion on IAQ Criteria Worldwide

Unlike the developed countries, Hong Kong is not supported by extensive research to determine the criteria for ‘healthy IAQ’ in terms of control on indoor pollutant concentrations. Therefore, the criteria set down in the GN of Hong Kong are borrowed from overseas cognizant authorities. The GN goes further to specify two levels of acceptable IAQ – the ‘good’ level and the ‘excellent’ level. The ‘good’ level targets for healthy IAQ and the ‘excellent’ level targets for healthy and comfortable IAQ. As mentioned earlier in the definition for acceptable IAQ in Section 2.2.3, comfortable

IAQ is measured by percentage of satisfaction. Sensory satisfaction depends on the strength of unpleasant odour. In general, the criteria of pollutant concentration for 'good' IAQ level would be beyond the odour threshold limit. Practically, 'good' IAQ would imply comfortable IAQ. If 'good' IAQ intends to be healthy, 'excellent' IAQ with a much more stringent control (lower allowances in pollutant concentrations) would become futile. The exponential increase in cost would then be squandered. Besides, the inclusion of thermal comfort parameters is thought to sustain an accepted indoor environmental quality (IEQ). However, IEQ is an integrated sensation of IAQ, thermal comfort, visual comfort and aural comfort. However, it is beyond the scope of this study.

2.5 Review of IAQ Design Method

2.5.1 ASHRAE Standard 62

ASHRAE standard 62-1973 'Standard for Natural and Mechanical Ventilation' provided a prescriptive approach to ventilation by specifying both minimum and recommended outdoor air flow rates to obtain acceptable IAQ for a variety of indoor applications. In 1981 edition, 'Ventilation for Acceptable Indoor Air Quality' deleted 'recommended' rate category. Two categories became smoking and non-smoking. Outdoor air flow rates were recommended for both categories. Alternative 'IAQ procedure' was added to allow for the use of innovative energy conservation practices that allowed for the use of whatever amount of outside air if shown that levels of indoor air contaminants could be maintained below recommended limits. In 1989 edition, the standard increased the minimum non-smoking ventilation rates specified in 1981 edition by triple and quadruple. Also, it did not distinguish between smoking and non-smoking. Ventilation Rate Procedure and Indoor Air Quality Procedure were retained for ventilation design. In 2001 edition converted from standard 62-1999 stated that minimum requirements were code-language, not a code. ASHRAE standard 62.1-2004 was written to be code-enforceable containing only mandatory language and had been updated and revised in a number of significant ways. The latest 2007 edition not only sets minimum ventilation rates and other requirements for commercial and institutional buildings, but also includes requirements for the separation of areas with environmental tobacco smoke (ETS) from areas without ETS in the same building. In this standard, either the Ventilation Rate Procedure or the IAQ Procedure shall be used to design each ventilation system in a building:-

(a) Ventilation Rate Procedure

This is a prescriptive procedure in which outdoor air intake rates are determined based on space type/application, occupancy level, and floor area. It is noted that the Ventilation Rate Procedure minimum rates are based on contaminant sources and source strengths that are typical for the listed space types.

(b) IAQ Procedure

This is a design procedure in which outdoor air intake rates and other system design parameters are based on an analysis of contaminant sources, contaminant concentration targets, and perceived acceptability targets. The IAQ Procedure allows credit to be taken for controls that remove contaminants or for other design techniques that can be reliably demonstrated to result in indoor contaminant concentrations equal to or lower than those achieved using the Ventilation Rate Procedure.

2.5.2 European Standard

In the European standard organization, CEN, a working group under the technical committee TC156 “Ventilation for Buildings” has developed a technical report CR 1752 “Ventilation for Buildings: Design Criteria for the Indoor Environment” (CR1752-1998) which specifies the requirements for, and methods of expressing the quality of the indoor environment for the design, commissioning, operation and control of ventilation and air-conditioning systems. It also specifies categories of environmental quality (desired perceived IAQ) which shall be selected for a space to be ventilated. Category A corresponds to a high level of expectation (15% dissatisfied), category B to a medium level of expectation (20% dissatisfied) and category C to a moderate level of expectation (30% dissatisfied). The required ventilation rate depends on the desired indoor air quality, on the indoor air pollution sources, on the outdoor air quality and on the ventilation effectiveness.

2.5.3 Discussion on IAQ Design Method

The above sections outline the three approaches in ventilation design for acceptable IAQ. In short, the Ventilation Rate Procedure of ASHRAE Standard 62 is a prescriptive method for comfort in case of that human odour is the main nuisance. The IAQ Procedure of ASHRAE Standard 62 is a performance based method for healthy and comfortable IAQ provided the outdoor air quality and indoor pollutant emission rates are known and that the IAQ criteria are set. Fanger's IAQ Comfort Equation is best used to deal with unpleasant odour of all kind at harmless concentrations. Ventilation Rate Procedure is the simplest design method and therefore is used almost entirely under all occasions without a true understanding of its limitation. IAQ Procedure is the most rational and engineering method for all cases. Unfortunately, it cannot be used readily because outdoor air quality is not readily available and the indoor pollutant emission rates is difficult to determine. Fanger's method highly depends on the subjective olfactory sensations which are not readily repeatable. Therefore, it is not readily applicable in general situations. However, it favours situations where unpleasant but not harmful odour dominates. Fanger's approach is best for ventilation design for toilets, bathrooms and store rooms and etc. for which no other approaches suit better anyway.

If there is no readily available outdoor air quality data and better means of determining indoor pollutant emission rates, Ventilation Rate Procedure will continue to be almost the only way of ventilation design. It then contradicts the campaign of GN as a means to specify IAQ criteria which dictates the use of IAQ Procedure. Having set this scene, this project therefore endeavors to turn the 8.9 millions of data of the outdoor air pollutants from the 17 EPD monitoring stations into an analyzable format. Analysis of the Hong Kong outdoor air quality is done in Chapter 3. The study goes further (Chapter 4) to develop a typical annual outdoor air pollutant profiles by statistical approaches for the engineers. The pollutant emission rates measurements are resolved by the concept of 'pollutant inventory' (Chapter 6). To take into account of the inherent degradation of the ventilating air along its path, a four-tier scheme is enhanced for such purpose (Chapter 5).

2.6 Philosophical Model of this Study

The outdoor air quality is often accused of a factor deterring tourism in Hong Kong and haunts economic growth. Correspondingly, the indoor air quality is alleged of causing allergy, asthma and many kinds of respiratory track sicknesses. The GN brings a hope to resolve the indoor health problems. As discussed in above sections, the GN could bring more confusions than solutions. It is the major drive of this study.

The candidate was involved in the testing of the protocol in the early development stage of the GN. The candidate was also involved in the drafting of the codes of IAQ management in public transport facilities. From the work, it is found that the alternative sampling methods may be more pragmatic than the comprehensive GN sampling protocol (Chapter 7). The philosophical model is therefore developed to cover the design, commissioning, operation and maintenance stages of the ventilation system with an aim for acceptable IAQ. The philosophical model can be viewed as the integration of three sub-modules which aim to the design processes. Although it is not readily to obtain emission rates of building material, these rates can be evaluated from measurements in similar environment or in laboratory chambers using the concept of 'pollutant inventory'. Then the sampling protocol comes into effect when post building commissioning. Finally, a handy computer aided tool is developed to facilitate building manager for a total IAQ management (Chapter 8).

2.7 Philosophical Model and the Modules

The philosophical model and the Modules are as shown in Figure 2.1. For achieving acceptable IAQ with comprehensive rationalized and practicable approach on designing, evaluating, sampling, monitoring, operation and maintenance, different modules of the philosophical model provide valuable analyzed information for building manager or operator to implement IAQ management in air-conditioned buildings. The basis of the model is expressed from the law of conservation of mass for the indoor space. The law of conservation of mass states that mass is neither created nor destroyed in a process or non-nuclear chemical reaction. When no reactions occur, a mass balance is a simple accounting of any chemical in the system. In words, a mass balance requires that the rate of chemical accumulation within any closed system is equal to the rate of mass into the system minus the rate of mass out of the system. Based on the concept of mass balance equation (further elaboration can refer to Chapter 7), the concentration of any pollutant in air-conditioned indoor space is a function of three elements:

- quality of the ventilating air,
- distribution of the air, and
- emission characteristics of significant pollutants.

The quality of the ventilating air for indoor space is mainly depended on outdoor air system via air distribution system. Therefore, by understanding what quality of outdoor air infiltrating into the building is very important for building operators to manage their IAQ strategies. Chapter 3 and 4 outlining the outdoor air quality for different regions in

Hong Kong can provide comprehensive background information not only for designing the outdoor air system based on the analyzed data of outdoor air, but also for operation and maintenance of outdoor air system in more practicable way by reviewing the outdoor air profiles. The quality of ventilating air and air distribution can also be affected different kinds of the degradation. Chapter 5 establishes a diagnosis scheme for investigating the effect of the degradation of the ventilating air. Emission characteristics of significant pollutants are concerned on acceptable IAQ too since they are sources of parameters affecting the quality of indoor air. Chapter 6 proposes an evaluation model on the pollutant inventories. For evaluating the quality of indoor air, economical and practical sampling protocol mentioned in Chapter 7 is a more rationalized approach. Chapter 8 provides other IAQ management technique on maintenance of acceptable indoor air quality.

The structure of the model is described in the following:

(a) The outer circle of the outdoor air quality mapping represents the 8.9 millions of outdoor air quality data labored into an analyzable format. (Chapter 3)

(b) The outdoor air quality module represents the statistical analysis of the outdoor air quality in relation to events occurring in Hong Kong (Chapter 3).

(c) The typical annual outdoor air quality profile module is the statistical derivation of the representative year for design purposes (Chapter 4).

(d) The degradation module is a mass balance model for evaluation of quality degradation of ventilating air (Chapter 5).

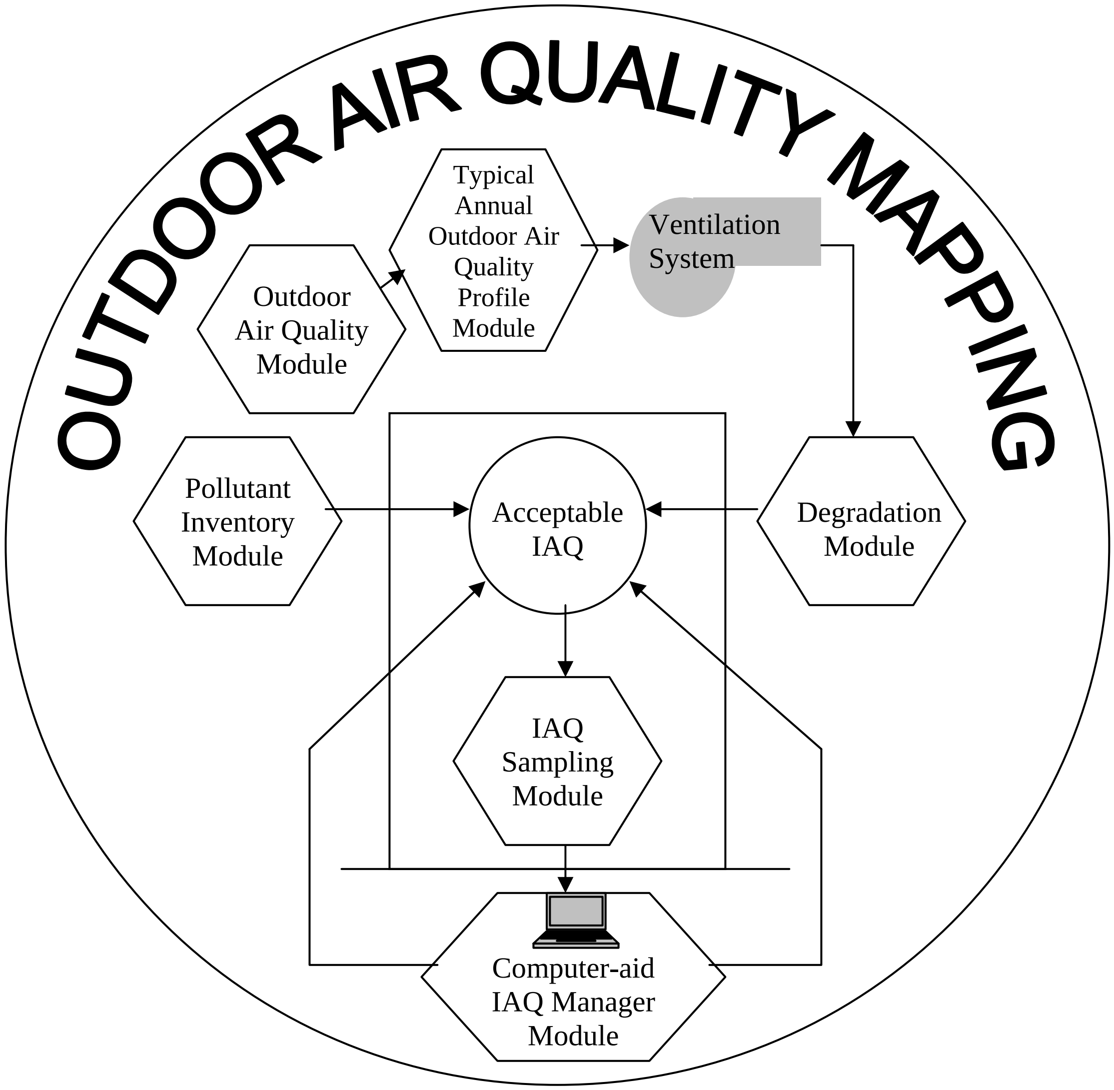
(e) The pollutant inventory module is a zone concentration model for evaluation of pollutant inventories with minimum error analysis (Chapter 6).

(f) IAQ sampling module is a proposed protocol based on thousands of IAQ sampling in buildings (Chapter 7).

(g) The IAQ manager module highlights the construction of the computer-aided tool for a total IAQ management (Chapter 8).

The detail of the module will be presented in the later chapters.

Figure 2.1 Philosophical Model and the Modules of the Study



CHAPTER 3 : OUTDOOR AIR QUALITY IN HONG KONG

3.1 Introduction

This chapter summarizes and discusses the air quality monitoring data of total 23 years (from the years 1983 to 2005) collected by the Environmental Protection Department's fixed outdoor air monitoring network.

The aims of this chapter are to:

- offer initial interpretation of some of the observations;
- discuss the major air pollutants, including their potential health effects;
- report the measured gaseous and particulates measurements, their comparison with the Air Quality Objectives, their relationships to each other, and possible causes of the measured values;
- explain the reasons for some episodes of high concentrations and long term trends in pollutants concentrations.

3.2 Hong Kong Air Quality Policy

The Air Pollution Control Ordinance is the principal law for managing air quality. Regulations cover specific areas related to air pollution, such as power plant emissions, motor vehicle fuel and emissions, asbestos control, construction dust and industrial emissions. The legislation related to air pollution control is listed in Appendix C.

3.3 Outdoor Air Monitoring Stations

3.3.1 Objective of Establishing Outdoor Air Monitoring Stations

For establishing comprehensive and systematic monitoring of the environment in Hong Kong, the Environmental Protection Department (the former named as Environmental Protection Agency) has developed a fixed network of air quality monitoring station covering the whole territory in Hong Kong since early 1980s.

The purpose of monitoring ambient air quality is to provide information on the ambient air pollutant levels in various districts and to relate them to the Hong Kong Air Quality Objectives (AQO), as specified under the Air Pollution Control Ordinance. Table 3.1 shows the Hong Kong Air Quality Objectives which established in 1987. The results assist in air quality management, including the development of emission control strategies and land use planning. Moreover, the long term trend results assist in air management in evaluating the effectiveness of various emission control strategies.

Table 3.1 Hong Kong Air Quality Objectives

Pollutant	Concentration in micrograms per cubic metre (i)					Health effects of pollutant at elevated ambient levels
	Averaging Time					
	1 Hour (ii)	8 Hour (iii)	24 Hour (iii)	3 Months (iv)	1 Year (iv)	
Sulphur Dioxide	800		350		80	Respiratory illness; reduced lung function; morbidity and mortality rates increase at higher levels.
Total Suspended Particulates			260		80	Respirable fraction has effects on health.
Respirable Suspended Particulates (v)			180		55	Respiratory illness; reduced lung function; cancer risk for certain particles; morbidity and mortality rates increase at high levels.
Nitrogen Dioxide	300		150		80	Respiratory irritation; increased susceptibility to respiratory infection; lung development impairment.
Carbon Monoxide	30,000	10,000				Impairment of co-ordination; deleterious to pregnant women and those with heart and circulatory conditions.
Photochemical Oxidants (as ozone) (vi)	240					Eye irritation, cough; reduced athletic performance; possible chromosome damage.
Lead				1.5		Affects cell and body processes; likely neuropsychological effects, particularly in children; likely effects on rates of incidence of heart attacks, strokes and hypertension.

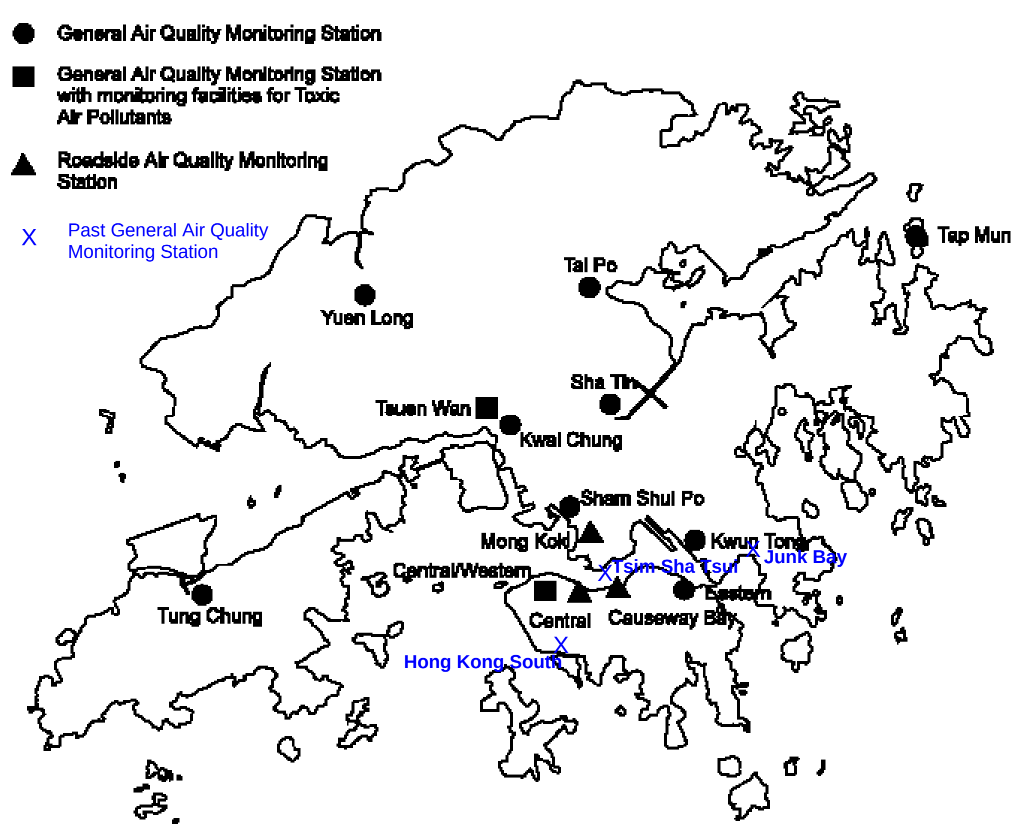
(i) Measured at 298K (25^{o}C) and 101.325kPa (one atmosphere).
(ii) Not to be exceeded more than three times per year.
(iii) Not to be exceeded more than once per year.
(iv) Arithmetic means.
(v) Respirable suspended particulates means suspended particulates in air with a nominal aerodynamic diameter of 10 micrometres and smaller.
(vi) Photochemical oxidants are determined by measurement of ozone only.

3.3.2 Monitoring Site Locations

For measuring concentrations of major outdoor air pollutants, there are total 14 air quality monitoring stations (i.e. 11 general stations for monitoring ambient air quality and 3 roadside stations for measuring street level air quality) operating by The Hong

Kong Environmental Protection Department. 11 general stations are located so as to monitor the ambient air quality in various districts and hence are sited on roof-tops. In addition, 3 roadside stations, at Causeway Bay, Central and Mong Kok respectively, have been placed at street level so as to measure air quality experienced by pedestrians close to traffic. The locations of the monitoring stations (including 14 existing monitoring stations and 3 past monitoring stations) are shown in Figure 3.1. The site information of the monitoring stations is listed in Appendix D.

Figure 3.1 Locations of Air Quality Monitoring Stations in Hong Kong



3.3.3 Instrumentation

Each station is equipped with continuous automatic gaseous analyzers which measure concentrations of sulphur dioxide, nitrogen oxides, ozone, respirable suspended particulates and carbon monoxide. Samples of both total suspended particulates (TSP) and respirable suspended particulates (RSP) were collected by Hi-Volume samplers regularly. Details of the measurement instrument and techniques are presented in Table 3.2. In addition to the discrete RSP sampling using the high volume samplers, continuous RSP measurements were made using Tapered Element Oscillating Microbalance (TEOM) monitors since 1993.

Data from the continuous instruments are sent back to the computer of the Environmental Protection Department through the public data communication network for further processing and compilation.

Two groups of toxic air pollutants (TAPs), viz. heavy metals and organic substances, were regularly monitored at the Central/Western and Tsuen Wan stations since mid 1997. Sampling and Analysis Methods Used in Measuring Toxic Air Pollutants are shown in Table 3.3.

Table 3.2 List of Equipment Used in Measuring Air Pollutant Concentration [source from Air Quality in Hong Kong, Environmental Protection Department (1983-2005)]

Pollutants	Measurement Principle	Detection Mode	Commercial Instrument used in the monitoring station
SO2	UV fluorescence	Continuous	**API 100E [2005]** **TECO 43A [1991-2005]** Environnement S.A. AF21M [2001-03] Monitor Laboratories 8850 [1989-2001] TECO Model 43 [1983-91]
NO, NO2, NOx	Chemiluminescence	Continuous	**API 200A [1997-2005]** **Monitor Laboratories 8840 [1983-2005]** TECO Model 42 [1989-99]
O3	UV absorption	Continuous	**API 400A [2002-05]** **API 400 [1997-2005]** TECO 49 [1993-2002] Dasibi 1003-RS [1983-94] Kimoto 840 [1989-92]
SO2, NO2, O3	Differential Optical Absorption Spectroscopy	Continuous	**Opsis AR 500 System [1992-2005]**
CO	**Non-dispersive infra-red absorption with gas filter correlation [1995-2005]** Non-dispersive infra-red [1989-94]	Continuous	**API 300 [2002-05]** **TECO 48C [1997-2005]** TECO Model 48 [1989-2002] Monitor Laboratories 8830 [1989-94]
TSP	Gravimetric	Discrete Sampling	**General Metals 2310 [1989-2005]** Andersen TSP [1983-95]
RSP	a) Gravimetric	Discrete Sampling	**Graseby Andersen PM10 [1996-2005]** Wedding and Associates PM10 [1989-95] Andersen PM10 [1983-95]
	b) Oscillating microbalance	Continuous	**R&P TEOM Series 1400a-AB-PM10 [1998-2005]** R&P TEOM Series 1400a-PM10 [1996-97] R&P TEOM Series 1400-PM10 [1992-95]

Table 3.3 Sampling and Analysis Methods Used in Measuring Toxic Air Pollutants [source from Air Quality in Hong Kong, Environmental Protection Department (1997-2005)]

Toxic Air Pollutants	Sampling and Analysis Method	Sampling Instrument	Sampling Media	Sampling Schedule	Sampling Period
Benzene	USEPA Method TO-14A [2004-05] USEPA Method TO-14 [1997-2003]	Xontech 910A / RM 910A [2004-05] Xontech 910A [1997-2003]	Canister	Twice per month [2004-05] Every 6 days [1997-2003]	24 hours
Perchloroethylene	USEPA Method TO-14A [2004-05] USEPA Method TO-14 [1997-2003]	Xontech 910A / RM 910A [2004-05] Xontech 910A [1997-2003]	Canister	Twice per month [2004-05] Every 6 days [1997-2003]	24 hours
1,3-Butadiene	USEPA Method TO-14A [2004-05] USEPA Method TO-14 [1997-2003]	Xontech 910A / RM 910A [2004-05] Xontech 910A [1997-2003]	Canister	Twice per month [2004-05] Every 6 days [1997-2003]	24 hours
Formaldehyde	USEPA Method TO-11A [2004-05] USEPA Method TO-11 [1997-2003]	Xontech 925 / RM 925 [2004-05] Xontech 925 [2003] Xontech 920 [1997-2002]	DNPH coated silica gel cartridge [2004-05] DNPH coated Sep-Pak Cartridge [1997-2003]	Once per month [2004-05] Every 12 days [1997-2003]	24 hours
Benzo(a)pyrene	USEPA Method TO-13	Graseby GPSI / Tisch TE-1000 [2004-05] Graseby GPSI [1997-2003]	Polyurethane Foam and XAD-2 resin [2004-05] PUF/XAD-2 Sorbents [1997-2003]	Once per month [2004-05] Twice per month [1999-2003] Once per month [1997-98]	24 hours
Dioxin [1998-2005] 2,3,7,8-TCDD 2,3,7,8-TCDF [1997]	USEPA Method TO-9A [2001-05] USEPA Method TO-9 / 23 [1997-2000]	Graseby GPSI / Tisch TE-1000 [2004-05] Graseby GPSI [1997-2003]	Polyurethane Foam	Once per month [2004-05] Twice per month [1999-2003] Once per month [1997-98]	24 hours
Hexavalent Chromium	CARB SOP MLD 039	Xontech 920 [2003-05] Xontech 925 [1997-2002]	Bicarbonate Impregnated Filter	Once per month[2004-05] Every 12 days [1997-2003]	24 hours

3.4 Air Pollution in Hong Kong

The concentration limits for the major air pollutants are specified as "Air Quality Objectives" (AQO) under the Air Pollution Control Ordinance. The pollutants include sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide and atmospheric particles. These pollutants are discussed in the following paragraphs.

3.4.1 Sulphur Dioxide (SO_2)

(a) Health Effect

Sulphur dioxide (SO_2) is an important component of air pollution. It is a colourless gas and can be tasted at concentrations greater than 850μg/m^3 and smelt at concentrations above 1500μg/m^3.

Exposure to high levels of SO_2 may cause impairment of respiratory function and aggravate existing respiratory and cardiac illnesses. Prolonged exposure at lower levels may also increase the risk of developing chronic respiratory disease.

Besides being harmful to both plants and people, SO_2 also contributes to the local and regional acid rain problem.

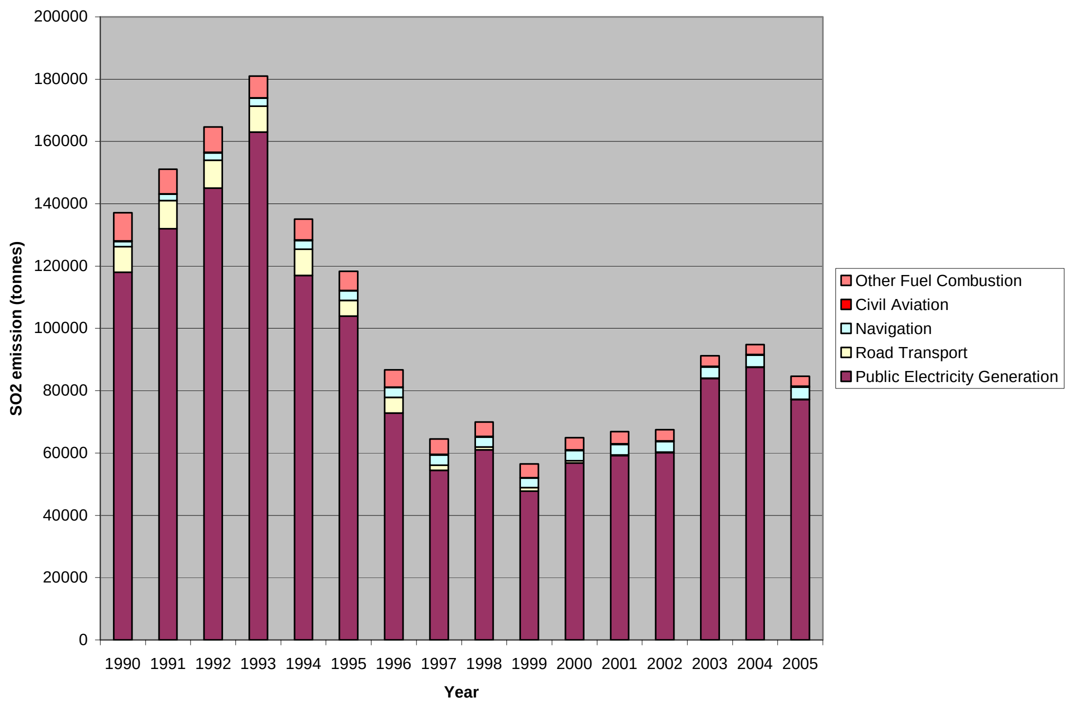
(b) Source

Sulphur dioxide (SO_2) is formed primarily from combustion of sulphur-containing fossil fuels. In urban area diesel vehicles and industrial emissions are the more important source of SO_2 because of their close proximity to the receptors.

In the atmosphere, the gas is oxidized to form sulphates. This occurs slowly in the gas phase but far more rapidly in atmospheric water droplets. The sulphate may precipitate in rain, which it acidifies, or in particles. SO_2 is known to contribute significantly to the regional acid rain problem.

Figure 3.2 shows the emissions from man made sources. It can be seen that electricity generation (near 90%) is the major contributor to total SO_2 emissions followed by fuel combustion, marine vessels and vehicles in Hong Kong.

Figure 3.2 SO_2 Emissions from Man Made Sources (1990-2005)



(c) Compliance on Air Quality Objectives

For protection of the public from adverse health effects, three objective limits, respectively the hourly (800μg/m^3), 24-hourly (350μg/m^3) and the annual (80μg/m^3) standards have been established.

In 1991, no measurement exceeded any of the sulphur dioxide AQO. This is the first time that this has happened ever since air monitoring started in 1983. The improvement is the direct result of the implementation of the Fuel Restriction Regulations in July

1990. The effects of the Regulations are becoming apparent in 1991 as shown in the SO_2 annual averages, and in the compliance with all the AQO values at all stations. However there were several exceedances of the 1-hour limit and 24-hour limit at Kwun Tong, Tsuen Wan and Mong Kok in the period of 1992 to 1994.

Since 1995, all monitoring stations have continuously complied with the relevant short and long term (1-hour, 24-hour and 1-year) Hong Kong Air Quality Objectives (AQOs) for SO_2 due to the past control efforts. Table 3.4, Table 3.5 and Table 3.6 show the percentage of compliance on 1-hour, 24-hour and 1-year Air Quality Objectives of SO_2 for all monitoring stations.

Table 3.4 Percentage of Compliance on 1-hour Air Quality Objectives of SO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
EN																	100%	100%	100%	100%	100%	100%	100%
KC						100%	99.94%	99.99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
KT	98.68%	99.47%	99.78%	100%	99.76%	99.94%	99.97%	99.98%	100%	99.99%	99.99%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
SSP		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
ST									100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TC																	100%	100%	100%	100%	100%	100%	100%
TM																100%	100%	100%	100%	100%	100%	100%	100%
TP								100%	100%	100%	100%				100%	100%	100%	100%	100%	100%	100%	100%	100%
TW						100%	100%	99.99%	100%	99.96%	99.96%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
YL													100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Roadside Air Quality Monitoring Station																							
CB	100%	100%	100%	100%	100%	100%	100%	99.93%								100%	100%	100%	100%	100%	100%	100%	100%
CL																100%	100%	100%	100%	100%	100%	100%	100%
MK									100%	100%	100%	99.97%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Past General Air Quality Monitoring Station																							
HKS							100%	100%	100%	100%	100%												
JB	100%	100%	100%	99.99%	100%	100%	100%	100%	100%	100%	100%												
TST	99.98%	99.99%	99.89%	99.96%	100%	100%	100%	100%	100%	100%	100%												

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

Table 3.5 Percentage of Compliance on 24-hour Air Quality Objectives of SO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
EN																	100%	100%	100%	100%	100%	100%	100%
KC						100%	99.17%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
KT	91.35%	98.15%	97.52%	100%	97.51%	98.36%	99.40%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
SSP		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
ST									100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TC																	100%	100%	100%	100%	100%	100%	100%
TM																100%	100%	100%	100%	100%	100%	100%	100%
TP								100%	100%	100%	99.56%				100%	100%	100%	100%	100%	100%	100%	100%	100%
TW						100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
YL													100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Roadside Air Quality Monitoring Station																							
CB	100%	100%	100%	100%	100%	100%	100%	100%								100%	100%	100%	100%	100%	100%	100%	100%
CL																100%	100%	100%	100%	100%	100%	100%	100%
MK									100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Past General Air Quality Monitoring Station																							
HKS							100%	100%	100%	100%	100%												
JB	99.52%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%												
TST	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%												

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

Table 3.6 Percentage of Compliance on 1-year Air Quality Objectives of SO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
EN																	O	O	O	O	O	O	O
KC						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
KT	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
SSP		O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
ST									O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
TC																	O	O	O	O	O	O	O
TM																O	O	O	O	O	O	O	O
TP								O	O	O	O				O	O	O	O	O	O	O	O	O
TW						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
YL													O	O	O	O	O	O	O	O	O	O	O
Roadside Air Quality Monitoring Station																							
CB	O	O	O	O	O	O	O	O								O	O	O	O	O	O	O	O
CL																O	O	O	O	O	O	O	O
MK									O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Past General Air Quality Monitoring Station																							
HKS							O	O	O	O	O												
JB	O	O	O	O	O	O	O	O	O	O	O												
TST	O	O	O	O	O	O	O	O	O	O	O												

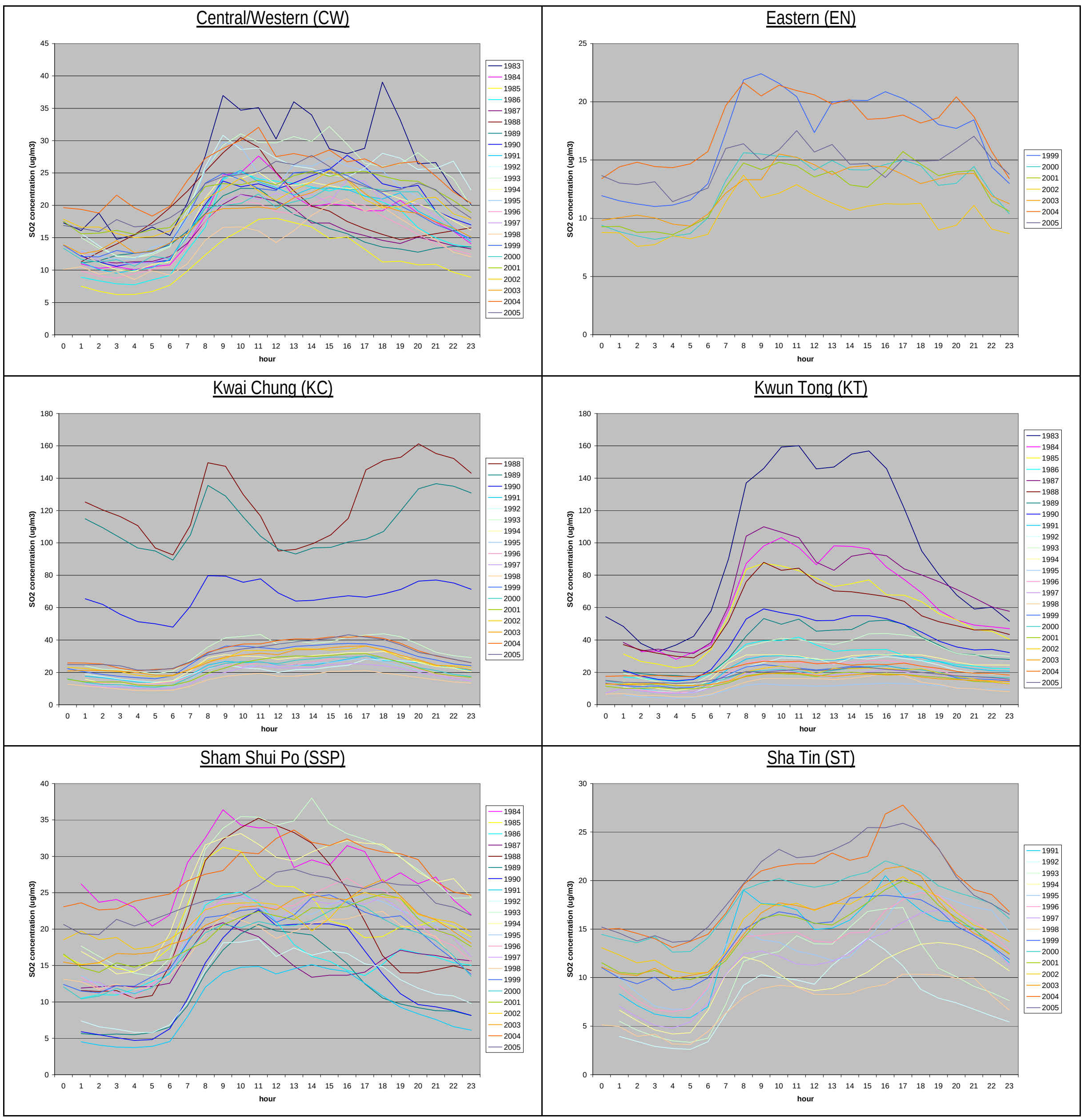
Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

(d) Time Series Variation

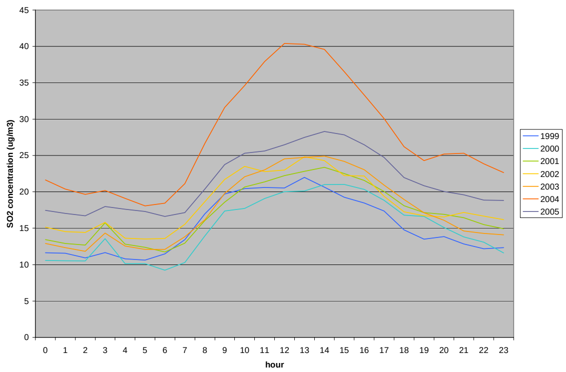
- Diurnal variation

The diurnal variations of SO_2 concentrations are depicted in Figures 3.3. Diurnal variations of SO_2 are more distinct in the densely populated urban areas and roadside, whilst smaller variations are found in the lower populated areas, such as Eastern, Shatin, Tap Mun and Tai Po. As would be expected, concentrations were higher in the day than at night, and peaked during the morning and afternoon work periods. This shows that human activities significantly affected the local pollutant concentrations during the day. Higher concentrations are observed in the morning and in the late afternoon when more traffic and industrial activities occur. The lowest concentration occurs at 4a.m. to 5a.m. when human activities are usually at their lowest. The twin peak of SO_2 concentrations obviously are coherent in most stations by following the timing of human activities. It is interesting to note that although the power stations emitted almost 90% of all sulphur dioxide in Hong Kong, in general, the impact of their emissions is not apparent from the sulphur dioxide measurements. This is because of their locations, as for much of the time the power station plumes are blown away from the land, and because the tall stacks allow efficient dispersion. Local sources tend to dominate local air quality.

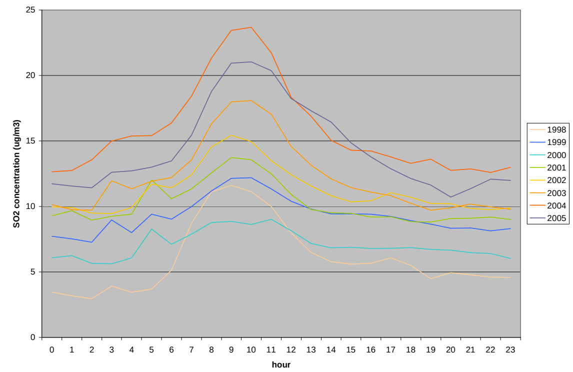
Figures 3.3 Diurnal SO_2 Variation of Air Monitoring Stations (from 1983 to 2005)



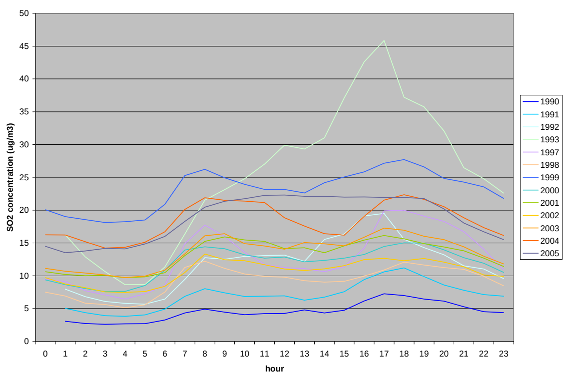
Tung Chung (TC)



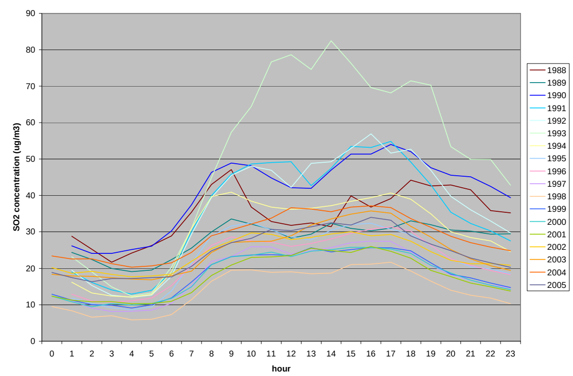
Tap Mun (TM)



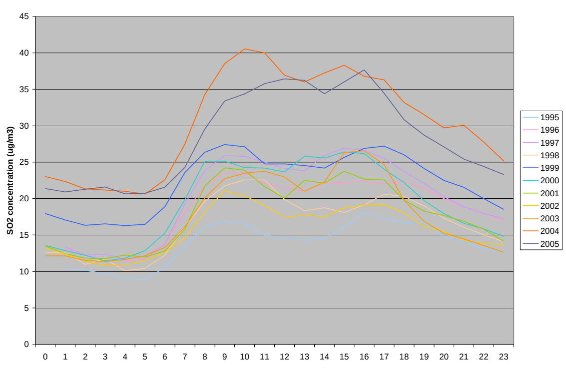
Tai Po (TP)



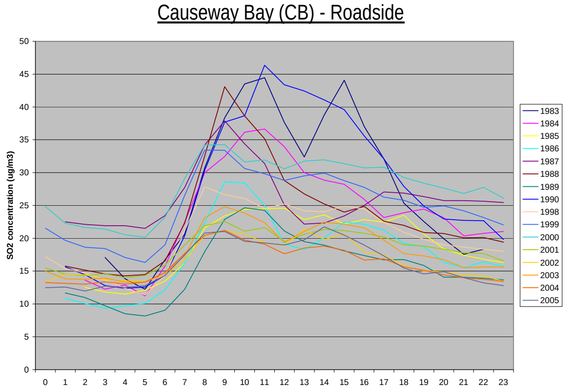
Tsuen Wan (TW)



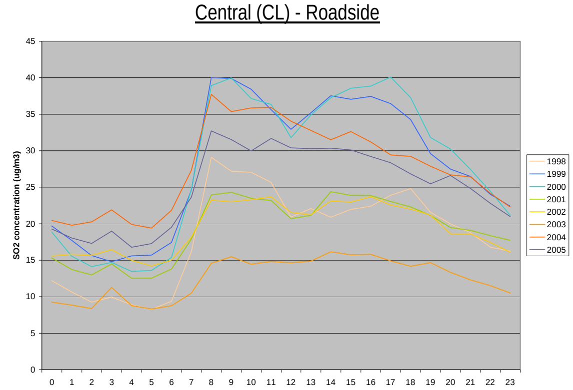
Yuen Long (YL)



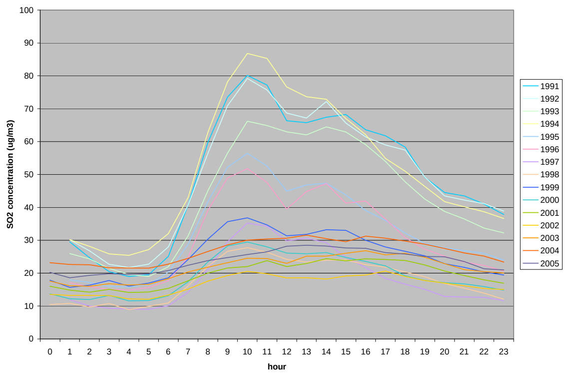
Causeway Bay (CB) - Roadside



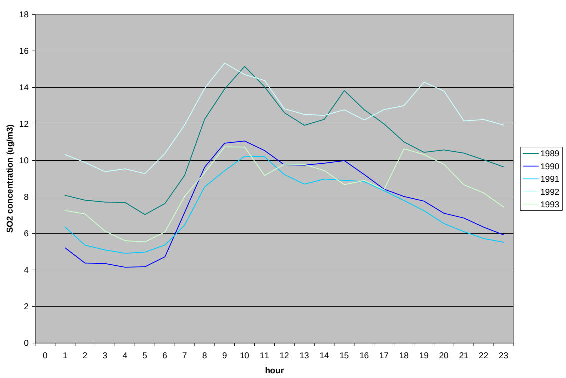
Central (CL) - Roadside



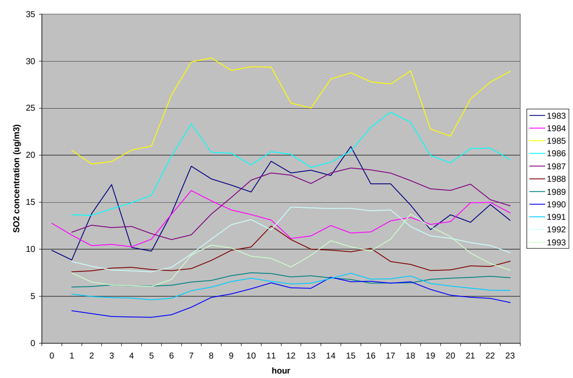
Mong Kok (MK) - Roadside



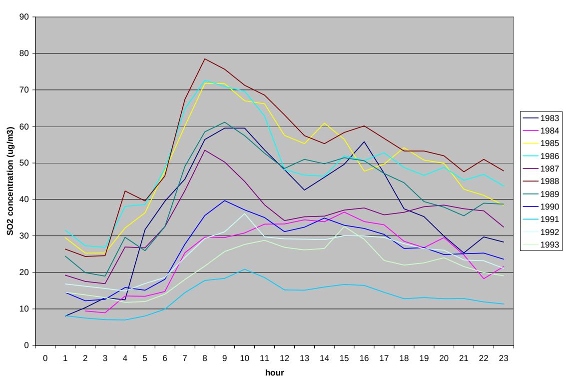
Hong Kong South (HKS) - Past



Junk Bay (JB) - Past



Tsim Sha Tsui (TST) - Past

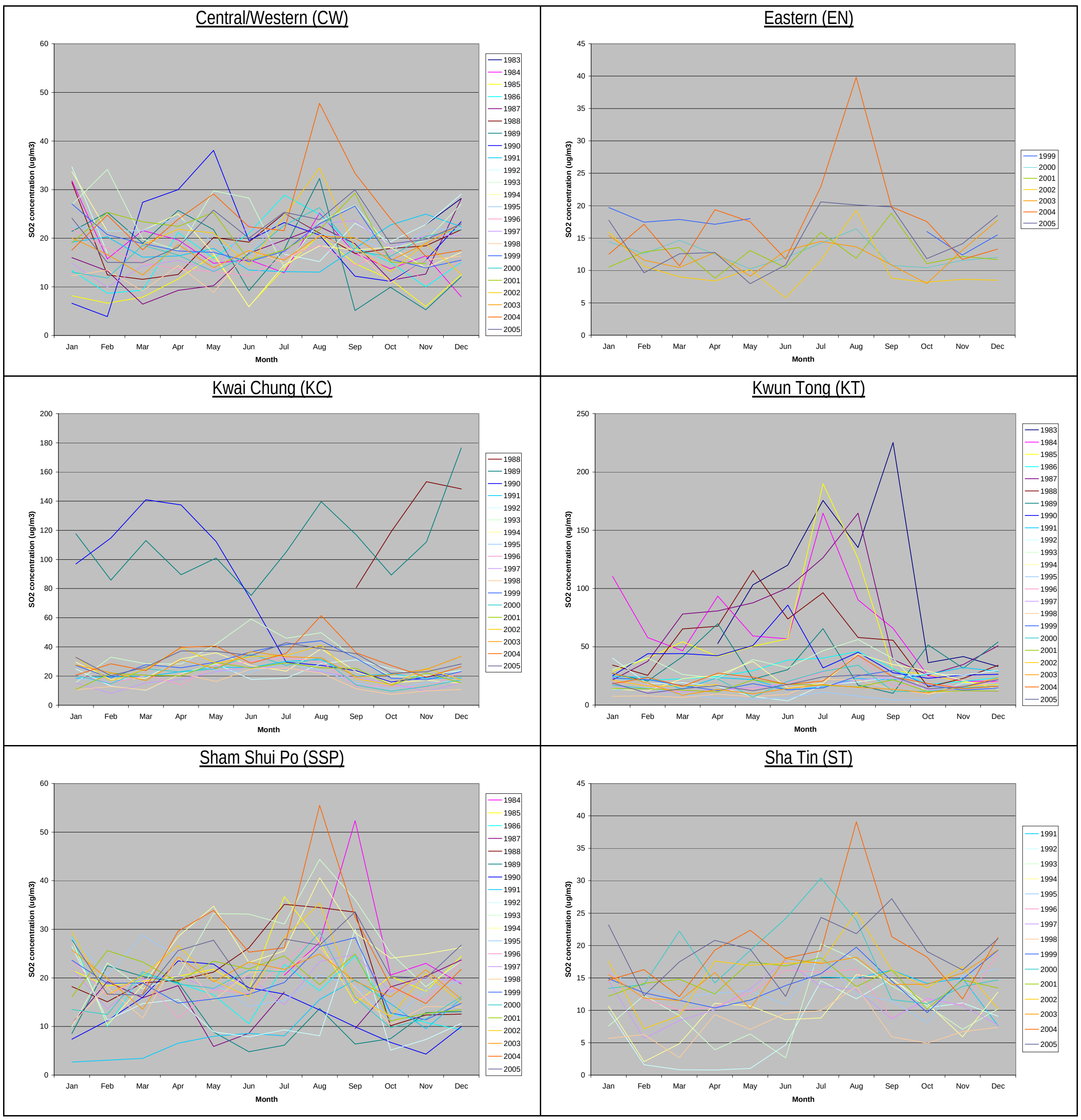


- Monthly variation

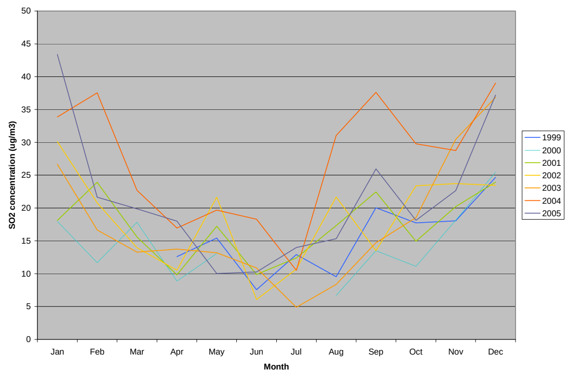
In general, the concentrations of air pollutants vary from season to season as the wind pattern changes. However, no simple pattern for most stations is apparent in the monthly time series in Figures 3.4. This is probably because the monthly averages of the sulphur dioxide concentration vary with the emission source strengths and dispersion characteristics in different areas.

The data of Tung Chung and Tap Mun presented in Figures 3.4 provide typical examples to show how SO_2 concentrations change with seasons. In summer, heavy rainfall washes out the soluble SO_2, resulting lower concentrations.

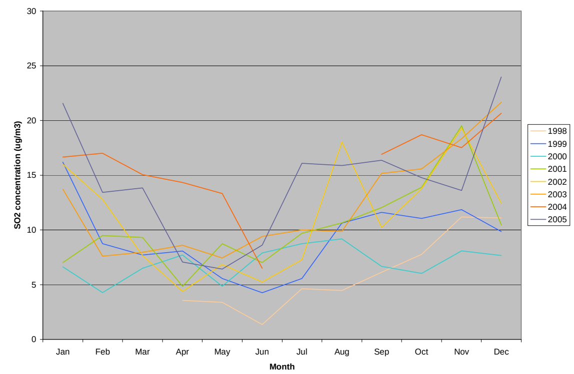
Figures 3.4 Monthly SO_2 Variation of Air Monitoring Stations (from 1983 to 2005)



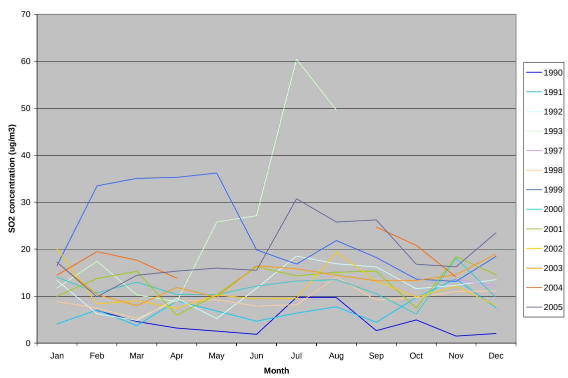
Tung Chung (TC)



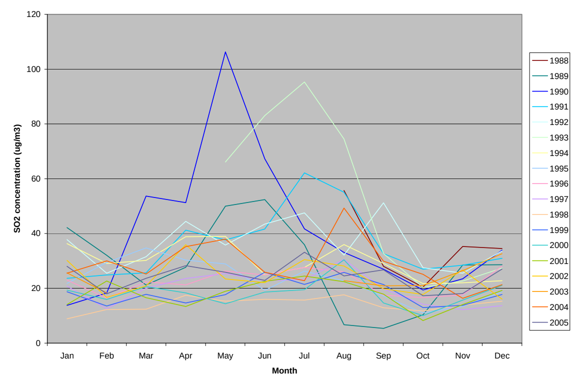
Tap Mun (TM)



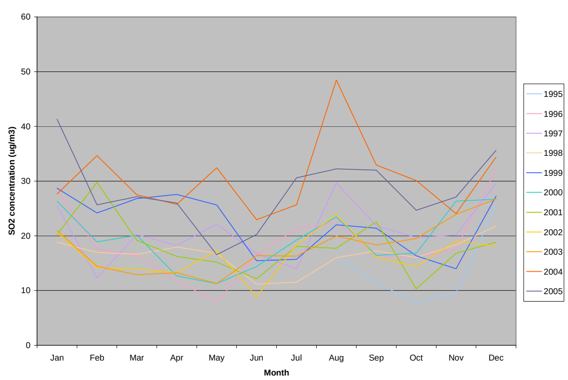
Tai Po (TP)



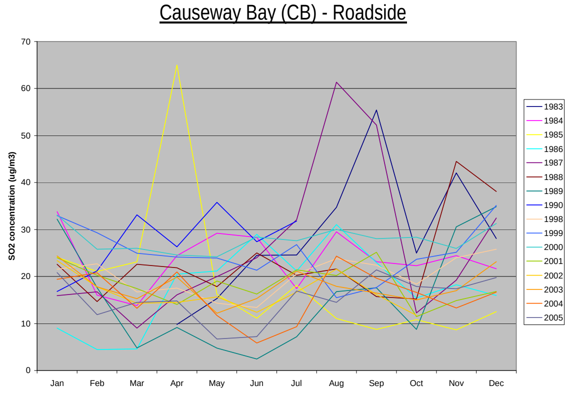
Tsuen Wan (TW)



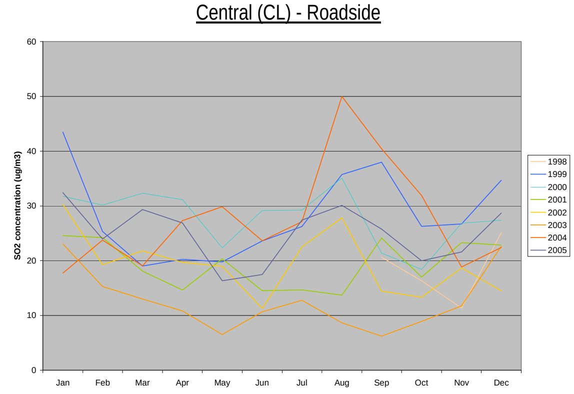
Yuen Long (YL)

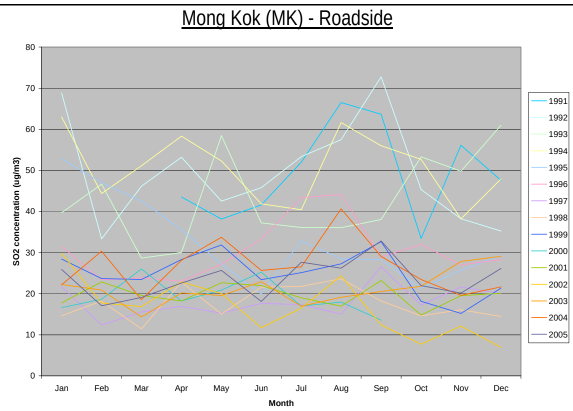


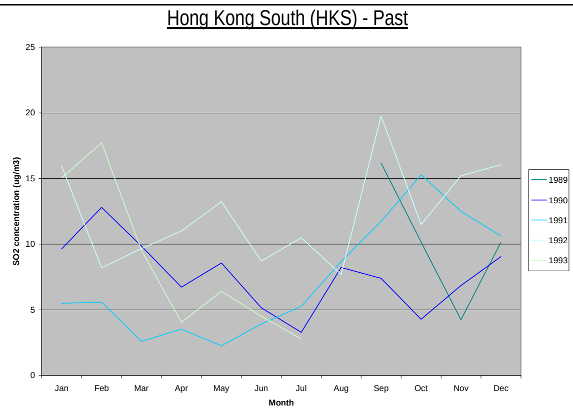
Causeway Bay (CB) - Roadside

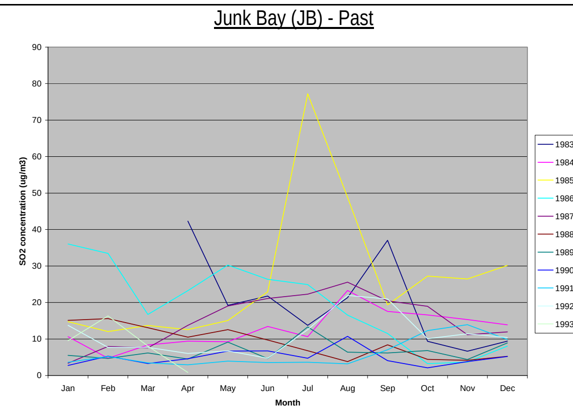


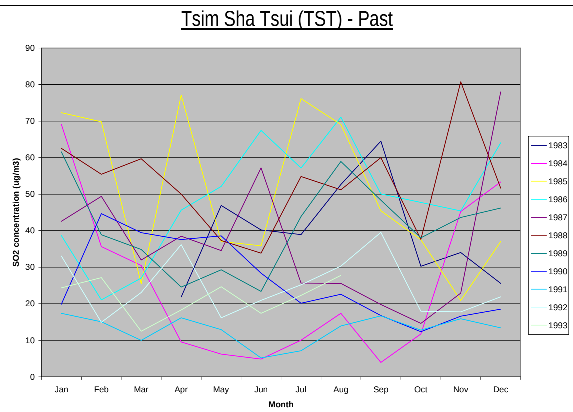
Central (CL) - Roadside











(e) Long Term Trend

Figure 3.5 shows the variations of the annual averages of SO_2 concentration from 1983 to 2005. As expected, sulphur dioxide concentrations are generally higher in urban districts near industrial areas like Kwai Chung, Tsuen Wan and Kwun Tong, and lower in rural and residential areas such as Tap Mun, Eastern and Tai Po.

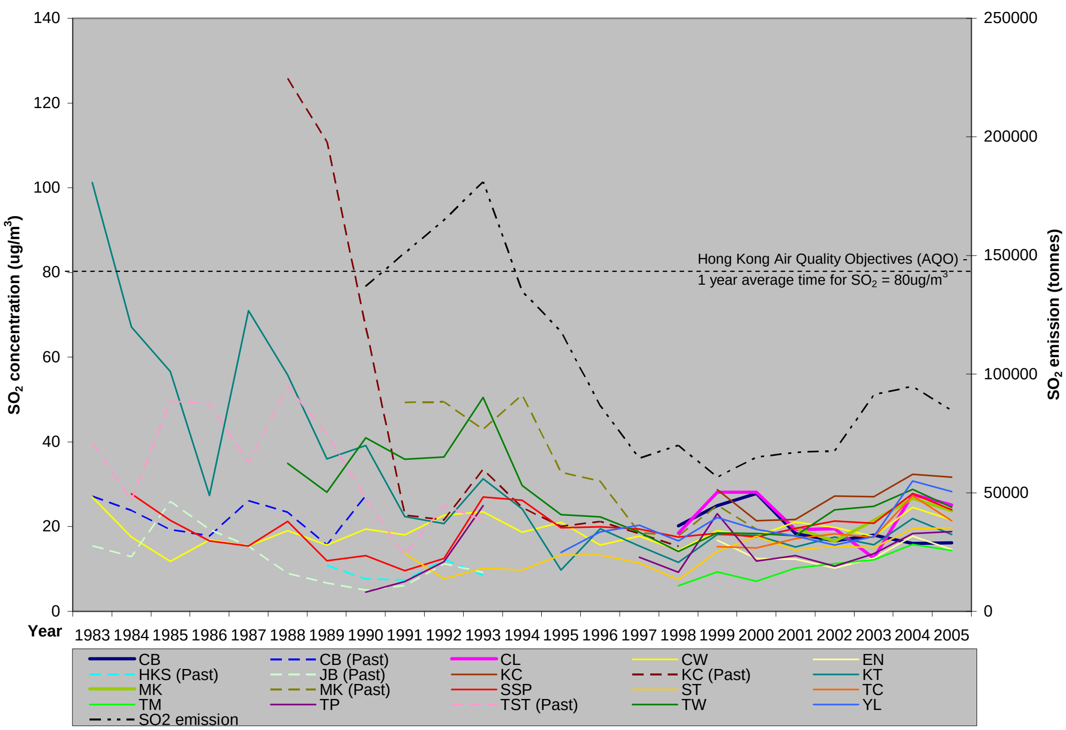
Sulphur dioxide levels at most stations in the network had shown a general decrease since 1983. The trend to a certain extent reflects the social and economic activities, and especially the industrial activities in Hong Kong. In general, sulphur dioxide concentrations have been decreasing in the past years both in industrial and urban areas. The decrease is obvious at stations near industrial areas of Kwai Chung and Kwun Tong. At Kwai Chung, levels have fallen dramatically since the first measurements in 1988. There was a sharp reduction in levels (from 1990 to 1991) at all industrial sites after the implementation of the Air Control (Fuel Restriction) Regulations in July 1990 of the restriction in sulphur content of industrial fuels. The Regulations ban the use of fuel oil with a sulphur content of more than 0.5% by weight or a viscosity more than 6 centistokes. In addition, the decrease is partly due to proper land use planning and the migration of the industries to China in the past years since 1990s.

However, sulphur dioxide concentrations at all stations have either increased since 1991 or the rate of decrease has been reduced. Since the implementation of the Air Pollution Control (Fuel Restriction) Regulations in 1990 for cutting sulphur content of industrial fuels and the Air Pollution Control (Motor Vehicle Fuel) Regulations in 1995 (April 1995) for controlling motor vehicle fuel quality, SO_2 concentrations in Hong Kong have reduced and remained at levels well below the annual AQO limit of $80\mu g/m^3$.

Besides, improvement was also seen in 1998 after the tightening of the sulphur content of automobile diesel from 0.2% to 0.05% from April 1997. By further tightening the vehicle sulphur content in law and the ultra-low sulphur diesel (0.005% sulphur content) is being widely available starting from July 2000, the average SO_2 concentration at roadside has been dropping. At present, the roadside level of SO_2 are very close to the average Hong Kong level indicating that contribution of SO_2 from vehicle emissions has become less important.

Although there has gentle rising trends over the past several years which could be attributed to the increases in emissions from local power plants as well as from sources in the neighbouring region, the SO_2 pollution should become less significant in the future with the continual control efforts on various emission sources.

Figure 3.5 Annual Averages of SO_2 Concentration from 1983 to 2005



3.4.2 Nitrogen Oxides (NO_x), Nitric Oxide (NO) and Nitrogen Dioxide (NO_2)

(a) Health Effect

Of the two nitrogen oxides, nitrogen dioxide is the pollutant of greater concern as in sufficient concentration it may attack the respiratory system. It can cause irritation of the lungs, especially for those with existing respiratory problems, and in children, impair lung development. NO_2 can aggravate the acute and chronic respiratory diseases. Long-term exposure to NO_2 can lower a person's resistance to respiratory infections and aggravate existing chronic respiratory diseases. Nitrogen dioxide also takes part in photochemical reactions that generate ozone and paroxyacetyl nitrate (PAN). For these reasons, the Air Quality Objectives for nitrogen oxides relate to nitrogen dioxide. Due to the interrelationship between the two oxides, the concentrations of NO are also reported, and for completeness, those of total NO_x.

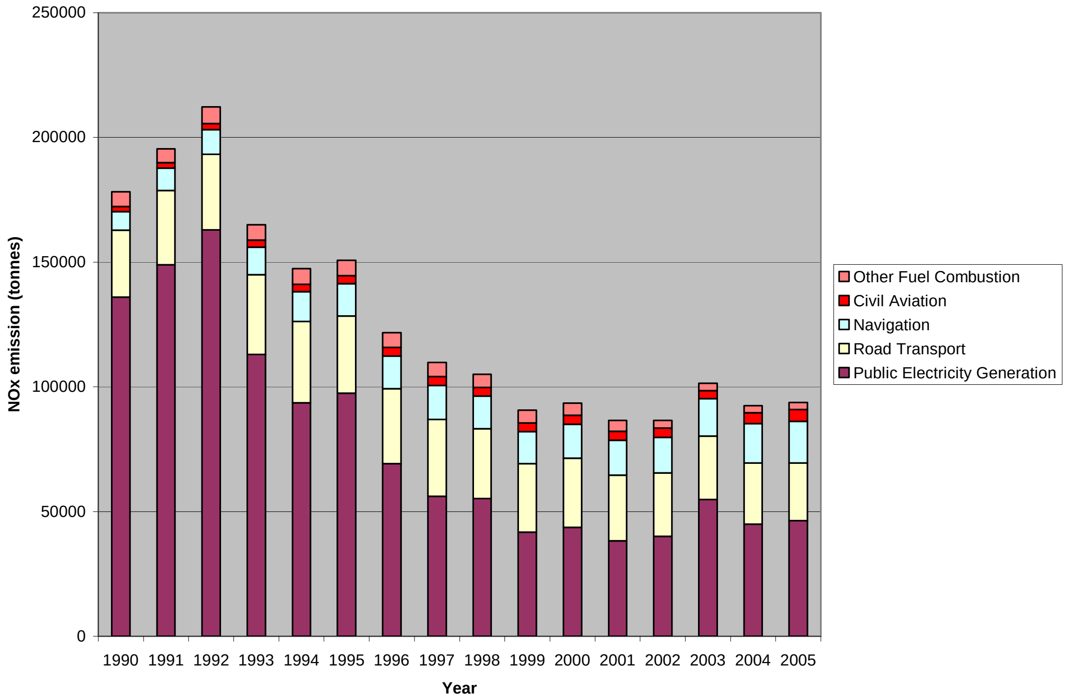
NO_2 also has an effect on materials such as the corrosion of metals and the degradation of rubber, as well as an adverse effect on vegetation. NO_2 gas may be further oxidized to form nitric acid, which can acidify rain. NO_2 absorbs light in the visible range and therefore contributes to reduction in visibility.

(b) Source

Total nitrogen oxides (NO_x) are defined as the sum of nitric oxide and nitrogen dioxide concentrations. NO_x may be produced by mankind or nature. The major anthropogenic source is fuel combustion. During combustion, oxides of nitrogen (NO_x), consisting of nitric oxide (NO) and NO_2, are formed. Nitric oxide (NO) is a colourless gas which is a reactive air pollutant emitted from diesel vehicles and other combustion sources. In the presence of hydrocarbons and sunlight, NO changes rapidly to the more harmful nitrogen dioxide (NO_2) by subsequent oxidation in the atmosphere. The relative concentrations of the two oxides in air depend on the amounts of the chemical oxidants and reactive hydrocarbons, insolation levels and the reaction time. As NO and NO_2, may convert to each other, considering total NO_x emissions allows the total potential impact of the major oxidized nitrogen species to be determined.

The natural sources of NO_x emissions include forest fires, lightning and soil bacteria. These natural emissions of NO_x are usually small compared to the anthropogenic emissions. Anthropogenic sources of NO_x include automobiles, thermal power plants, incineration and aircraft. Similar to sulphur dioxide, most of the NO_x emissions in Hong Kong are attributable to electricity generation (near 50%). In urban areas, vehicles (about 25%), especially diesel vehicles, are the most important sources due to the proximity to the receptors. NO_x emissions from motor vehicles are of greater concern due to their dominant impact on the roadside air quality, especially in windless days. Figure 3.6 shows the NO_x emissions from man made sources.

Figure 3.6 NO_x Emissions from Man Made Sources (1990-2005)



(c) Compliance on Air Quality Objectives

For protecting the public health, Hong Kong has established three objective limits for NO_2: the hourly (300µg/m^3), 24-hourly (150µg/m^3) and the annual (80µg/m^3) standards. The NO_2 concentrations in Hong Kong have remained at a fairly high level especially recorded in roadside stations. The accumulation and photochemical oxidation of nitric oxide from vehicular emissions under calm wind conditions led to frequent exceedances of the 1-hour, 24-hour and annual AQO levels at roadside stations. Table 3.7, Table 3.8 and Table 3.9 show the percentage of compliance on 1-hour, 24-hour and 1-year Air Quality Objectives of NO_2 for all monitoring stations.

Table 3.7 Percentage of Compliance on 1-hour Air Quality Objectives of NO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	100%	99.31%	99.85%	99.88%	99.41%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99.96%	100%	100%	99.95%	100%	99.98%
EN																	100%	100%	100%	100%	100%	100%	100%
KC						100%	100%	100%	99.98%	100%	100%	100%	100%	99.99%	100%	100%	99.98%	100%	99.99%	99.99%	99.93%	100%	100%
KT		100%	96.19%	93.16%	99.70%	99.63%	100%	99.98%	100%	100%	100%	100%	100%	100%	99.97%	100%	99.99%	100%	100%	100%	99.98%	100%	100%
SSP							100%	99.97%	100%	100%	100%	100%	100%	99.99%	99.98%	100%	100%	100%	100%	100%	99.96%	100%	100%
ST												100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TC																	99.95%	100%	100%	100%	100%	100%	100%
TM																100%	100%	100%	100%	100%	100%	100%	100%
TP								100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TW						100%	100%	100%	100%	100%	100%	100%	100%	99.99%	100%	100%	99.94%	100%	100%	100%	99.90%	100%	100%
YL											100%	100%	100%	100%	100%	100%	99.98%	100%	100%	100%	100%	99.97%	100%
Roadside Air Quality Monitoring Station																							
CB							99.92%	99.90%								100%	99.92%	99.99%	100%	100%	99.95%	100%	99.93%
CL																100%	99.96%	99.90%	99.92%	99.92%	99.89%	99.86%	99.88%
MK									99.97%	100%	100%	100%	100%	99.99%	99.94%	100%	99.96%	100%	100%	99.99%	99.95%	99.92%	99.99%
Past General Air Quality Monitoring Station																							
HKS								100%	100%	100%	100%												
JB			99.62%	99.39%	99.66%	100%	100%	100%	100%	100%	100%												
TST	99.98%	100%	100%																				

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

Table 3.8 Percentage of Compliance on 24-hour Air Quality Objectives of NO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	99.44%	95.86%	98.31%	99.73%	98.08%	99.71%	100%	100%	100%	100%	100%	100%	100%	100%	99.73%	99.73%	100%	100%	99.45%	99.73%	100%
EN																	100%	99.73%	100%	100%	100%	99.73%	100%
KC						100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98.90%	99.45%	99.18%	98.90%	98.90%	98.63%	100%
KT		96.99%	74.10%	77.01%	92.52%	96.17%	99.66%	99.73%	99.73%	99.45%	99.42%	100%	100%	99.73%	99.42%	99.69%	98.86%	99.66%	99.73%	98.29%	98.36%	98.91%	100%
SSP							100%	98.58%	100%	100%	99.34%	99.69%	99.71%	99.41%	99.17%	99.71%	99.45%	99.73%	100%	99.18%	99.41%	99.66%	100%
ST												100%	100%	100%	100%	100%	100%	100%	100%	100%	99.73%	100%	100%
TC																	99.27%	100%	100%	99.73%	99.18%	99.73%	100%
TM																100%	100%	100%	100%	100%	100%	100%	100%
TP								100%	100%	100%	100%	100%	100%	100%	99.71%	100%	100%	99.71%	100%	100%	99.72%	100%	100%
TW						100%	99.45%	100%	100%	100%	100%	100%	100%	100%	100%	99.72%	98.90%	99.73%	100%	99.73%	98.83%	99.45%	100%
YL											100%	100%	100%	99.73%	100%	99.72%	99.17%	100%	100%	100%	100%	99.10%	100%
Roadside Air Quality Monitoring Station																							
CB							97.18%	99.43%								93.18%	92.05%	97.81%	95.62%	96.46%	98.08%	96.99%	99.06
CL																95.40%	95.33%	97.25%	96.16%	95.62%	94.52%	91.80%	96.43%
MK									99.27%	99.17%	98.63%	98.60%	99.71%	99.44%	98.18%	99.17%	98.08%	98.91%	98.36%	98.08%	96.99%	91.80%	99.18%
Past General Air Quality Monitoring Station																							
HKS								100%	100%	100%	100%												
JB			99.11%	97.79%	98.61%	100%	100%	100%	100%	100%	100%												
TST	100%	100%	100%																				

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

Table 3.9 Percentage of Compliance on 1-year Air Quality Objectives of NO_2

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
EN																	O	O	O	O	O	O	O
KC						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
KT		O	X	X	O	X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
SSP							O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
ST												O	O	O	O	O	O	O	O	O	O	O	O
TC																	O	O	O	O	O	O	O
TM																O	O	O	O	O	O	O	O
TP								O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
TW						O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
YL											O	O	O	O	O	O	O	O	O	O	O	O	O
Roadside Air Quality Monitoring Station																							
CB							O	O								X	X	X	X	X	X	X	X
CL																X	X	X	X	X	X	X	X
MK									O	O	O	X	X	X	X	X	X	X	X	X	X	X	X
Past General Air Quality Monitoring Station																							
HKS								O	O	O	O												
JB			O	O	O	O	O	O	O	O	O												
TST	O	O	O																				

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, Causeway Bay and Mong Kok)

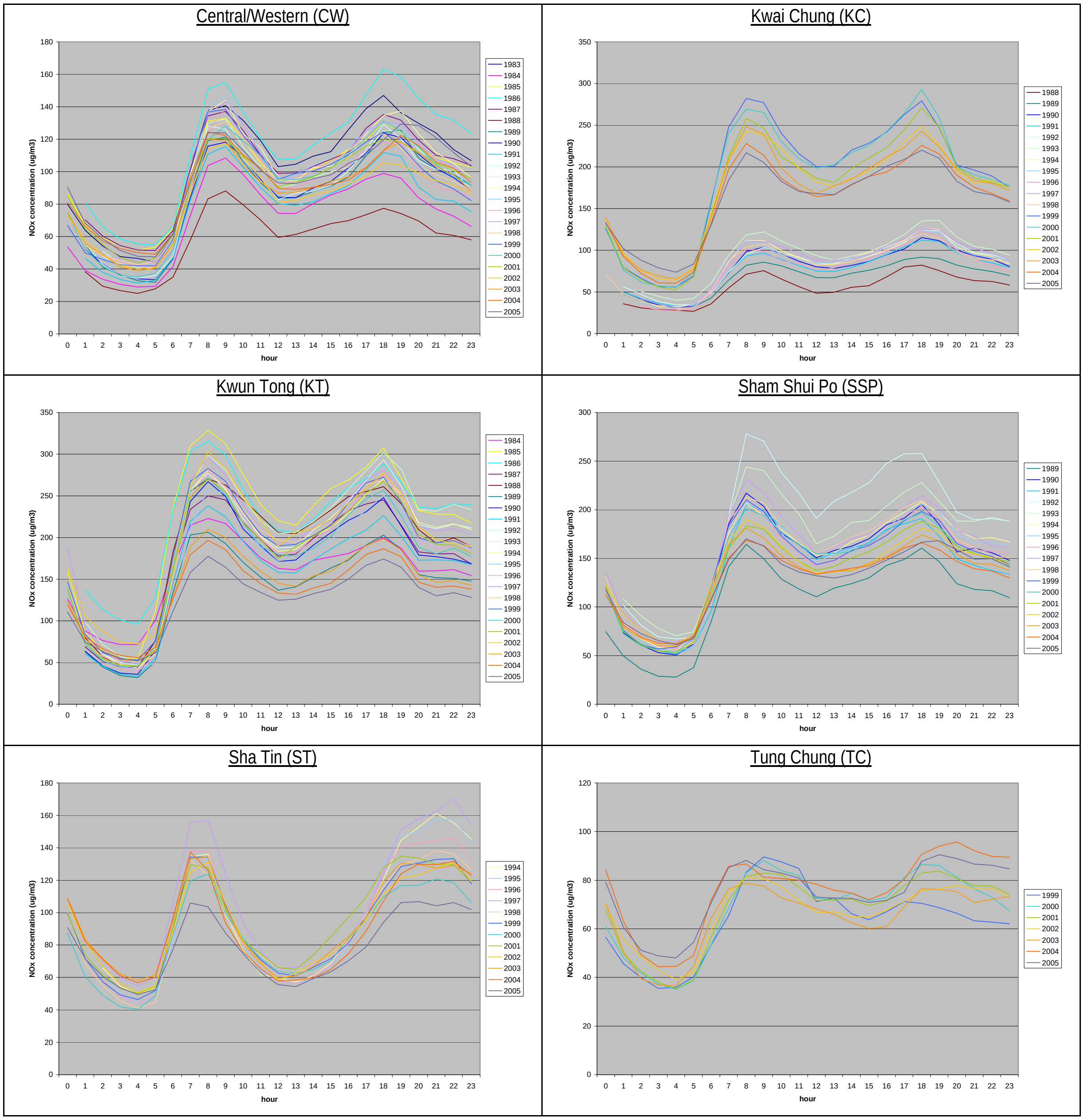
(d) Time Series Variation

- Diurnal variation

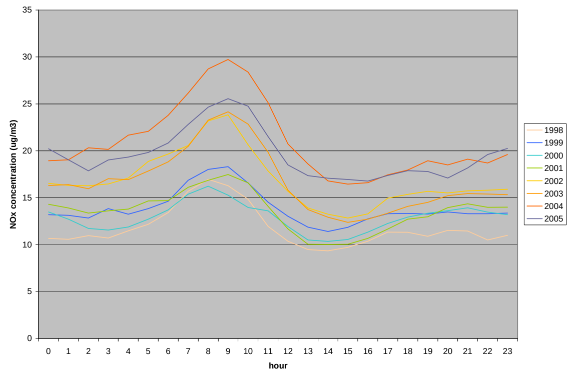
The diurnal variation of nitrogen oxides, nitric oxide and nitrogen dioxide are shown in Figures 3.7, 3.8 and 3.9 respectively. It can be seen that the twin peak pattern of NO_x, NO and NO_2 coincides with the urban traffic peaks in most of the stations. The morning peak of NO is in general higher than its afternoon peak, whilst the reverse happens for NO_2. This is probably due to the fact that the higher solar radiation levels in the afternoon encourage the oxidation of NO in the atmosphere to NO_2.

The NO_2 twin peak pattern is less distinct, and the concentrations are higher in the afternoon then in the morning. This less distinct peak structure is probably because NO_2 is formed by oxidation of NO primarily with ozone in the atmosphere. Hence, it shows less temporal relationship to emission sources. The greater concentrations of NO_2 in the afternoon than the morning occur because the higher insolation levels in the afternoon produce more ozone.

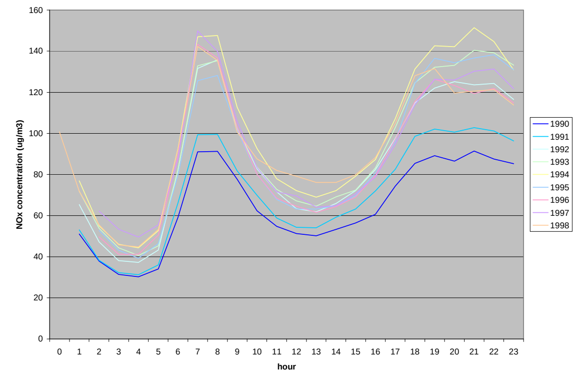
Figures 3.7 Diurnal NO_x Variation of Air Monitoring Stations (from 1983 to 2005)



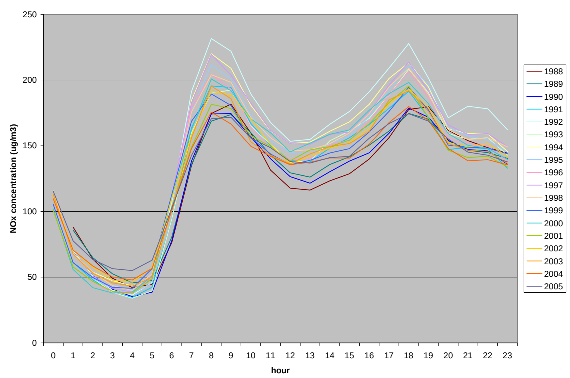
Tap Mun (TM)



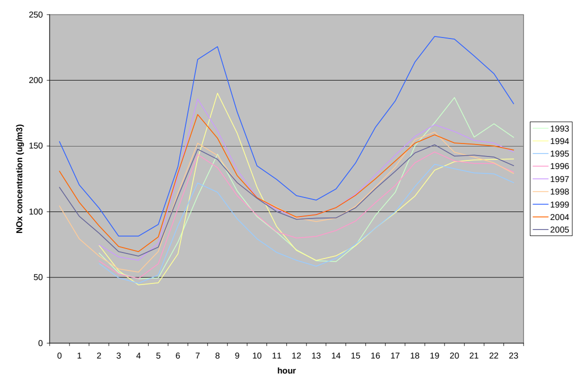
Tai Po (TP)



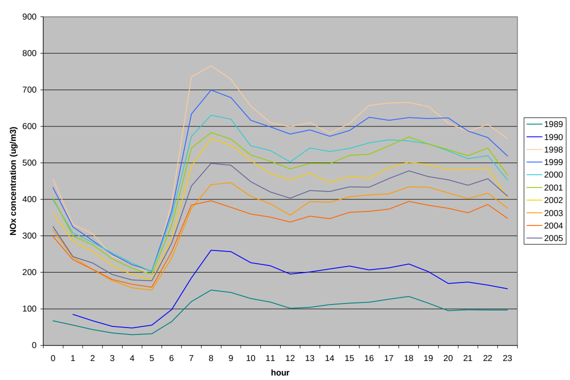
Tsuen Wan (TW)



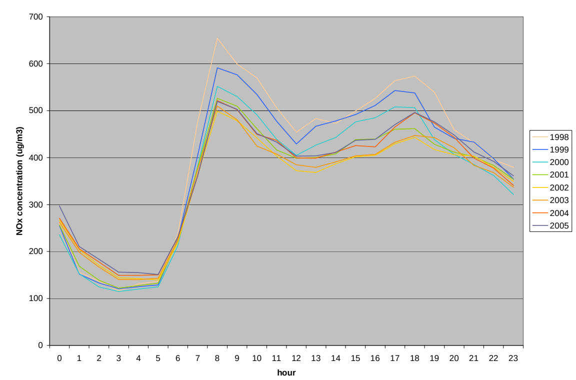
Yuen Long (YL)



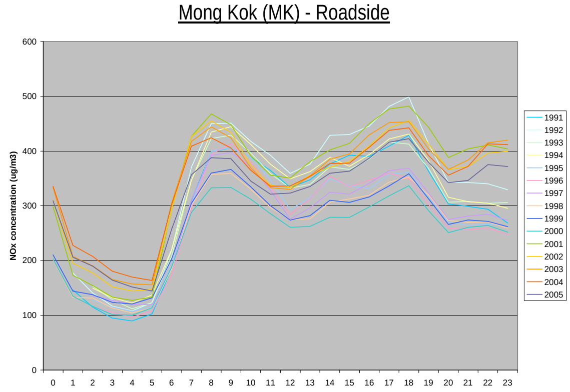
Causeway Bay (CB) - Roadside



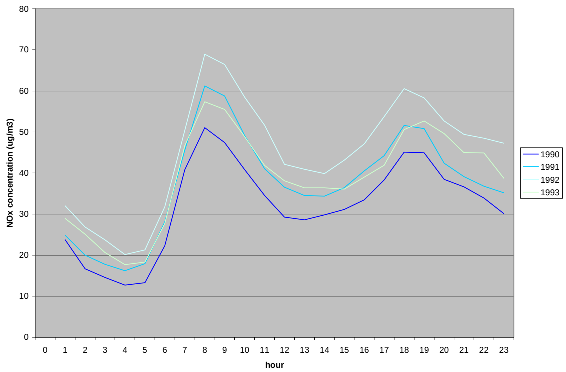
Central (CL) - Roadside



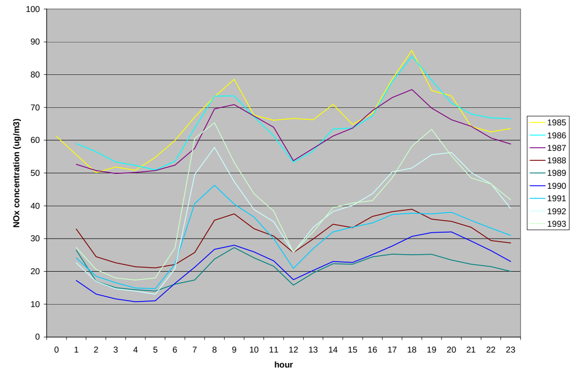
Mong Kok (MK) - Roadside



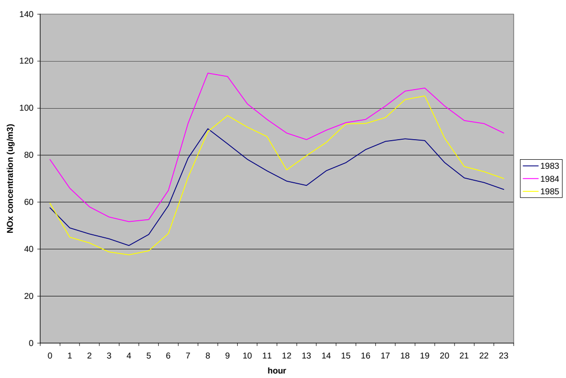
Hong Kong South (HKS) - Past



Junk Bay (JB) - Past

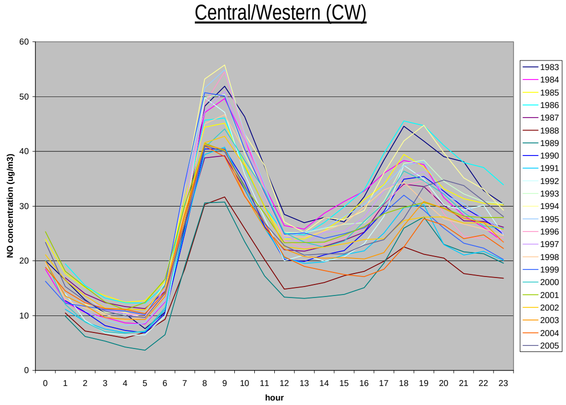


Tsim Sha Tsui (TST) - Past

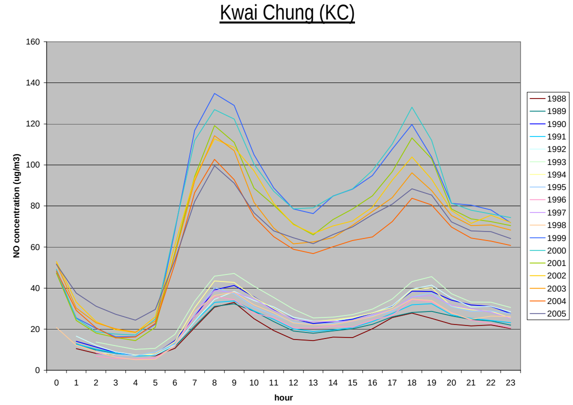


Figures 3.8 Diurnal NO Variation of Air Monitoring Stations (from 1983 to 2005)

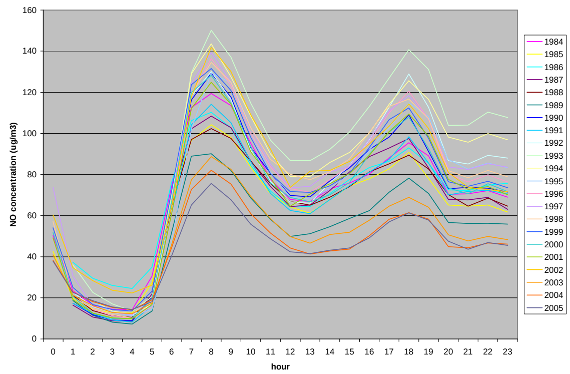
Central/Western (CW)



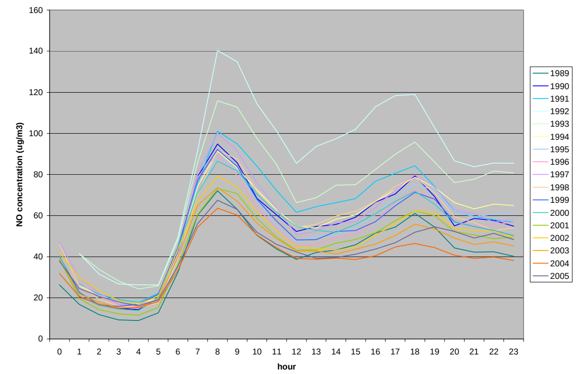
Kwai Chung (KC)



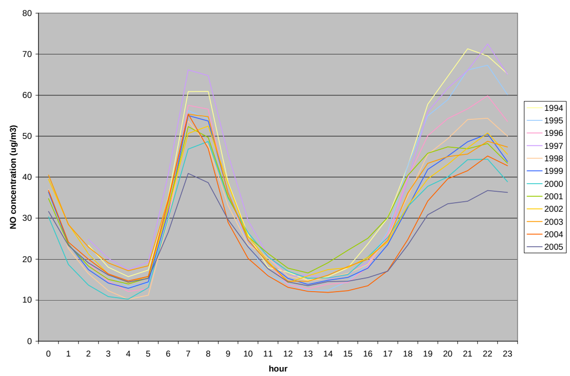
Kwun Tong (KT)



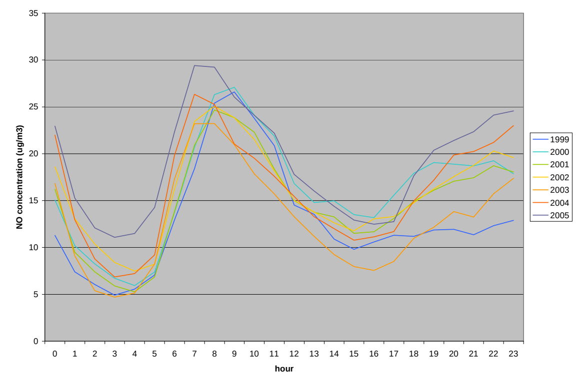
Sham Shui Po (SSP)



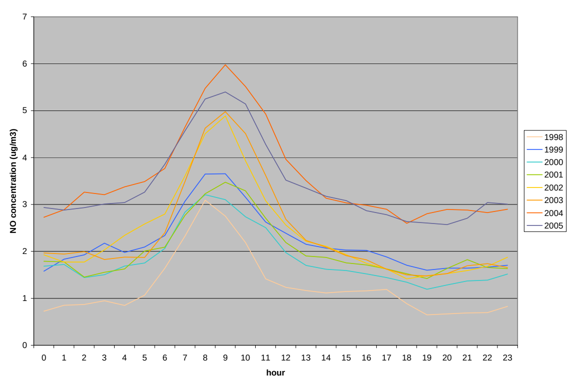
Sha Tin (ST)



Tung Chung (TC)



Tap Mun (TM)



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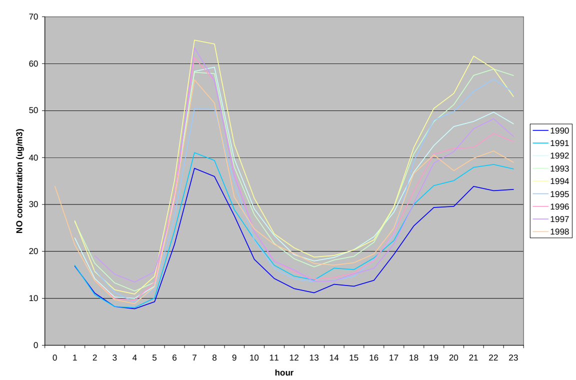

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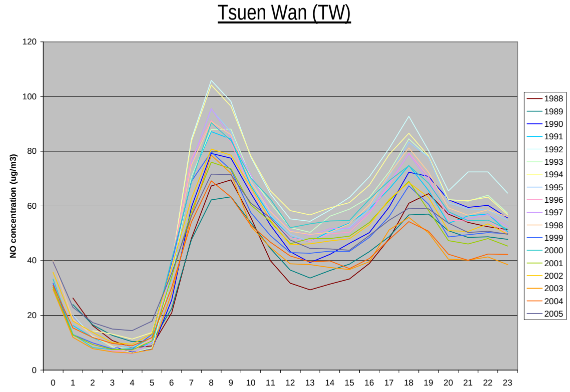

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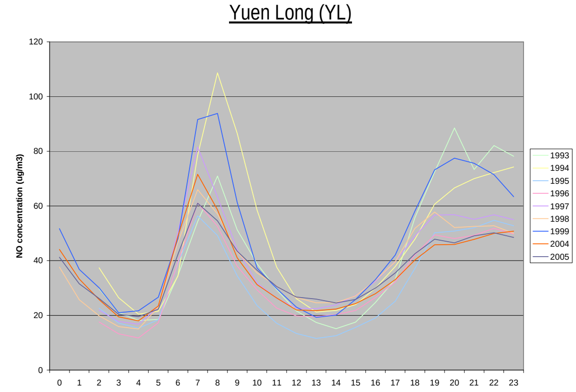
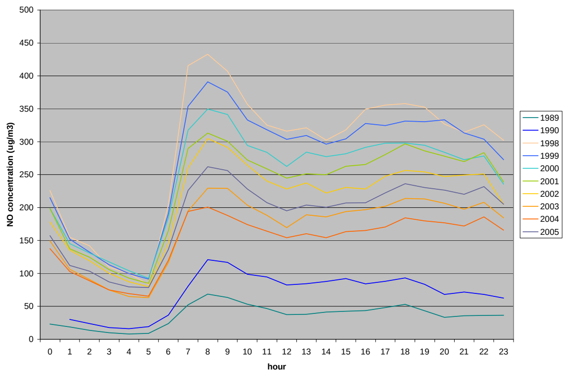
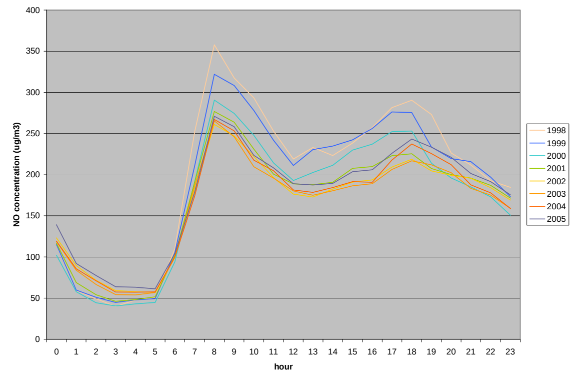


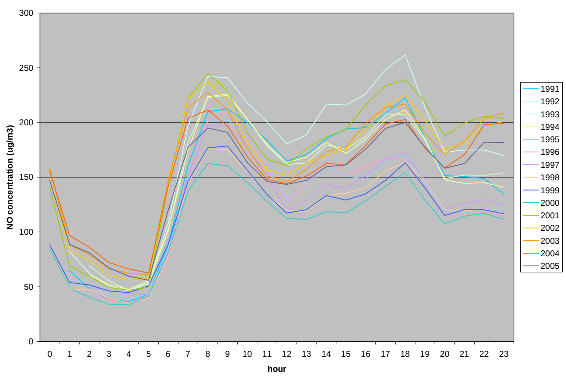
Causeway Bay (CB) - Roadside



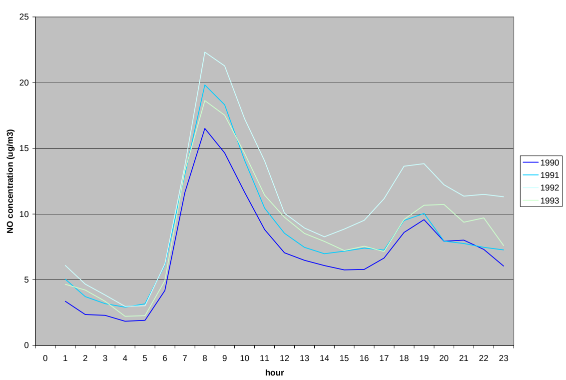
Central (CL) - Roadside



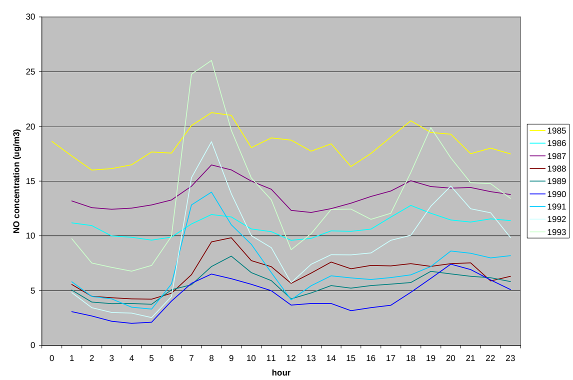
Mong Kok (MK) - Roadside



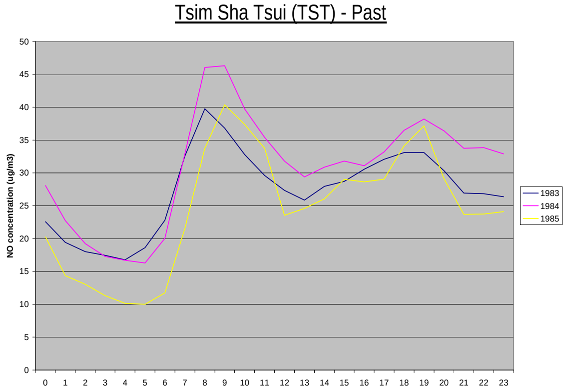
Hong Kong South (HKS) - Past



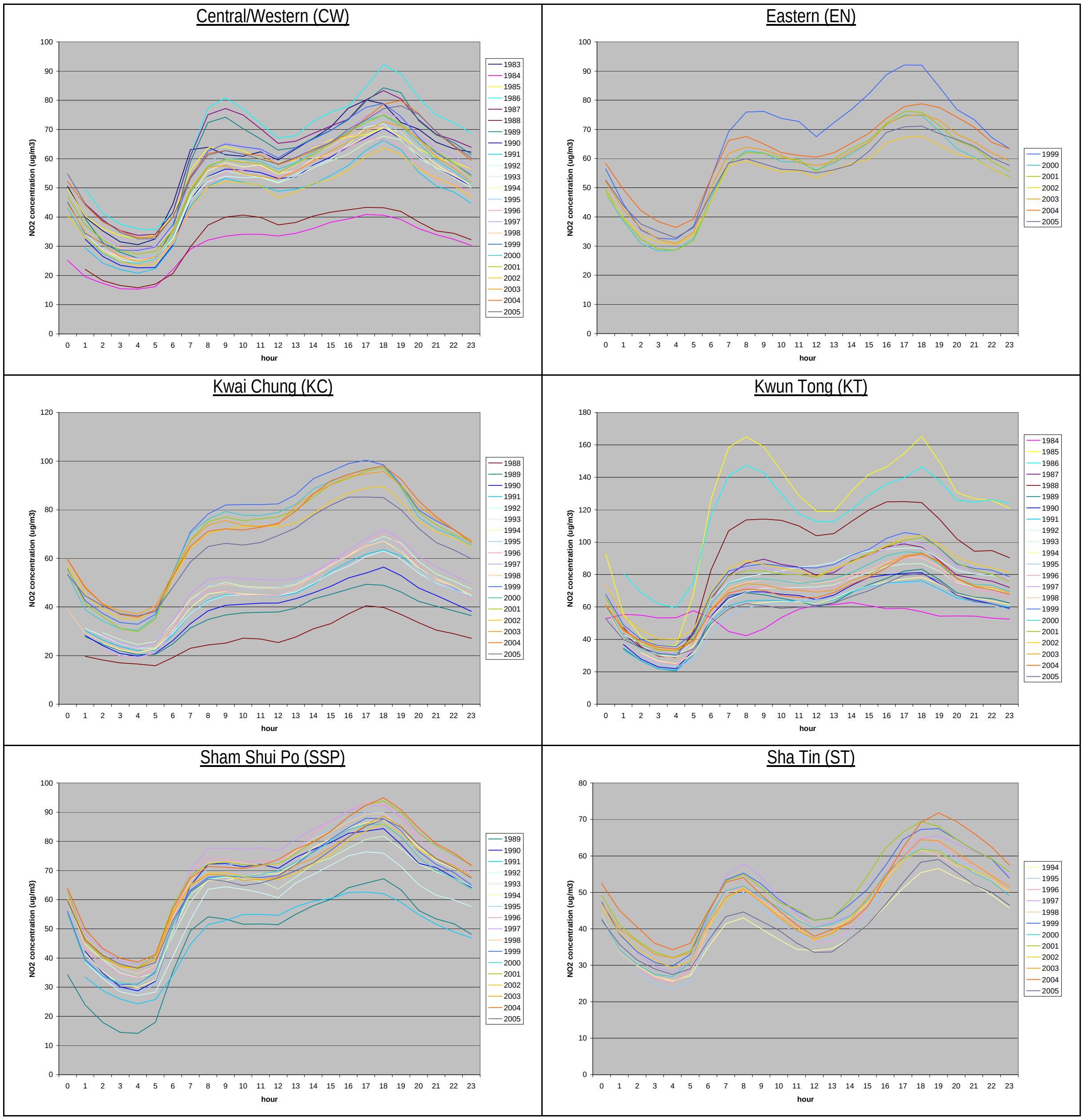
Junk Bay (JB) - Past



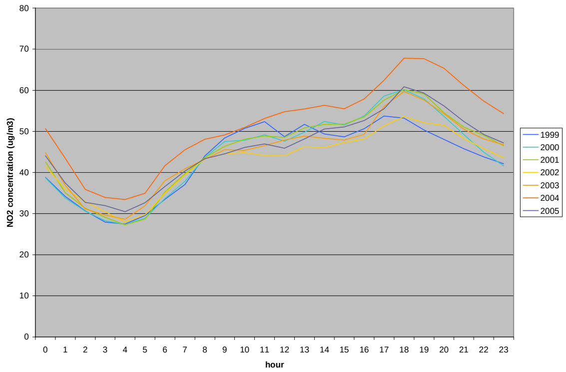
Tsim Sha Tsui (TST) - Past



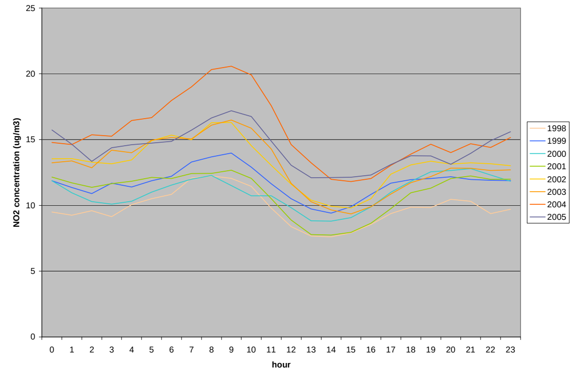
Figures 3.9 Diurnal NO_2 Variation of Air Monitoring Stations (from 1983 to 2005)



Tung Chung (TC)



Tap Mun (TM)



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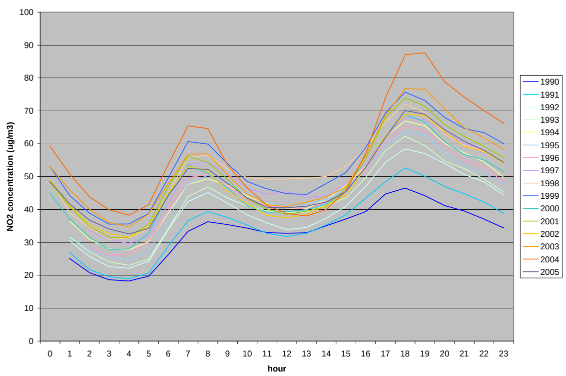
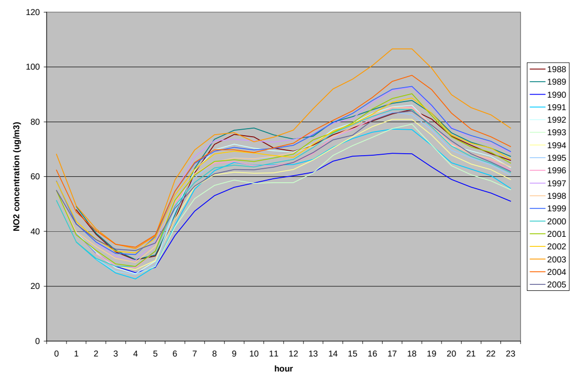
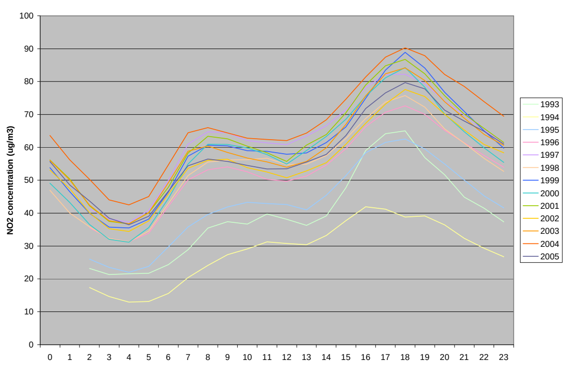


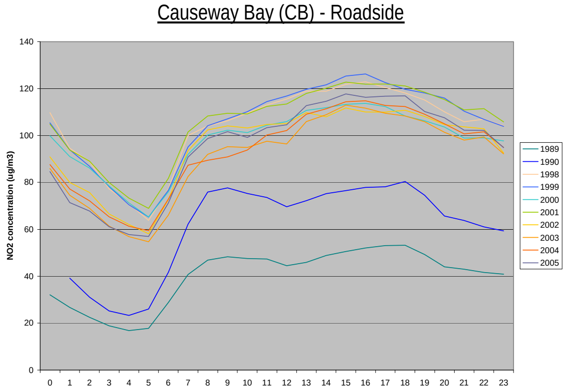
Tsuen Wan (TW)



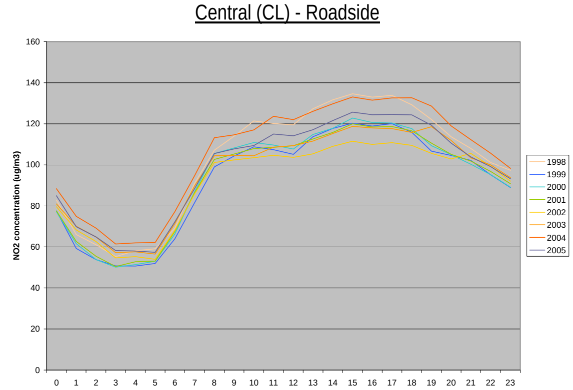
Yuen Long (YL)



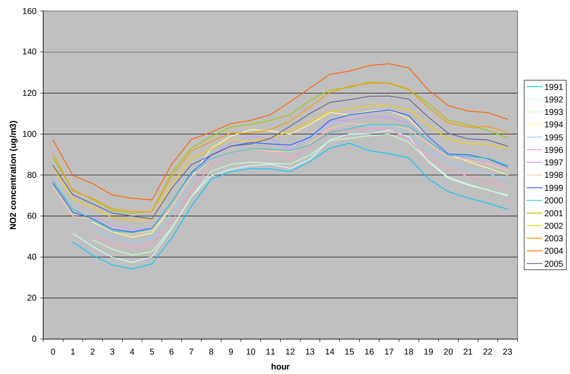
Causeway Bay (CB) - Roadside



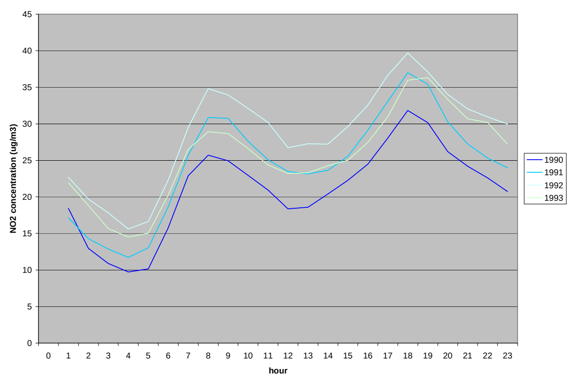
Central (CL) - Roadside



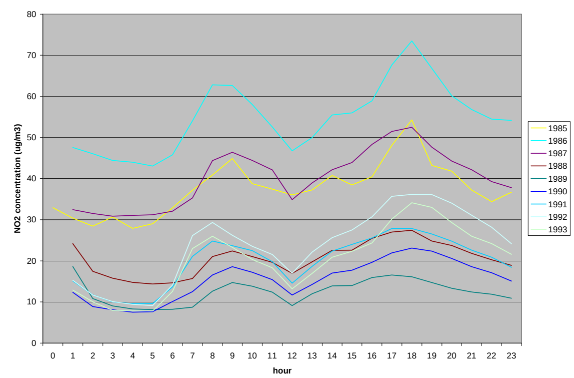
Mong Kok (MK) - Roadside



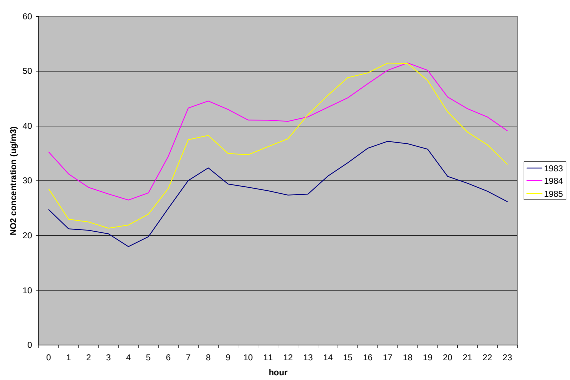
Hong Kong South (HKS) - Past



Junk Bay (JB) - Past



Tsim Sha Tsui (TST) - Past

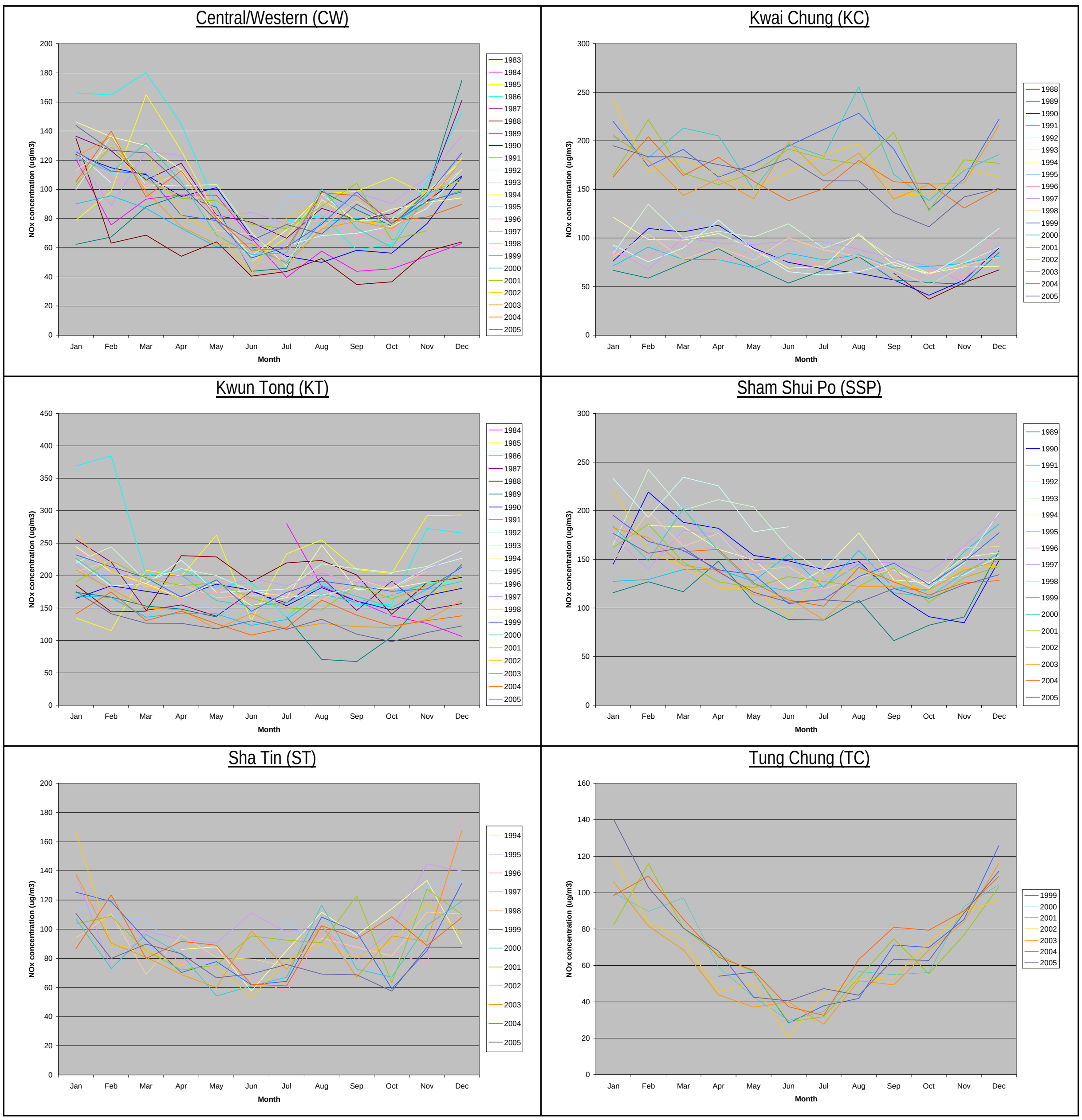


- Monthly variation

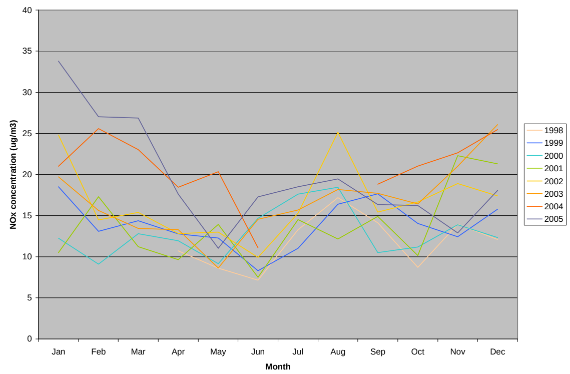
Monthly trends of NO_x, NO and NO_2 at all sites from 1983 to 2005 are depicted in Figures 3.10, 3.11 and 3.12 respectively. Similar to sulphur dioxide, there was no distinct monthly variation in NO_x and NO among the stations except Tung Chung.

It can be seen that the NO_2 levels were general lower in summer months and higher in winter months as the heavy rainfall in summer washed out the soluble NO_2. In addition, this is probably due to the fact that the atmosphere was generally more stable in winter and there was more sunshine.

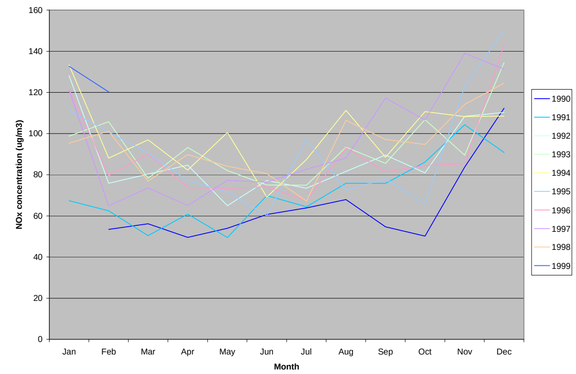
Figures 3.10 Monthly NO_x Variation of Air Monitoring Stations (from 1983 to 2005)



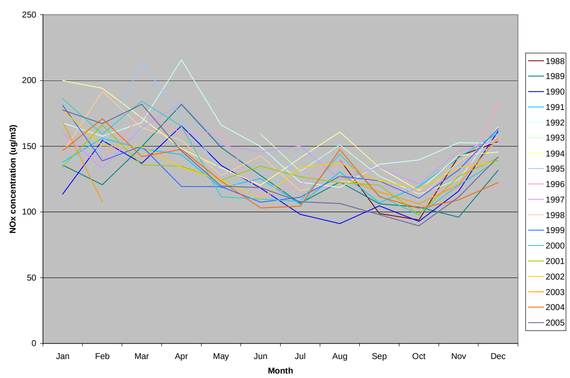
Tap Mun (TM)



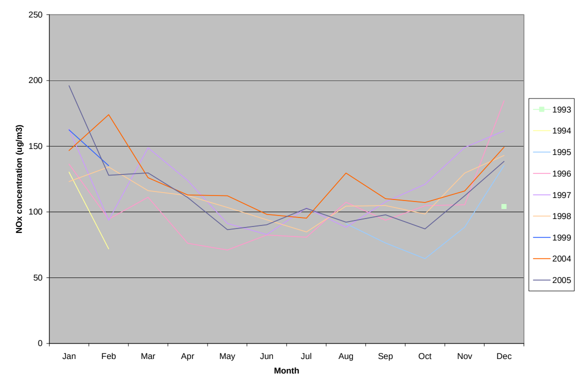
Tai Po (TP)



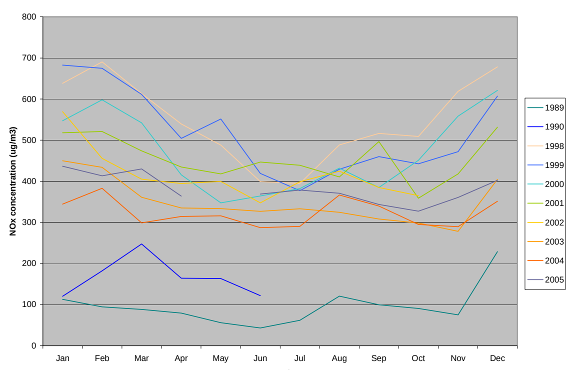
Tsuen Wan (TW)



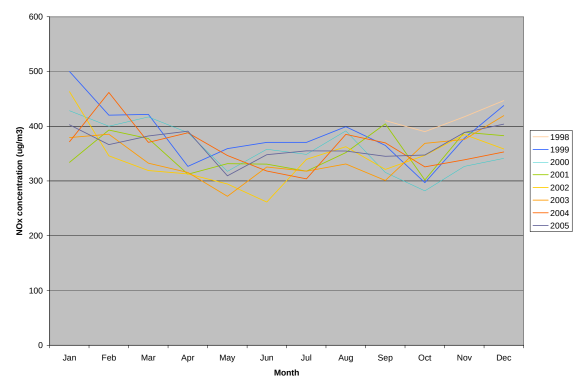
Yuen Long (YL)



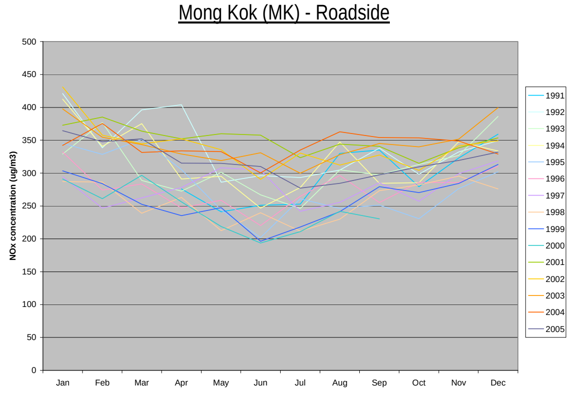
Causeway Bay (CB) - Roadside

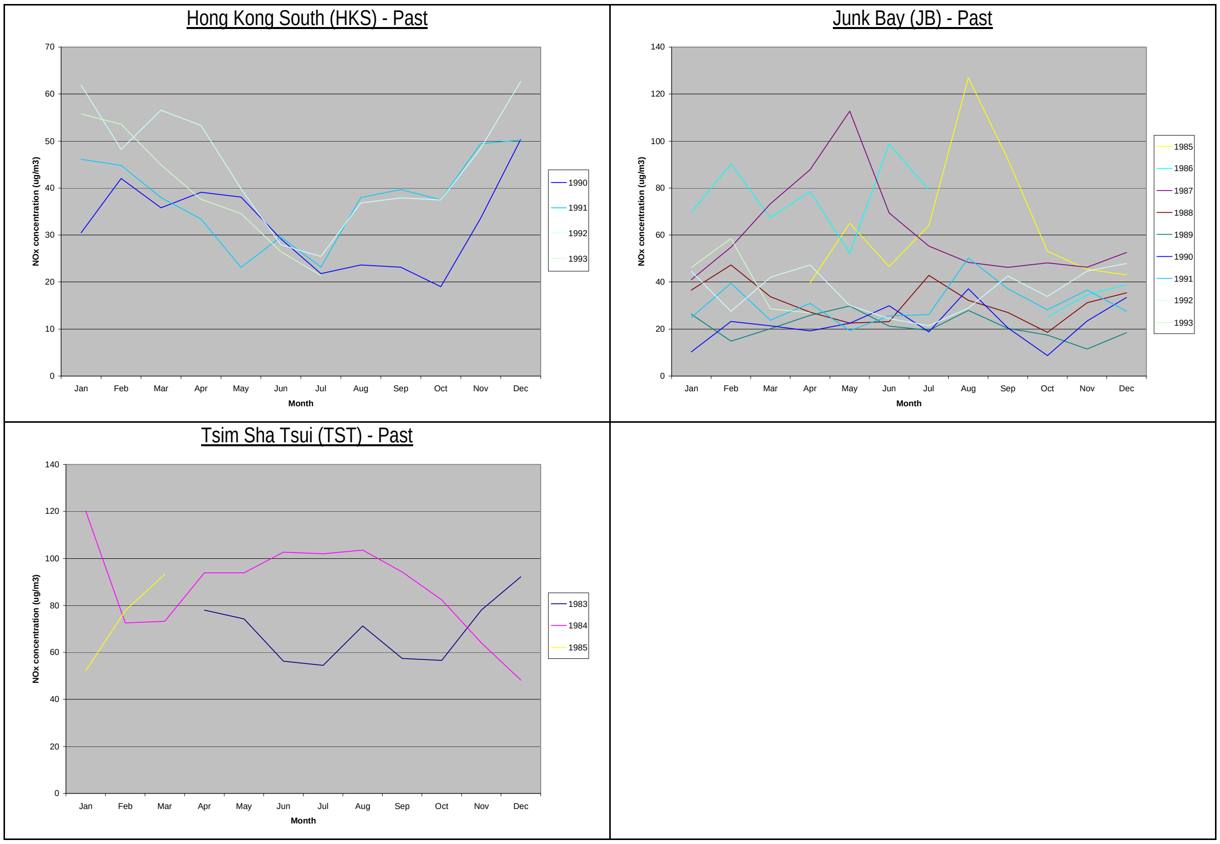


Central (CL) - Roadside

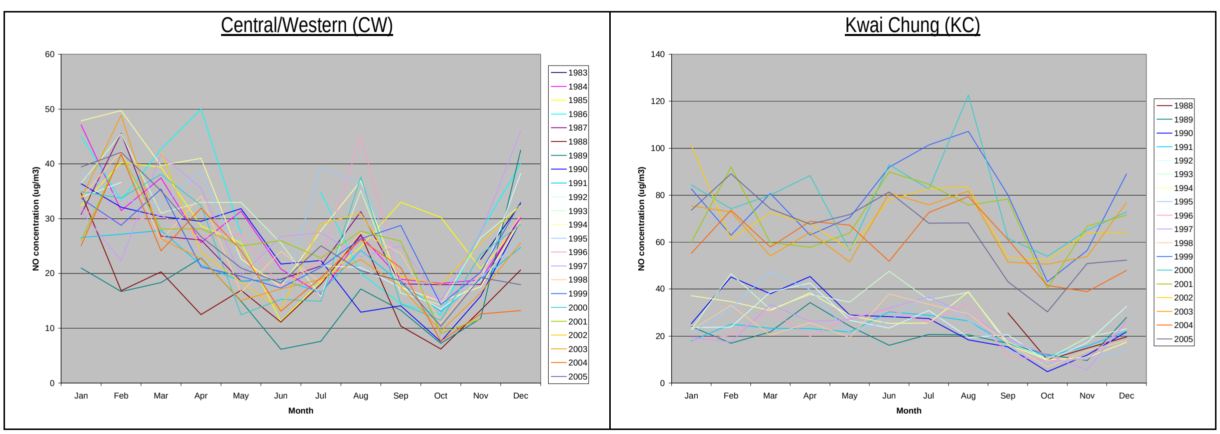


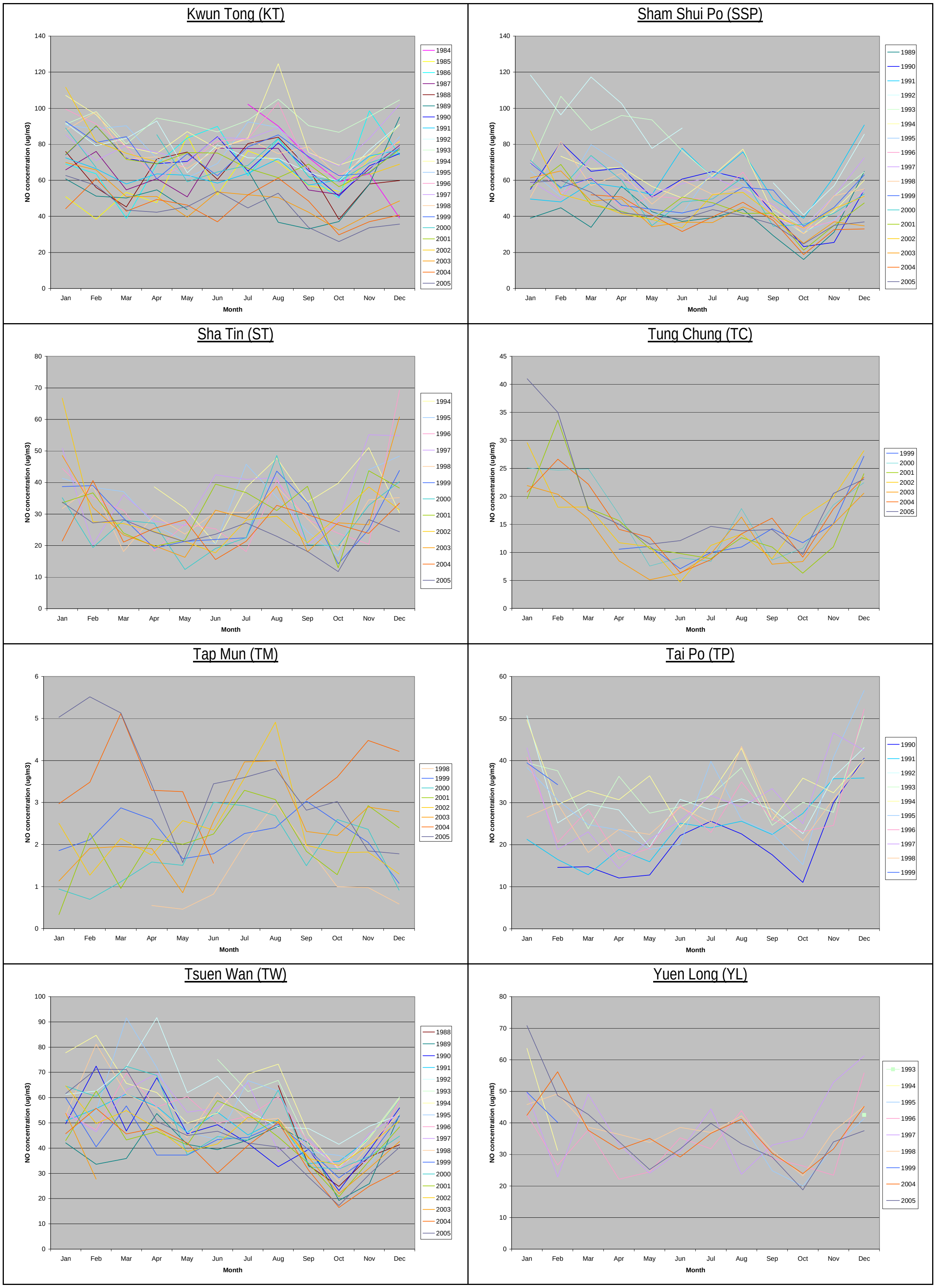
Mong Kok (MK) - Roadside





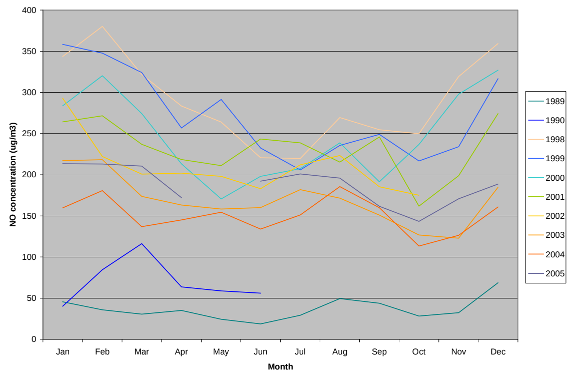
Figures 3.11 Monthly NO Variation of Air Monitoring Stations (from 1983 to 2005)



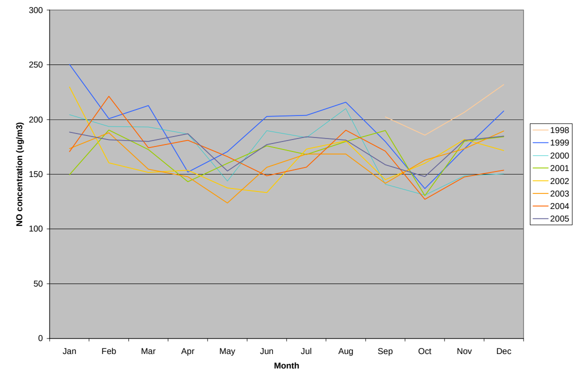


Kwun Tong (KT)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Sham Shui Po (SSP)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Sha Tin (ST)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Tung Chung (TC)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1999 2000 2001 2002 2003 2004 2005
Tap Mun (TM)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1998 1999 2000 2001 2002 2003 2004 2005
Tai Po (TP)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
Tsuen Wan (TW)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Yuen Long (YL)
NO concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1993 1994 1995 1996 1997 1998 1999 2004 2005

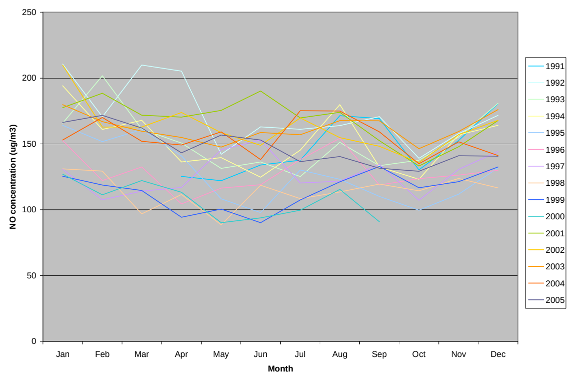
Causeway Bay (CB) - Roadside



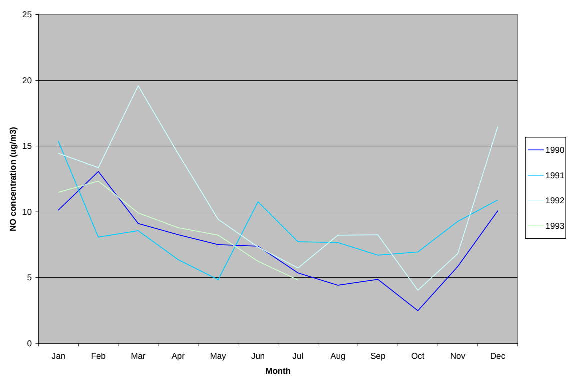
Central (CL) - Roadside



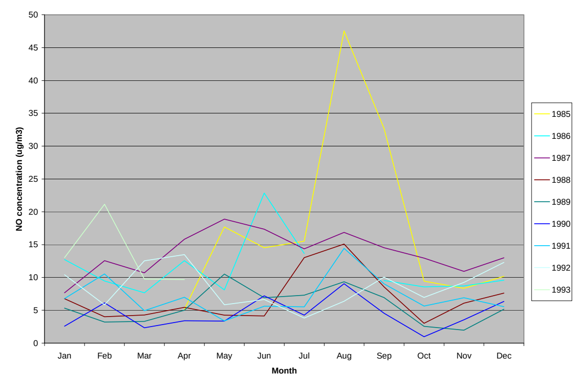
Mong Kok (MK) - Roadside



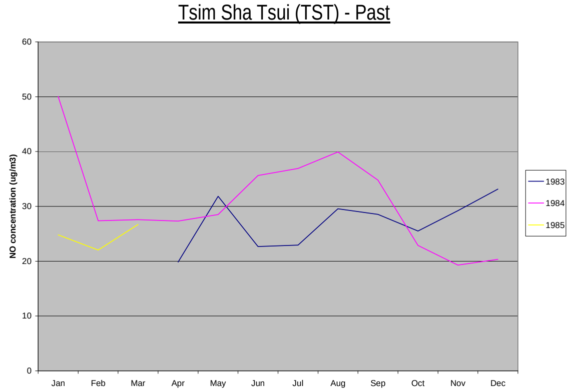
Hong Kong South (HKS) - Past



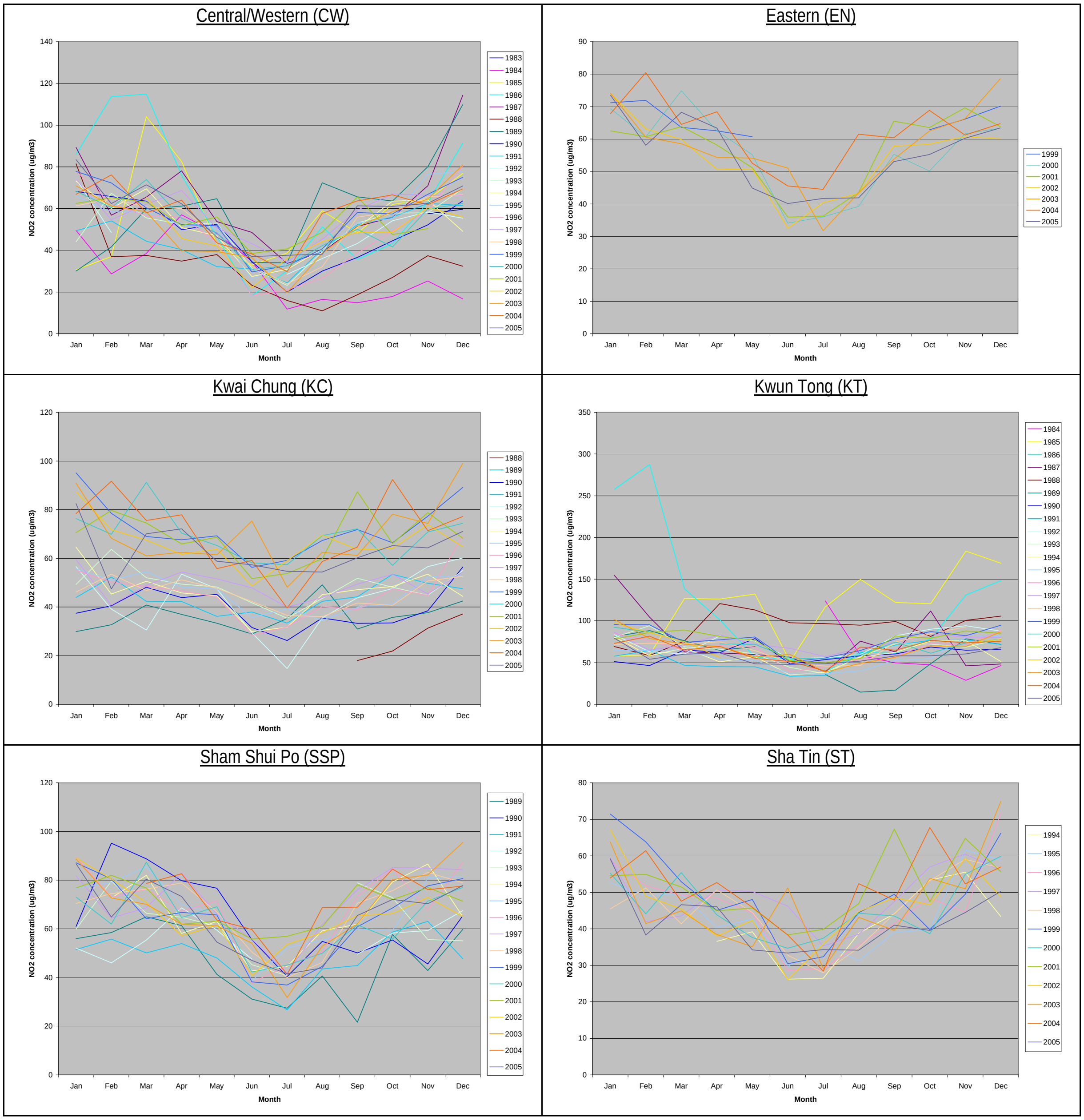
Junk Bay (JB) - Past



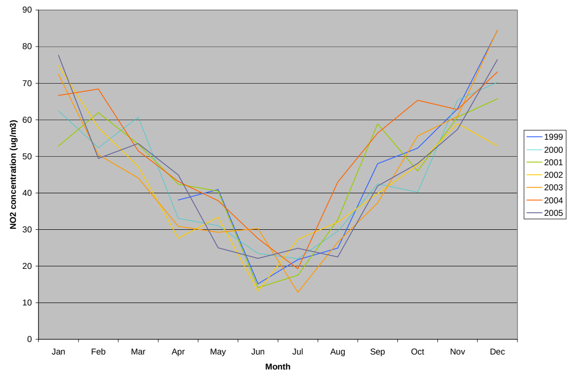
Tsim Sha Tsui (TST) - Past



Figures 3.12 Monthly NO_2 Variation of Air Monitoring Stations (from 1983 to 2005)



Tung Chung (TC)



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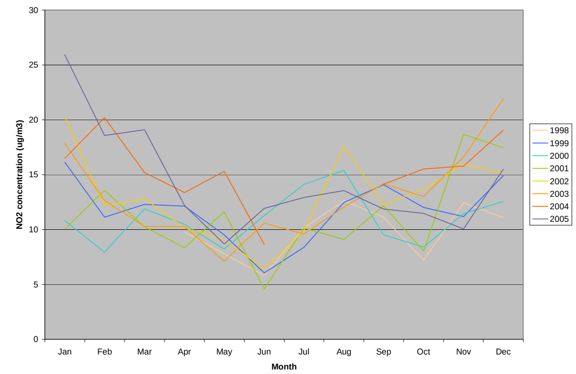

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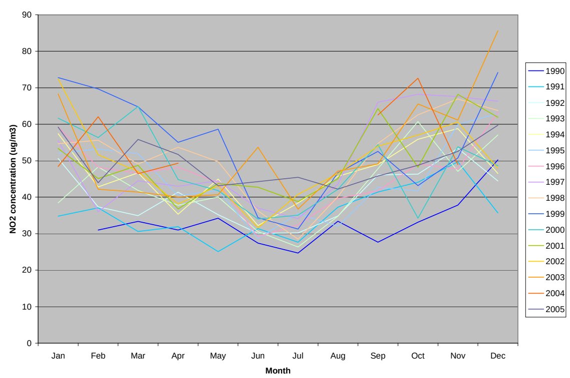
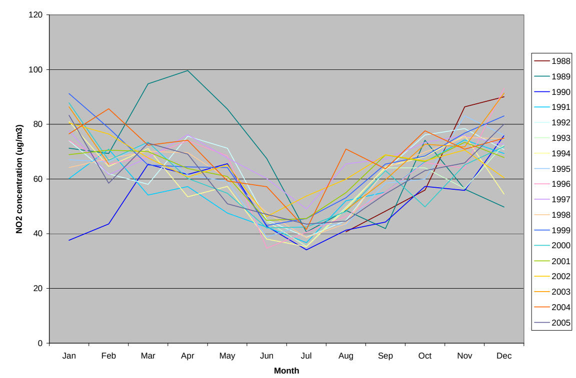
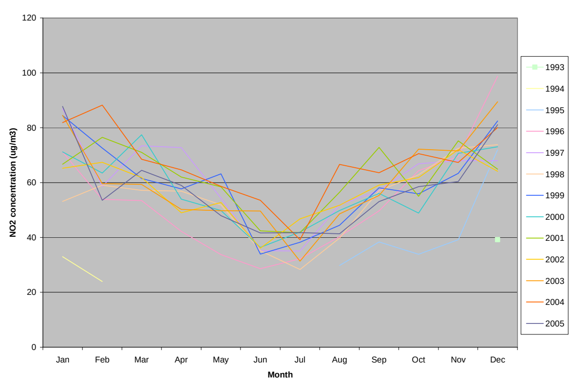


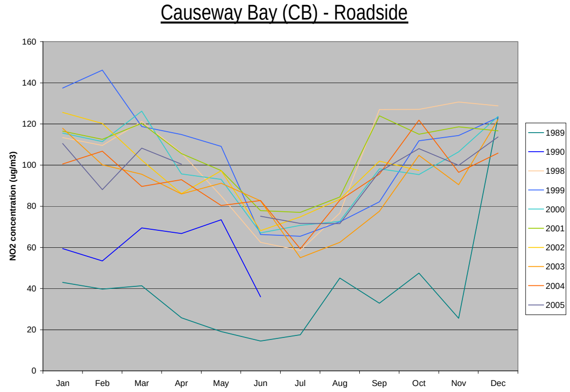
Tsuen Wan (TW)



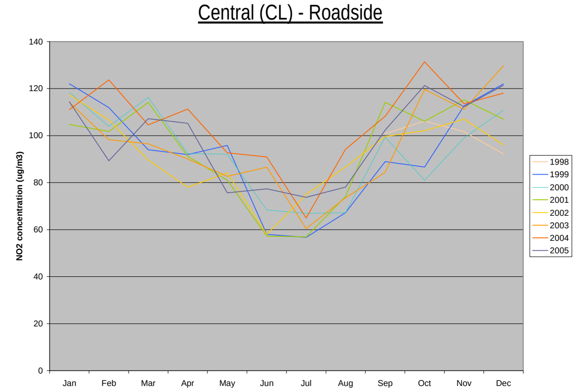
Yuen Long (YL)

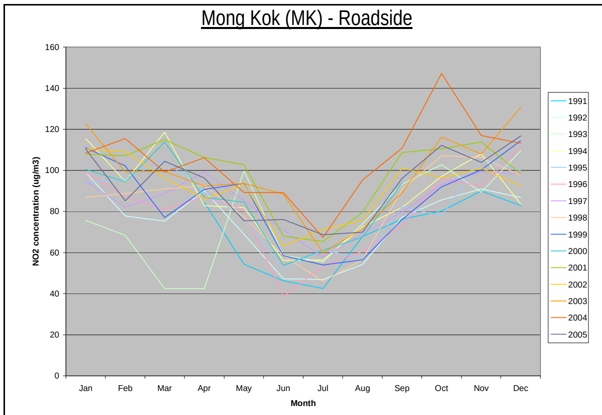


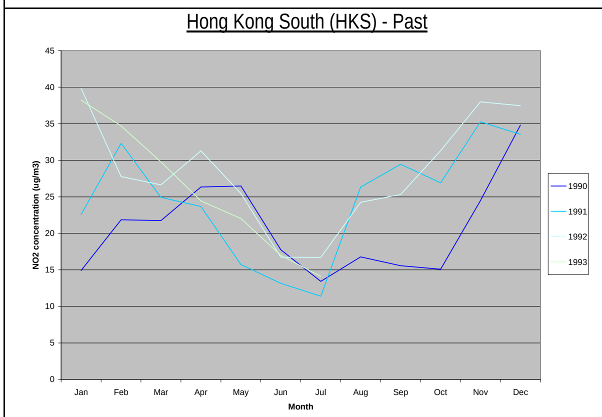
Causeway Bay (CB) - Roadside

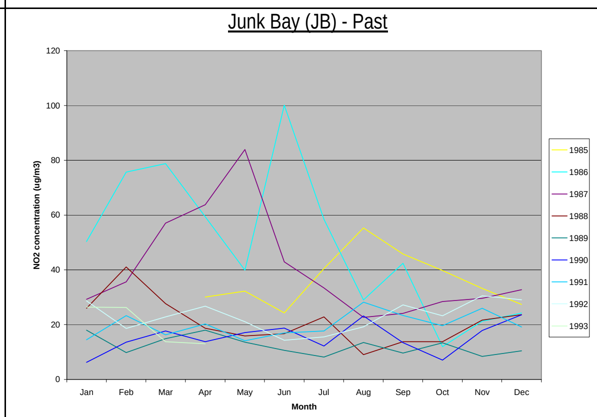


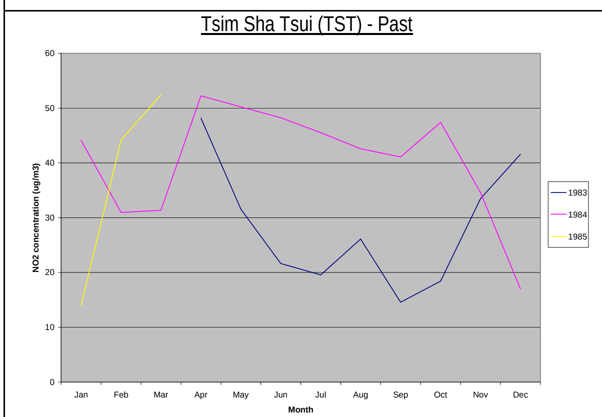
Central (CL) - Roadside











(e) Long Term Trend

Figures 3.13, 3.14 and 3.15 show the variations of the annual averages of NO_x, NO and NO_2 concentration from 1983 to 2005 respectively. The annual average of NO_x in urban areas has increased slightly since 1996 but levelled off after 1999. The annual average of NO_x in urban areas has remained quite constant over the past decade, which reflects a reduction in emission levels as a result of vehicle emission control measures implemented over the past years. As would be expected, Tap Mun rural station usually measured lower levels of NO_x, NO and NO_2 due to the lack of mobile sources there.

Contrary to SO_2, the overall NO_2 level exhibited an unmistakable increasing trend in the past years. NO_2 is mainly formed from the oxidation of nitric oxide, a major component of NO_x. The concentrations of NO_2 are dependent on the levels of NO_x as well as the concentrations of ozone and VOCs in the ambient air which promotes the conversion of nitric oxide to NO_2. Since 1990, the NO_2 levels in urban and new town areas have exhibited slow rising trends similar to those of ozone. As shown in Figure 3.15, concentrations of NO_2 decreased to the lowest in 1990 and stabilized since 1993 in industrial areas. A steady increase in annual concentrations has, however, occurred in other areas because of the increase of traffic volume of diesel vehicles. The situation is particularly poor at roadside stations. Due to closer proximity to the sources, the levels at roadsides were very close to or even higher than the permissible limits in recent years. A continual non-compliance of the relevant annual AQO limit has been observed since 1994. Unless stringent control of the emissions from motor vehicles is imposed, the generally increasing trend of NO_2 would likely persist in the future years.

Figure 3.13 Annual Averages of NO_x Concentration from 1983 to 2005

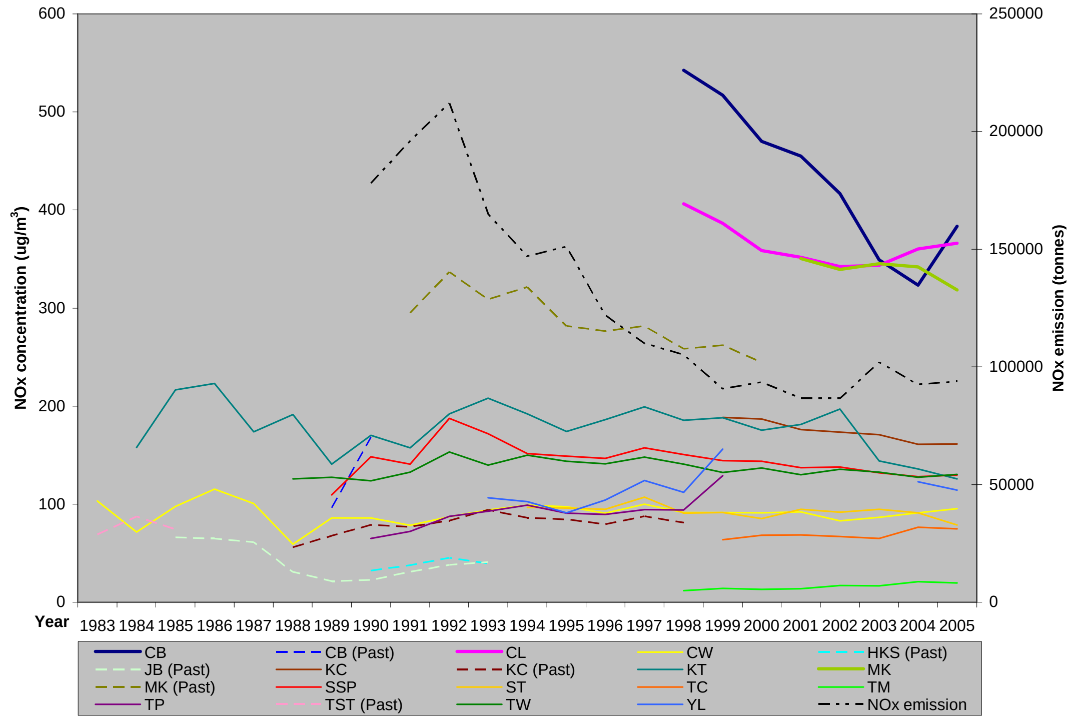


Figure 3.14 Annual Averages of NO Concentration from 1983 to 2005

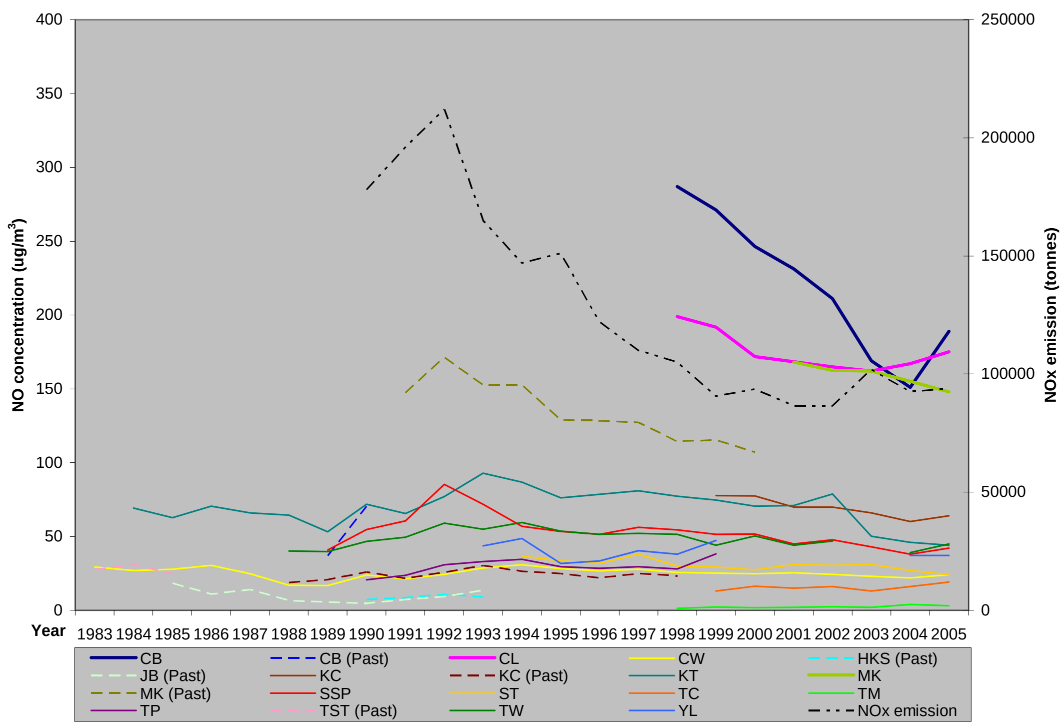
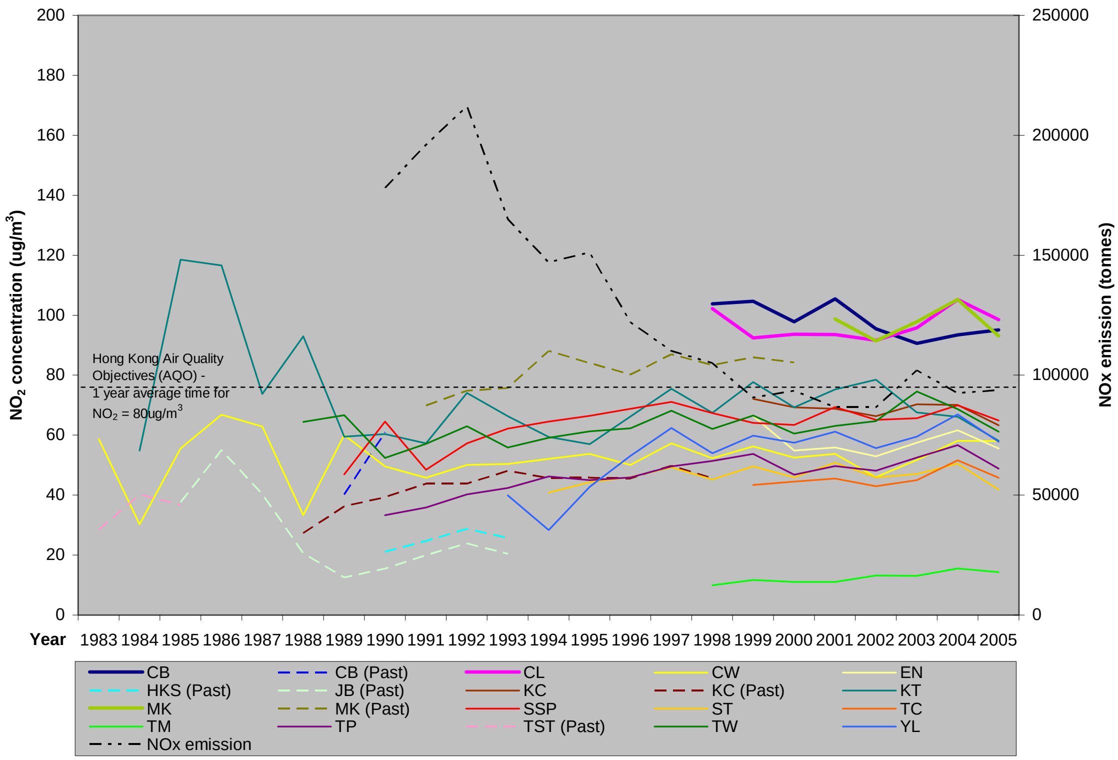


Figure 3.15 Annual Averages of NO_2 Concentration from 1983 to 2005



3.4.3 Ozone (O_3)

(a) Health Effect

Ozone (O_3) is a colourless gas at low concentrations. It is a powerful oxidizer. In the stratosphere, it protects life on earth by absorbing much of the harmful ultraviolet radiation from the sun. However, ozone occurring in the lower atmosphere is a health hazard.

Ozone (O_3) is used to present the photochemical oxidants which can cause irritation to the eye, nose and throat even at low concentrations. At elevated levels, it can increase a person's susceptibility to respiratory infections and aggravate pre-existing respiratory illnesses such as asthma.

Ozone can cause damage to plants, and injury to vegetation is one of the earliest signs of photochemical air pollution. Ozone also accelerates the aging of materials, resulting in the cracking of rubber, the fading of dyes and paint damage.

(b) Source

Ozone (O_3), a major constituent of photochemical smog, is formed by a series of complicated photochemical reactions of oxygen, nitrogen oxides and volatile organic compounds in the presence of sunlight and warm temperature. Some industrial processes also generate ozone.

Ozone can be formed naturally by various processes. These include electrical discharge and the intrusion of stratospheric ozone into the troposphere.

(c) Compliance on Air Quality Objectives

For protecting the public health, Hong Kong has established the hourly ($240\mu g/m^3$) objective limit for O_3. Table 3.10 shows the percentage of compliance on 1-hour Air Quality Objectives of O_3 for all monitoring stations.

Similar to previous cases of ozone pollution, all these incidences of high ozone level could be directly related to photochemical reactions triggered by bright sunlight under calm wind conditions. Almost all stations also had the several exceedances of AQO in past recent years and breached the AQO for ozone. This means that ozone pollution has become serious in Hong Kong.

Table 3.10 Percentage of Compliance on 1-hour Air Quality Objectives of O_3

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	99.94%	99.99%	100%	99.98%	100%	99.99%	99.99%	100%	99.86%	99.90%
EN																	100%	100%	100%	100%	100%	100%	100%
KC						100%	100%	100%	100%	100%	100%	99.97%	100%	99.95%	100%	100%	100%	100%	100%	100%	100%	100%	100%
KT															100%	100%	100%	100%	100%	100%	100%	100%	99.99%
SSP																100%	100%	100%	100%	99.99%	100%	99.97%	99.98%
ST															99.93%	100%	99.95%	99.98%	99.98%	100%	99.98%	99.87%	99.88%
TC																	99.90%	99.92%	99.75%	99.58%	99.69%	99.10%	99.73%
TM																100%	99.90%	99.99%	99.92%	99.96%	99.85%	99.91%	99.61%
TP								100%	100%	100%	100%				100%	100%	100%	100%	99.98%	99.99%	99.98%	100%	100%
TW						100%	100%	100%	100%	100%	100%				100%	100%	100%	100%	99.99%	99.99%	100%	99.96%	99.98%
YL											100%	100%	100%	99.96%	100%	100%	100%	100%	100%	100%	100%	99.88%	99.84%
Past General Air Quality Monitoring Station																							
JB			100%	100%	100%	100%	99.97%	100%	100%	100%	100%												
TST	100%	100%	100%																				

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung)

(d) Time Series Variation

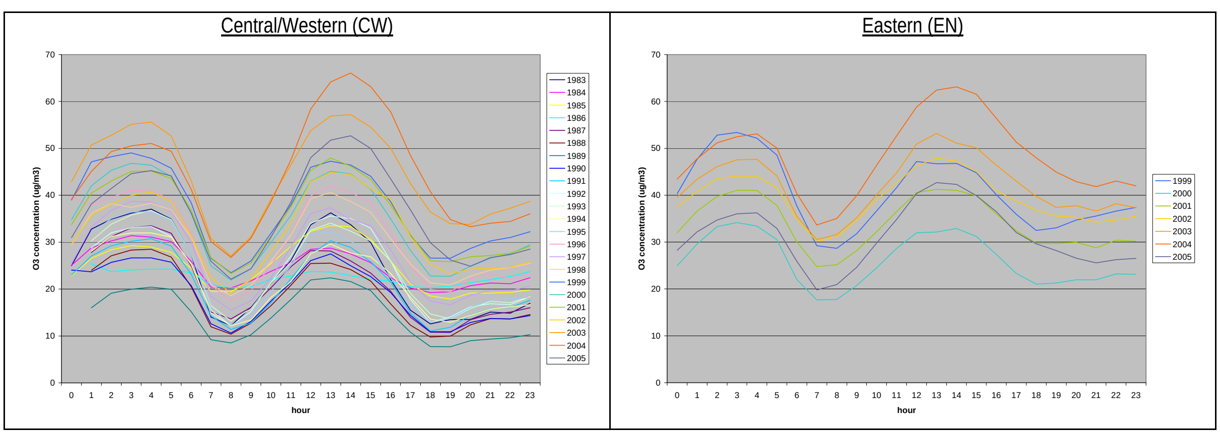
- Diurnal variation

Diurnal variations of ozone at all monitoring stations are shown in Figures 3.16. As the formation of ozone is driven by sunlight, it is expected that the magnitude of the day time peaks should be higher than the night time peaks. Non-urban stations of Shatin, Tung Chung, Tap Mun, Tai Po and Junk Bay are obvious for this phenomenon.

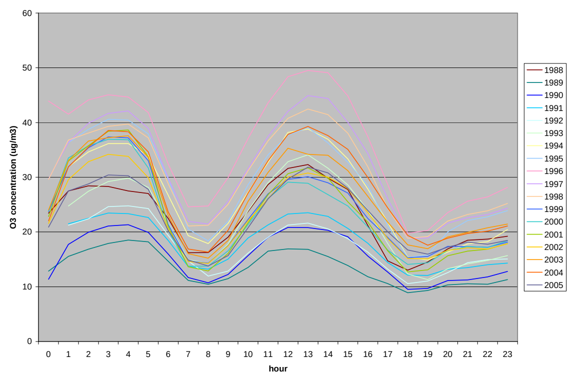
Each day, concentrations were highest at night and during the early afternoon. Those periods corresponded to the time when NO concentrations were lower. There were higher concentrations in the early afternoon when higher solar radiation levels helped the formation of O_3.

In addition, diurnal variation of ozone is the inverse of the nitrogen oxides concentrations, with lower concentrations occurring in the morning and early evening. This is because the ozone is consumed by the nitric oxide emitted by traffic during rush hours.

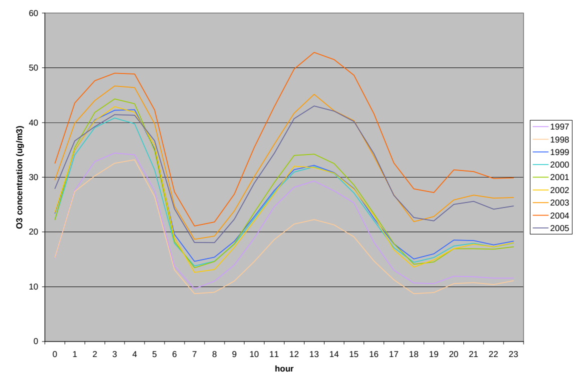
Figures 3.16 Diurnal O_3 Variation of Air Monitoring Stations (from 1983 to 2005)



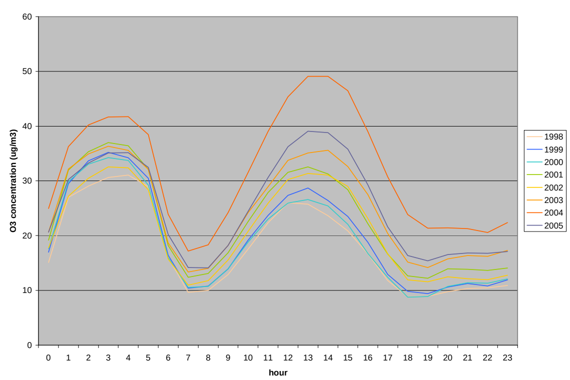
Kwai Chung (KC)



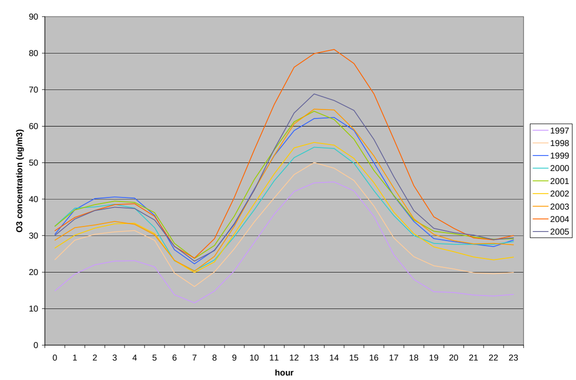
Kwun Tong (KT)



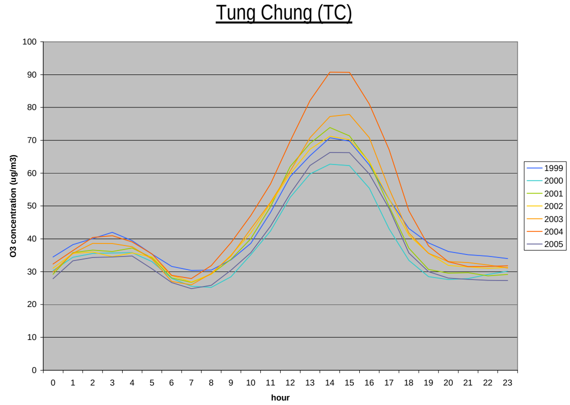
Sham Shui Po (SSP)



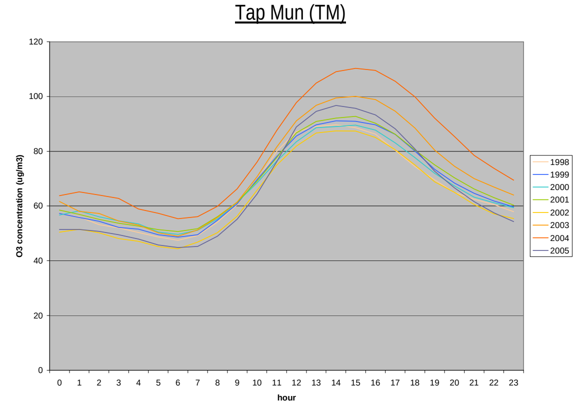
Sha Tin (ST)



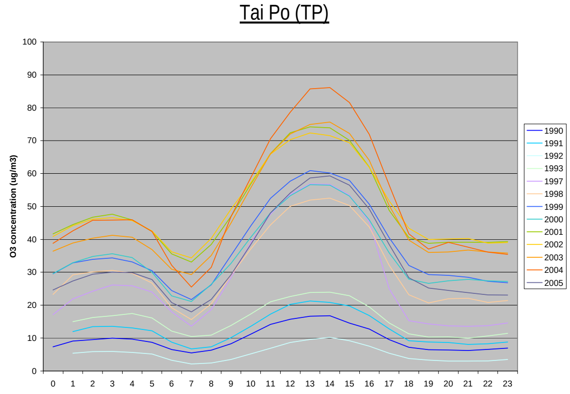
Tung Chung (TC)



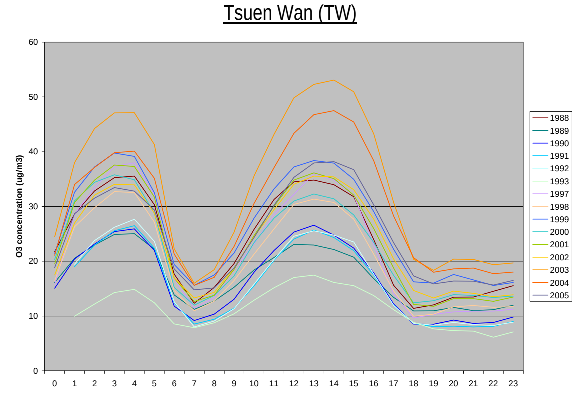
Tap Mun (TM)

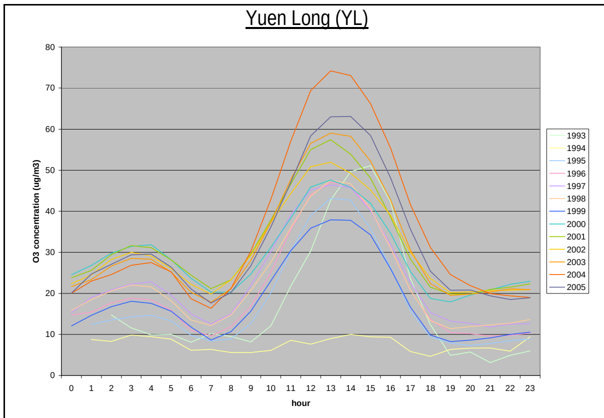


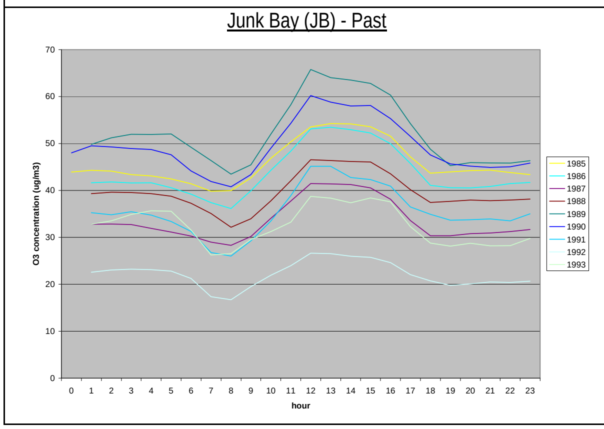
Tai Po (TP)

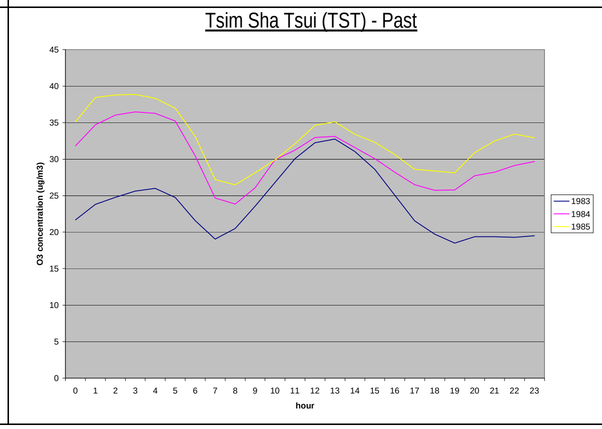


Tsuen Wan (TW)





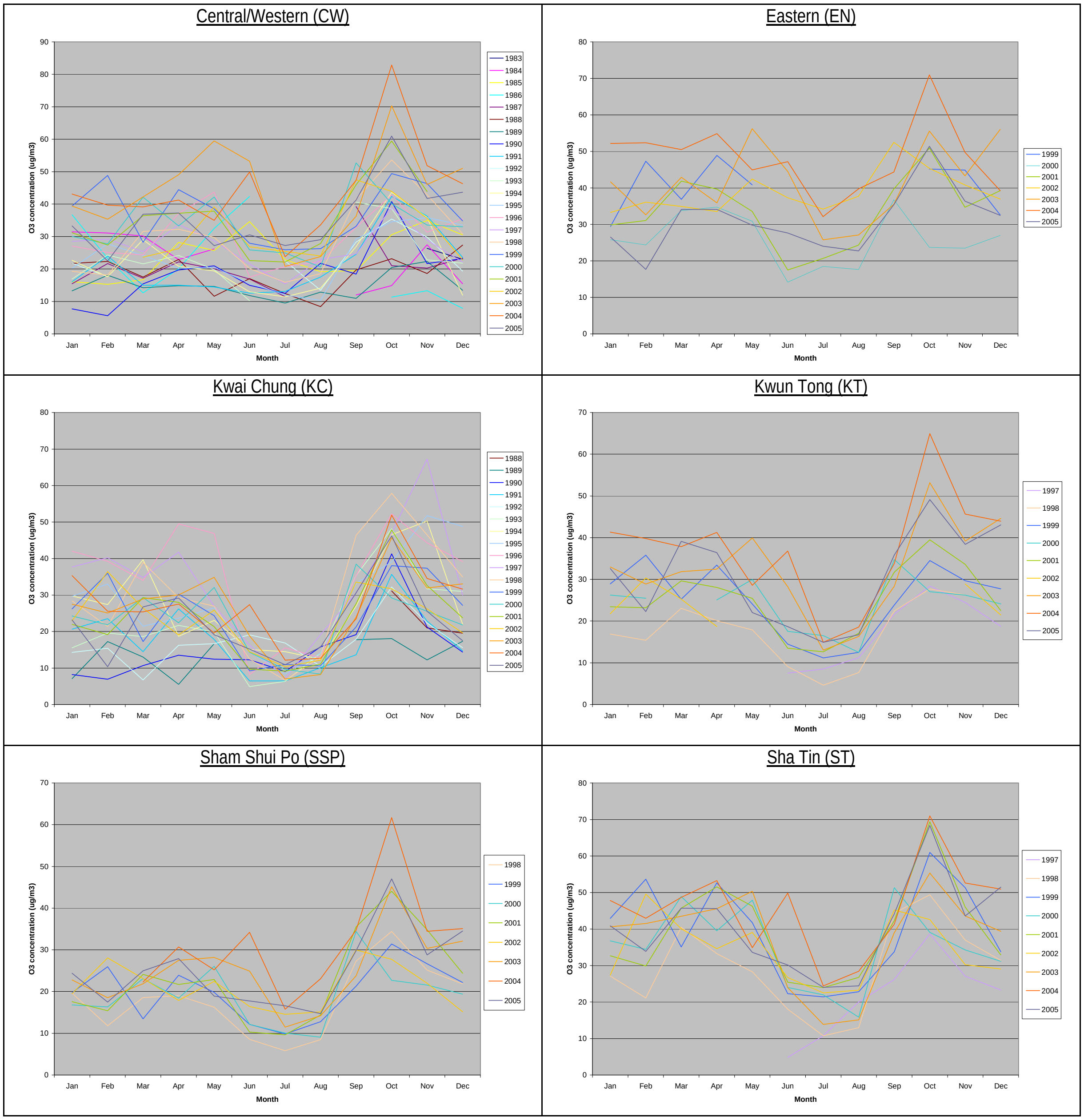




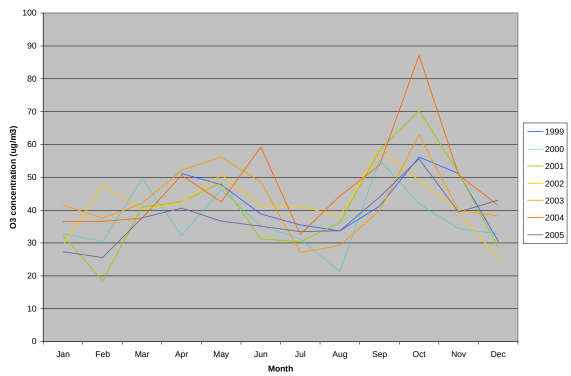
- Monthly variation

The monthly O_3 trends from 1983 to 2005 were similar at all sites. The data in Figures 3.17 shows that the ozone concentrations were highest in the autumn (October to November) during the period of most sunshine but lower in summer seasons (July and August).

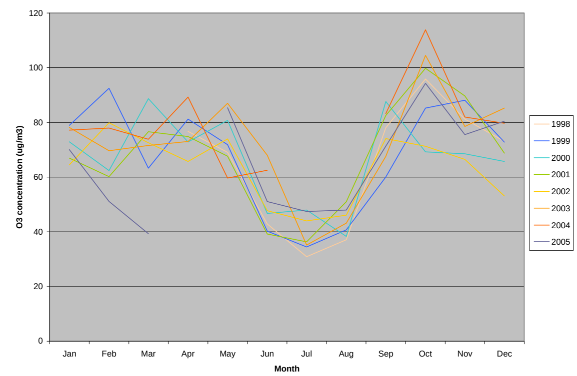
Figures 3.17 Monthly O_3 Variation of Air Monitoring Stations (from 1983 to 2005)



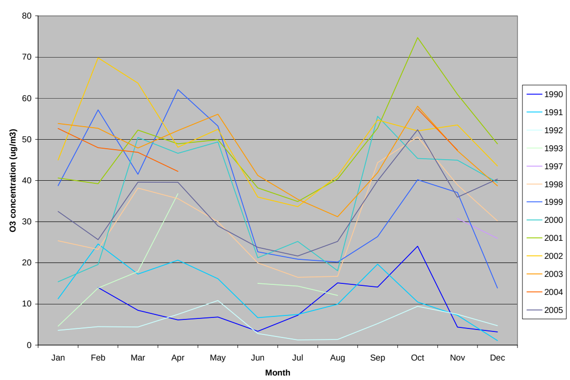
Tung Chung (TC)



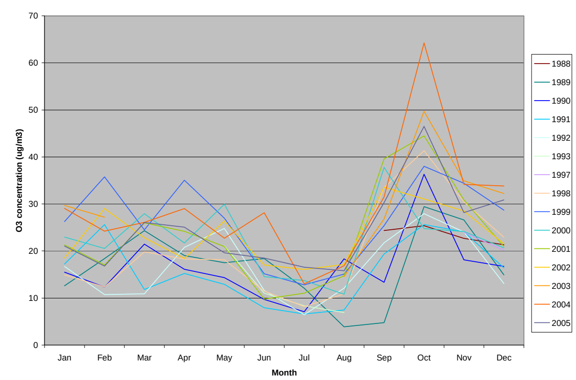
Tap Mun (TM)



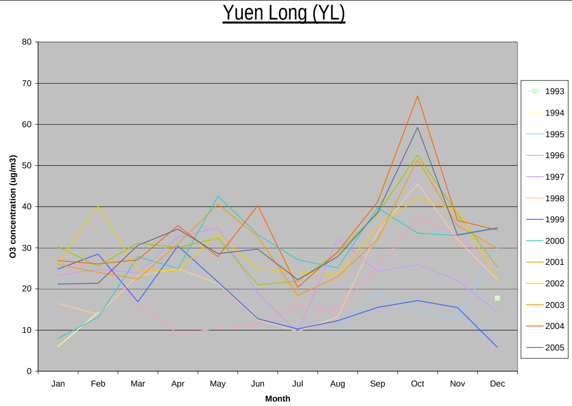
Tai Po (TP)



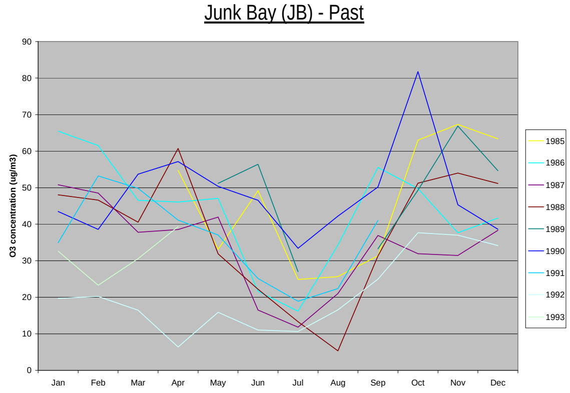
Tsuen Wan (TW)



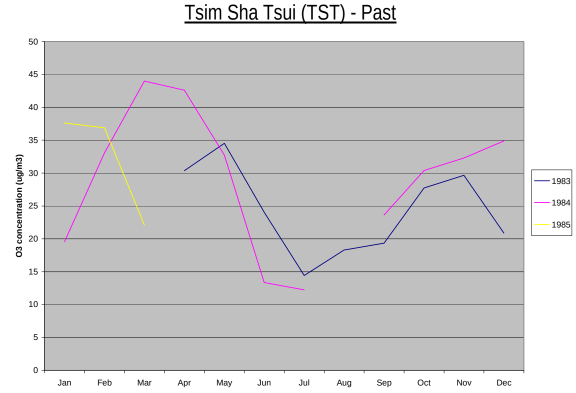
Yuen Long (YL)



Junk Bay (JB) - Past



Tsim Sha Tsui (TST) - Past



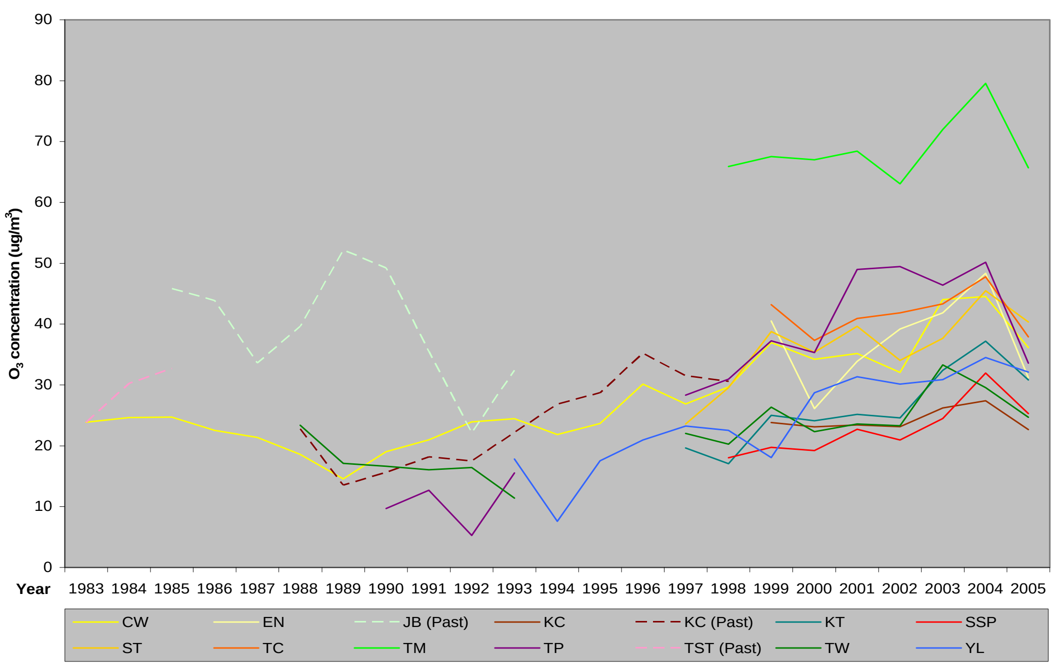
(e) Long Term Trend

As nitric oxide emissions from motor vehicles can react with and remove ozone in the air, areas with heavy traffic normally have lower ozone levels than areas with light traffic. Hence, Tap Mun rural station has steadily recorded more than twice the ozone levels measured in urban areas since 1998.

The ozone formed by photochemical oxidation has shown a more definite increasing trend than other air pollutants. The mean annual averages of ozone concentrations measured at all stations from 1983 to 2005 in Figure 3.18 have shown a clear increasing trend. Despite the drop in 2005, ozone levels in the territory have showed a general rising trend since 1990.

Ozone is a regional air pollution issue. The rising trend of ozone generally reflects deterioration in air quality on a regional scale over the past decade. It is possible that ozone will emerge as a future air pollution issue needs to be addressed.

Figure 3.18 Annual Averages of O_3 Concentration from 1983 to 2005



3.4.4 Carbon monoxide (CO)

(a) Health Effect

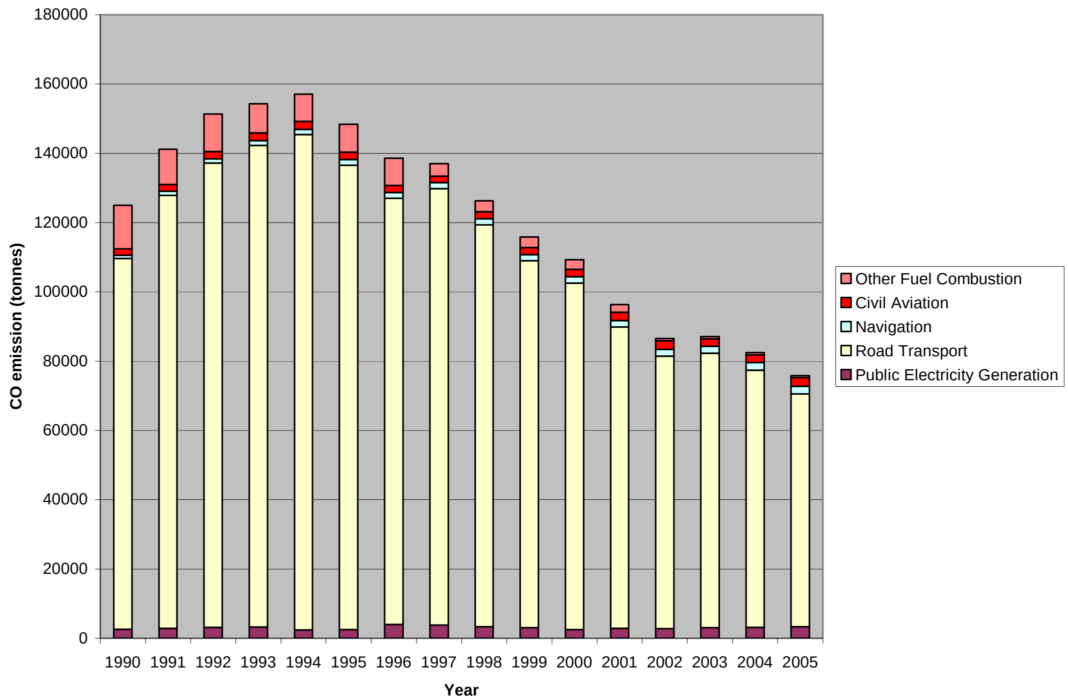
Carbon monoxide is a colourless and odourless gas which can be inhaled without one's knowledge. It has a higher affinity than oxygen for the haemoglobin in the blood and hence deprives body tissues of necessary oxygen.

Those already suffering from heart and circulatory conditions are most vulnerable to its effects. Healthy individuals are also affected but only at higher concentrations. Typical symptoms of CO poisoning include shortness of breath, chest pain, headaches, and loss of co-ordination. The health threat from CO is more severe for those who suffer from heart disease.

(b) Source

Carbon monoxide (CO) comes mainly from vehicular emissions although small amount of which may also be arisen from incomplete combustion of fuels from factories and power stations. The primary source of man-made carbon monoxide in the urban air is motor vehicles (near 90%). Figure 3.19 shows the CO emissions from man made sources.

Figure 3.19 CO Emissions from Man Made Sources (1990-2005)



(c) Compliance on Air Quality Objectives

There are two AQOs, the hourly (30,000μg/m^3) and 8-hourly (10,000μg/m^3) limits, established for this pollutant for the protection of the public health.

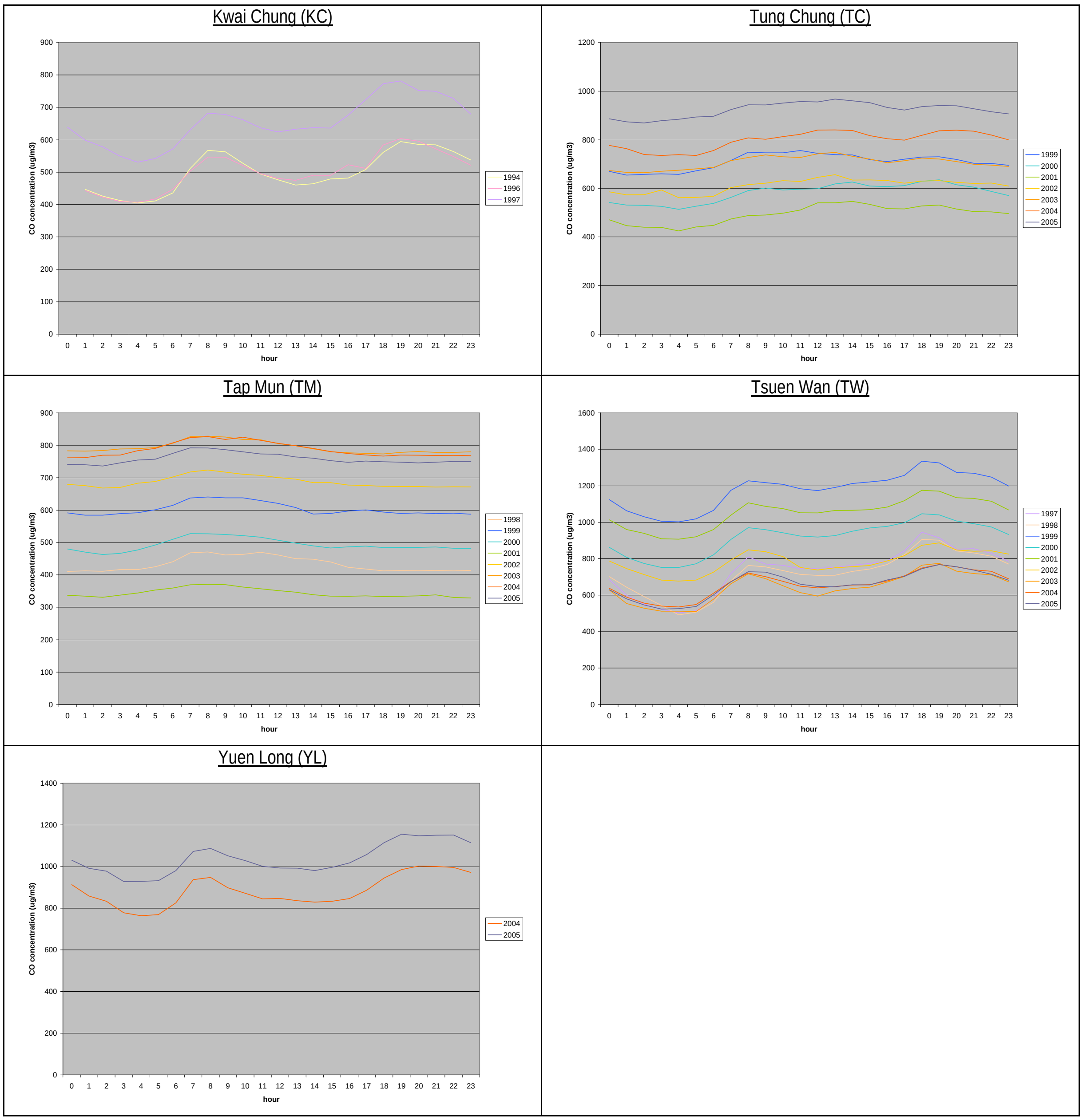
In Hong Kong, the ambient and roadside concentrations of CO continue to stay at a very low level. During all measured years, all stations complied with the 1-hour and 8-hour AQOs. There were no exceedances of either the 1 hour or the 8 hour Air Quality Objectives for carbon monoxide.

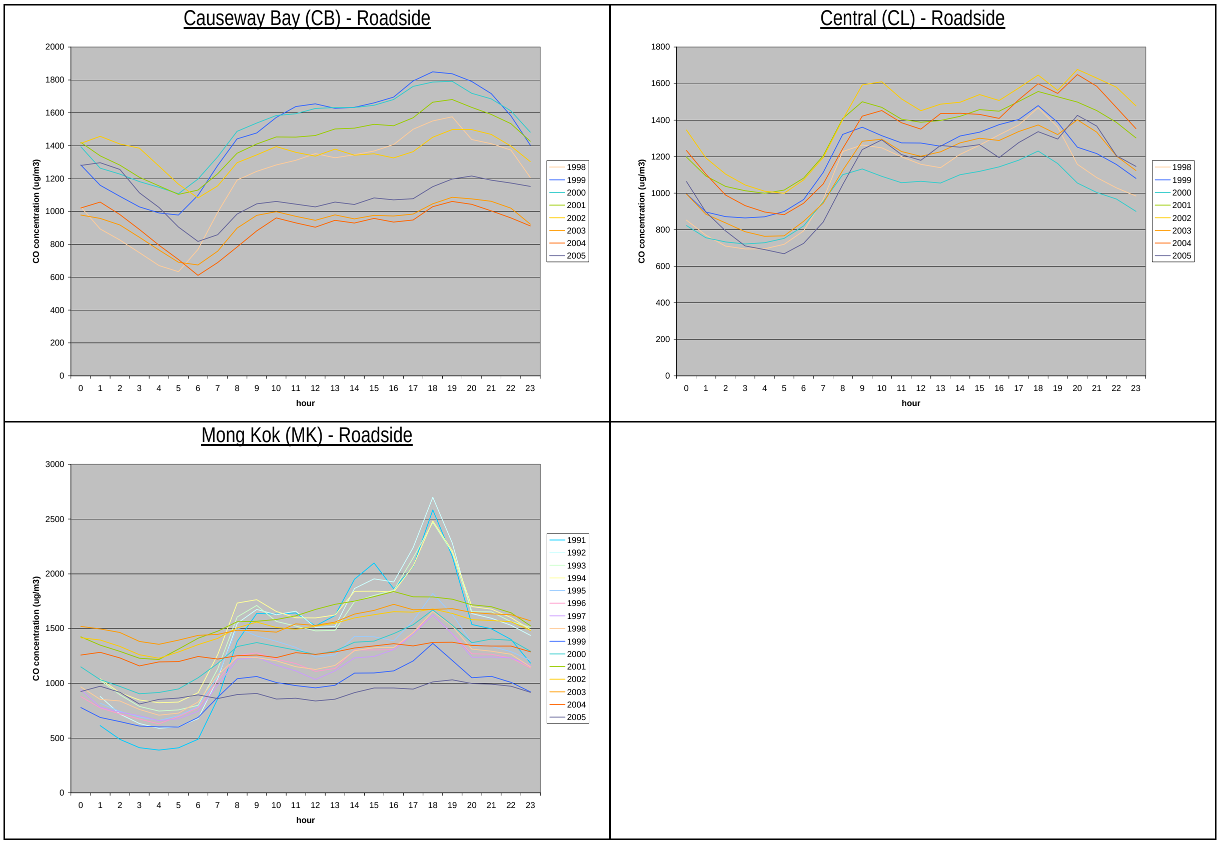
(d) Time Series Variation

- Diurnal variation

The CO hourly variation in a day (Figures 3.20) follows the traffic pattern in the area. In the diurnal variation plot, it exhibited characteristic twin peaks which are higher in the late afternoon than in the morning. The CO concentrations were highest in the evening because the traffic was usually more busy in the evening in conjunction with the social activities in the area.

Figures 3.20 Diurnal CO Variation of Air Monitoring Stations (from 1991 to 2005)

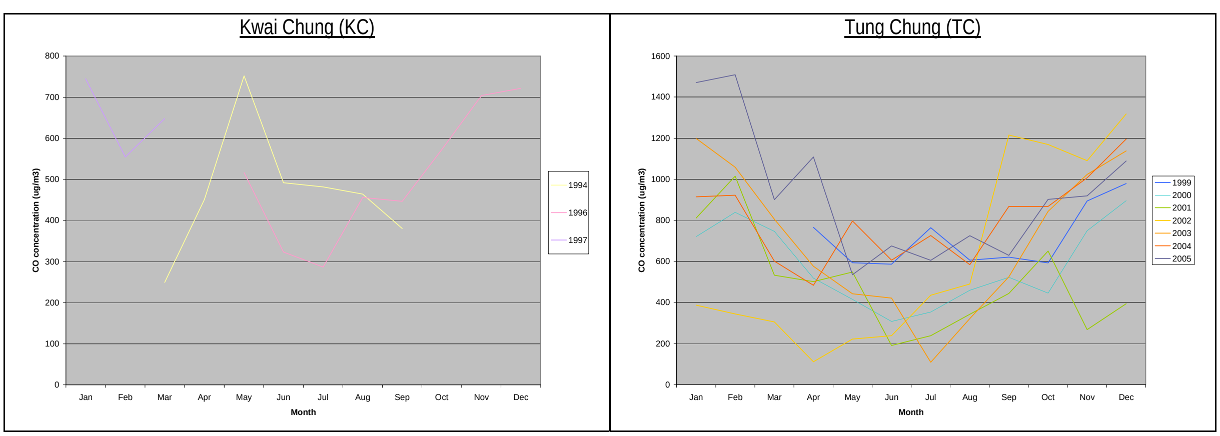




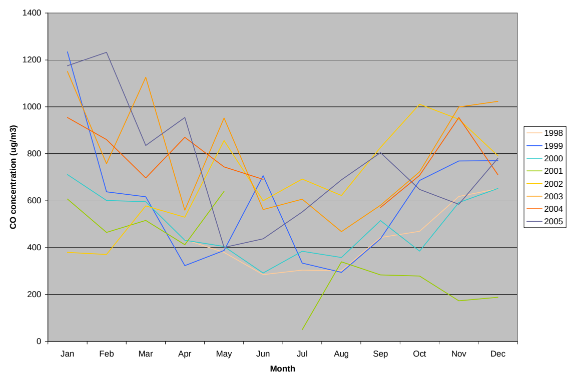
- Monthly variation

Similar to other air pollutants, CO exhibits monthly changes. The monthly trend of CO as depicted in Figures 3.21 shows that the CO concentrations were higher from August to January but lower in June and July.

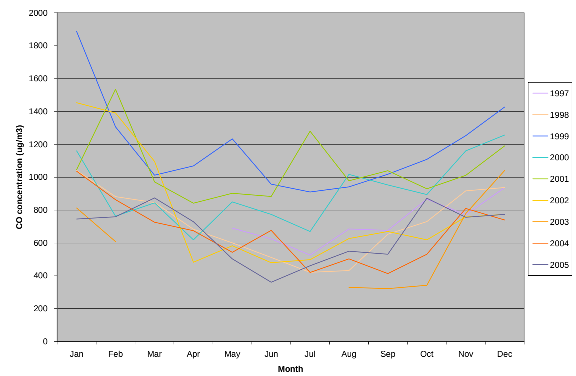
Figures 3.21 Monthly CO Variation of Air Monitoring Stations (from 1991 to 2005)



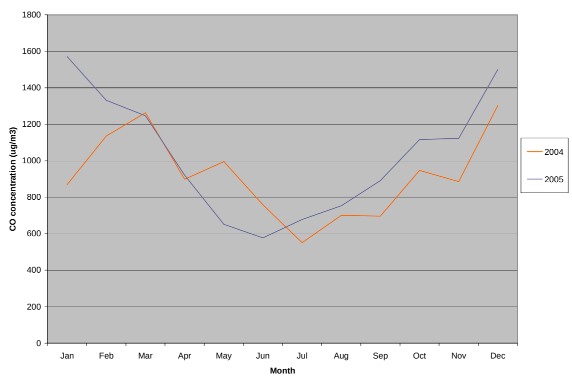
Tap Mun (TM)



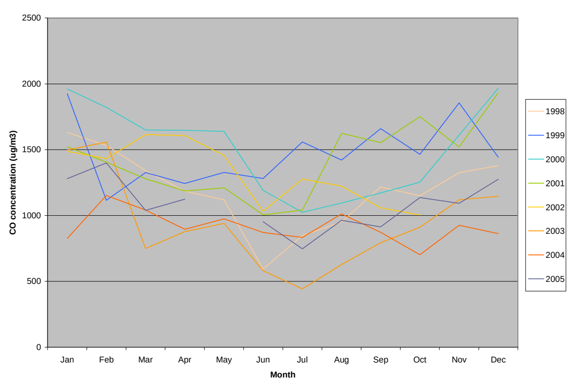
Tsuen Wan (TW)



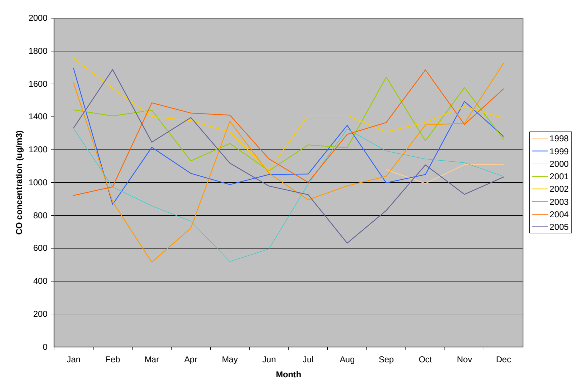
Yuen Long (YL)



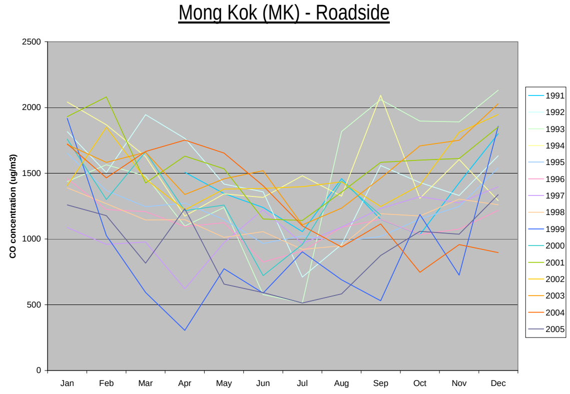
Causeway Bay (CB) - Roadside



Central (CL) - Roadside



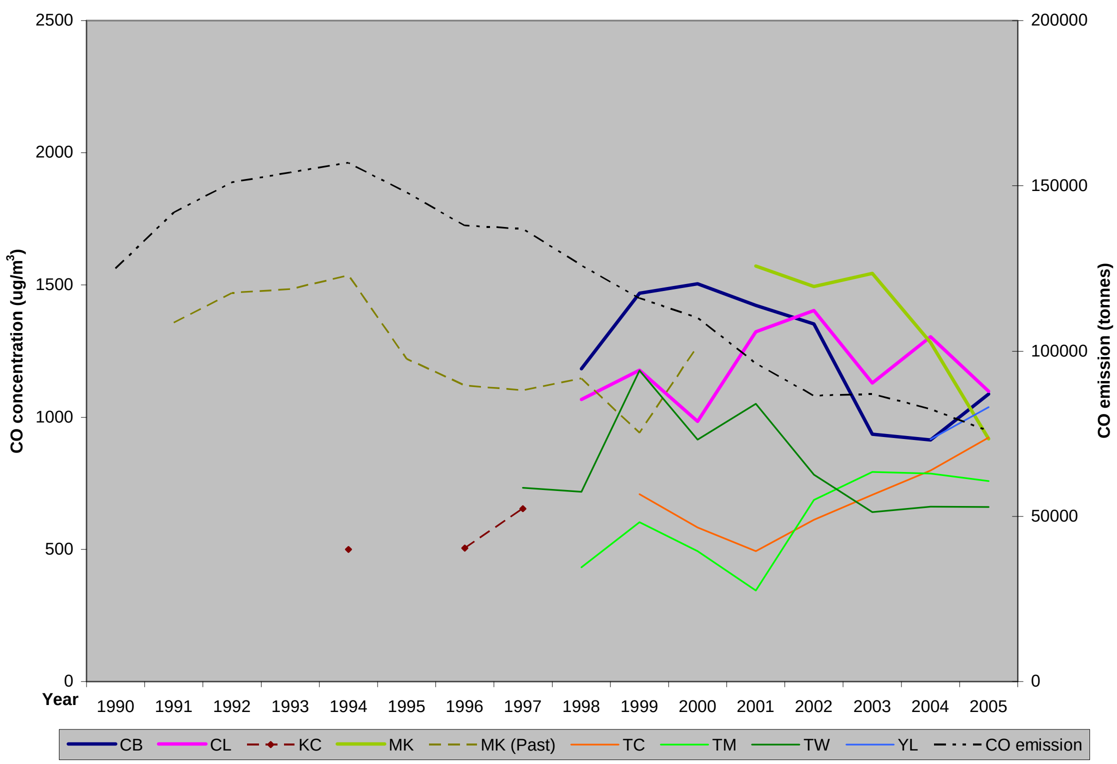
Mong Kok (MK) - Roadside



(e) Long Term Trend

CO concentrations in Hong Kong remained very low in the past several years. Even at the roadside close to the vehicular emission sources, the CO levels were well within the 1-hour AQO (30000µg/m^3) and 8-hour AQO (10000µg/m^3). With the continual implementation of a more stringent vehicle emission standard, it is expected that CO levels in Hong Kong will continue to be well within the relevant AQOs in the future. Figure 3.22 shows the variations of the annual averages of CO concentration from 1983 to 2005.

Figure 3.22 Annual Averages of CO Concentration from 1991 to 2005



3.4.5 Total Suspended Particulates (TSP)

(a) Health Effect

The greatest concern is for the small particles, less than 10 microns in diameter, which can penetrate deep into the lungs and contribute to respiratory disease. The health effects can be more serious if the inhaled particles contain, or have absorbed on their surface, toxic compounds. Small particles, typically those less than 2 microns in diameter, scatter light and therefore contribute to a reduction in visibility. All sizes of particles can cause soiling and corrosion.

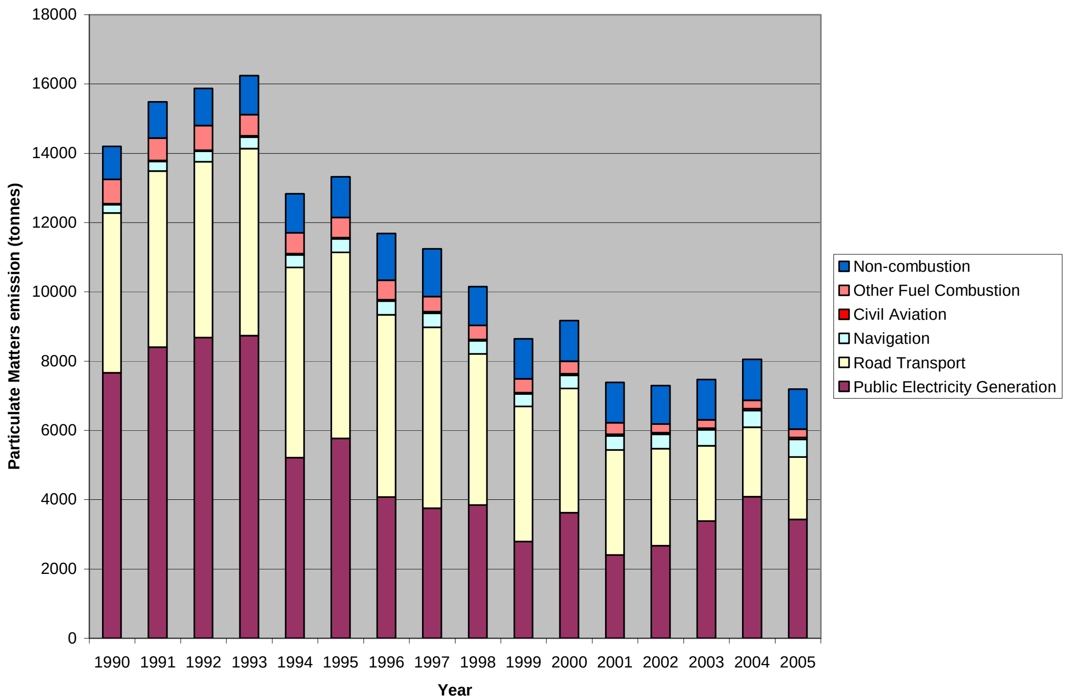
(b) Source

Total suspended particulates (TSP) are small airborne particles such as dust, fume and smoke with diameters less than 100 micrometres. These airborne particles include smoke, fumes, dust and fly ash of various sizes, shape and composition.

Particles are generated from natural sources and human activities. Man-made sources include power stations (over 40%), vehicles exhausts (near 30%), construction activities, incineration, etc. However in the urban air, vehicular exhaust and road dust are the major sources of particulate emissions. Figure 3.23 shows the Particulate Matters emissions from man made sources. Natural sources include soil blowoff and sea salt aerosols.

Total suspended particulates (TSP) include both the fine and coarse particles. The fine portion, which are known as the respirable suspended particulates, are of greater health concern. The coarse particles are mainly related to the dust nuisance and soiling.

Figure 3.23 Particulate Matters Emissions from Man Made Sources (1990-2005)



(c) Compliance on Air Quality Objectives

There are two AQOs, the 24-hourly (260μg/m^3) and annual (80μg/m^3) limits respectively, established for TSP. Tables 3.11 and 3.12 show the percentage of compliance on 24-hour and 1-year Air Quality Objectives of TSP for all monitoring stations.

Total suspended particulates levels causing non-compliance are mostly occurring in urban areas where anthropogenic sources like fuel combustion, construction and demolition activities are very active. Traffic dust is mainly responsible for the high TSP levels at roadside station, so Mongkok stations all recorded violation of the annual AQO. Yuen Long also recorded violation of the annual AQO. Only two stations at residential sites in Sha Tin and Tung Chung can all comply with the annual AQO.

Table 3.11 Percentage of Compliance on 24-hour Air Quality Objectives of TSP

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	100%	100%	100%	100%	100%	99.07%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98.36%
KC						96.97%	99.12%	100%	100%	98.15%	98.33%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98.33%	100%	98.33%
KT	100%	97.06%	100%	100%	100%	98.06%	96.40%	100%	100%	96.61%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
SSP		100%	99.11%	100%	100%	99.05%	96.26%	95.61%	100%	96.55%	100%	100%	100%	100%	100%	100%	98.33%	100%	100%	100%	100%	100%	100%
ST									100%	96.36%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TC																	100%	100%	100%	100%	100%	100%	98.11%
TP								100%	100%	96.61%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98.36%	100%	100%
TW						97.92%	100%	100%	100%	96.55%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	98.36%	100%
YL												90%	100%	98.31%	100%	100%	98.33%	98.33%	100%	100%	96.77%	96.67%	100%
Roadside Air Quality Monitoring Station																							
MK									100%	93.33%	100%	94.92%	96.49%	96.67%	98.33%	100%	100%	97.44%	100%	100%	100%	100%	100%

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, and Mong Kok)

Table 3.12 Percentage of Compliance on 1-year Air Quality Objectives of TSP

Station	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station																							
CW	X	O	X	X	X	X	X	O	X	X	X	X	X	X	X	O	X	O	O	O	O	O	X
KC						X	X	X	X	X	X	X	X	O	O	O	X	X	O	O	O	X	O
KT	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O	X	O	O	X	O	X	X
SSP		O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	O	O	O	X	X	X
ST									O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
TC																	O	O	O	O	O	O	O
TP								O	O	X	X	X	X	O	O	O	O	O	O	O	O	X	O
TW						X	X	X	X	X	X	X	X	X	X	O	O	O	O	O	X	X	X
YL													X	X	X	X	X	X	X	X	X	X	X
Roadside Air Quality Monitoring Station																							
MK									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung, and Mong Kok)

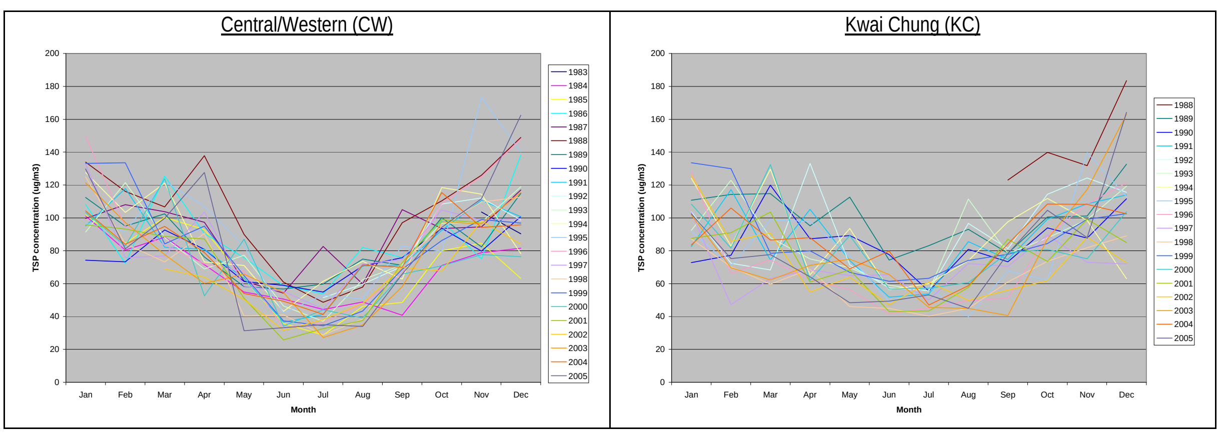
(d) Time Series Variation

- Monthly variation

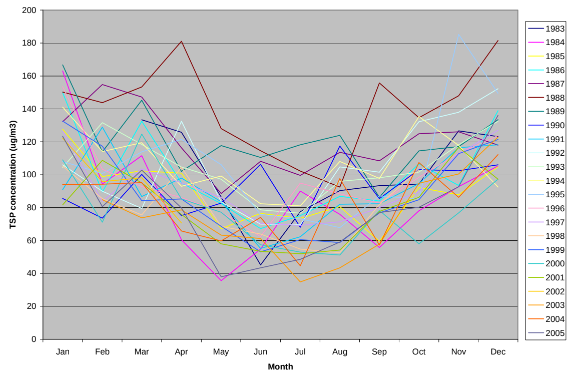
The monthly variation of total suspended particulates at all monitoring stations are shown in Figure 3.24. The monthly trends were similar at all the sites.

Because of the washout and road surface wetting effects of rainfall and better dispersion of the pollution, the TSP levels were substantially lower in the summer months.

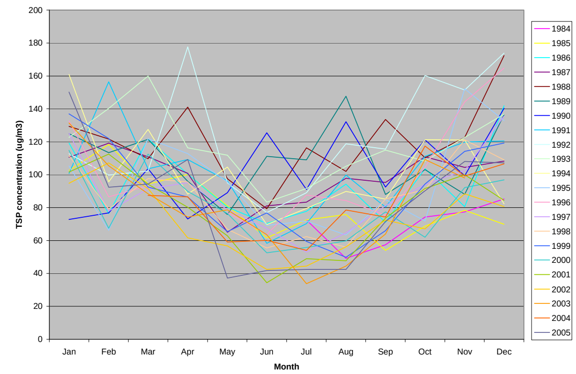
Figures 3.24 Monthly TSP Variation of Air Monitoring Stations (from 1983 to 2005)



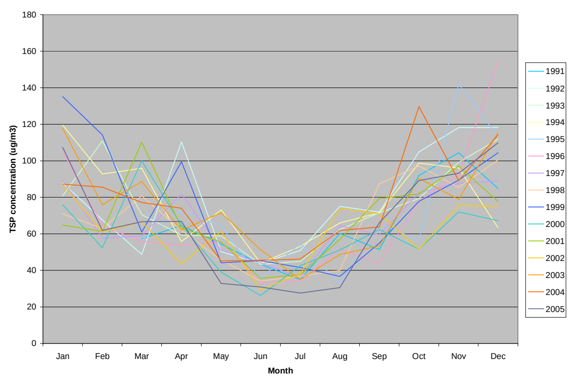
Kwun Tong (KT)



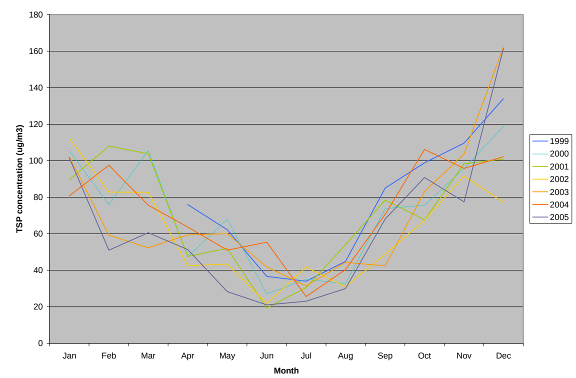
Sham Shui Po (SSP)



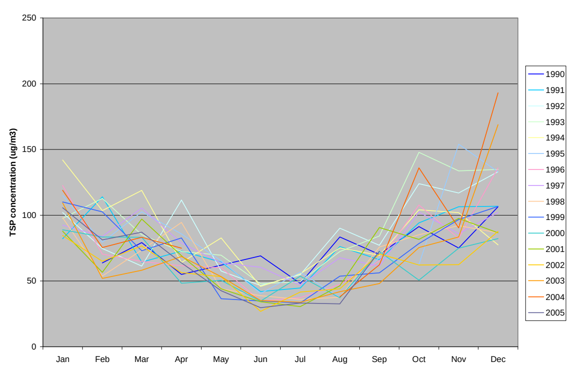
Sha Tin (ST)



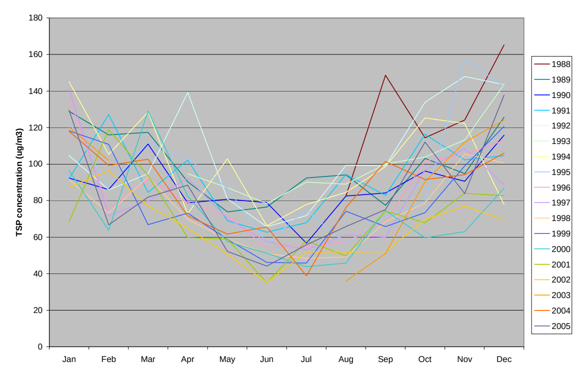
Tung Chung (TC)



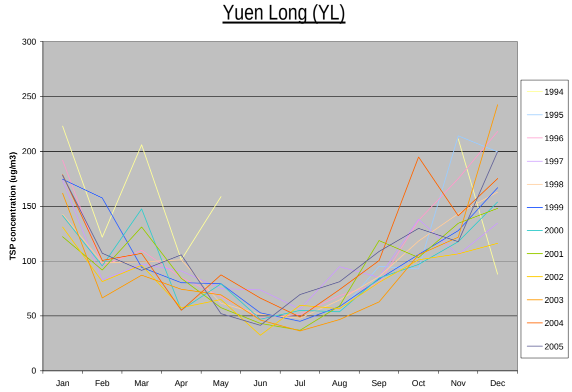
Tai Po (TP)

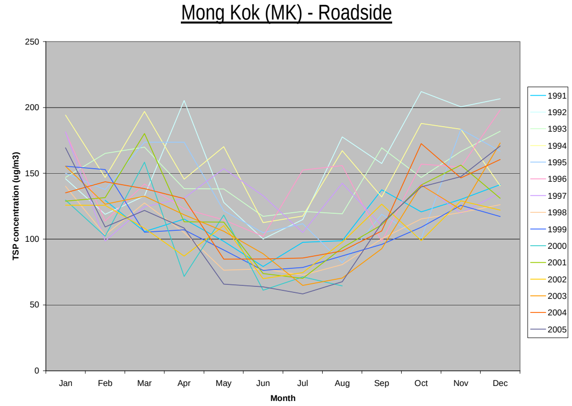


Tsuen Wan (TW)



Yuen Long (YL)





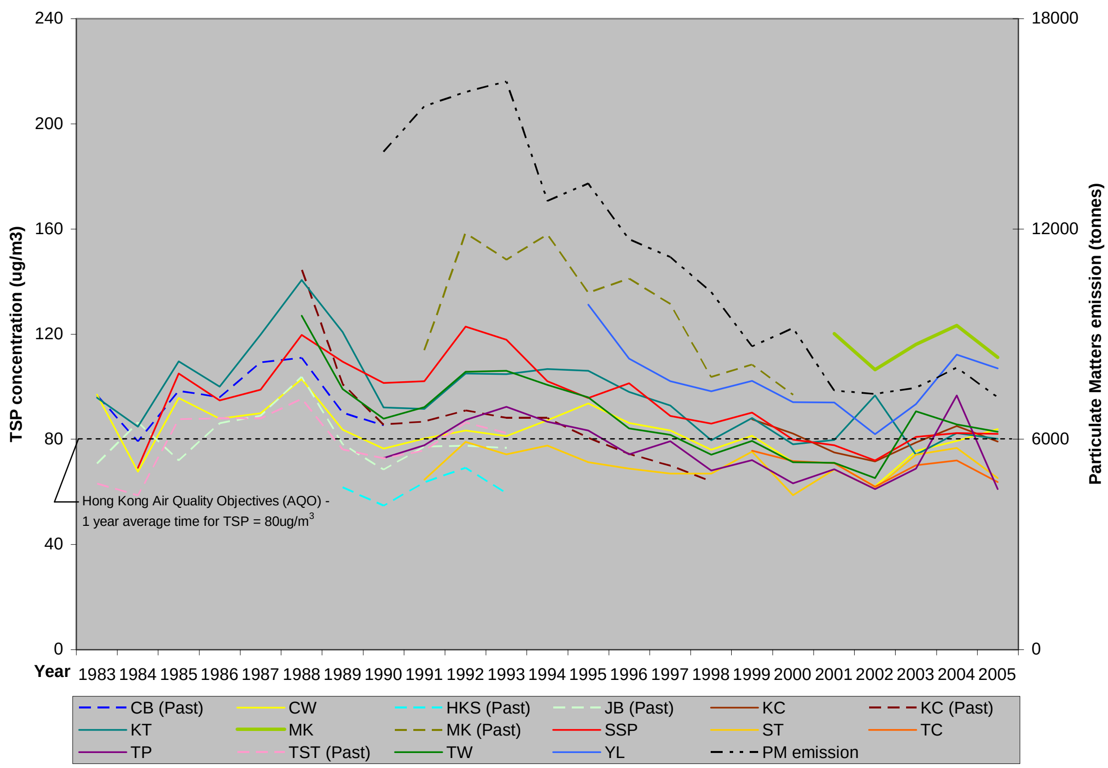
(e) Long Term Trend

Long term trends of TSP are presented in Figure 3.25. In general, total suspended particulates concentrations were higher in industrial regions and densely populated urban areas and lower in rural areas. Industrial fuel combustion and emissions from vehicles are thought to be responsible for higher particulate levels in industrial areas, whist the dense traffic and intensive construction activities are thought to account for the high particulate levels in the residential/commercial areas.

Hong Kong experienced high dust levels in 1988 which gradually decreased to 1990. However, in 1991, the decreasing trends are either stopped or reversed in most of the industrial and highly populated urban areas. The TSP levels have slightly increased in 1992 but stabilized recently at all different areas, possibly because of the reduced industrial and reclamation activities in Hong Kong. As with NO2, the elevated roadside level of TSP was also due to the close proximity to the emission sources. So the situation is particularly worst at the roadside station at Mong Kok. The ambient TSP concentrations have been maintaining at a rather high level throughout the territory since 1990, although apparent decreasing trend was observed in 1998. The most significant drop in 1998 occurred in the roadside areas where the TSP concentrations dropped back to the 1991 level.

TSP levels in urban and new town areas remained high in the past years. The TSP concentrations exhibited primarily declining trends from 1995 to 2002 but rebounded afterwards. Despite a drop in 2005, the TSP concentrations in the territory have shown rising trends since 2002, which could be mainly attributed to the increase in regional background TSP levels.

Figure 3.25 Annual Averages of TSP Concentration from 1983 to 2005



3.4.6 Respirable Suspended Particulates (RSP)

(a) Health Effect

Respirable Suspended Particulates (RSP) are the fraction of the Total Suspended Particulates with aerodynamic diameters less than or equal to 10µm.

As a result of their small size, during inhalation some of these smaller particles may reach and deposit deep into the thoracic region of the lung. RSP at high levels may cause chronic and acute effects on human health. The major health effects associated with exposure to RSP are effects on the pulmonary function. These include respiratory illness, reduced lung function and cancer risk for certain particles. These effects are enhanced if high RSP levels are associated with higher levels of other pollutants, such as SO_2. The smaller particulates in RSP have a major impact on visibility. Soiling, corrosion and visibility reduction are additional effects of concern.

(b) Source

Respirable suspended particulates (RSP) refer to those suspended particulates with nominal aerodynamic diameters of 10 micrometres or less. Combustion sources, in particular diesel vehicle exhaust and emissions from power plants, are the major sources of RSP in Hong Kong. Besides, RSP can be formed by atmospheric oxidation of sulphur dioxide and nitrogen oxides. Although to a lesser extent, crustal derived dust and marine aerosols are significant sources of RSP as well.

(c) Compliance on Air Quality Objectives

For protecting the public health, Hong Kong has established the 24-hourly and annual limits of 180μg/m^3 and 55μg/m^3, respectively. Tables 3.13 and 3.14 show the percentage of compliance on 24-hour and 1-year Air Quality Objectives of RSP for all monitoring stations respectively.

The analysis is only considered on continuous RSP measurements which have been made using Tapered Element Oscillating Microbalance (TEOM) monitors since 1993.

The RSP concentrations continued to maintain at very high levels throughout the territory especially in 1999. During the year, all monitoring stations had experienced at least one exceedance of the 24-hour AQO level.

Due to the exceptionally frequent regional air pollution events happened under calm weather conditions, the annual average concentrations of RSP increased across the whole territory in 2004, resulting in non-compliance with the annual AQO for RSP at most of the stations.

The roadside stations with the relatively high background concentrations of RSP as compared with NO_2 indicated the possibility of regional sources in addition to the known local urban sources of diesel vehicle emission. Same as TSP, the roadside stations all recorded violation of the annual AQO. Only two stations at rural and residential sites in Tap Mun and Eastern can all comply with the annual AQO.

Table 3.13 Percentage of Compliance on 24-hour Air Quality Objectives of RSP

Station	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station													
CW	97.76%	100%	100%	100%	100%	100%	99.45%	99.18%	100%	100%	99.45%	99.73%	100%
EN							99.72%	100%	100%	100%	99.73%	100%	100%
KC	100%	100%	100%	100%	100%	100%	99.73%	99.45%	100%	100%	99.73%	99.45%	100%
KT	99.69%	100%	100%	99.72%	99.71%	100%	99.72%	99.73%	100%	100%	99.73%	100%	100%
SSP						100%	99.45%	99.73%	100%	100%	99.41%	100%	100%
ST	99.72%	100%	100%	100%	99.71%	100%	99.73%	100%	100%	100%	100%	99.73%	100%
TC							98.91%	100%	100%	100%	99.18%	99.18%	99.73%
TM						100%	99.72%	100%	100%	100%	100%	100%	100%
TP						100%	99.72%	100%	100%	100%	99.73%	100%	100%
TW	100%	100%	100%	100%	100%	100%	99.45%	100%	100%	100%	98.84%	99.45%	100%
YL			100%	99.72%	100%	100%	99.45%	99.73%	100%	100%	99.18%	99.10%	99.45%
Roadside Air Quality Monitoring Station													
CB						98.89%	98.90%	99.45%	99.45%	100%	99.17%	99.45%	99.72%
CL						100%	98.89%	99.45%	100%	99.45%	98.63%	99.45%	100%
MK				100%	100%	100%	99.72%	99.27%	100%	100%	99.45%	99.45%	100%

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung and Mong Kok)

Table 3.14 Percentage of Compliance on 1-year Air Quality Objectives of RSP

Station	93	94	95	96	97	98	99	00	01	02	03	04	05
Existing General Air Quality Monitoring Station													
CW	X	O	O	O	O	O	O	O	O	O	O	X	O
EN							O	O	O	O	O	O	O
KC	O	O	O	O	O	O	X	O	O	O	X	X	X
KT	X	X	X	X	X	O	O	O	X	X	O	X	X
SSP						O	X	O	O	O	X	X	X
ST	O	O	O	O	O	O	O	O	O	O	O	X	O
TC							O	O	O	O	O	X	X
TM						O	O	O	O	O	O	O	O
TP						O	O	O	O	O	O	X	O
TW	X	O	X	X	O	O	O	O	O	O	X	X	X
YL			X	X	X	X	X	X	X	O	X	X	X
Roadside Air Quality Monitoring Station													
CB						X	X	X	X	X	X	X	X
CL						X	X	X	X	X	X	X	X
MK				X	X	X	X	X	X	X	X	X	X

Remark: The underlined % figures were recorded at old locations of the monitoring stations (i.e. Kwai Chung and Mong Kok)

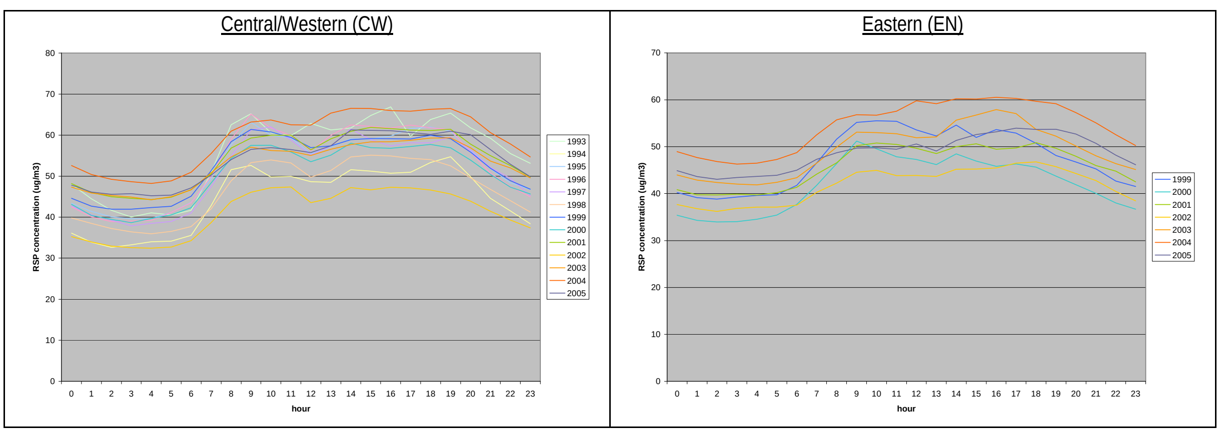
(d) Time Series Variation

- Diurnal variation

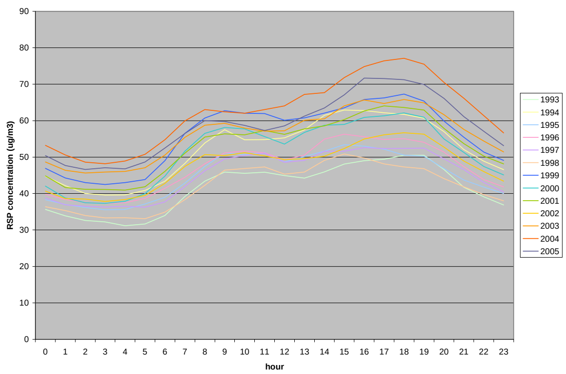
The diurnal plots of RSP concentration at all stations in Figures 3.26, show the variations related to human activities. Concentrations rose during the early morning and remained at the elevated levels till the late afternoon.

Each station has its characteristic diurnal curve, related to the traffic pattern in that area. Central/Western and Sha Tin have morning maxima at 7-8am while Kwai Chung and Tsuen Wan peak at 8-9am. People living in Central/Western and Sha Tin might start their journey to work at about 7-8am. It is interesting to note that Central/Western has small peaks at noon time and 3pm. Such maxima may be associated with the increase in the number of vehicles which bring school children back home. Many trucks are driving to Kwai Chung and Tsuen Wan from other areas to rush for their business at 8-9am. The evening maxima at all stations occur around 6-7pm.

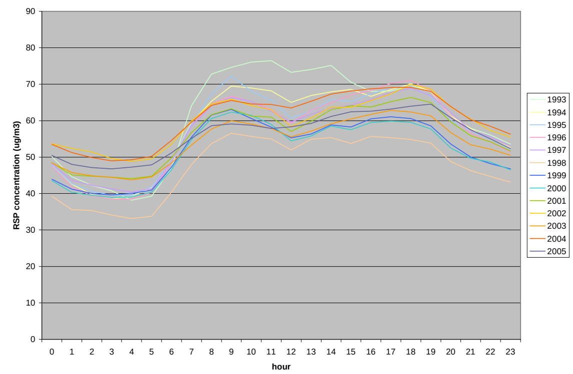
Figures 3.26 Diurnal RSP Variation of Air Monitoring Stations (from 1993 to 2005)



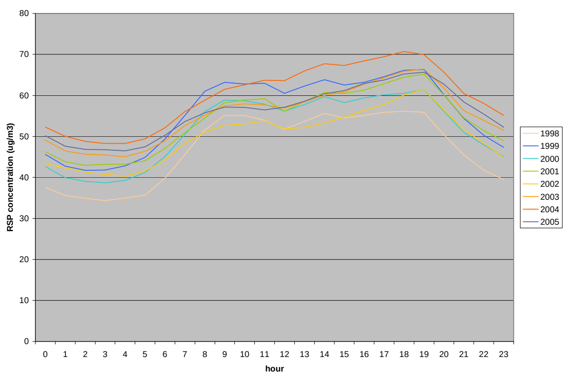
Kwai Chung (KC)



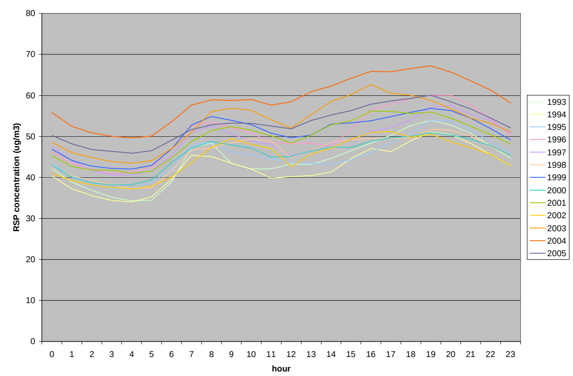
Kwun Tong (KT)



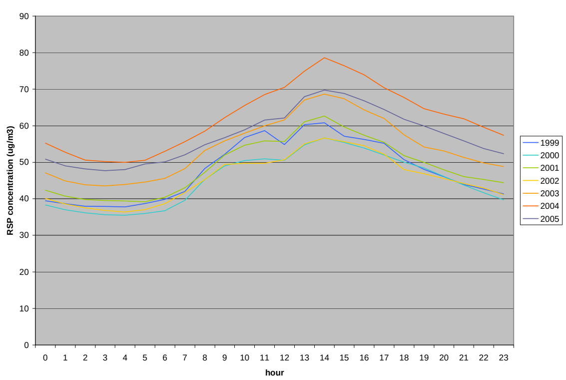
Sham Shui Po (SSP)



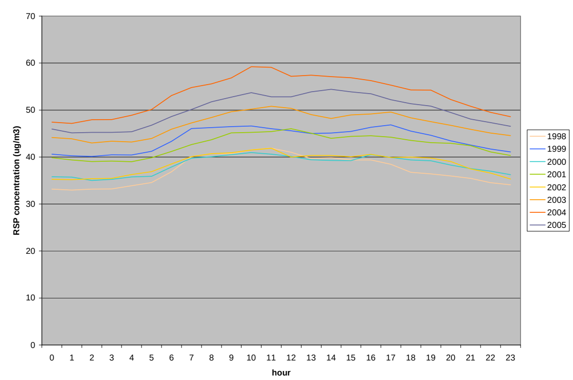
Sha Tin (ST)



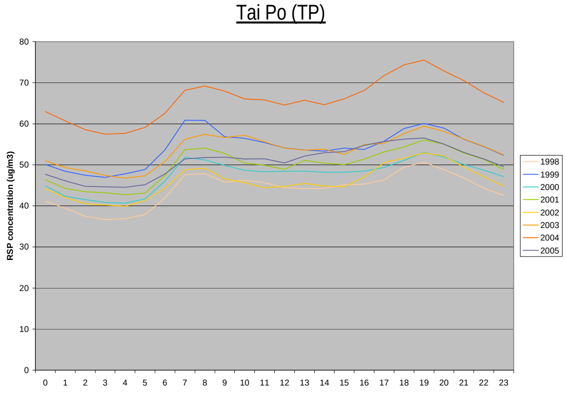
Tung Chung (TC)



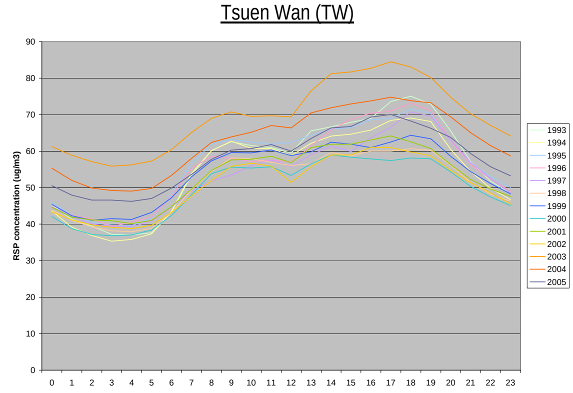
Tap Mun (TM)



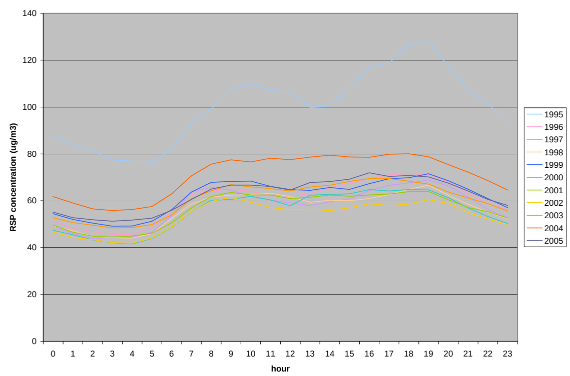
Tai Po (TP)



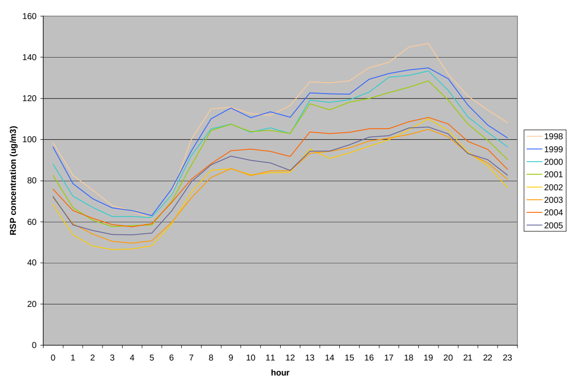
Tsuen Wan (TW)



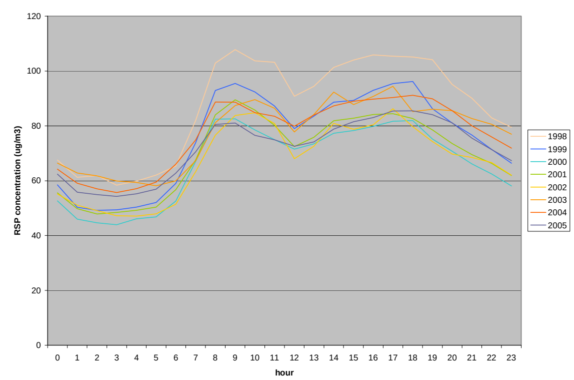
Yuen Long (YL)



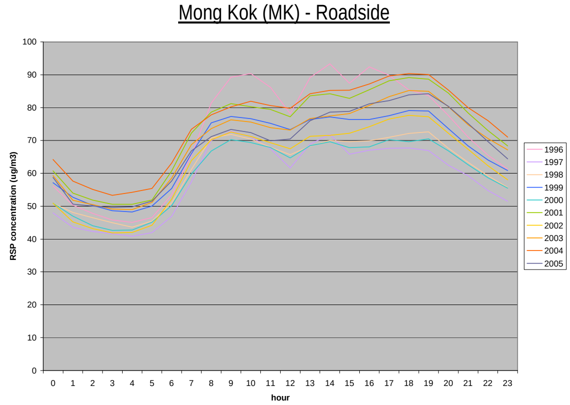
Causeway Bay (CB) – Roadside



Central (CL) - Roadside



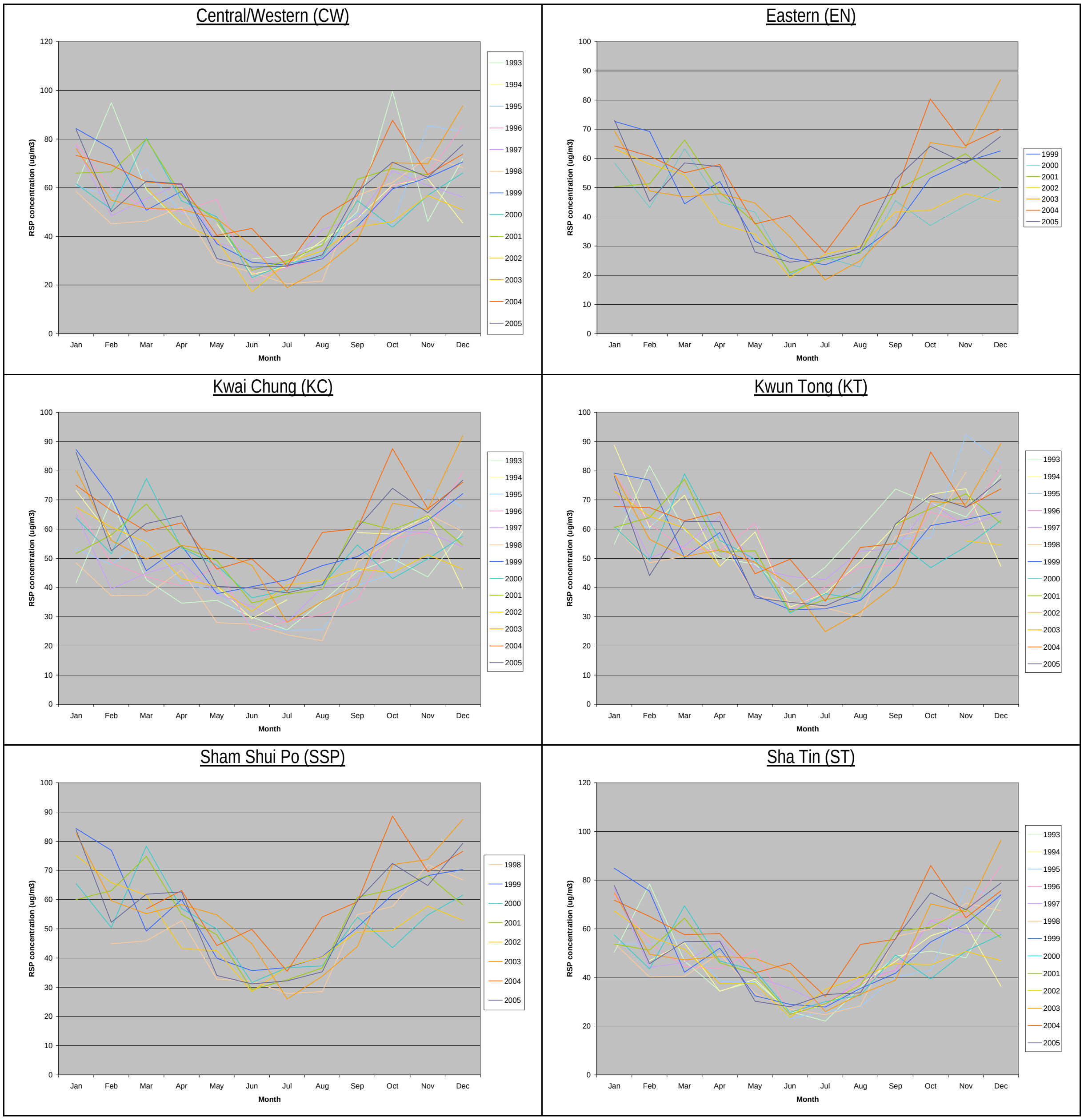
Mong Kok (MK) - Roadside



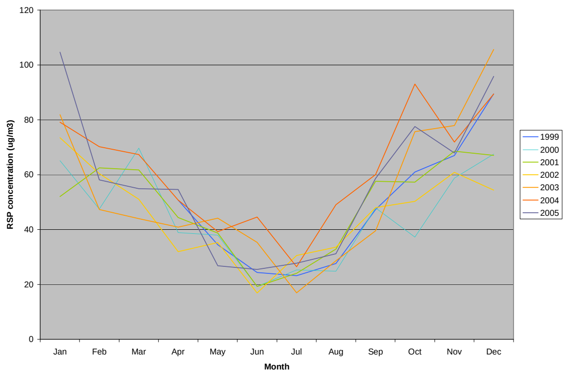
- Monthly variation

Same as the TSP, RSP levels were lower in summer because of the better dispersion capability and the washout and road surface wetting effect of rainfall. Figures 3.27, which show the monthly RSP data of all stations with the similar patterns as TSP.

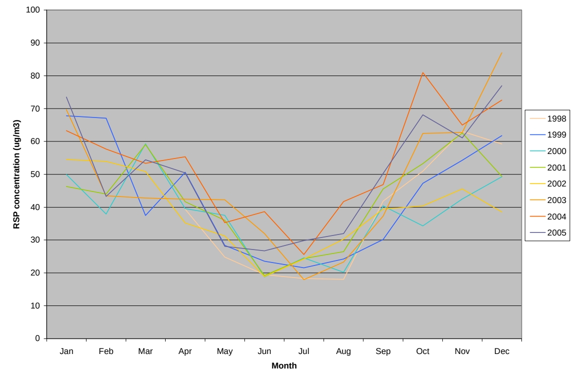
Figures 3.27 Monthly RSP Variation of Air Monitoring Stations (from 1993 to 2005)



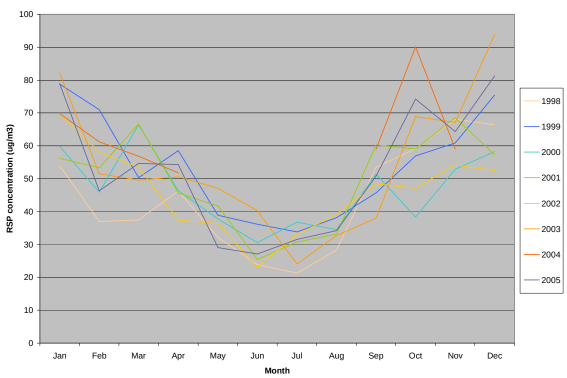
Tung Chung (TC)



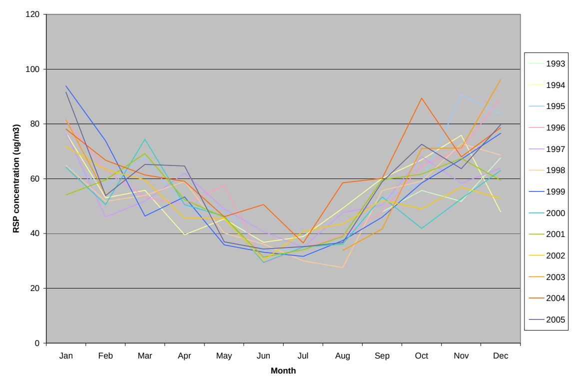
Tap Mun (TM)



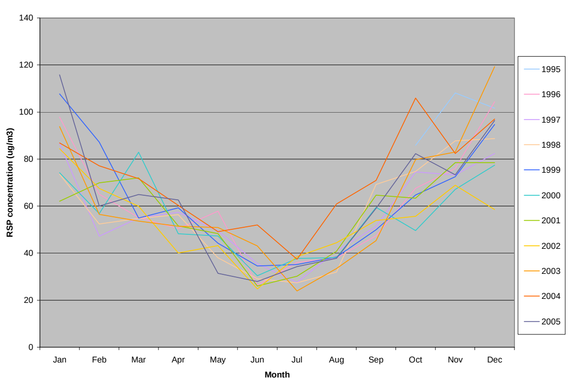
Tai Po (TP)



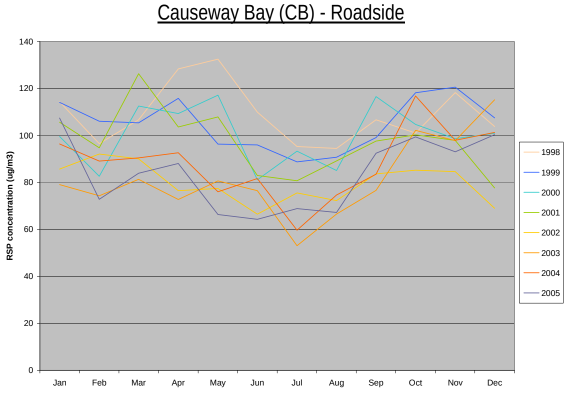
Tsuen Wan (TW)



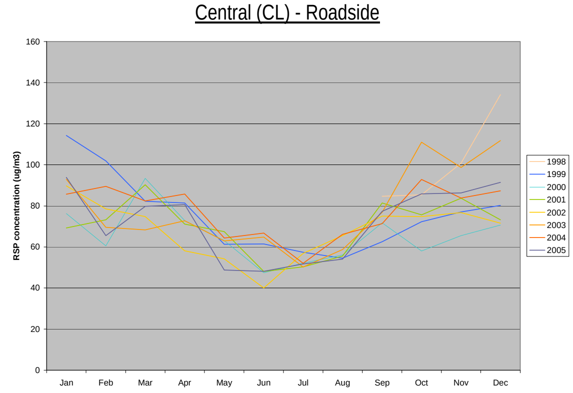
Yuen Long (YL)

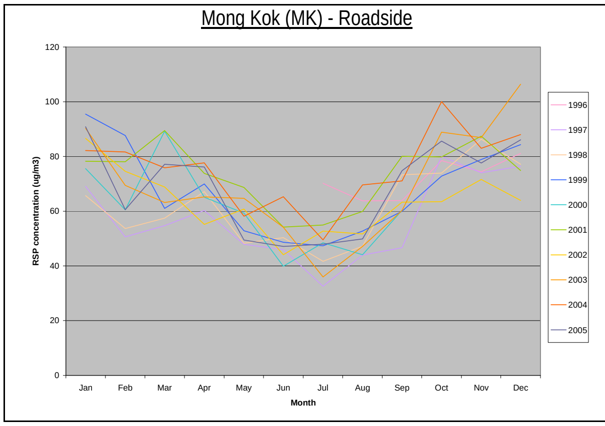


Causeway Bay (CB) - Roadside



Central (CL) - Roadside



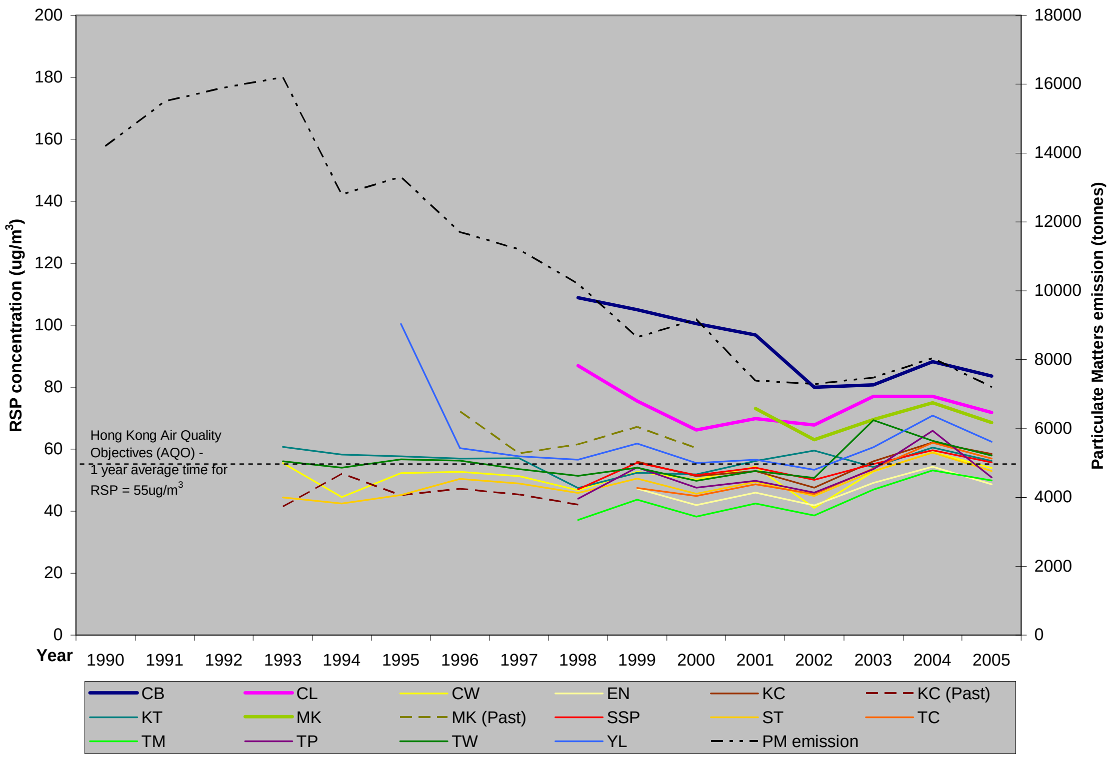


(e) Long Term Trend

Long term trends of RSP are presented in Figure 3.28. Similar to TSP, RSP concentrations have been maintaining at relatively high levels particularly at roadside for the past years. The problem was also attributed to the high concentration of vehicles especially diesel vehicles at urban roadside.

The RSP concentrations recorded in the territory showed a primarily downward trend between 1995 and 2002 but rebounded afterwards. Due to higher rainfall and less frequent photochemical smog incidents, the RSP concentrations in the territory in 2005 reduced as compared with 2004. Nevertheless, the RSP concentrations recorded in all the urban, new town and rural stations have exhibited rising trends since 2002. Such territory-wide rise in RSP concentrations generally reflects an increase in regional background RSP levels in recent years.

Figure 3.28 Annual Averages of RSP Concentration from 1993 to 2005



3.4.7 Lead (Pb)

(a) Health Effect

Lead is well known as a pollutant that can damage the neurological system and produce behavioural changes in children.

(b) Source

Lead occurs in the atmosphere primarily in particulate form and mostly originates from the combustion of leaded petrol. Motor vehicles using leaded petrol are the major source of lead in ambient air. To lessen the threat of airborne lead, the sale and supply of leaded petrol, which is a known major source of lead, was banned in Hong Kong from 1 April 1999.

(c) Compliance on Air Quality Objectives

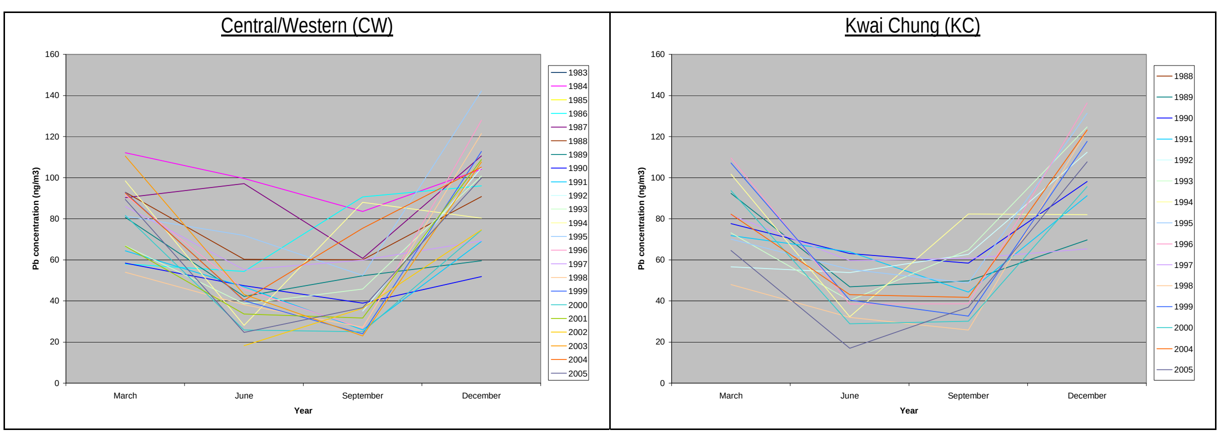
Among various Toxic Air Pollutants, lead is the only one criteria pollutant included in the AQO established in Hong Kong. Due to the reduction of lead in petrol programme, the ambient lead concentrations continued to linger at very low levels. The overall 3-month averages of all measured stations were well within the relevant limit of 1,500 ng/m^3.

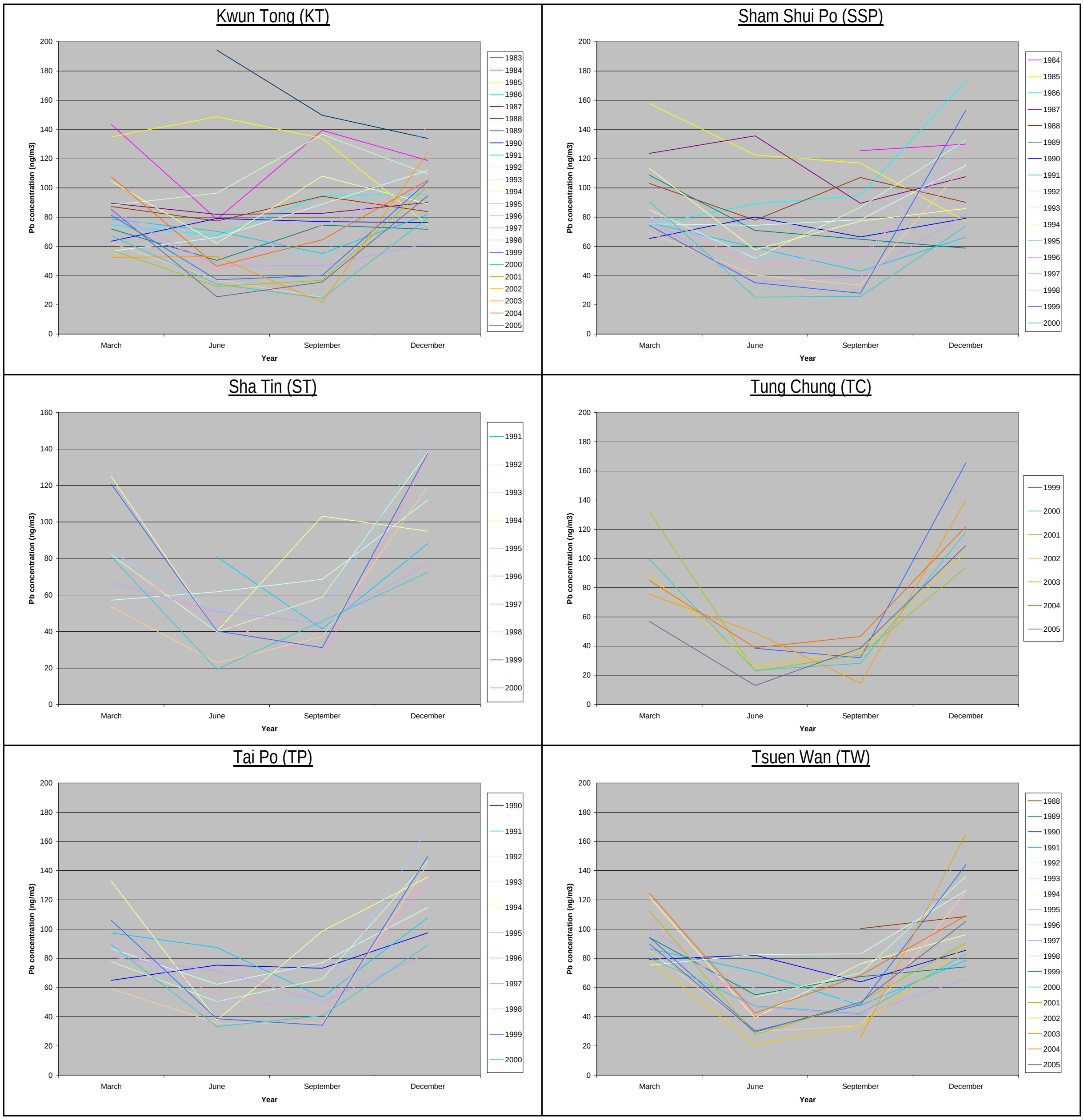
(d) Time Series Variation

- Quarterly variation

Same as the TSP and RSP, Pb levels were lower in summer (June and September) because of the better dispersion capability and the washout and road surface wetting effect of rainfall. Figures 3.29 show the quarterly Pb data of all stations.

Figures 3.29 Quarterly Pb Variation of Air Monitoring Stations (from 1983 to 2005)




Kwun Tong (KT)
Pb concentration (ng/m3)
Year
March
June
September
December
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Sham Shui Po (SSP)
Pb concentration (ng/m3)
Year
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Sha Tin (ST)
Pb concentration (ng/m3)
Year
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Tung Chung (TC)
Pb concentration (ng/m3)
Year
1999
2000
2001
2002
2003
2004
2005
Tai Po (TP)
Pb concentration (ng/m3)
Year
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Tsuen Wan (TW)
Pb concentration (ng/m3)
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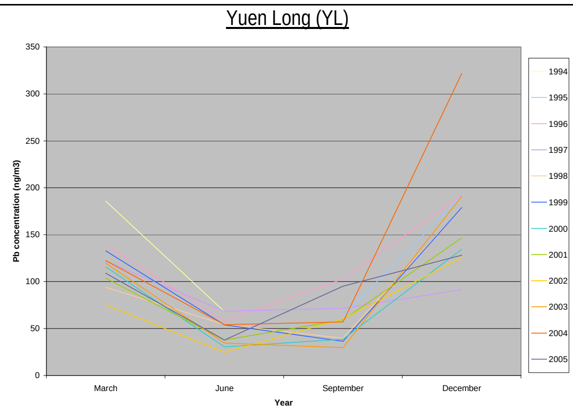
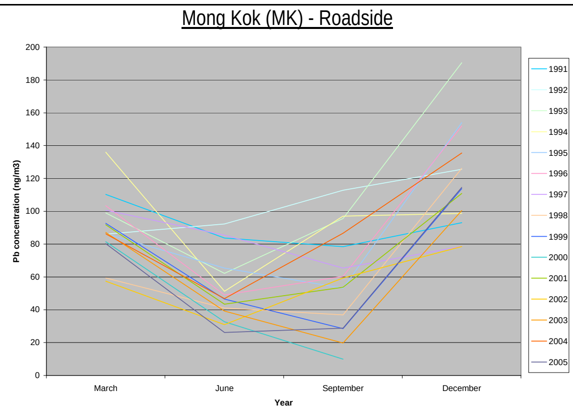
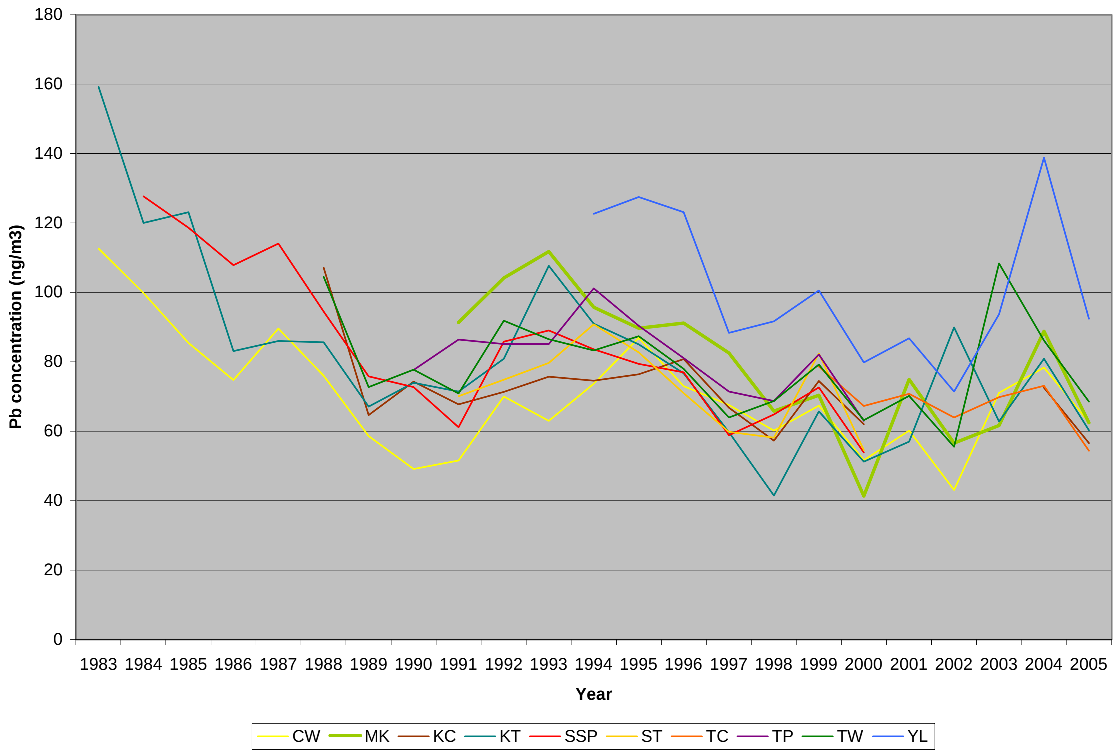




(e) Long Term Trend

The ambient lead concentrations have been lingering at very low levels since the oil companies took voluntary action in reducing the lead content of petrol by almost 90% in the early eighties. Lead emissions from vehicles were further reduced as a result of the introduction of unleaded petrol in April 1992 and completely eliminated when the sale and supply of leaded petrol was banned in April 1999. Figure 3.30 shows that the lead in air has been maintained at low levels (about 10% of the HKAQO) since 1983. It is expected that ambient lead concentrations will remain very low in the future.

Figure 3.30 Annual Averages of Pb Concentration from 1983 to 2005



3.4.8 Toxic Air Pollutants (TAPs)

Two groups of toxic air pollutants (TAPs), viz. heavy metals and organic substances, were regularly monitored at the Central/Western and Tsuen Wan stations since mid 1997. The TAPs being monitored can be broadly classified as volatile organic compounds (e.g. benzene, perchloroethylene and 1,3-butadiene), dioxins and furans (e.g. 2,3,7,8-TCDF and 2,3,7,8-TCDD), carbonyl compounds (e.g. formaldehyde), polycyclic aromatic hydrocarbons (e.g. benzo(a)pyrene), and hexavalent chromium. Five distinct methods were used to analyze the collected samples for target TAPs (please refer to Table 3.3 for details). Sampling media used include stainless steel canisters, Sep-Pak cartridges, polyurethane foams and bicarbonate impregnated filters. TAP samples are analyzed by the Government Laboratory.

Preliminary analysis of the monitoring results of 1,3-butadiene and formaldehyde indicates that vehicle emission may be a major source of toxic air pollutants in Hong Kong. The ambient levels of benzene and perchloroethylene were also relatively high implying that petrol filling stations and dry cleaning facilities may also be important stationary sources of toxic air pollutants.

The measured ambient concentrations of hexavalent chromium remained at a low level possibly due to a recent decline in the number of electroplating factories in Hong Kong. Ambient levels of TAPs such as cadmium, nickel, dioxins and furans were relatively low. These TAPs were typically emitted from power plants and incinerators which were all under licensing control of the Specified Processes regulations. Table 3.15 shows the levels of TAPs from 1997 to 2005 for all monitoring stations.

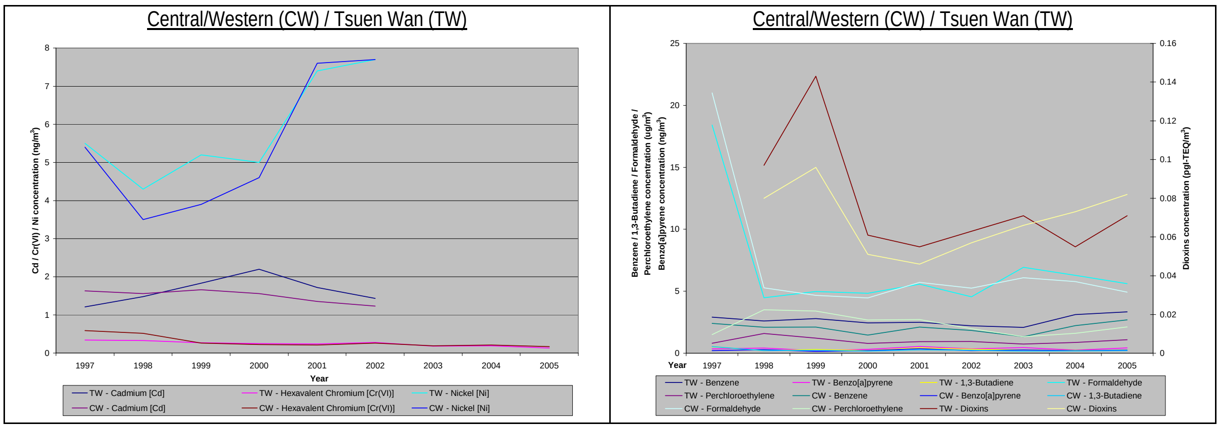
Table 3.15 Levels of Toxic Air Pollutants for 1997-2005 [source from Air Quality in Hong Kong, Environmental Protection Department (1997-2005)]

Toxic Air Pollutants	Possible Sources	Unit for concentration	Range of Average Concentration (1997-2005) / (1997-2002)*[1]		Levels Observed in other Urban Areas [2]
			Tsuen Wan	Central/ Western	
Heavy Metals [3]					
Cadmium	Electricity works	ng/m^3	1.21-2.2*	1.23-1.66*	0.1-10
Hexavalent chromium	Electroplating and paint manufacturing facilities	ng/m^3	0.13-0.34	0.17-0.59	5-10
Nickel	Electricity works	ng/m^3	4.3-7.7*	3.5-7.7	1-10
Organic Substances					
Benzene	Vehicle exhaust and fugitive emission from petrol filling stations	$\mu g/m^3$	2.08-3.34	1.33-2.68	5-20
Benzo [a] pyrene	Tar and bitumen works, incomplete combustion	ng/m^3	0.21-0.54	0.15-0.37	1-10
1,3-Butadiene	Incomplete combustion of petrol and diesel fuels	$\mu g/m^3$	0.2-0.52	0.16-0.53	<2-22
Formaldehyde	Vehicle exhaust	$\mu g/m^3$	4.47-18.4	4.46-21	1-20
Perchloroethylene	Dry cleaning facilities	$\mu g/m^3$	0.8-1.6	1.33-3.5	<5
Dioxins	Incinerators	$pgl\text{-}TEQ/m^3$	0.055-0.143	0.046-0.096	0.1

[1] For TAP concentrations that are lower than the method detection limit (MDL), one half of the MDL is used in calculating the average concentration.
[2] World Health Organization, Updating and Revision of the Air Quality Guidelines for Europe, Copenhagen Denmark, 1994 and 1995.
[3] For nickel and cadmium, the reported figures are the respective 1997 annual average concentrations in the elemental analysis of total suspended particulates.

Among the various TAPs monitored from 1997 to 2005, the monitoring data collected so far indicate that the level of toxic air pollutants in Hong Kong is in general lower than or comparable to those observed in other urban areas. Figures 3.31 show annual TAPs variation from 1997 to 2005.

Figures 3.31 Annual Heavy Metals and Organic Substances Variation of General Monitoring Stations (from 1997 to 2005)



3.5 Summary and Conclusions

The source of indoor air is originated from 'outdoor air'. By a full review on analyzing over 8.9 millions air monitoring data on outdoor air quality among 23 years in Hong Kong, the comprehensive analyzed data from various pollutants can provide adequate information on design, operating and maintenance for fresh air systems in different districts in Hong Kong. In addition, the outdoor air pollutant trends and profiles are found closely in relation to governmental policies, social and financial incidences.

CHAPTER 4 : APPLICATION OF OUTDOOR AIR DATA

4.1 Introduction

This chapter utilizes the air quality monitoring data of total 23 years (from the years 1983 to 2005) collected by the Environmental Protection Department's fixed outdoor air monitoring network to establish:-

- example outdoor air quality years for setting up typical outdoor air pollutant concentration profiles as to facilitate outdoor air quality load calculation for fresh air system design for buildings.
- represented surrogate indicators for monitoring air quality at outdoor air intake.

4.2 Typical Outdoor Air Quality Year

The outdoor air required for maintaining an acceptable indoor air quality inside a building for its occupants has attracted growing concerns. In general outdoor air design, people usually use ventilation rate procedure described in ASHRAE 62 standard to determine minimum ventilation rates in breathing zone for different kinds of occupancy category. For energy conservation, many efforts, such as using CO_2 demand control on outdoor air system, have been devoted to use minimum energy consumption with a view to maintain the indoor air quality at optimum level. However, Indoor Air Quality Procedure also described in ASHRAE 62 standard can be applied to maintain acceptable indoor air quality with consideration of delivering minimum ventilation rate of outdoor air. The Indoor Air Quality Procedure is a performance-based design approach in which the building and its ventilation system are designed to maintain the concentrations of specific contaminants at or below certain limits identified during the building design and to achieve the design target level of perceived indoor air quality acceptability by building occupants and/or visitor. This procedure which requires the input of certain contaminant concentrations including indoor and outdoor sources, perceived indoor air quality, design approaches, etc. It would, therefore, be desirable to have some agreed set of outdoor air quality data in order to make use for this procedure on designing fresh air system.

In order to obtain more representative data primarily for calculating the outdoor air quality load, the most average year is proposed to be a standard reference for designing fresh air systems for buildings in Hong Kong by using the concept of CIBSE example year approach.

4.2.1 Utilization of Outdoor Air Quality Data

In practice, the figures on outdoor air quality data for a building are useful and relevant for indoor air quality management or ventilation system performance evaluation purpose. However, long-term outdoor air quality prediction is very difficult. A more feasible and convenient alternative is the use of historical data which should provide a reasonable projection of the outdoor air that is anticipated. These data would normally be available from air monitoring stations of Hong Kong Environmental Protection Department.

In this analysis, outdoor air data required for fresh air system design calculation was full data recorded at hourly intervals for each month over the period concerned. The appropriate duration for representing the outdoor air quality cycle was suggested to be one year owing to the annual cyclic behaviour of the weather. Located in the sub-tropical region of the northern hemisphere, Hong Kong enjoys a year-round dry-bulb temperature ranging between 5 ^{o}C and 35 ^{o}C with a relatively short low-temperature winter period but a long hot and humid summer. In general, the outdoor air contaminant concentrations are strongly affected by the weather conditions. As a consequence, it would be logical and also convenient to use the calendar year for the examination of outdoor air quality patterns in Hong Kong.

Synthetic outdoor air data obtained by taking the long-term mean of the relevant parameters may also be useful in outdoor air system calculations. However, such an approach was considered to be difficult to realize. The major advantage of using real year data over the synthetic ones will be the preservation of the inter-relationship among outdoor air elements and of the serial characteristics on preceding values of a particular element. The actual year data will also provide associated data, such as constituents of suspended particulates, etc. which may have implications for the outdoor air system calculations or other applications.

4.2.2 Selection Process

The selection process of example outdoor air quality year is based on the objective that is to select a year for which the monthly mean values of a number of pertinent parameters do not differ by more than a specific number of standard deviations from their long term mean.

Owing to the complex nature of the outdoor air, it will be extremely difficult to find a year that contains only standard outdoor air quality readings. The selection of the example outdoor air quality year would, therefore, involve the nomination of the year that contains the least abnormalities. To achieve this, the method suggested by Holmes and Hitchin was adopted in which monthly mean values of the outdoor air parameters and their standard deviation from the long-term mean were sought. The years containing any monthly mean that varied more than a specific standard deviation were then rejected and the last remaining year would become the example year chosen. It was proposed that the number of standard deviations used was two which was equivalent to rejecting those years with less than 5% probability of being a random variation. If more than one year had passed the screening test, the year with the lowest sum of deviation of all parameters would be selected. This method enables the use of any combination of outdoor air parameters as well as the application of weighting factors on any of these parameters that may sometimes be significant to particular applications.

The outdoor air data used for the selection process included the following monthly readings of outdoor air parameters:

- mean sulphur dioxide (SO_2) concentration;
- mean nitrogen oxides (NO_x), nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations;
- mean ozone (O_3) concentration;
- mean carbon dioxide (CO) concentration;
- mean respirable suspended particulates (RSP) concentration.

The selection method is at first to calculate the difference from the long term mean (D_{LTM}) of each pertinent outdoor air parameter for every month of the past recorded years:

$$D_{LTM} = \left(\frac{\sum_{y=1}^{N_y} \bar{p}(m,y)}{N_y} - \bar{p}(m,y) \right) \Big/ \sigma_p(m,y)$$

where $\bar{p}(m,y)$ = Mean pertinent outdoor air parameter for each month of every recorded year

$\sigma_p(m,y)$ = Standard deviation of pertinent outdoor air parameter for each month of every recorded year

N_y = Number of recorded year

The selection process is carried on if the absolute value of D_{LTM} is no greater than 2. Otherwise, the year can be rejected. If all months of the year pass this test, the year is a 'potential example outdoor air quality year'. As the case that if more than a single potential example year is selected, the year with the lowest total deviation (i.e. minimum of sum of deviation of all parameters for the year) becomes the example outdoor air quality year.

4.2.3 Results of Selecting Typical Outdoor Air Quality Year

Since the hourly continuous RSP data have been measured from 1993, the outdoor air data for 13 years (1993 – 2005) including mean SO_2, NO_x, NO, NO_2, O_3, CO, RSP concentrations recorded by Hong Kong Environmental Protection Department were analyzed for this study. Monthly mean figures of each year published by the Environmental Protection Department of Hong Kong were input for analysis and the respective sum of values, sum of squares of values, long-term means and standard deviations for each of the parameters were evaluated. The screening process was carried out by rejecting those years that contain any monthly mean value greater than two standard deviations. For those years that passed the test, sums of deviations of all parameters were evaluated. The year with the lowest total deviation becomes the example outdoor air quality year.

By considering that the outdoor air pollution concentrations are distinct among various regions in Hong Kong and different air monitoring stations should have different geographical and environmental characteristics, it is necessary to have different example years for different air monitoring stations to express the most 'representative' yearly profile. Therefore, 14 typical outdoor air quality years are proposed based on the locations of air monitoring stations.

As a result of the selection process, the listed years in Table 4.1 become the logical choice for the sample outdoor air quality year for different air monitoring stations in Hong Kong. A summary of the outdoor air quality data for the proposed example years are also included for reference and the outdoor air quality load calculation. The years not only enjoy the lowest sum of deviation amongst 13-year period under analysis, but also perform best in the screening procedures. The monthly mean and diurnal mean outdoor air data with various parameters of the selected years are listed in Figures 4.1 and 4.2 respectively for reference.

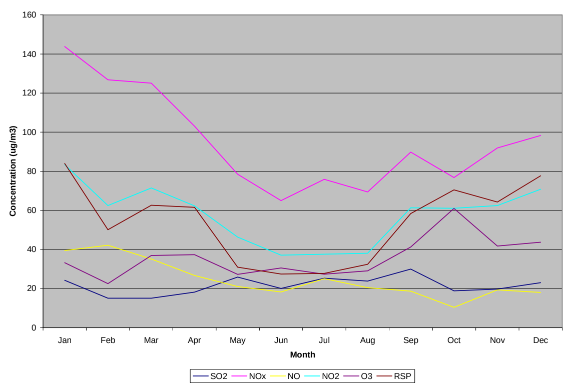
Table 4.1 Summary of Typical Outdoor Air Quality Years for Different Air Monitoring Stations

Monitoring Stations	Analyzed Year	**Selected Typical Year**	Range of monthly mean values (μg/m^3)						
			SO2	NOx	NO	NO2	O3	CO	RSP
General Monitoring Stations									
Central/Western (CW)	1993 – 2005	**2005**	15.0 – 29.9	64.9-143.8	10.4 – 42.1	37.0 – 83.4	22.5 – 61.0	N/A	27.4 – 83.9
Eastern (EN)	1999 – 2005	**2001**	8.8 – 18.8	N/A	N/A	36.0 – 69.7	17.5 – 50.9	N/A	20.9 – 66.4
Kwai Chung (KC)	1999 – 2005	**2002**	14.0 – 41.2	144.2 – 242.5	52.3 – 101.3	48.7 – 87.4	10.4 – 36.4	N/A	31.8 – 67.6
Kwun Tong (KT)	1997 – 2005	**2001**	11.3 – 21.7	146.8 – 222.4	56.5 – 90.3	50.1 – 89.1	12.6 – 39.5	N/A	31.8 – 77.1
Sham Shui Po (SSP)	1998 – 2005	**2001**	11.1 – 25.6	105.7 – 186.2	21.3 – 68.8	55.8 – 82.0	9.6 – 44.1	N/A	29.2 – 74.8
Sha Tin (ST)	1997 – 2005	**1999**	9.6 – 19.8	59.1 – 131.7	14.2 – 43.8	30.5 – 71.5	21.4 – 61.0	N/A	27.8 – 84.9
Tung Chung (TC)	1999 – 2005	**2003**	4.9 – 36.9	27.7 – 116.0	5.1 – 21.9	12.8 – 84.6	27.1 – 62.9	109.4 – 1198.7	17.0 – 105.6
Tap Mun (TM)	1998 – 2005	**2000**	4.3 – 9.2	9.1 – 18.5	0.7 – 3.0	7.9 – 15.4	38.3 – 88.6	291.3 – 711.0	18.8 – 59.3
Tai Po (TP)	1998 – 2005	**2000**	6.2 – 18.1	N/A	N/A	34.1 – 64.8	15.3 – 55.6	N/A	30.5 – 66.4
Tsuen Wan (TW)	1997 – 2005	**1998**	8.9 – 17.6	110.9 – 191.6	26.9 – 81.2	38.5 – 75.2	8.1 – 41.3	420.6 – 1040.4	27.6 – 72.8
Yuen Long (YL)	1995 – 2005	**1997**	12.3 – 29.7	N/A	N/A	35.1 – 87.0	9.4 – 34.9	N/A	27.6 – 86.6
Roadside Monitoring Stations									
Causeway Bay (CB)	1998 – 2005	**2001**	11.5 – 25.2	358.7 – 531.6	161.7 – 274.4	77.0 – 123.9	N/A	1004.7 – 1931.7	77.7 – 126.3
Central (CL)	1998 – 2005	**2001**	13.7 – 24.6	301.8 – 404.4	130.5 – 190.5	56.9 – 115.2	N/A	1071.6 – 1641.2	48.0 – 90.3
Mongkok (MK)	2001 – 2005	**2002**	6.9 – 29.8	290.6 – 431.0	135.9 – 209.8	63.2 – 110.3	N/A	1222.4 – 1947.1	44.1 – 86.6

Figures 4.1 Monthly Mean Outdoor Air Data of Various Parameters on Selected Example Years among Different Air Monitoring Stations

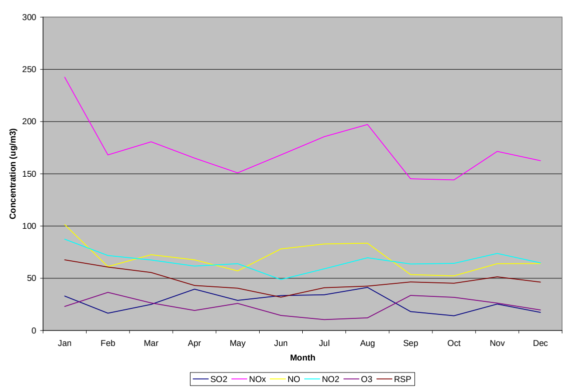
General Monitoring Stations

Central/Western (CW) - 2005

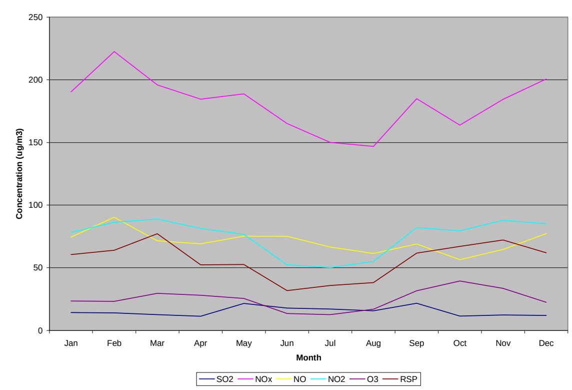


Eastern (EN) - 2001

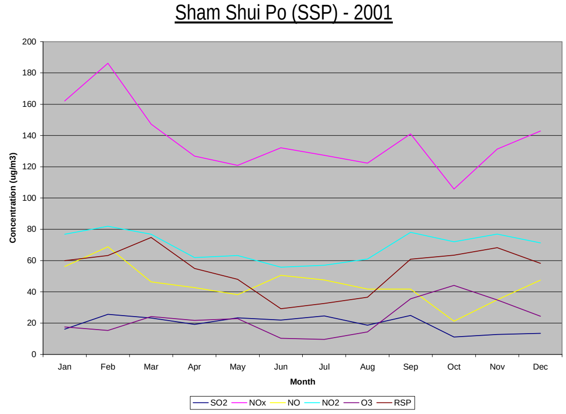
Kwai Chung (KC) - 2002



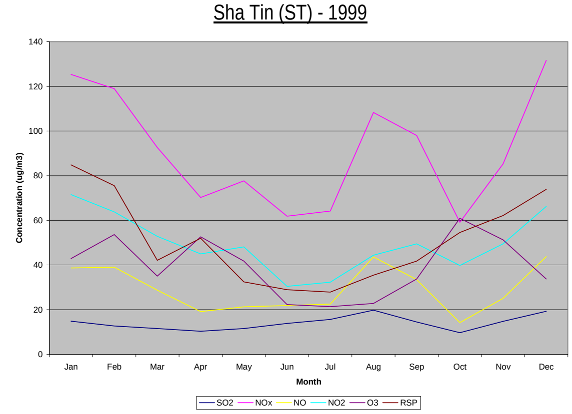
Kwun Tong (KT) - 2001

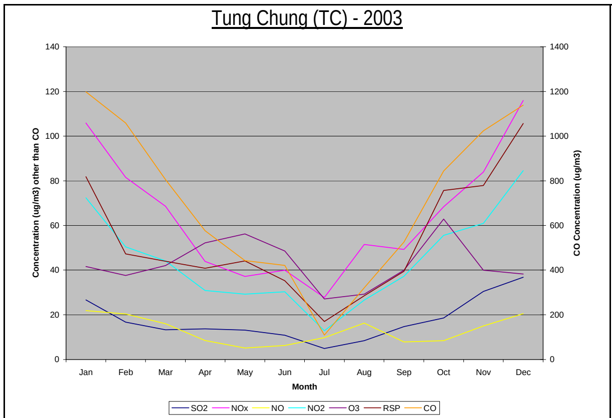


Sham Shui Po (SSP) - 2001

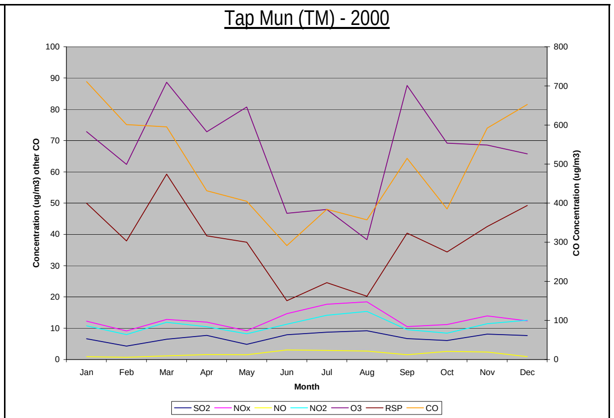


Sha Tin (ST) - 1999

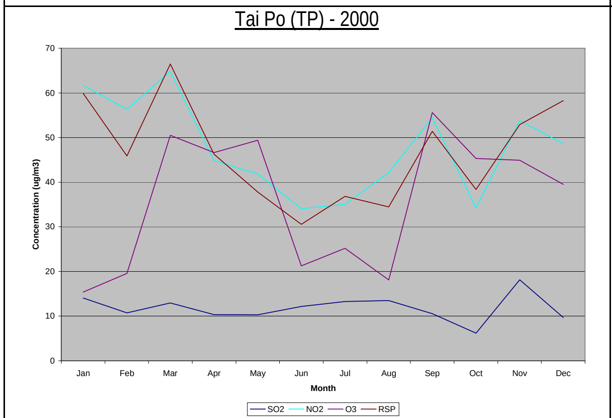




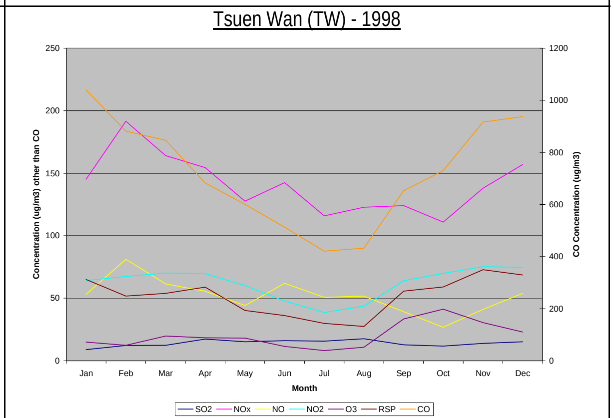
Tung Chung (TC) - 2003
Concentration (ug/m3) other than CO
CO Concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SO2 NOx NO NO2 O3 RSP CO



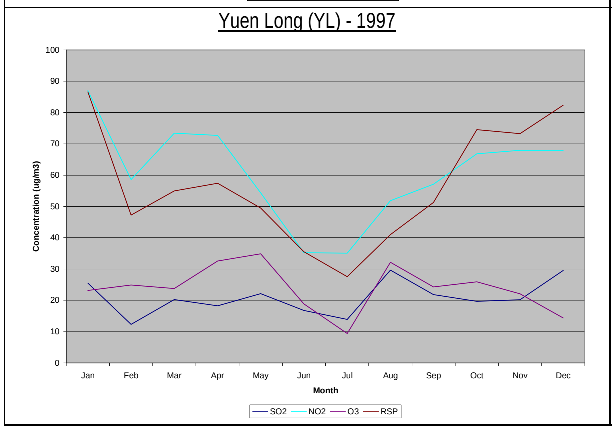
Tap Mun (TM) - 2000
Concentration (ug/m3) other than CO
CO Concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SO2 NOx NO NO2 O3 RSP CO



Tai Po (TP) - 2000
Concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SO2 NO2 O3 RSP



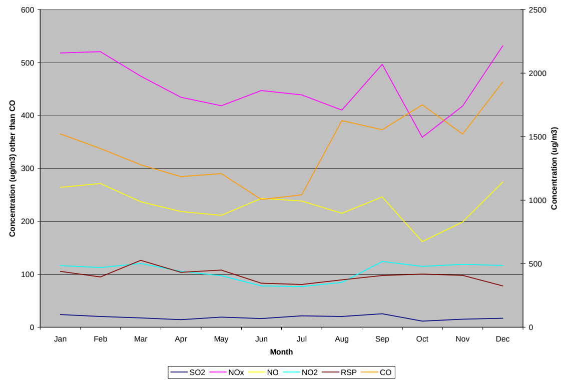
Tsuen Wan (TW) - 1998
Concentration (ug/m3) other than CO
CO Concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SO2 NOx NO NO2 O3 RSP CO



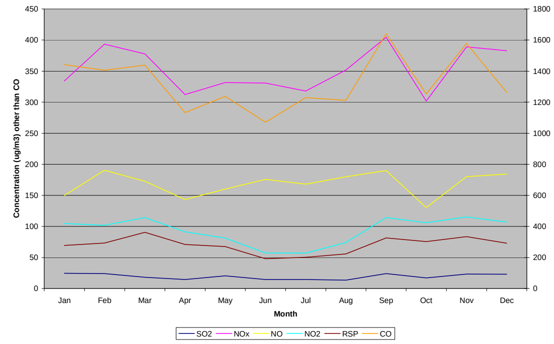
Yuen Long (YL) - 1997
Concentration (ug/m3)
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SO2 NO2 O3 RSP

Roadside Monitoring Stations

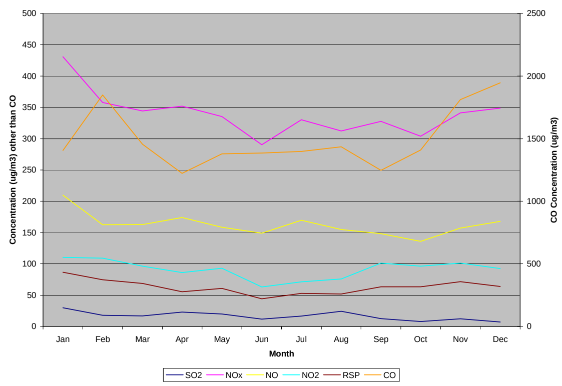
Causeway Bay (CB) - 2001



Central (CL) - 2001

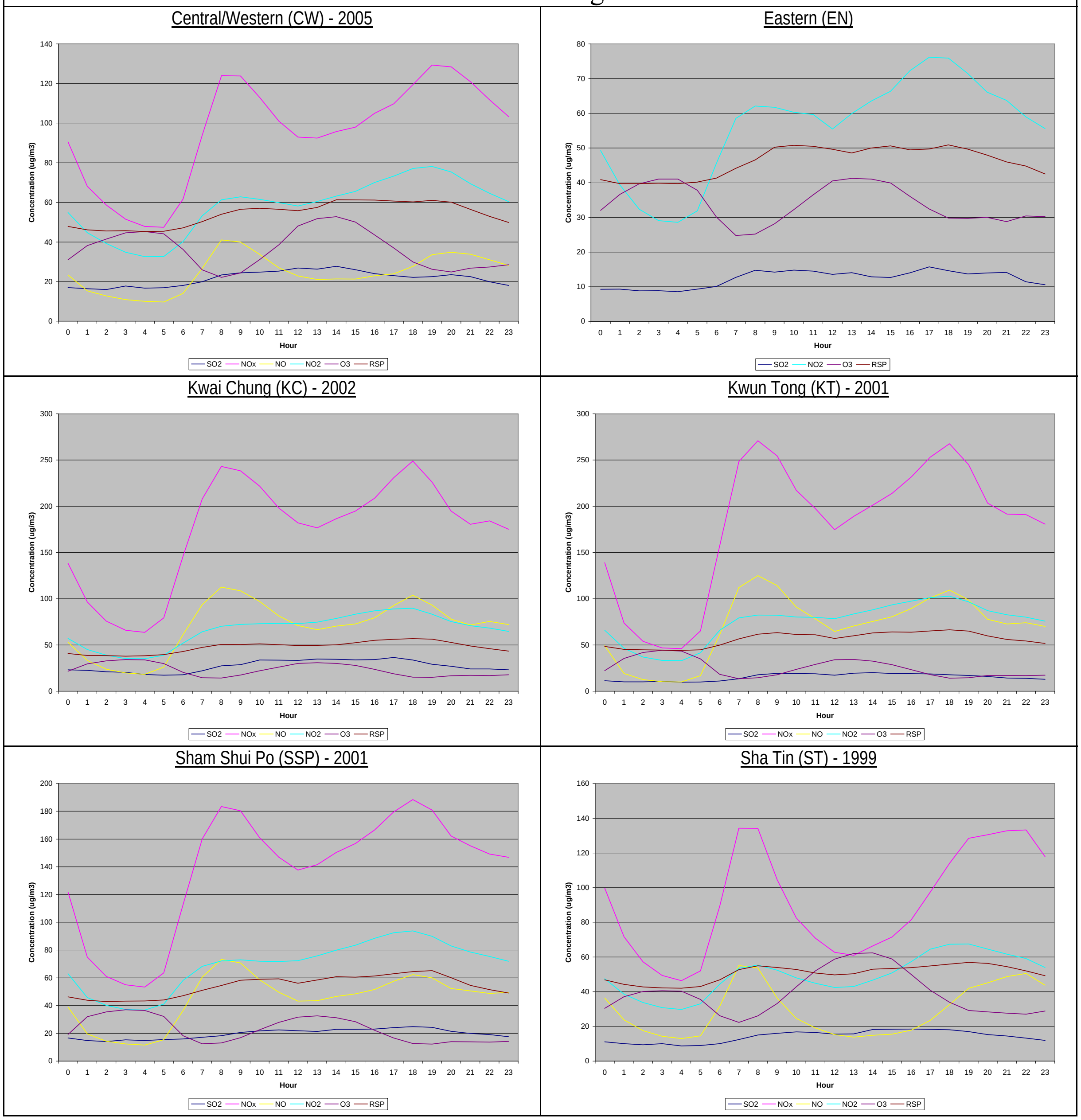


Mong Kok (MK) - 2002

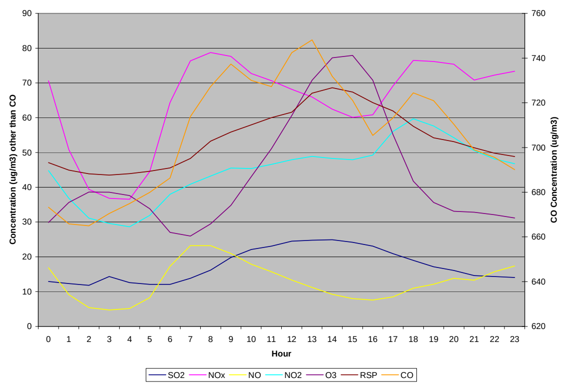


Figures 4.2 Diurnal Mean Outdoor Air Data of Various Parameters on Selected Example Years among Different Air Monitoring Stations

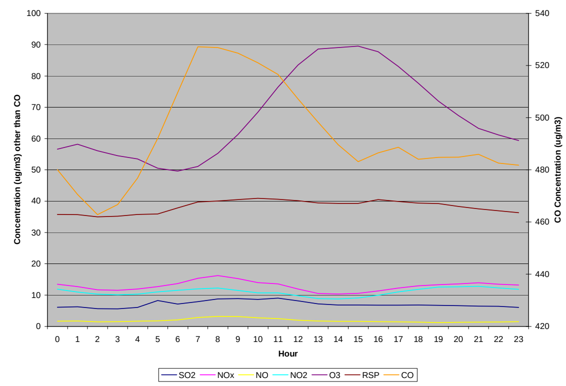
General Monitoring Stations



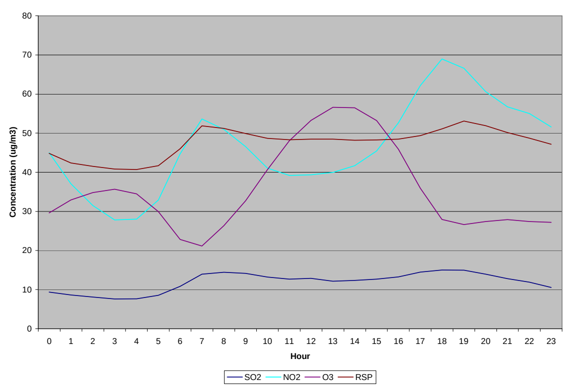
Tung Chung (TC) - 2003



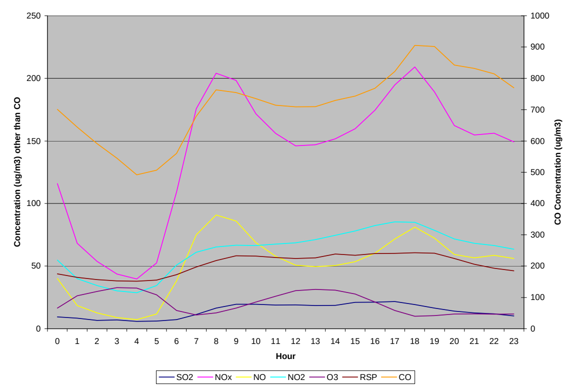
Tap Mun (TM) - 2000



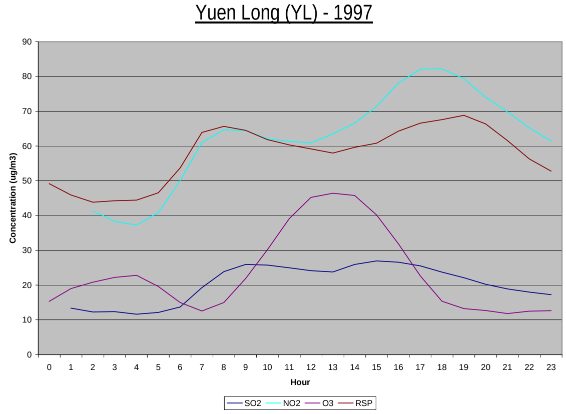
Tai Po (TP) - 2000

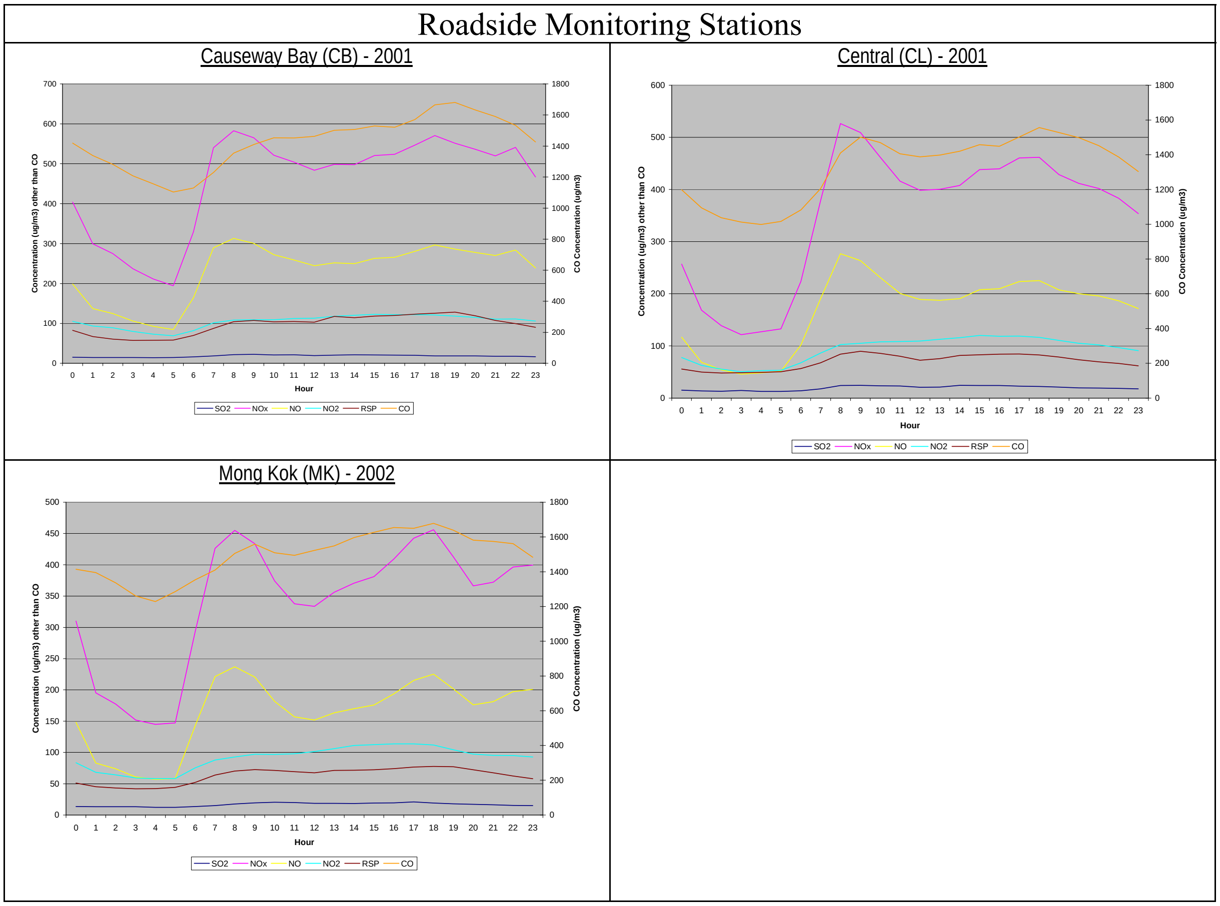


Tsuen Wan (TW) - 1998



Yuen Long (YL) - 1997





4.3 Inter-correlations between Major Air Pollutants in Hong Kong Territory

4.3.1 Rationale to Study Inter-correlations between Major Air Pollutants

In Hong Kong, the air pollution resulting from vehicle exhaust has always been a dominant pollutant source, like other major metropolitan cities in the world. The main primary pollutants emitted from vehicle exhaust include sulphur dioxide (SO_2), nitrogen oxides (NO_x), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), respirable suspended particulates (RSP), volatile organic compounds (VOC), etc. Figure 4.3 shows the percentages of various pollutants emitted from road transportation against their total emissions from 1991 to 2005. These pollutants may have potential harmful effect to the human health by direct inhalation or other ways of infection in certain levels of concentration.

For concerning the interrelationships between pollutants for understanding the micro-environmental air quality in Hong Kong, the correlations among the pollutants of SO_2, NO_x, NO, NO_2, O_3, CO and RSP are investigated. The field data of these pollutants from selected eight monitoring stations in Hong Kong during the period of 1994 – 2005 are reviewed and analyzed using statistical methods. Figure 4.4 indicates the figures between the total number of motor vehicle licensed and emission quantities of various pollutants from road transportation from 1991 to 2005.

Figure 4.3 Percentages of Various Pollutants Emitted from Road Transportation against Their Total Emissions from 1991 to 2005 [source from website: Hong Kong Air Pollutant Emission Inventory, Environmental Protection Department]

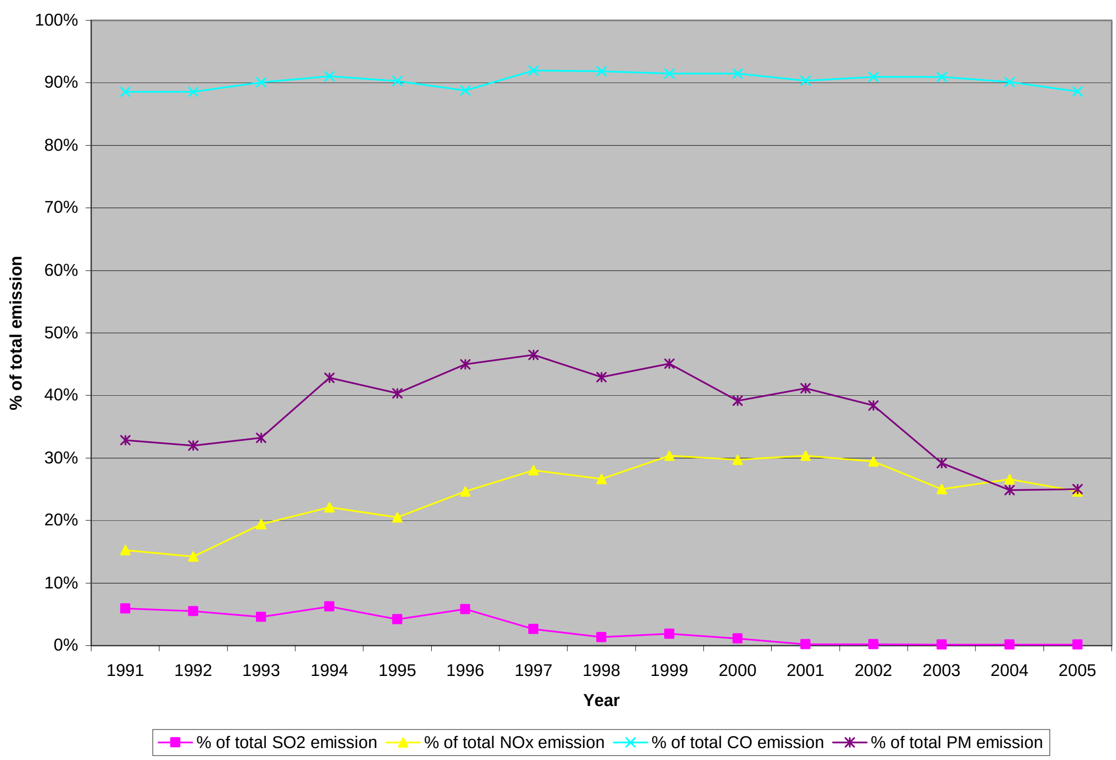
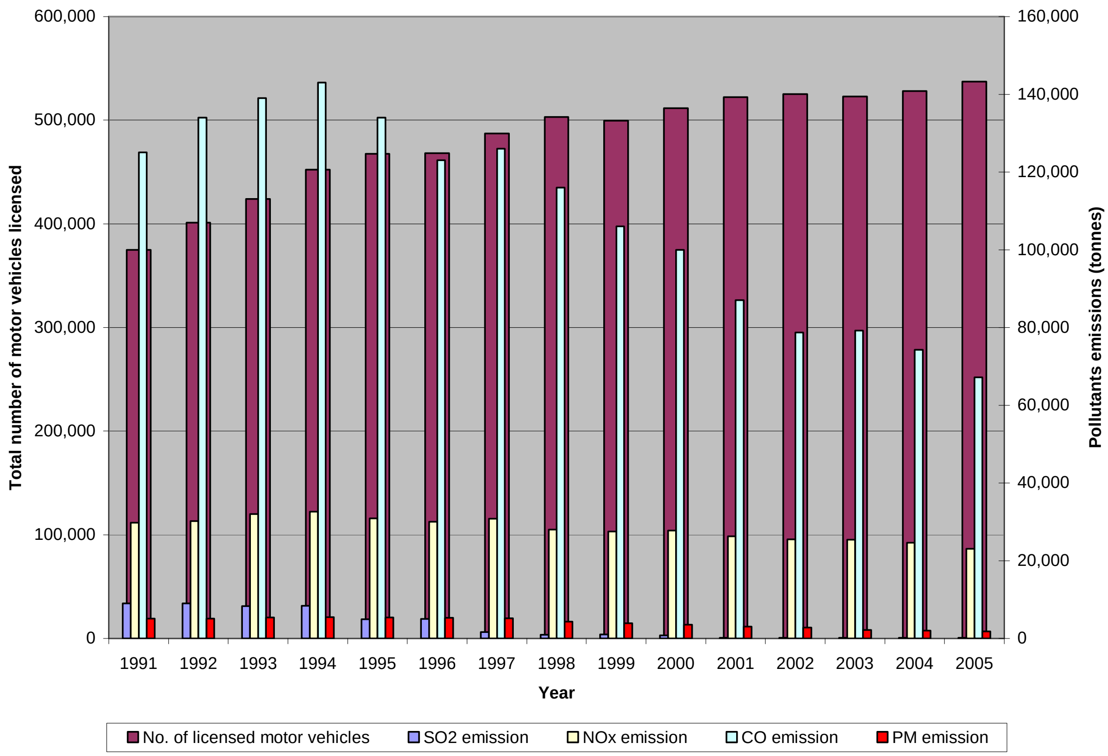


Figure 4.4 Total Number of Motor Vehicle Licensed and Emission of Various Pollutants from Road Transportation from 1991 to 2005 [source from website: (1) Transport Figures, Transport in Hong Kong, Transport Department (2) Hong Kong Air Pollutant Emission Inventory, Environmental Protection Department]



4.3.2 Information of Selected Monitoring Stations

To understand the characteristics of interrelationships against all traffic-related pollutants, the pollutant levels of SO_2, NO_x, NO, NO_2, O_3, CO and RSP recorded at eight monitoring stations in Hong Kong during 1994-2005 are selected to study. Since only eight monitoring stations have recorded all targeted pollutants, hourly raw data measured from these eight monitoring sites include five general stations (Kwai Chung, Tung Chung, Tap Mun, Tsuen Wan and Yuen Long) and three roadside stations (Causeway Bay, Central and Mongkok) are used to analyze the coefficient relations on seven pollutants, i.e. sulphur dioxide (SO_2), nitrogen oxides (NO_x), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), respirable suspended particulates (RSP) and ozone (O_3). The detailed information of these eight selected monitoring stations are listed in Table 3.3 of the previous Chapter.

4.3.3 Statistical Analysis among Pollutants

Based on the above pollutant database monitored in selected sites during the period of 1994-2005, the hourly mean concentrations of relevant pollutants during the same period are directly correlated with each other. The range of inter-correlations among SO_2, NO_x, NO, NO_2, O_3, CO and RSP are summarized in Table 4.2.

4.3.4 Significant Test for Correlation Coefficients among Pollutants

For quality assurance, a significance of the correlation coefficients among pollutants were examined and tested. The correlation coefficient r measures the correlation between x and y in the measured pollutant database, and a similar linear correlation coefficient exists for the population from which the data points were selected. The population correlation coefficient ρ is estimated by the corresponding sample statistics r.

In a two-tailed test, the hypothesis H_0: $\rho = 0$ against H_a: $\rho \neq 0$ were tested, i.e. test the hypothesis that x contributes no information for the prediction of y using the regression line model against the alternative hypothesis that the two variables are at least linearly related.

Test statistics: $t = \dfrac{r\sqrt{n-2}}{\sqrt{1-r^2}}$

Reject region:

$t > t_\alpha$ (or $t < -t_\alpha$) $\qquad\qquad |t| > t_{\alpha/2}$

where the distribution of t depends on $(n - 2)$ degree of freedom, and t_α and t_α are the critical values obtained from the Student t-distribution table. The range of significant test for correlation coefficients among SO_2, NO_x, NO, NO_2, O_3, CO and RSP are summarized in Table 4.4.

From the Student t-distribution table with ∞ degree of freedom, at 95% confidence level,

$$\text{if } t_{0.025} = 1.96 < t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}},$$

Hence we reject the null hypothesis and conclude that the two variables are linearly related.

Table 4.2 Range of Correlation Coefficients (R-squared values) among Different Air Monitoring Stations from 1994-2005

Area Type	Urban: Mixed residential/commercial/industrial				New Town: Residential				Background: Rural		Urban Roadside: Busy area surrounded by many tall buildings					
Station	Kwai Chung (KC)		Tsuen Wan (TW)		Tung Chung (TC)		Yuen Long (YL)		Tap Man (TM)		Causeway Bay (CB)		Central (CL)		Mong Kok (MK)	
Pollutants	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
SO2-NOx	0.4717	0.5245	0.2604	0.4183	0.2992	0.3931	0.1414	0.1688	0.3386	0.6689	0.1519	0.473	0.1473	0.5816	0.078	0.4159
SO2-NO	0.367	0.4494	0.1409	0.3647	0.1055	0.1886	0.0557	0.0586	0.084	0.334	0.1143	0.45	0.1273	0.5498	0.0457	0.4045
SO2-NO2	0.2927	0.3699	0.2048	0.3943	0.3181	0.4254	0.2459	0.2997	0.3599	0.6561	0.1532	0.2911	0.114	0.3474	0.052	0.2237
SO2-O3	0.1094	0.1152	0.0001	0.059	0.00003	0.005	0.0068	0.0134	0.000003	0.0185						
SO2-CO	0.0137	0.1526	0.0303	0.2106	0.1285	0.3542	0.123	0.167	0.022	0.2735	0.0994	0.225	0.102	0.3222	0.0048	0.1569
SO2-RSP	0.1244	0.224	0.1257	0.4852	0.3317	0.4736	0.2877	0.3288	0.0546	0.3254	0.0318	0.2244	0.1674	0.4696	0.1385	0.428
NOx-NO	0.8403	0.8934	0.8321	0.9276	0.6644	0.8024	0.8464	0.8823	0.4817	0.6098	0.9521	0.9871	0.963	0.9828	0.8943	0.9585
NOx-NO2	0.5302	0.6058	0.4	0.6274	0.6694	0.8474	0.5081	0.541	0.8897	0.919	0.2978	0.499	0.4402	0.5281	0.2745	0.4884
NOx-O3	0.1948	0.2539	0.1136	0.2478	0.0682	0.1382	0.1122	0.1296	0.066	0.1817						
NOx-CO	0.1827	0.3839	0.1428	0.3114	0.1748	0.4347	0.3052	0.4194	0.036	0.1913	0.2593	0.5932	0.22	0.6601	0.0687	0.5535
NOx-RSP	0.1953	0.2924	0.1649	0.2688	0.2688	0.4707	0.2219	0.2624	0.0029	0.1177	0.0434	0.1649	0.2203	0.4846	0.1624	0.4824
NO-NO2	0.2115	0.2554	0.138	0.2604	0.1984	0.3416	0.1692	0.1841	0.1919	0.3087	0.1222	0.3722	0.2748	0.3828	0.0477	0.2515
NO-O3	0.2107	0.2509	0.164	0.257	0.1799	0.2267	0.1813	0.2282	0.0555	0.0931						
NO-CO	0.0763	0.3745	0.0913	0.1925	0.106	0.3382	0.1677	0.2828	0.0007	0.0765	0.2055	0.5445	0.2103	0.6201	0.0637	0.4807
NO-RSP	0.0456	0.1226	0.0318	0.104	0.0389	0.1513	0.0454	0.1003	4E-08	0.0075	0.0253	0.0963	0.1328	0.3966	0.0364	0.3294
NO2-O3	0.054	0.1358	0.000002	0.1489	0.0072	0.0263	0.0001	0.0001	0.0385	0.1734						
NO2-CO	0.1193	0.3763	0.1109	0.3841	0.1515	0.421	0.3333	0.382	0.0515	0.1994	0.1296	0.4138	0.1306	0.4141	0.0158	0.3402
NO2-RSP	0.4203	0.4705	0.4461	0.5489	0.4907	0.6079	0.4955	0.5326	0.0112	0.1769	0.1859	0.5954	0.5258	0.6467	0.5054	0.6459
O3-CO	0.0045	0.2468	0.0007	0.1597	0.0005	0.0219	0.0029	0.0049	0.00003	0.0817						
O3-RSP	0.023	0.0525	0.0138	0.1099	0.0591	0.1084	0.0668	0.0998	0.2607	0.3818						
CO-RSP	0.1271	0.4172	0.1358	0.5024	0.1715	0.4948	0.4094	0.5737	0.0044	0.4714	0.0535	0.1869	0.165	0.5237	0.0395	0.3794

Table 4.3 Range of Significant Test for Correlation Coefficients among Different Air Monitoring Stations from 1994-2005

Area Type	Urban: Mixed residential/commercial/industrial				New Town: Residential				Background: Rural		Urban Roadside: Busy area surrounded by many tall buildings					
Station	Kwai Chung (KC)		Tsuen Wan (TW)		Tung Chung (TC)		Yuen Long (YL)		Tap Man (TM)		Causeway Bay (CB)		Central (CL)		Mong Kok (MK)	
Pollutants	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
SO2-NOx	80.54	90.75	41.20	78.49	51.45	66.02	37.24	41.72	53.01	121.68	36.41	87.24	38.62	96.38	26.92	73.24
SO2-NO	64.90	78.06	25.56	70.13	28.09	40.94	22.49	22.90	22.44	57.44	30.90	83.29	35.49	94.07	20.26	71.54
SO2-NO2	56.31	65.31	46.02	53.98	62.47	76.04	52.40	60.57	55.55	126.62	38.26	59.01	32.47	54.50	21.29	43.83
SO2-O3	30.83	31.75	**0.64**	23.03	**0.50**	6.52	7.64	10.66	**0.16**	12.43						
SO2-CO	8.61	19.53	16.39	35.27	35.14	64.06	34.28	41.45	12.41	46.91	28.03	49.64	31.26	52.97	6.42	38.91
SO2-RSP	28.20	47.09	34.79	61.62	61.12	86.44	57.74	63.74	21.63	63.19	16.24	45.30	35.95	58.13	36.67	56.51
NOx-NO	202.95	247.18	146.11	331.32	128.65	184.66	217.34	251.31	72.57	114.80	409.54	806.91	339.15	621.50	269.37	421.01
NOx-NO2	92.22	109.68	75.83	113.75	130.41	184.74	93.29	100.52	228.88	301.91	60.19	85.46	40.07	97.46	56.96	88.60
NOx-O3	41.99	49.55	21.80	45.37	21.11	36.52	32.52	35.62	21.58	38.30						
NOx-CO	26.72	40.30	30.32	59.98	41.97	80.37	61.34	77.81	17.55	44.49	50.65	108.30	48.47	83.89	25.14	100.74
NOx-RSP	38.70	46.14	32.71	55.37	54.83	72.81	48.63	54.19	4.86	33.22	19.27	37.79	37.04	83.28	40.46	66.60
NO-NO2	44.96	50.00	35.01	54.65	45.59	56.47	41.78	43.60	36.68	61.37	34.49	66.88	30.53	72.55	20.73	52.56
NO-O3	44.10	50.89	21.85	54.17	36.54	49.44	43.04	50.19	19.25	29.01						
NO-CO	20.59	32.78	19.99	44.64	31.40	65.51	41.54	57.49	2.40	26.33	46.42	98.06	47.10	78.18	24.14	86.89
NO-RSP	19.12	27.54	12.41	30.31	18.25	33.47	19.86	30.34	**0.02**	7.90	14.57	27.95	30.97	71.30	17.86	50.40
NO2-O3	20.40	33.67	**0.13**	15.89	6.64	14.99	**0.91**	**0.92**	17.85	37.06						
NO2-CO	20.07	55.64	32.63	66.86	38.53	78.29	65.44	71.98	21.11	45.66	35.27	75.35	35.37	73.89	11.73	64.97
NO2-RSP	56.75	74.47	64.37	101.56	88.77	104.28	90.05	97.22	9.58	42.16	42.26	110.34	51.68	116.27	71.44	124.12
O3-CO	4.95	25.68	2.44	16.51	2.05	13.60	4.98	6.40	**0.50**	22.79						
O3-RSP	12.72	21.15	4.26	32.18	20.32	31.80	24.24	30.24	47.42	60.72						
CO-RSP	10.26	61.87	36.50	78.07	41.19	89.98	75.81	105.20	6.02	72.44	20.04	43.55	40.07	67.76	18.70	58.44

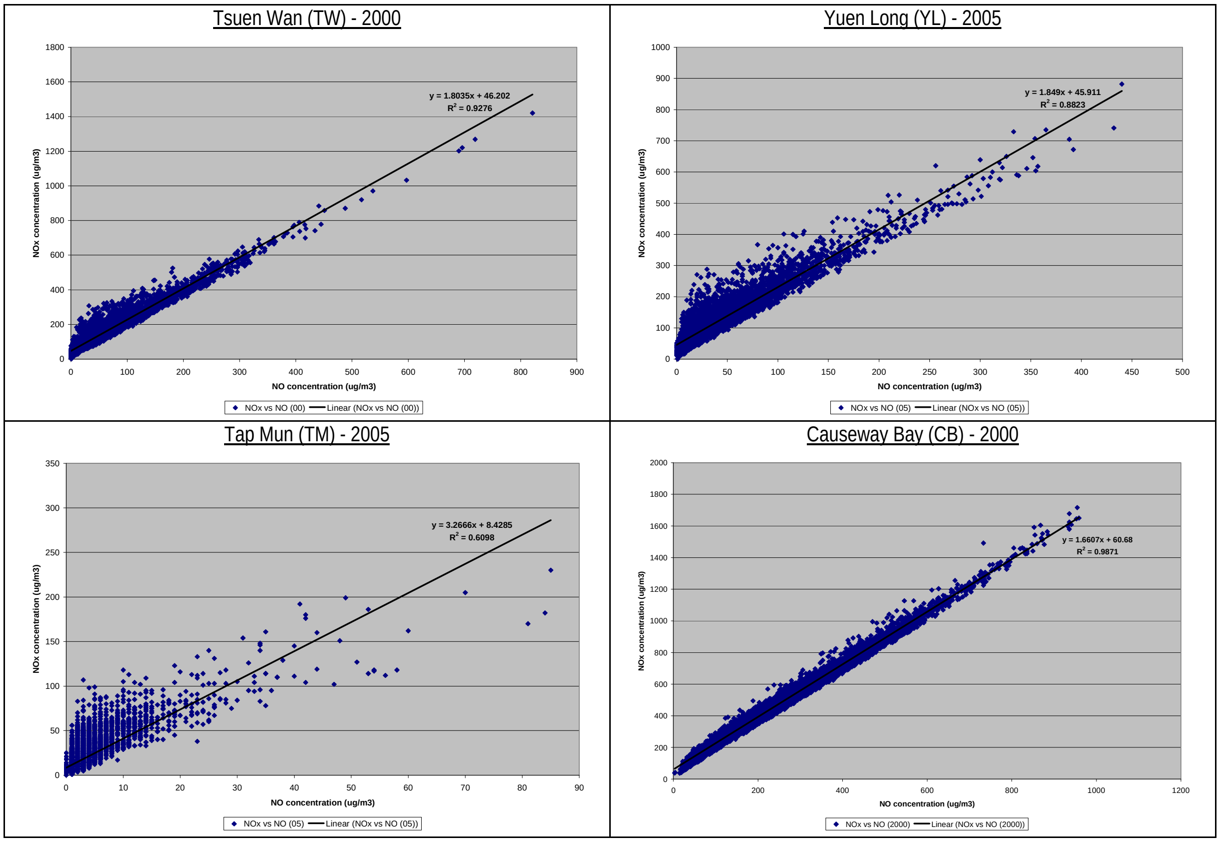
4.3.5 Findings in Correlations among Pollutants

The following sections indicate the correlation analysis on the relevant pollutants among 8 air monitoring stations.

(a) Correlation between NO_x and NO

Figures 4.5 present the correlation analysis between NO_x and NO levels. According to Table 4.2, the results indicate that very strong positive correlations exist between NO_x and NO levels in all selected sites. Besides, the linear relations (with correlation coefficients as high as or over 0.90) between NO_x and NO can also be noticed in Table 4.2 and Figures 4.5, particularly in roadside stations. In addition, it is clearly indicated that the correlation coefficients at roadside stations are the highest by comparing with the other non-roadside stations. The correlation coefficients at rural station (Tap Mun) are the lowest. The slopes of NO_x-NO lines are approximately 2.0 in mixed, residential and roadside stations, which imply that the major emission of NO_x (NO_2 and NO) comes from the same type of pollutant source, e.g. vehicle exhaust.

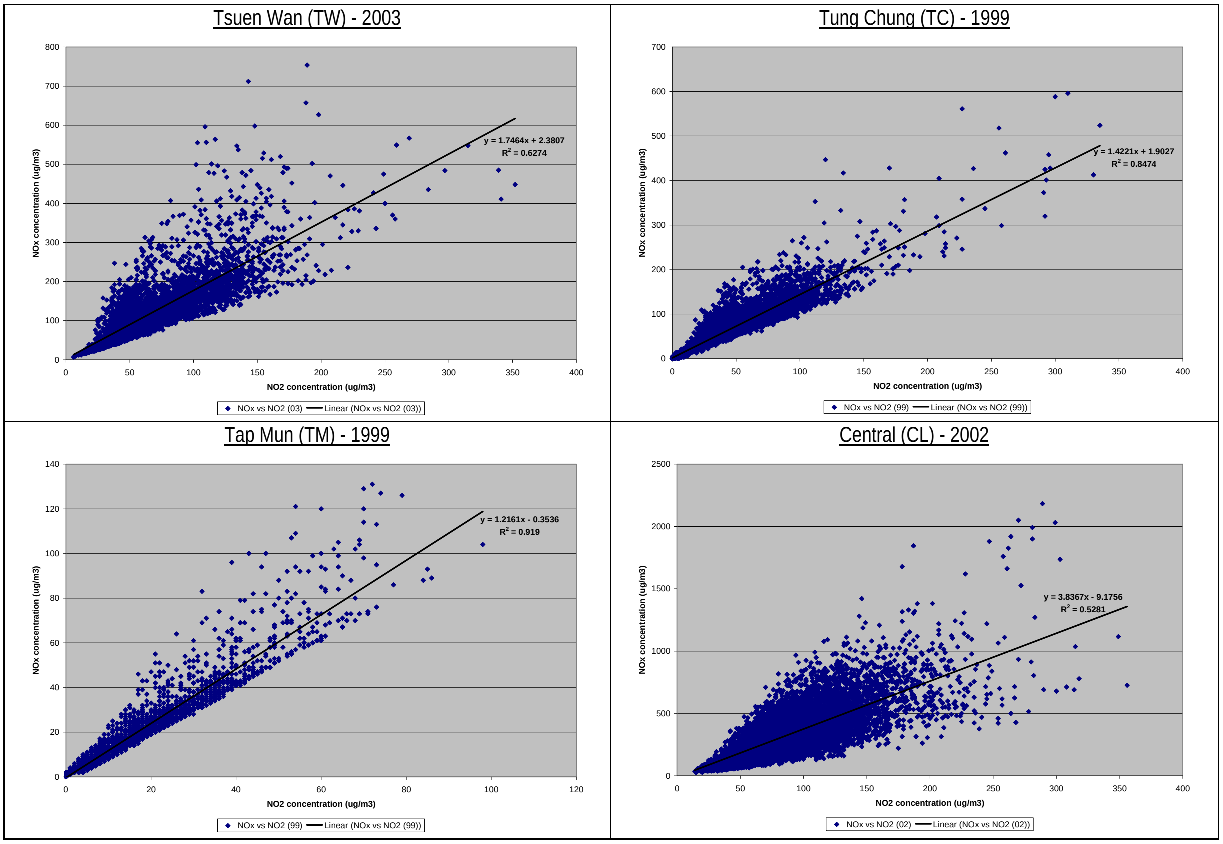
Figures 4.5 The Best Correlation Coefficient (R-squared Values) between NO_x and NO among Different Area Types (Mixed, Residential, Rural and Roadside) of Monitoring Stations



(b) Correlation between NO_x and NO_2

The relations between NO_x and NO_2 also demonstrate strong positive correlation with high coefficients shown in Table 4.2 and Figures 4.6. However, it is interesting that the correlation coefficients at rural station (Tap Mun) are the highest by comparing with other stations. Contrarily, the correlation coefficients at roadside stations are the lowest.

Figures 4.6 The Best Correlation Coefficient (R-squared Values) between NO_x and NO_2 among Different Area Types (Mixed, Residential, Rural and Roadside) of Monitoring Stations



(c) Correlation between NO and NO_2

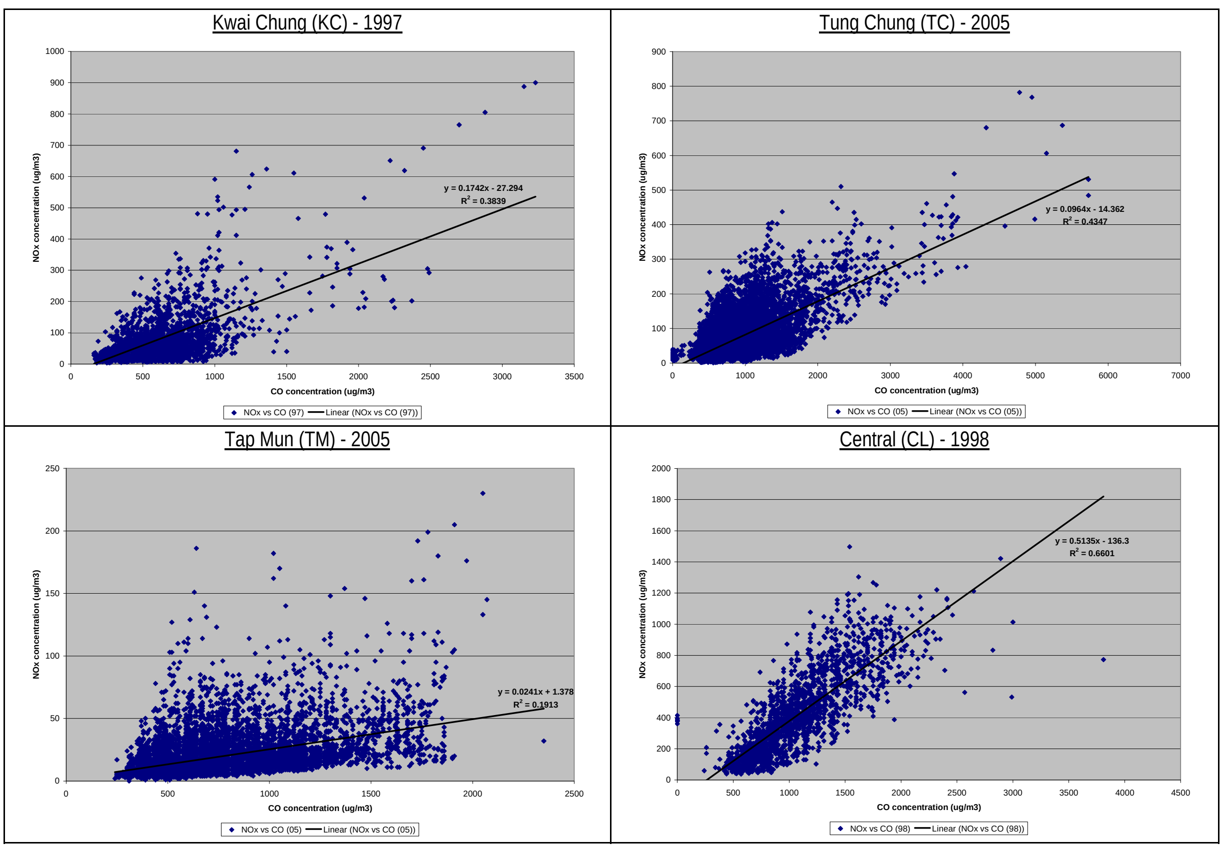
As mentioned in Section 3.4.2(b) of Chapter 3, total nitrogen oxides (NO_x) are defined as the sum of nitric oxide and nitrogen dioxide concentrations. NO changes rapidly to nitrogen dioxide (NO_2) by subsequent oxidation in the presence of hydrocarbons and sunlight.

However, the correlation between NO and NO_2 is not very strong in every area type shown in Table 4.2 since the relative concentrations of the two oxides in air depend on the amounts of the chemical oxidants and reactive hydrocarbons, insolation levels and the reaction time.

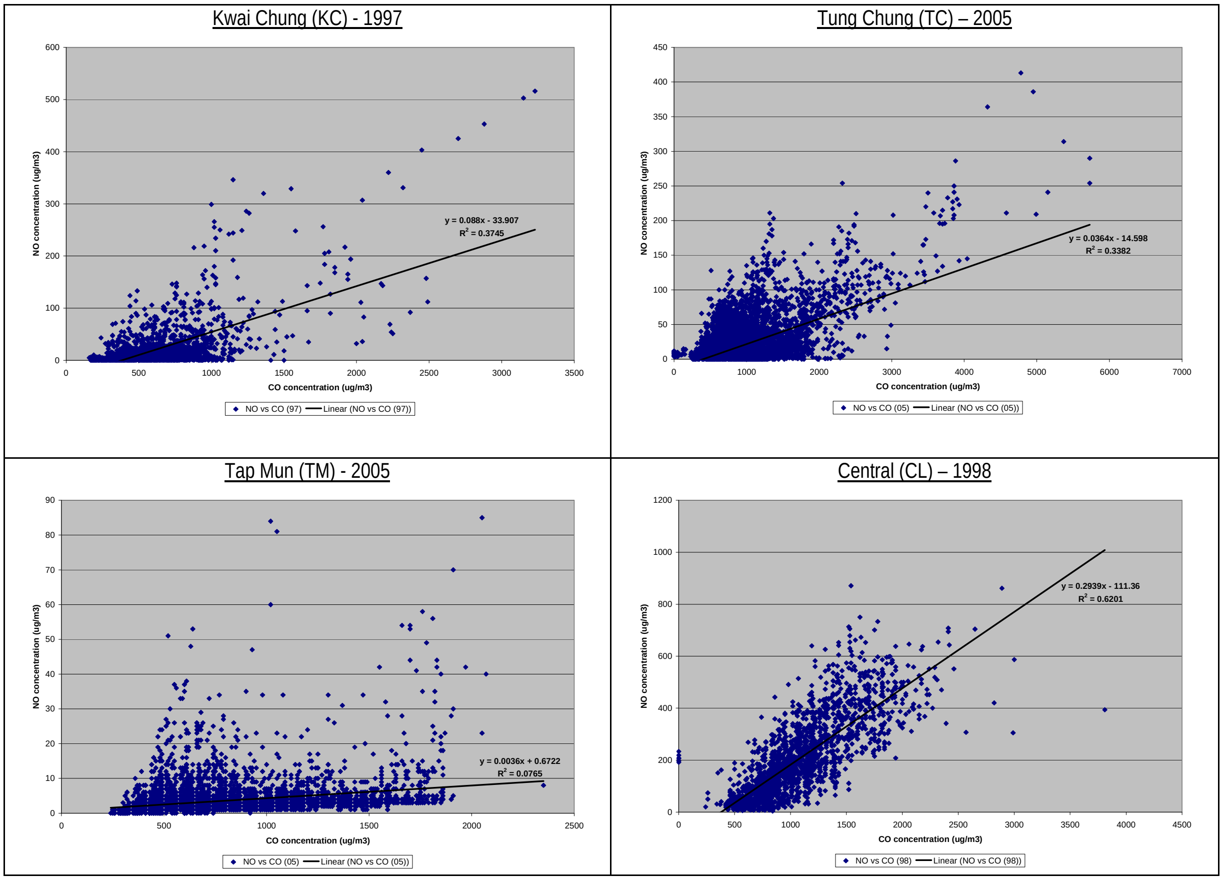
(d) Correlation between NO_x, NO and CO

Figures 4.7 and 4.8 present the correlation analysis between NO_x and CO levels; and the correlation analysis between NO and CO respectively. According to Table 4.2, the results indicate that positive correlations exist between NO_x/NO and CO levels in all selected sites. But much stronger linear relations between NO_x/NO and CO can also be appeared in roadside stations which are shown in Table 4.2 and Figures 4.7-4.8. Similarly in correlation of NO_x and NO, the correlation coefficients at roadside stations are the highest by comparing with the other non-roadside stations. The correlation coefficients at rural station (Tap Mun) are the lowest.

Figures 4.7 The Best Correlation Coefficient (R-squared Values) between NO_x and CO among Different Area Types (Mixed, Residential, Rural and Roadside) of Monitoring Stations



Figures 4.8 The Best Correlation Coefficient (R-squared Values) between NO and CO among Different Area Types (Mixed, Residential, Rural and Roadside) of Monitoring Stations



(e) Correlation between O_3 and other pollutants

Correlations between O_3 and other pollutants are relatively weak shown in Table 4.2 and the values of significant test are less than 1.96 ($t_{0.025}$) in some cases according to Table 4.3, i.e. the null hypothesis are accepted and conclude that the two variables are linearly unrelated. It notes that the correlations between O_3 and NO_2 are very weak and subtle, especially in residential areas.

4.4 Surrogate Indicator for Monitoring Outdoor Air Quality

4.4.1 Criteria to Choosing Surrogate Indicators

The choice of surrogate indicator for monitoring outdoor air quality depends on many factors such as:

- how representative they are of actual air quality;
- ease of measurement;
- ease of interpretation of results;
- possibility of real-time monitoring; and
- feasibility of incorporating measurements into a schedule of routine maintenance procedures.

4.4.2 Rationale of Choosing Carbon Monoxide as Monitoring Indicator

The building, should be 'built tight, but ventilated right'. An airtight indoor space ensures that the design conditions can be maintained by the mechanical ventilation system. The parameter used to indicate unacceptable infiltration of outdoor air is important. Carbon monoxide is chosen as a surrogate indicator for monitoring outdoor air quality, because CO is a major pollutant from vehicular emissions which also are a main source of nitrogen oxides (NOx), nitric oxide (NO), nitrogen dioxide (NO_2), particulate matters including total and respirable suspended particulates (TSP and RSP) and other volatile organic compound (VOC) especially in urban areas. Monitoring CO also has the criteria described in Section 4.4.1 Therefore, CO is considered as a surrogate for other pollutants. Figures 4.9 – 4.14 are the correlations of CO with other pollutants recorded in Hong Kong Monitoring Stations. They illustrate good correlations between CO and other related pollutants except with ozone. Although the correlations are not strong, the direct proportional relationships are most likely occurred (except with ozone) and the trends are definite. On the other hand, CO is also much easier to measure. Handheld or stationary instruments for CO measurement having acceptable accuracy and reading resolution in the expected concentration range are readily available in the market, and are relatively easy to calibrate.

4.4.3 Correlation of Carbon Monoxide with other Pollutants

(a) Correlation between Carbon Monoxide (CO) with Sulphur Dioxide (SO_2)

Table 4.4 and Figures 4.9 present the correlation analysis between SO_2 and CO levels. It is interesting to note that the correlation coefficients at all roadside stations have been decreased steadily because of the effect of policy on the implementation of the Air Pollution Control (Motor Vehicle Fuel) Regulations since 1995 for controlling motor vehicle fuel quality. Moreover, the recent low correlation coefficients appeared in roadside stations because of the great reduction of SO_2 emission from vehicle exhaust.

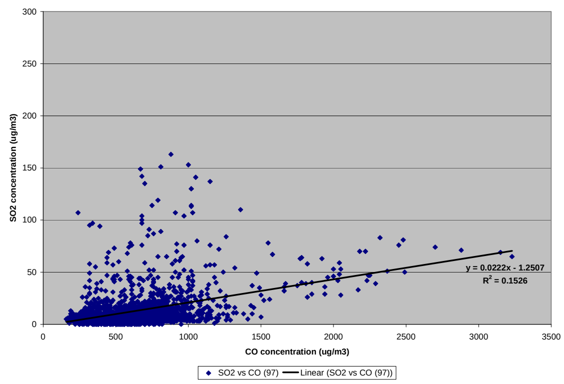
Table 4.4 R-squared Values of the Correlation between CO and SO_2

Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.0993		0.0137	0.1526								
TC						0.2382	0.3542	0.2282	0.1285	0.2889	0.2938	0.3281
TM					0.2735	0.1599	0.0358	0.022	0.0536	0.1514	0.0911	0.0639
TW				0.0766	0.0626	0.0534	0.0873	0.1273	0.0303	0.2106	0.0901	0.0717
YL											0.167	0.123
Roadside Air Quality Monitoring Station												
CB					0.2202	0.225	0.1766	0.1508	0.1468	0.1274	0.1723	0.0994
CL					0.3222	0.2514	0.1405	0.205	0.1333	0.1082	0.102	0.1055
MK			0.1569	0.0939	0.0706	0.0211	0.0548	0.0407	0.018	0.0413	0.0227	0.0048

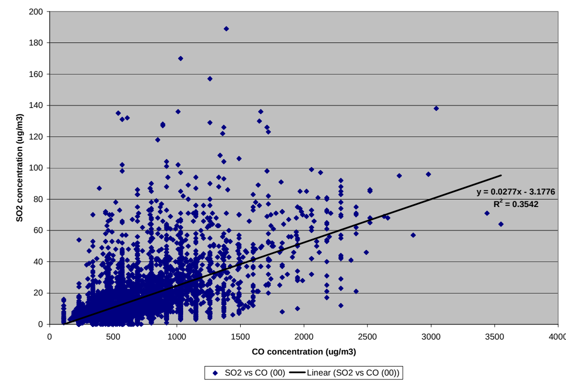
Figures 4.9 The Best Year on R-squared Values of Correlation between CO and SO_2 among Different Air Monitoring Stations

General Monitoring Stations

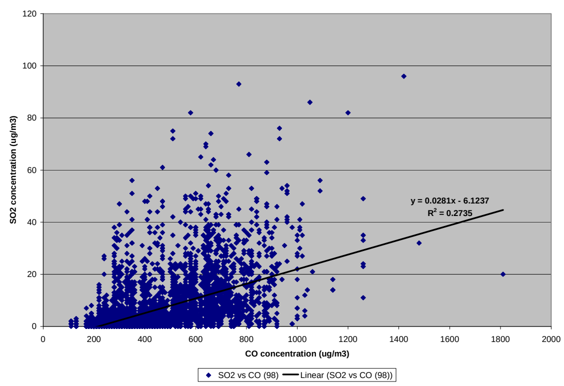
Kwai Chung (KC) – 1997



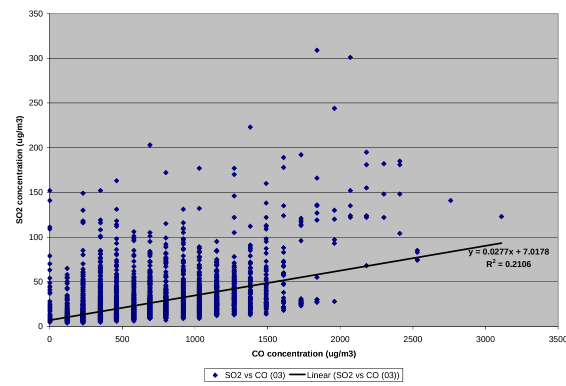
Tung Chung (TC) - 2000



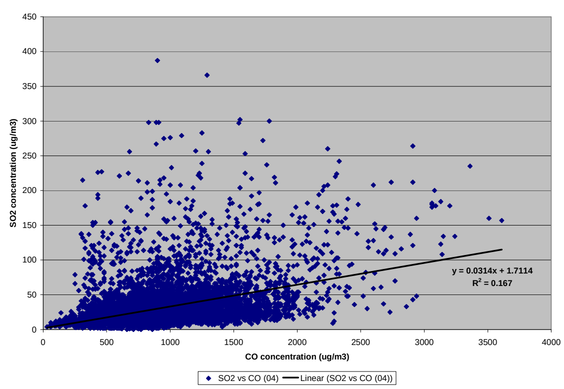
Tap Mun (TM) - 1998

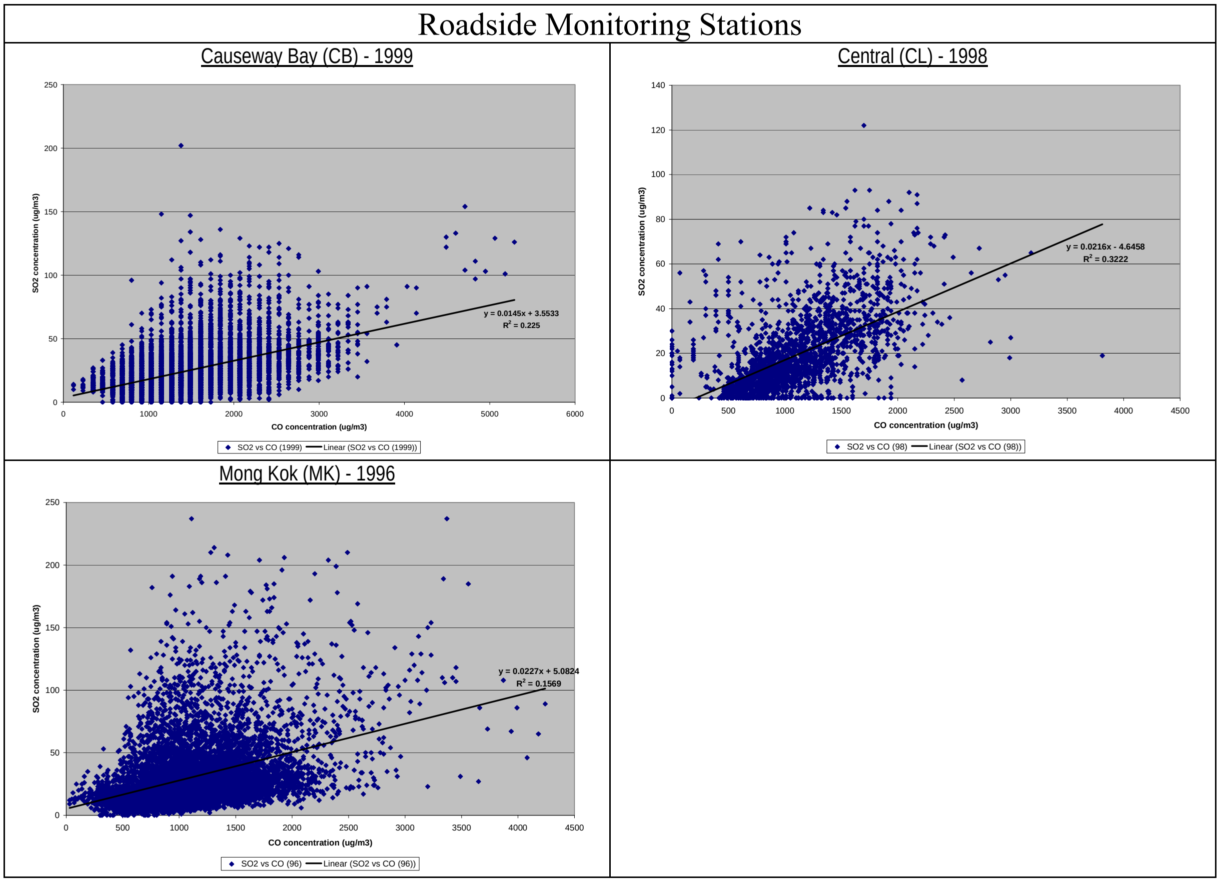


Tsuen Wan (TW) - 2003



Yuen Long (YL) - 2004





(b) Correlation between Carbon Monoxide (CO) with Nitrogen Oxides (NO_x) / Nitric Oxides (NO) / Nitrogen Dioxide (NO_2)

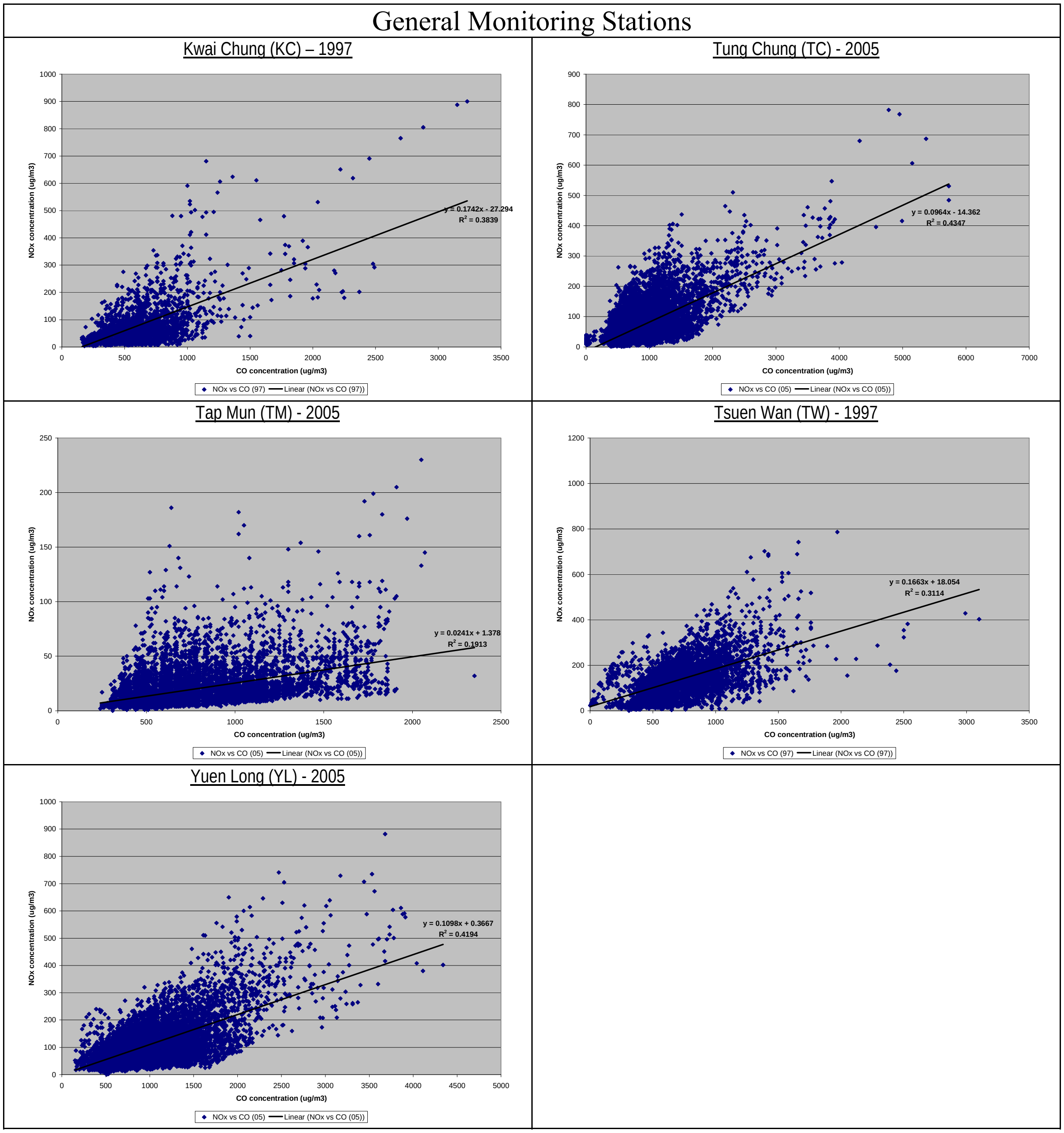
Tables 4.5-4.7 and Figures 4.10-4.12 present the correlation analysis between NO_x/NO/NO_2 and CO levels respectively. It can be noted that the correlation coefficients at residential (Tung Chung and Yuen Long) and rural (Tap Mun) stations has been increased because the same type of source, like vehicle exhaust, is increased. On the other hand, the correlation coefficients at all roadside stations have been decreased steadily because of the effect of policy on the implementation of the Air

Pollution Control (Motor Vehicle Fuel) Regulations since 1995 for controlling motor vehicle fuel quality.

Table 4.5 R-squared Values of the Correlation between CO and NO_x

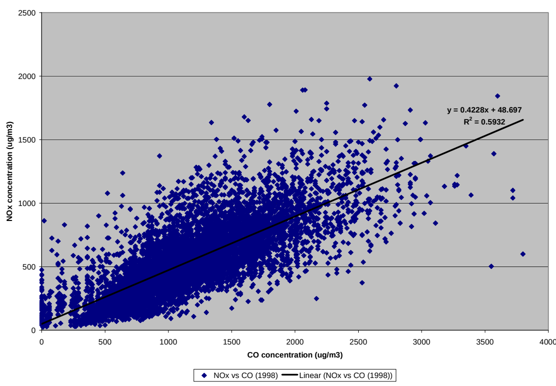
Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.1827		0.2404	0.3839								
TC						0.3339	0.4071	0.3098	0.1748	0.3737	0.3388	0.4347
TM					0.1197	0.0681	0.036	0.084	0.0547	0.0995	0.1095	0.1913
TW				0.3114	0.3009	0.2646	0.1475	0.1428	0.158	0.1877	0.2355	0.2777
YL											0.3052	0.4194
Roadside Air Quality Monitoring Station												
CB					0.5932	0.3221	0.4528	0.2879	0.2593	0.2695	0.3124	0.3163
CL					0.6601	0.4219	0.22	0.3756	0.4194	0.3006	0.3668	0.453
MK			0.5476	0.4198	0.5535	0.22	0.3317	0.2339	0.168	0.1649	0.0687	0.1567

Figures 4.10 The Best Year on R-squared Values of Correlation between CO and NO_x among Different Air Monitoring Stations

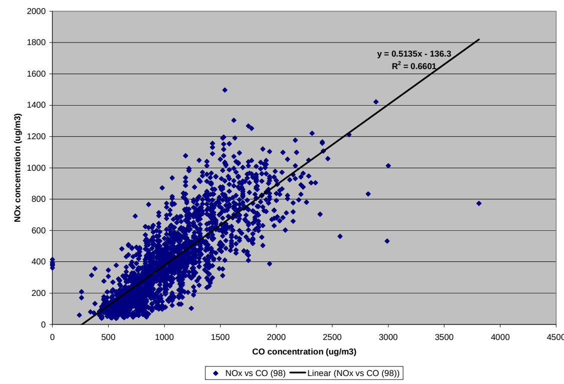


Roadside Monitoring Stations

Causeway Bay (CB) - 1998



Central (CL) - 1998



Mong Kok (MK) - 1996

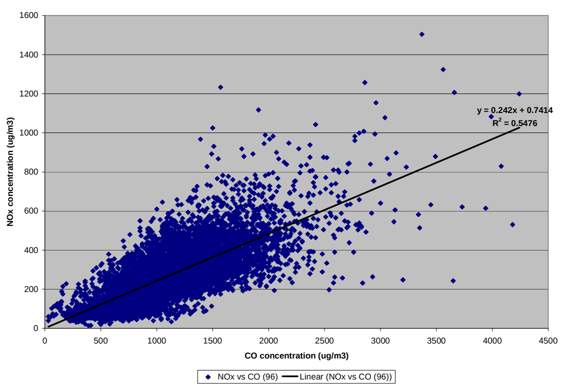


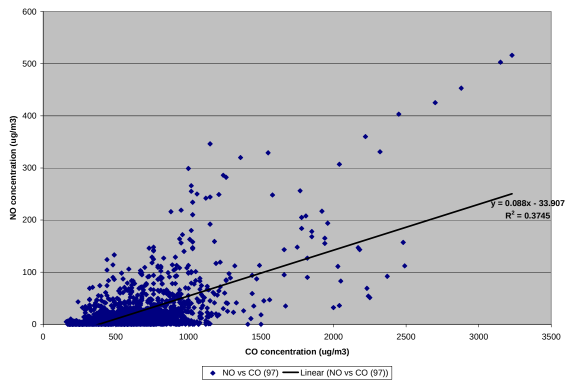
Table 4.6 R-squared Values of the Correlation between CO and NO

Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.1411		0.0763	0.3745								
TC						0.1851	0.2249	0.2015	0.106	0.1325	0.178	0.3382
TM					0.0035	0.002	0.0007	0.0713	0.0294	0.0011	0.0566	0.0765
TW				0.181	0.1925	0.1544	0.0959	0.1055	0.1001	0.0913	0.1165	0.1743
YL											0.1677	0.2828
Roadside Air Quality Monitoring Station												
CB					0.5445	0.3117	0.4117	0.2514	0.2422	0.2055	0.2814	0.2868
CL					0.6201	0.3901	0.2103	0.3325	0.3693	0.2417	0.2993	0.4184
MK			0.4807	0.3804	0.4798	0.1671	0.2795	0.1798	0.1355	0.1027	0.0637	0.0863

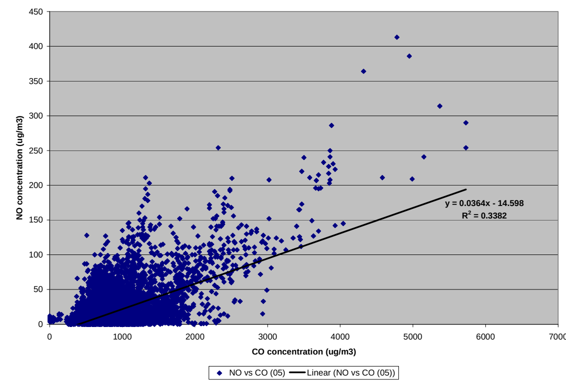
Figures 4.11 The Best Year on R-squared Values of Correlation between CO and NO among Different Air Monitoring Stations

General Monitoring Stations

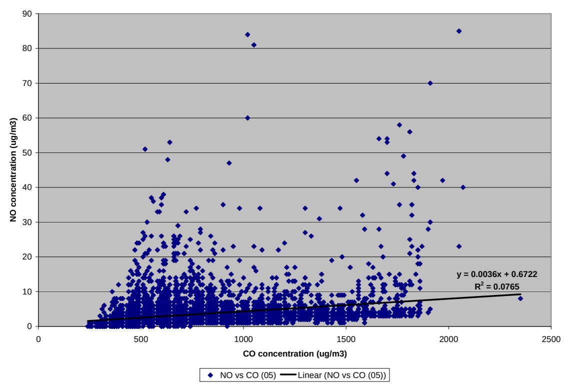
Kwai Chung (KC) – 1997



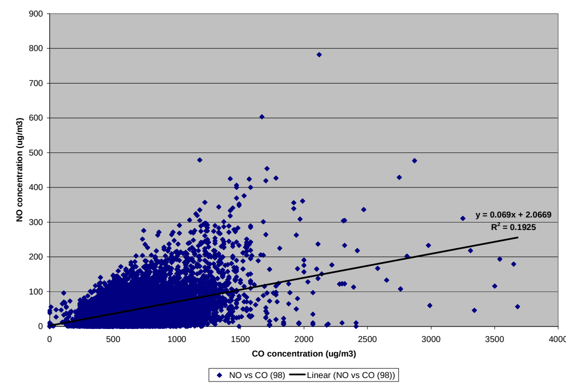
Tung Chung (TC) - 2005



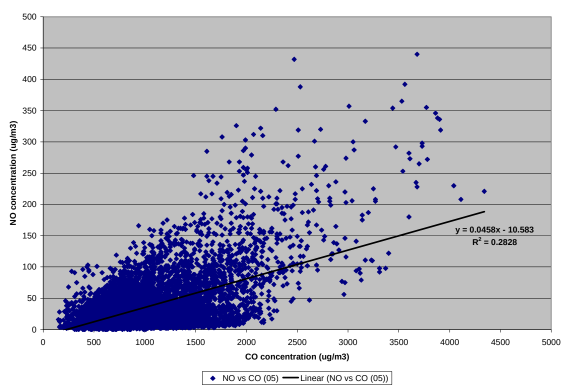
Tap Mun (TM) - 2005



Tsuen Wan (TW) - 1998



Yuen Long (YL) - 2005



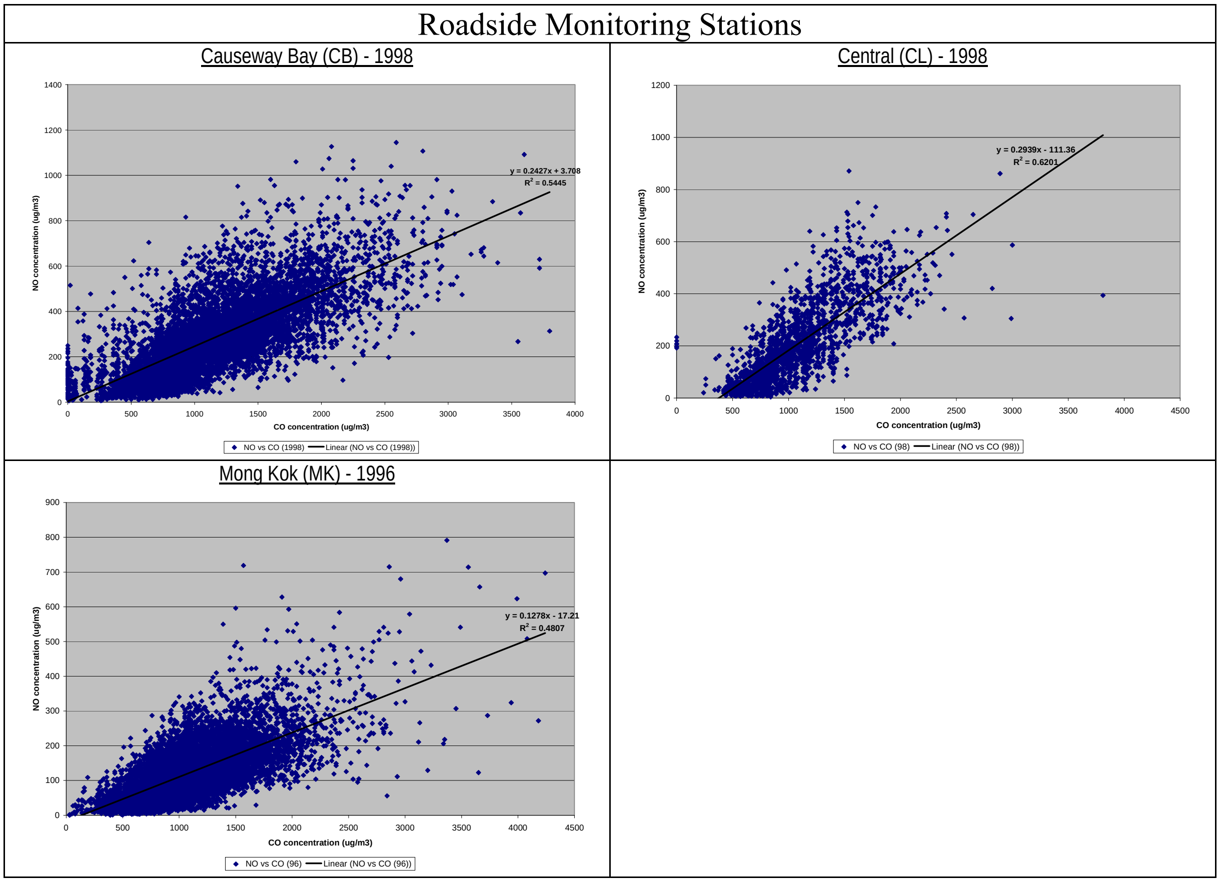
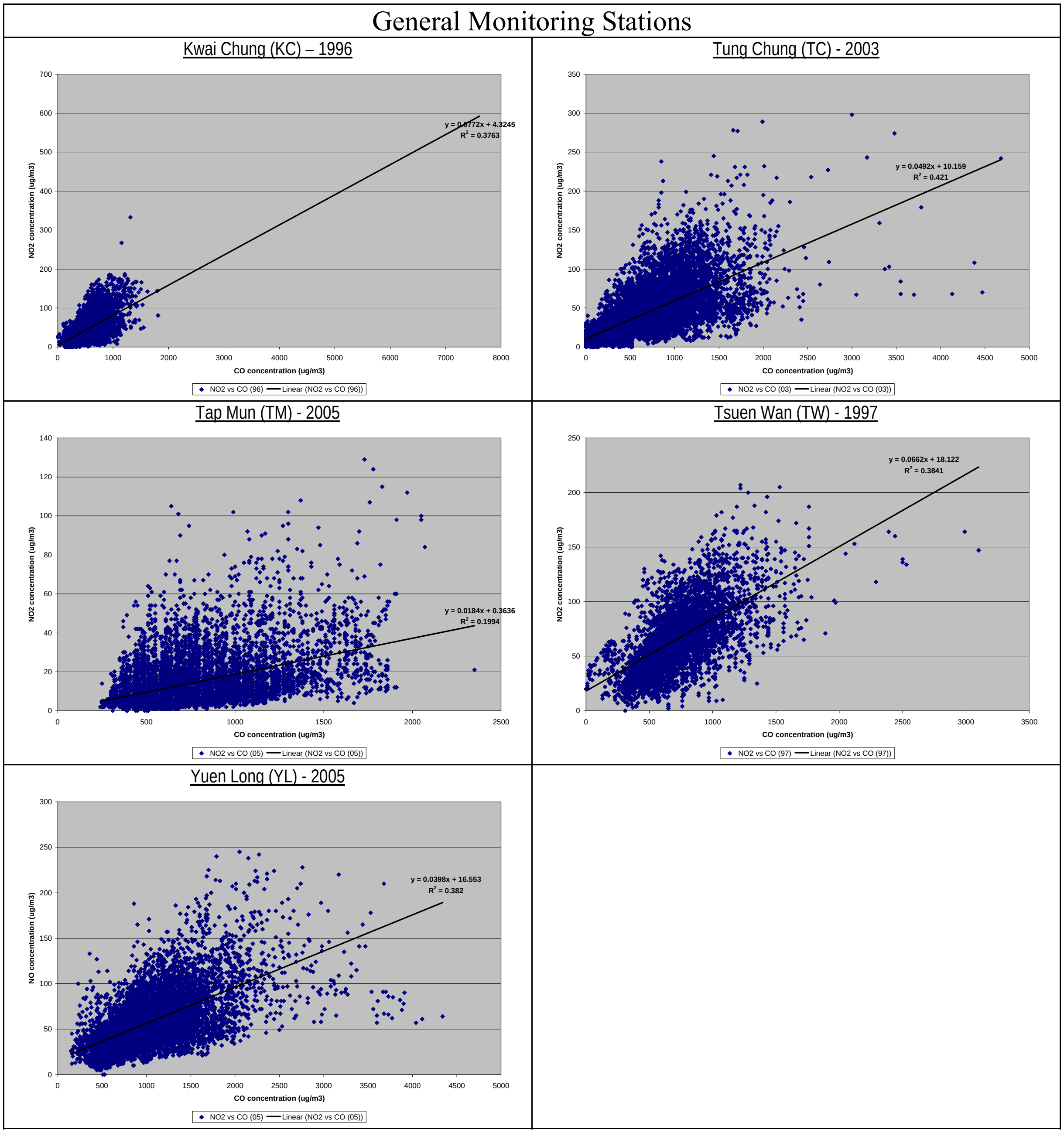
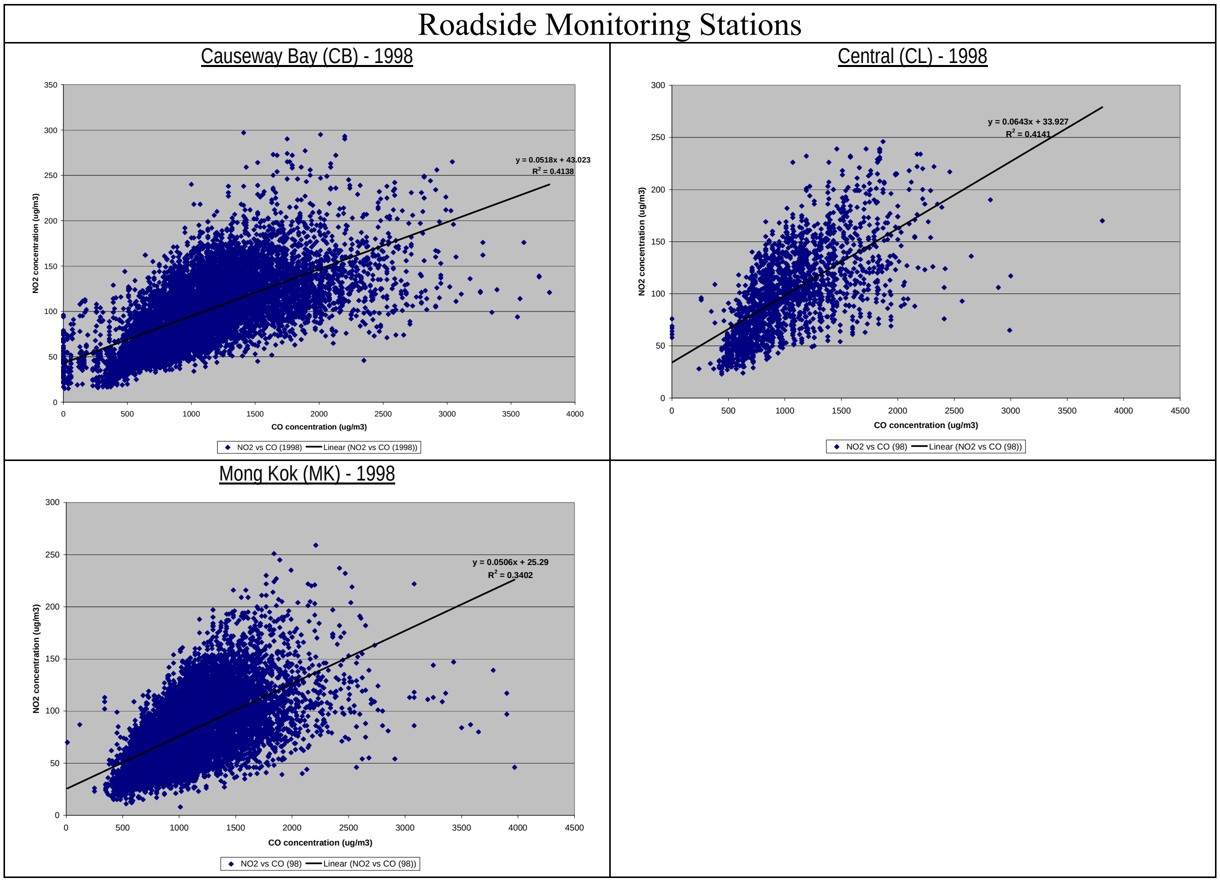


Table 4.7 R-squared Values of the Correlation between CO and NO_2

Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.1193		0.3763	0.1833								
TC						0.3385	0.3971	0.2478	0.1515	0.421	0.3189	0.3037
TM					0.1656	0.096	0.053	0.0657	0.0515	0.141	0.1035	0.1994
TW				0.3841	0.3485	0.3147	0.1875	0.1109	0.1808	0.2405	0.2725	0.3073
YL											0.3333	0.382
Roadside Air Quality Monitoring Station												
CB					0.4138	0.1712	0.3728	0.2658	0.1896	0.3157	0.1296	0.1762
CL					0.4141	0.3001	0.1306	0.2841	0.3917	0.3411	0.3516	0.2678
MK			0.318	0.2473	0.3402	0.2199	0.24	0.2272	0.1278	0.217	0.0158	0.2152

Figures 4.12 The Best Year on R-squared Values of Correlation between CO and NO_2 among Different Air Monitoring Stations





(c) Correlation between Carbon Monoxide (CO) with Ozone (O_3)

Table 4.8 and Figures 4.13 present the correlation analysis between O_3 and CO levels. It can be noted that the correlation coefficients are very low at all measured monitoring stations. It seems that there is no direct correlation between CO and O_3.

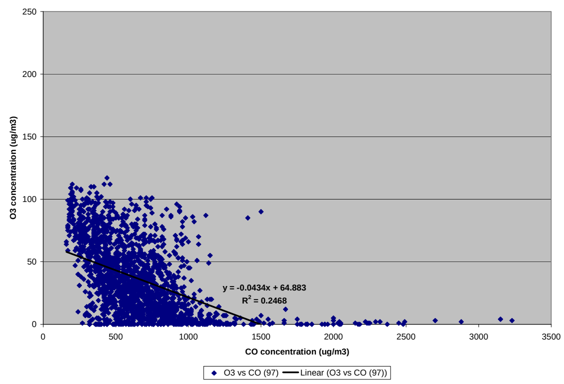
Table 4.8 R-squared Values of the Correlation between CO and O_3

Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.0151		0.0045	0.2468								
TC						0.001	0.0219	0.0112	0.0007	0.0005	0.0016	0.0058
TM					0.0817	0.0275	0.0055	0.0279	0.000034	0.0292	0.0145	0.0004
TW				0.1597	0.0103	0.0053	0.0211	0.0219	0.0007	0.0174	0.0024	0.0044
YL											0.0029	0.0049

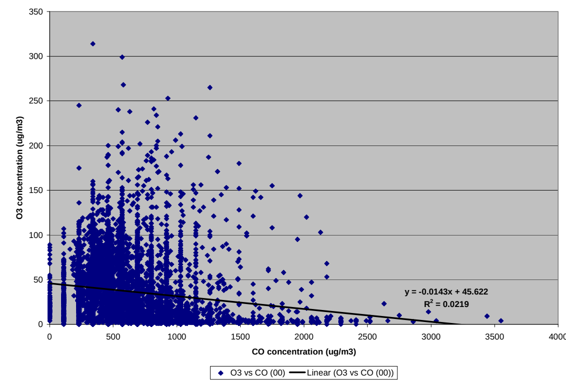
Figures 4.13 The Best Year on R-squared Values of Correlation between CO and O_3 among Different Air Monitoring Stations

General Monitoring Stations

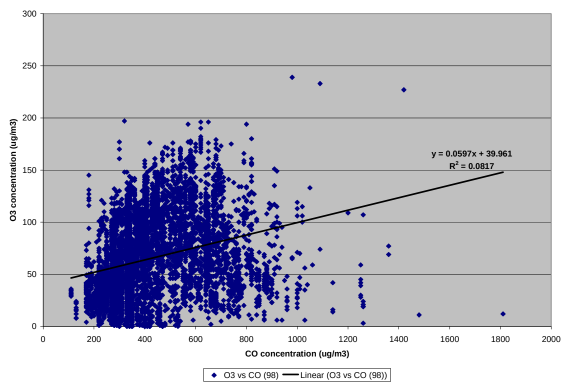
Kwai Chung (KC) – 1997



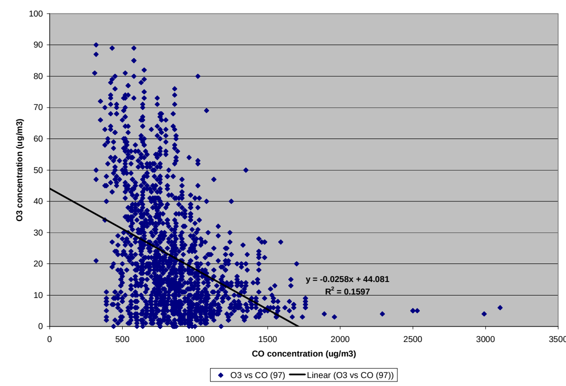
Tung Chung (TC) - 2000



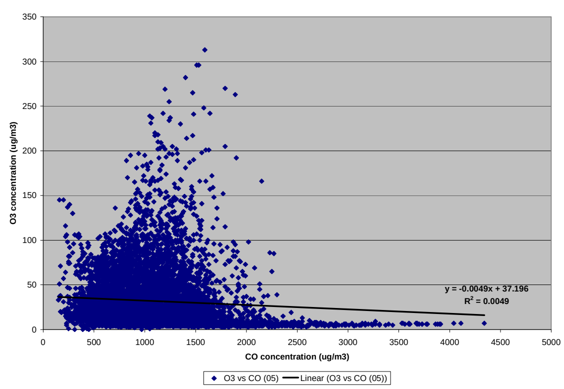
Tap Mun (TM) - 1998



Tsuen Wan (TW) - 1997



Yuen Long (YL) - 2005



(d) Correlation between Carbon Monoxide (CO) with Respirable Suspended Particulates (RSP)

Table 4.9 and Figures 4.14 present the correlation analysis between RSP and CO levels. It is surprising to note that the correlation coefficients at general monitoring stations have greater values than at roadside stations.

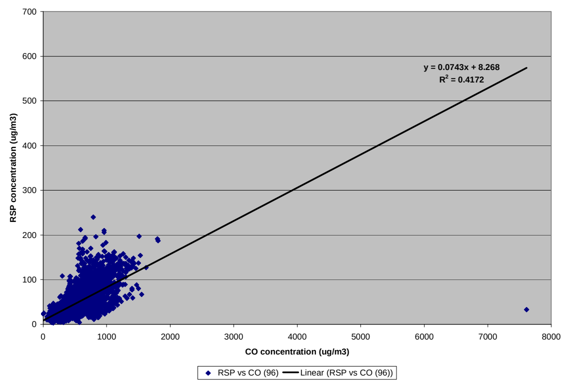
Table 4.9 R-squared Values of the Correlation between CO and RSP

Station	94	95	96	97	98	99	00	01	02	03	04	05
General Air Quality Monitoring Station												
KC	0.1271		0.4172	0.2228								
TC						0.435	0.3886	0.2606	0.1715	0.4948	0.403	0.4337
TM					0.4714	0.2019	0.1244	0.0254	0.0044	0.3504	0.0489	0.2018
TW				0.5024	0.4296	0.4051	0.1369	0.1358	0.2995	0.451	0.3427	0.4162
YL											0.4094	0.5737
Roadside Air Quality Monitoring Station												
CB					0.1803	0.1869	0.0794	0.0556	0.0535	0.1841	0.1298	0.1381
CL					0.5237	0.3578	0.165	0.2627	0.3553	0.3104	0.2876	0.1894
MK			0.3794	0.2944	0.293	0.2123	0.1996	0.1755	0.1368	0.291	0.0395	0.237

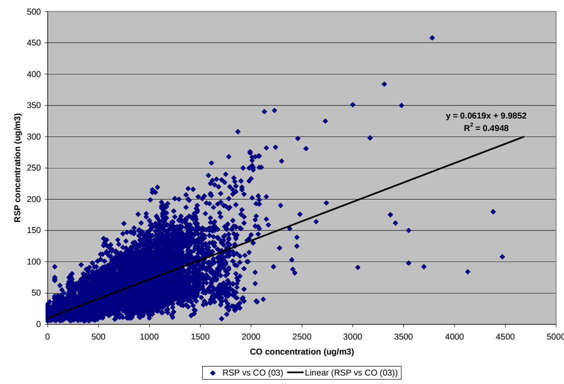
Figures 4.14 The Best Year on R-squared Values of Correlation between CO and RSP among Different Air Monitoring Stations

General Monitoring Stations

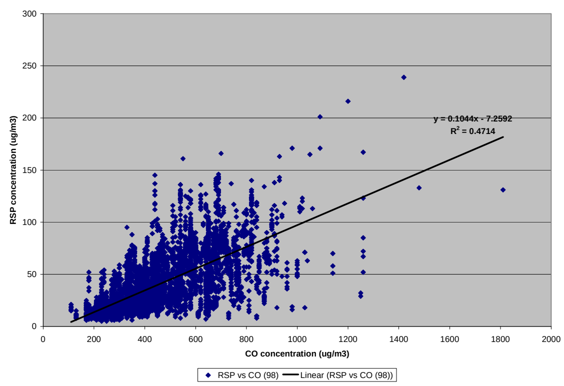
Kwai Chung (KC) – 1996



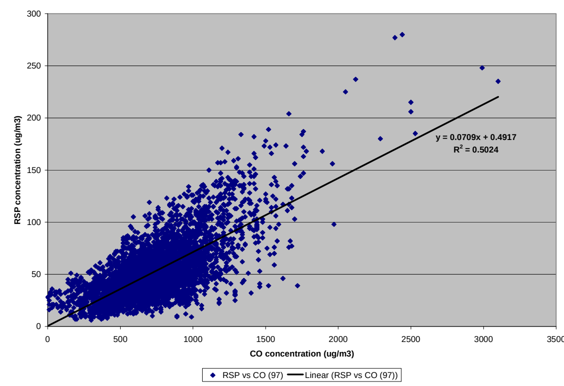
Tung Chung (TC) - 2003



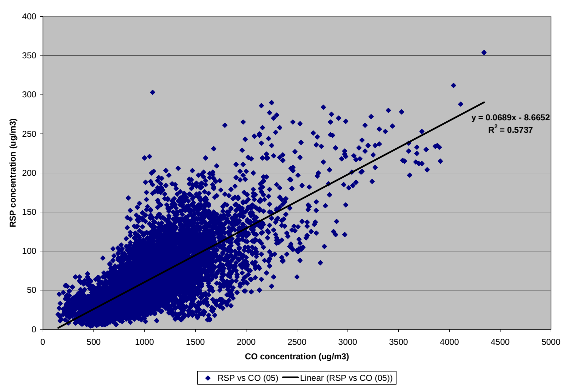
Tap Mun (TM) - 1998



Tsuen Wan (TW) - 1997

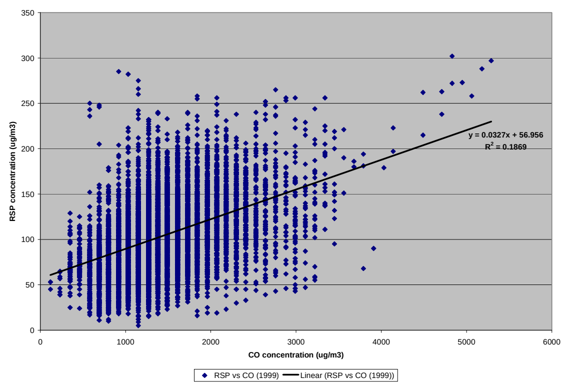


Yuen Long (YL) - 2005

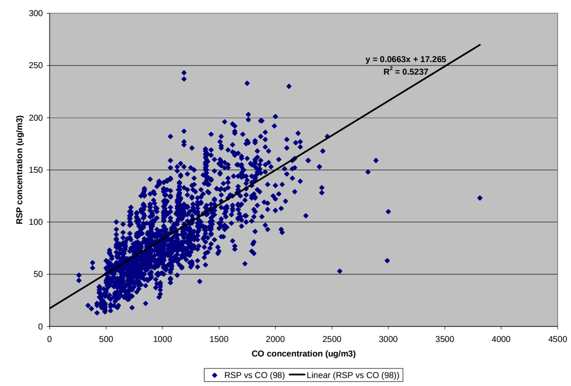


Roadside Monitoring Stations

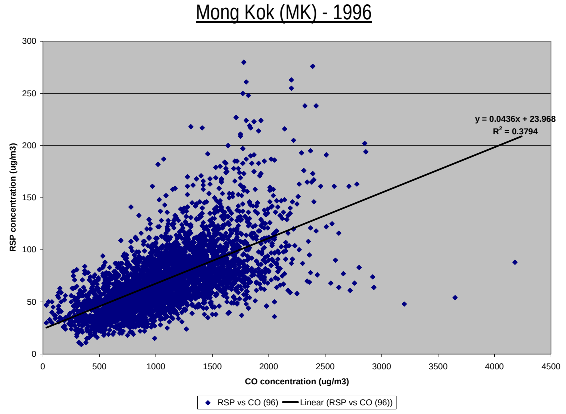
Causeway Bay (CB) - 1999



Central (CL) - 1998



Mong Kok (MK) - 1996



4.5 Summary and Conclusions

Example outdoor air quality years have been established for Hong Kong to facilitate outdoor air quality load for calculation of fresh air system of mechanical ventilated air conditioning buildings. The selection process involved the studying of outdoor air data for the years 1993 – 2005 and eliminating the years which contain any monthly mean of air pollutant parameter that differs significantly from the long term mean of that particular month. It is recommended that several calendar years be selected as the example outdoor air quality years for different air monitoring stations.

The values of different air pollutant parameters from example outdoor air quality years of various monitoring stations can provide valuable information (outdoor contaminant concentration, C_o) for calculating the required outdoor airflow or space contaminant concentration by applying the IAQ Procedure mentioned in Informative Appendix D of ANSI/ASHRAE Standard 62.1-2007. For example, in a Variable-air-volume system with no filter and 100% outdoor airflow:-

Required Outdoor Airflow, $V_o = \dfrac{G}{E_v F_r (C_s - C_o)}$

where G = contaminant generation rate

E_v = system ventilation efficiency

F_r = flow reduction factor

C_s = Space contaminant concentration

C_o = Outdoor contaminant concentration

or Space Contaminant Concentration, $C_s = C_o + \dfrac{G}{E_v F_r V_o}$

In order that gradual changes in global climate may be observed and reflected in the identification of a sample outdoor air year as a result of affecting outdoor air quality in Hong Kong. It is advisable that the selection process should be reviewed at regular intervals.

A detailed correlation characteristic study among major air pollutants, e.g. sulphur dioxide (SO_2), nitrogen oxides (NO_x), nitric oxides (NO), nitrogen dioxide (NO_2), ozone (O_3), carbon monoxide (CO) and respirable suspended particulates (RSP) in eight monitoring stations in Hong Kong territory is reported. The parameter of CO is proposed as a surrogate indicator for monitoring outdoor air quality due to the ease of measurement. In addition, this study illustrates the correlations between CO and other related pollutants. Except with ozone, the direct proportional relationships are existed although the correlations are not strong but the trends are definite.

CHAPTER 5 : FOUR-TIER DIAGNOSIS SCHEME FOR FRESH AIR SYSTEM

5.1 Introduction

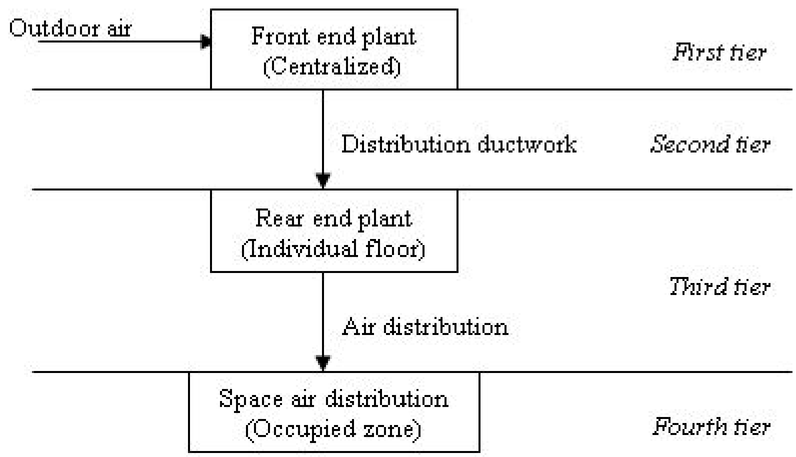
"The solution to pollution is dilution" is a dictum which summarizes a traditional approach to pollution management whereby sufficiently diluted pollution is not harmful. In an air-conditioned building, the dilution of indoor pollutants is achieved mainly by mechanical ventilation. Outdoor air will pass through a series of air handling equipment and ductwork before it is finally delivered to the breathing zone. Any degradation of the outdoor air during this process will impact on the IAQ. On the other hand, it is usually assumed that the outside air drawn into the system is delivered to the occupied zone in 'fresh' quality with 'sufficient' quantity. The occurrence of unacceptable IAQ may well be recognized in part to the fact that this is not always the case and the lack of a methodology to deal the multitudinous nature of the mechanical ventilation system.

This chapter describes a tier scheme for indicating the stages of fresh air system delivered to the occupied zone with a potential risk of three levels of degradation that affect the quality and quantity of outdoor air.

5.2 Anatomy of Fresh Air Systems

The main function of mechanical ventilation is to provide a comfortable environment for the majority of its occupants. The IAQ focus makes sure the indoor environment is comfortable and healthy. The purpose of the fresh air system is mainly to draw 'sufficient', 'fresh' and 'treated' outdoor air into the building in order to replace air and dilute contaminants. In order to understand the functions of each component within the system and their possible contribution to degradation, the fresh air system is dissected into four tiers. Figure 5.1 illustrates the broad concept of the four-tier scheme.

Figure 5.1 Broad Concept of the Four-tier Scheme



5.2.1 First Tier — Front End Plant

The first tier is defined as the components of fresh air system from outdoor air intake at the plant room or building façade to front end equipment. The main component of the front end equipment is a fan to draw the air into fresh air system from outside. In centralized system, the front end equipment can generally be a primary air unit (PAU) or fresh air fan (FAF). The outdoor air usually goes through the preliminary filtration for removal of particulate matter before entering into the front end equipment. The fan has the capacity for the sum of the outdoor air requirement of all the floors this system serves. If this equipment is a PAU, it will have a cooling coil to pre-cool and pre-humidify the outdoor air to the condition of the space return air. The plant of front end equipment is normally located on the roof or the mechanical floor. The common components of the first tier (front end plant) are:

- outdoor air intake lourve
- ductwork between intake lourve and front end equipment (not applicable in some system design)
- filtration system
- front end equipment (PAU or FAF)

The front end equipment is normally a constant air volume (CAV) system, although in principle, it can be a variable air volume (VAV) system to comply with the air side if the office distribution works with a VAV or demand control volume (DCV) system.

5.2.2 Second Tier — Distribution Ductwork

The drawn air from the front end equipment is then distributed to individual floors by a ductwork system. This distribution ductwork usually transports the outdoor air directly to the rear end equipment or plant rooms of individual floor via a balancing damper. The second tier is defined as the ductwork of fresh air system from the front end equipment to rear end equipment.

Depend on the system design, the outdoor air outlets are fitted with a constant or variable volume control damper to provide fixed or changeable but with minimum quantities of outdoor air to the rear end equipment. Therefore, the common components of the second tier (distribution ductwork) are:

- ductwork between front end and rear end equipment
- air control damper

5.2.3 Third Tier — Rear End Plant

The third tier is defined as the components of fresh air system from the rear end equipment to occupied zone. After receiving the outdoor air from the second tier, the rear end equipment usually delivers the mixed air with outdoor air and return air to the occupied zone. The common components of the third tier (rear end plant) are:-

- rear end equipment (AHU or FCU)
- filtration system
- mixing plenum
- ductwork between rear end equipment and occupied zone
- supply diffuser
- return grilles
- air control damper

The supply mixed air is normally distributed to the occupied zone by air handling unit (AHU) or fan coil unit (FCU), the outdoor air drawn into the rear end equipment or plant room meets with the space re-circulated air in mixing plenum. The mixture is then distributed to the occupied zone.

5.2.4 Fourth Tier — Space Air Distribution

This is the final stage of the fresh air system. The fourth tier is defined as the space of occupied zone where is the destination of fresh air system. Ideally, the outdoor air with 'sufficient' quantity, 'fresh' quality and 'treated' conditioned is delivered into the breathing zone with perceived ventilation efficiency. The 'used' outdoor air is then either re-circulated or exhausted out of the building and completes its life cycle.

5.3 Degradation of Outdoor Air

There are three means that the outdoor air can be degraded. They are:

- pre-contamination,
- short-circuit, and
- by-pass.

5.3.1 Pre-contamination

Outdoor air is considered 'fresh' if it is 'acceptable' for the purpose of dilution of indoor contaminants, and is defined as air complying with the Hong Kong (Ambient) Air Quality Objectives. If the outdoor air is contaminated by the micro-environment around the building before entering, or within the fresh air system, it is said to be pre-contaminated.

Pre-contamination of outdoor air may be due to mixing with polluted air from external sources (such as vehicular exhaust, industrial exhaust or exhaust from other buildings) and internal sources (such as off-gassed from building materials and surface finishes, from working processes, from cleaning materials, from micro-biological activity and from human activity).

The importance of choosing the right locations for outdoor air intake is also influenced by the height of the intake with respect to the vertical pollutant profile from ground level vehicular sources. ASHRAE 62.1-2007 also specifies that the minimum separation distance from the location of outdoor air intake to any specific potential outdoor contaminant source.

5.3.2 Short-circuit

This is defined as short-circuiting of exhaust air from the building itself into the fresh air system. ‘Short-circuit’ of exhaust air from sources other than from that of the building can be regarded as pre-contamination. The effect of short-circuit is contamination of the outdoor air.

5.3.3 By-pass

By-pass refers to the leakage of outdoor air from the supply system to somewhere else instead of being distributed to the breathing zone. The effect of by-pass is the reduction in outdoor air supply rate. The reduction may be replaced by short-circuited air or the space return air, both of which contaminate and degrade the incoming outdoor air. If the outdoor air is pre-treated by filtration, by-pass also represents the by-passing of the outdoor air over the filter without treatment. The by-pass can reduce the outdoor air quality and the effective dilution margin of the outdoor air.

5.4 Walkthrough Survey Protocol for Diagnosing IAQ Problems from Degradation

5.4.1 ‘Read the Building’

Before diagnosing IAQ problems in building, preliminarily investigation is required to acquire a good overview of building information in terms of building functions, system designs, operation, maintenance, building materials used, occupant activities, etc. A *Building Evaluation (Indoor Air Quality) Form* (Appendix E) is designed for building management group to provide general information of the building which is related to IAQ issues to IAQ inspector in order to give some basic ideas on building operation before he carries out a walkthrough survey. The content of this form embraces the following issues:

(a) Building information

(b) Outdoor environmental information

(c) HVAC system information

(d) Pollutant inventory

(e) Occupancy information

(f) Overall comment

(g) Required document checklist

5.4.2 Walkthrough Inspection

A walkthrough inspection can be conducted after reviewing the building operation related on IAQ issues. The overall aim of the walkthrough inspection is to identify areas with a high potential for creating IAQ problems. In addition, the walkthrough inspection also helps:

(a) to look for IAQ problem indicators,

(b) to provide an opportunity to introduce facility staff and other building occupants to the topic of IAQ,

(c) to understand current staff (and contractor) responsibilities in relation to housekeeping and maintenance activities which affect IAQ,

(d) to provide information on outdoor air quality, indoor pollutant sources and air distribution system which are the three basic factors influencing IAQ,

(e) to define the population of IAQ measuring points (if necessary), and

(f) to determine the optimum number of sampling points based on the rationalization of IAQ zones (if necessary).

A fresh air system in air-conditioned building is crucial to the indoor air quality. A Four-Tier Diagnosis Scheme has been introduced in the previous sections as a methodology for walkthrough inspection of the fresh air system to qualify and quantify the effect of degradation of outdoor air along its path from the intake point to exhaust out of the building.

One of the tasks for the inspector is to identify three types of outdoor air degradation in four tiers, i.e. pre-contamination, short-circuit and bypass. The walkthrough inspection includes not only visual check but also real-time measurements by hand-held instruments. The advantage of hand-held measurement is to provide the instantaneous values of IAQ parameters for real time and on site judgment of the IAQ conditions of the investigated systems. The carbon dioxide monitor is at least expected to measure the concentration of carbon dioxide during the walkthrough inspection in order to have an indication of determining the IAQ zones and potential risk of IAQ problems because CO_2 can be used as surrogate indicator for health as well as comfort once the relationship between the pollutant concentrations with ventilation rate have known. GN also mentioned that CO_2 concentration is nonetheless important to IAQ management and is commonly adopted as a surrogate in measuring air freshness. The lower the concentration of CO_2 the fresher the air supply is likely to be. Carbon monoxide level is also considered to measure during the walkthrough which can indicate unacceptable infiltration of outdoor airborne pollutant. CO is a major pollutant from vehicular emissions which also are a main source of nitrogen oxides (NOx), nitric oxide (NO), nitrogen dioxide (NO_2), particulate matters including total and respirable suspended particulates (TSP and RSP) and other volatile organic compound (VOC) especially in urban areas. As discussed in Chapter 4, CO also has significant correlations among the outdoor airborne pollutants.

There are two forms to help the IAQ inspector and building management group to identify the IAQ issues during walkthrough inspection. A *Walkthrough Survey Form* (Appendix F) is designed for IAQ inspector to examine the IAQ conditions inside building as to determine the initial IAQ problems on design, management as well as ignorant faults during the walkthrough inspection. An *Indoor Air Quality Evaluation Checklist* (Appendix G) is designed for IAQ inspector or building management group to validate the zoning of indoor air quality. The zoning of indoor air quality is defined by parameters including pollutant concentration are uniform with a tolerance band.

5.5 Examples of Degradation

For identifying the different kinds of degradation in the four-tier scheme, a comprehensive survey for over 200 buildings from the analyzed results of site inspection by a group of part-time Bachelor of Engineering in Building Services Engineering of the Hong Kong Polytechnic University in the academic year 2000-2002. These students were all working in the building services sector and were capable to access to buildings for detail investigations. A *Building Evaluation (Indoor Air Quality) Form* (Appendix E) and Walkthrough Survey Form (Appendix F) were passed to this group for providing good guidance in qualifying the performance of air side systems by understanding the configuration of the fresh air system into four tiers and the definition of the three kinds of degradation during the walkthrough inspection. Based on analyzing the survey results of over 200 buildings, typical sources of degradation in the four tiers through walkthrough inspection have summarized in the following section.

5.5.1 Degradation of First Tier

(a) First Tier — Pre-contamination

- High ambient pollution concentration: for example, high concentrations of total suspended particulates (TSP), respirable suspended particulates (RSP), nitrogen dioxide (NO_2) and ozone (O_3) sometimes recorded in the outdoor air.
- Pre-contamination by nearby sources: for example, the outdoor air intake faces the plume from stacks of cooling towers or other equipment exhaust.
- Service core pre-contamination in the mechanical floor: where it is served as a storage space for materials, maintenance workshop, and even an illegal smoking place in non-smoking office building.
- Pre-contamination close to the air intake: for example, the intake location faces some external construction sites, industrial plants, busy roads, car parks, etc.
- Dirty equipment: unclean or under-maintained front end equipment is usually a major source of contamination.

(b) First Tier — Short-circuit

- Short-circuit from the kitchen exhaust: for example the kitchen exhaust adjacent to the intake.

- Short-circuit of the foul air exhaust: exhaust and outdoor air louvres are located too close.

(c) First Tier — By-pass

- Leakage at the discharge end of the fan: air leakage at the discharge end of the fan between the fan outlet and the discharge duct.
- By-pass of outdoor air over filters: for example, a gap in the filter frame not properly sealed or the size of the filter media does not match the filter frame size.

5.5.2 Degradation of Second Tier

(a) Second Tier — Pre-contamination

- Component source of pollution: pollutants from the components in the distribution ductwork such as bare insulation, dirty dampers, and dirt accumulated over ductwork.

(b) Second Tier — Short-circuit

- Improper air balance: for example, dampers used for balancing outdoor air in second tier are prone to short-circuit of space air into the system due to improper air balance in the rear end equipment room or rear end FCU plenums.

(c) Second Tier — By-pass

- By-pass through worn out access panels: for example, significant leakage through worn access panels.

5.5.3 Degradation of Third Tier

(a) Third Tier — Pre-contamination

- Dirtiness of the system: for example, unsanitary rooms, dirty equipment and ductwork are all sources of pollutants.
- Misuse of the rear end plant room: where it is used as a storage space for materials, a workshop for maintenance.

(b) Third Tier — Short-circuit

- Short-circuit due to strong negative pressure in rear plant room: the rear end plant rooms are under strong negative pressure. Foul air can easily be short-circuited from space back into the plant room through cracks on walls, poor air-tightness of doors and poorly made-up openings on walls and floors for air ducts, electrical ducts, conduits and cable trays. Drainage pipes, poorly ventilated spaces, toilet exhaust and strong pollutant sources such as those from garbage handling rooms are common sources of foul air.

(c) Third Tier — By-pass

- By-pass due to leakage in supply air ducts: by-pass of the outdoor air in the air stream is frequently found in the duct riser or distribution plenums.

5.5.4 Degradation of Fourth Tier

(a) Fourth Tier — Pre-contamination

- Inherent sources: building material;
- Dirtiness of the indoor conditions: unclean or under-maintained indoor environment can usually be a major source of contamination
- Indoor activity sources: occupants, furnishings, office equipment, smoking, indoor plants and etc;
- Indoor infiltration: pollutants infiltrated into the zone of concern from other zones in the same building, such as lift shafts;
- Outdoor infiltration: pollutants infiltrated into the zone of concern through the building fabric.

(b) Fourth Tier — Short Circuit

- Poor design and location of return air louver: short-circuit is more prominent for corridor return systems. With the core service design, the suction side of the AHU room faces the corridor, or is close to toilets, staircases, lift lobbies and etc. These places are either higher polluted areas or areas with low ventilation rates. Core service designs are more prone to short-circuit of foul air which otherwise would have been exhausted mechanically or by exfiltration.

(c) Fourth Tier — By-pass

- By-pass between supply air diffuser and return air grille or return slots of return air plenum: in the ceiling supply and ceiling plenum return system, by-pass of the supply air is common due to the proximity of the supply diffusers and the return air slots in the false ceiling.
- By-pass due to poor design, workmanship and co-ordination: by-pass of the supply air can also be due to poor design, workmanship of the airside system and poor co-ordination between the builders and engineers.

5.6 Four-Tier Diagnosis Scheme for Fresh Air System

The IAQ Procedure of ASHRAE 62.1-2007 only deals with the contaminant concentration of the sources, by-pass (recirculation flow factor) and ventilation efficiency in the space, that is, the fourth tier in the four-tier scheme. The outdoor air, along its path from the intake point to the breathing zone, is under all kinds of risks of degradation and each has its own effect.

Each type of degradation in each tier either reduces the outdoor air quantity due to by-pass or reduces the capacity of dilution margin due to pre-contamination and short-circuit. The net effect is the reduction of the designed outdoor air quantity for the dilution of pollutants in the space. If the same requirement of IAQ is to be maintained, the outdoor air quantity has to be increased or appropriate measures on reducing pollutants have to be taken. A scheme can be constructed based on the mass balance of each pollutant at each stage. This scheme can be used to calculate a multiplying factor to modify the designed outdoor air quantity to compensate for the degradation in outdoor air quality.

5.6.1 Modelling the Degradation

(a) First Tier

For the First Tier, a simple equation can be used to represent the degradation parameters.

By mass balance equation,

$Q_oC_o + \Sigma(Q_{p1}C_{p1}) + \Sigma(Q_{s1}C_{s1}) - \Sigma(Q_{b1}C_{b1}) = Q_1C_1$

That is,

$$C_1 = \frac{Q_oC_o + \Sigma(Q_{p1}C_{p1}) + \Sigma(Q_{s1}C_{s1}) - \Sigma(Q_{b1}C_{b1})}{Q_1} \qquad \text{(Eq. 5.1)}$$

where C_o = concentration of outdoor air

C_1 = concentration at discharge of first tier

C_{p1} = concentration of pre-contaminated air at first tier

C_{s1} = concentration of short-circuited air at first tier

C_{b1} = concentration of by-passed air at first tier

Q_o = outdoor volumetric flow rate

Q_1 = volumetric flow rate at discharge of first tier

Q_{p1} = volumetric flow rate of pre-contaminated air at first tier

Q_{s1} = volumetric flow rate of short-circuited air at first tier

Q_{b1} = volumetric flow rate of by-passed air at first tier

(b) Second Tier

For the Second Tier, a simple equation can be used to represent the degradation parameters.

Likewise with first tier,

$$C_2 = \frac{Q_1 C_1 + \Sigma(Q_{p2} C_{p2}) + \Sigma(Q_{s2} C_{s2}) - \Sigma(Q_{b2} C_{b2})}{Q_2} \qquad \text{(Eq. 5.2)}$$

where C_1 = concentration of air at inlet to distribution duct

C_2 = concentration at discharge from the second tier

C_{p2} = concentration of pre-contaminated air at second tier

C_{s2} = concentration of short-circuited air at second tier

C_{b2} = concentration of by-passed air at second tier

Q_1 = volumetric flow rate at inlet to distribution duct

Q_2 = volumetric flow rate at discharge of second tier

Q_{p2} = volumetric flow rate of pre-contaminated air at second tier

Q_{s2} = volumetric flow rate of short-circuited air at second tier

Q_{b2} = volumetric flow rate of by-passed air at second tier

(c) Third Tier

For the Third Tier, a simple equation can be used to represent the degradation parameters.

Likewise with second tier,

$$C_3 = \frac{Q_2 C_2 + \Sigma(Q_{p3} C_{p3}) + \Sigma(Q_{s3} C_{s3}) - \Sigma(Q_{b3} C_{b3})}{Q_3} \qquad \text{(Eq. 5.3)}$$

where C_2 = concentration of air at inlet of distribution duct

C_3 = concentration at discharge from the third tier

C_{p3} = concentration of pre-contaminated air at third tier

C_{s3} = concentration of short-circuited air at third tier

C_{b3} = concentration of by-passed air at third tier

Q_2 = volumetric flow rate at discharge from distribution duct

Q_3 = volumetric flow rate at supply to space at third tier

Q_{p3} = volumetric flow rate of pre-contaminated air at third tier

Q_{s3} = volumetric flow rate of short-circuited air at third tier

Q_{b3} = volumetric flow rate of by-passed air at third tier

(d) Fourth Tier

For the Fourth Tier, a simple equation can be used to represent the degradation parameters.

Likewise with third tier,

$$C_4 = \frac{Q_3 C_3 + \Sigma(Q_{p4} C_{p4}) + \Sigma(Q_{s4} C_{s4}) - \Sigma(Q_{b4} C_{b4})}{Q_4} \qquad \text{(Eq. 5.4)}$$

where C_3 = concentration of air at diffuser outlets of third tier

C_4 = concentration of air at the fourth tier

C_{p4} = concentration of pre-contaminated air at fourth tier

C_{s4} = concentration of short-circuited air at fourth tier

C_{b4} = concentration of by-passed air at fourth tier

Q_3 = volumetric flow rate at discharge from diffuser outlets of third tier

Q_4 = volumetric flow rate at space of fourth tier

Q_{p4} = volumetric flow rate of pre-contaminated air at fourth tier

Q_{s4} = volumetric flow rate of short-circuited air at fourth tier

Q_{b4} = volumetric flow rate of by-passed air at fourth tier

5.6.2 General Equation for Diagnosis Scheme

Therefore, the general equation for the 4-tier diagnosis scheme can be described as:

$$C_{\mathrm{n}} = \frac{Q_{n-1}C_{n-1} + \Sigma(Q_{pn}C_{pn}) + \Sigma(Q_{sn}C_{sn}) - \Sigma(Q_{bn}C_{bn})}{Q_n} \qquad \text{(Eq. 5.5)}$$

where C_{n-1} = concentration of air at previous tier

C_n = concentration of air at that tier

C_{pn} = concentration of pre-contaminated air at that tier

C_{sn} = concentration of short-circuited air at that tier

C_{bn} = concentration of by-passed air at that tier

Q_{n-1} = volumetric flow rate at discharge from previous tier

Q_n = volumetric flow rate at that tier

Q_{pn} = volumetric flow rate of pre-contaminated air at that tier

Q_{sn} = volumetric flow rate of short-circuited air at that tier

Q_{bn} = volumetric flow rate of by-passed air at that tier

5.7 Outdoor Air Quality Dilution Margin Multiplier

The two design procedures, IAQ Procedure and Ventilation Procedure of ASHRAE 62.1-2007 calculate the required outdoor air quantity based on the occupied zone, that is 'fourth tier'. In the Four-tier diagnosis scheme, the whole fresh air system, which starts from the outdoor air intake to the occupied zone, is considered. Equations 5.1 to 5.4 can be taken as modelling the degradations of the outdoor air at the first, second, third and fourth tiers and are based on the mass balance of pollutants of concern. In the general equation (Equation 5.5), each term representing each type of degradation can be considered as a reduction of dilution margin. The dilution margin of a particular pollutant is defined as "*the difference in concentrations of a particular pollutant between the target design concentration for a pollutant in concern and the background ambient concentration for dilution purpose*". An outdoor air quality dilution margin multiplier should be added up to the required outdoor air flow rate to compensate for the degradation.

5.8 Evaluation of Fresh Air System in University Campus

The Campus of The Hong Kong Polytechnic University is located at the exit of the Cross-Harbour Tunnel. It is also bounded by three roads (Chatham Road South, Hong Chong Road and Cheong Wan Road) carrying large amount of vehicles everyday. Therefore, the ambient air quality within the campus depends to some extent on the level of pollutants emitted from vehicles. Another potential pollutant source, mainly suspended particulate, comes from the funeral parlour located not far away from the campus. However, whether suspended particulate enters the campus depends on the direction and the speed of the prevailing wind. Its influence is not as important as pollutants emitted from vehicles. Also, construction inside the campus can affect both the ambient and indoor air quality of the campus.

Figure 5.2 Outdoor Environment of the University Campus

Environment outside the campus

Many vehicles pass through the campus everyday

Construction work

5.8.1 Walkthrough Survey for Identifying Outdoor Air Degradation in Campus

(a) Understanding the Fresh Air System

The campus includes 6 main phases and the fresh air system distributed into various rooms can be divided into the following three main types. Table 5.1 summarizes the various fresh air systems applied in the University Campus.

- Type 1: Centralized Supply System

In this system, outdoor air is drawn in from the outdoor air intake located on the roof, distributed to PAU or AHU on each floor and then delivered to the occupied space through supply air diffusers. In some rooms, there is no duct connection between the central duct transferred from the roof and the PAU/AHU while some of the plants have a duct connected between the roof duct and the PAU/AHU.

The previous one is having greater chance to face the problem of pre-contamination, by-pass or short-circuit because there is no air duct connected which may cause significant effect on the outdoor air quality of the PAU intake.

- Type 2: Individual Supply System

In this system, outdoor air intake is situated on each floor. Outdoor air is directly distributed to PAU located on each floor and then to the indoor space through air diffusers. Under this circumstance, the quality of the outdoor air supply depends wholly on the sources of the outdoor air and the tightness of the air system

- Type 3: Split Type Units

In some buildings (such as research offices in X-Block), split type A/C units are adopted. Usually, split type A/C units have no fresh air supply. However, in these research offices, there are independent air duct distributing outdoor air to the indoor space.

Table 5.1 Various Fresh Air Systems in University Campus

Phase No.	System adopted	Examples
I	Centralized air conditioning system	Cores C,D,E,F,J Library
II	Centralized air conditioning system	Student Union – Shaw Amenities Building
II	Individual air conditioning system	Fong Shu Chuen Hall Shaw Sports Complex Old Canteen Table Tennis Court
IIA	Centralized air conditioning system	Cores F,G
IIB	Centralized air conditioning system	Cores H,J
IIIA	Individual air conditioning system	Administration Building and Theatre (A core) General Teaching Area (BC Core)
IIIB	Centralized air conditioning system	Cores S,T
IVA	Centralized air conditioning system	Cores W, U
V	Individual air conditioning system	Cores P,Q
VI	Individual air conditioning system	Core R
-	Split Units	X-Block

(b) Walkthrough Inspection

- Pre-contamination

In this case, the outdoor air is contaminated by the micro-environment (such as vehicle exhaust and construction site) before entering or within the fresh air system (see Figure 5.2). The effect would lead to pollution of the outdoor air.

In the campus, the outdoor air degradation is easily found due to the presence of traffic pollutants from vehicles, waste disposal dumps, sources of allergens. Apart from these, construction and renovation work in buildings would worsen the outdoor air quality since these activities produce lots of dusts and VOC.

- By-pass

Some ductworks, access panels were found leakage of the outdoor air to somewhere else instead of being distributed to the breathing zone. The results would be reduction of the outdoor ventilation rate.

- Short-circuit

Some locations of outdoor air intake were found potential risk on short-circuiting of exhaust / foul air (such as toilet stack and kitchen exhaust) from the sources of the building itself. This would contaminate the outdoor air as well.

5.8.2 Outdoor Air Intake Condition in Campus

The location of the outdoor air intake directly affects the indoor air quality. If it is very close to the traffic, exhaust grille, construction site, factories, etc. then the outdoor air taken in will certainly be affected. The outdoor air intakes in the campus were reviewed through walkthrough inspection. There are altogether 165 fresh air plantrooms inside the University Campus. Among them, 33% of the plantrooms were selected to have investigation. According to the inspection, it was discovered that about 20% of the plantrooms had potential risk of having pre-contamination and 3% of them had the phenomenon of short-circuit. This may be due to the fact that the outdoor air intakes were too close to the exhaust pipes or the dirty environment inside the plantroom.

5.8.3 Example for Determination of Outdoor Air Quality Dilution Margin Multiplier

To determine the outdoor air quality dilution margin multiplier, one example was investigated inside the campus. Based on the system design for office, outdoor air quantity was required to control the indoor carbon dioxide (CO_2) concentration below 1,000 ppm for staff office.

For ideal case of design stage,

- the fresh air system was designed to deliver the outdoor air at a rate of 10 m^3/s and the expected CO_2 concentration of outdoor air was 350 ppm (0.63g/m^3);
- the outdoor air was expected to mix with the return air having 1000 ppm (1.8g/m^3) of CO_2 concentration at a rate of 3 m^3/s in the AHU room (third tier). By mass balance equation, the CO_2 level delivered to the occupied area was then calculated 500 ppm (0.9g/m^3) at total rate of 13 m^3/s;
- therefore, the dilution margin of CO_2 at the occupied zone was expected as (1000 – 500) ppm which was equal to 500 ppm.

However, the degradations were found during walkthrough inspection. The following records were taken in relation to the degradation of outdoor air:

(a) First Tier — At Intake Louver to Front End Equipment Room

- At the intake location, the outdoor CO_2 concentration was 350 ppm (0.63g/m^3). There was no pre-contamination and by-pass found at this tier. However, the short-circuited air with 900 ppm (1.62g/m^3) of CO_2 concentration at 0.2m^3/s was introduced into the outdoor air system. Since the design flow rate of the outdoor air system was 10 m^3/s, the actual intake of outdoor air would be (10 – 0.2) m^3/s, i.e. 9.8 m^3/s.

- By the equation 5.1, the concentration of CO_2 at the first tier was 361 ppm (0.65g/m^3) at the flow rate of 10 m^3/s.

(b) Second Tier — Distribution Duct

- Since there was no CO_2 source and short-circuit at this tier, the concentrations of pre-contaminated and short-circuit air were zero.
- There was a leakage of 1 m^3/s air at the distribution plenum. The CO_2 concentration of by-passed air was the same as that at the first tier, i.e. 361 ppm.
- By the equation 5.2, the concentration of CO_2 at the second tier was still 361 ppm (0.65g/m^3). However, the flow rate of outdoor air system was reduced to 9 m^3/s.

(c) Third Tier — Rear End Equipment Room

- In the third tier, there was no CO_2 source inside this AHU room. However, the return air from occupied zone having 1000 ppm (1.8g/m^3) of CO_2 concentration at 3 m^3/s flow rate was mixed or 'pre-contaminated' with outdoor air.
- There was a short-circuit air of 0.2 m^3/s and the CO_2 concentration of the short-circuited air was 800 ppm (1.44g/m^3). There was no by-pass found at this tier.
- By the equation 5.3, the concentration of CO_2 at the third tier was 526 ppm (0.95g/m^3) and the flow rate of outdoor air system was changed to 12.2 m^3/s.

(d) Fourth Tier — Office Space

- The CO_2 sources in office space were taken into account in the design process and therefore did not consider as pre-contamination to the outdoor air. If there was no 'surprised' CO_2 source, the pre-contamination at this tier was zero.
- There was a short-circuited air with 700 ppm (1.26g/m^3) of CO_2 concentration as it was flowed into the space at 0.2 m^3/s from other zone.
- It is a common phenomenon that the outdoor air at supply air diffuser could easily by-pass into the return air diffusers or grilles. The by-passed air with 550 ppm (0.99g/m^3) of CO_2 concentration at 2 m^3/s was inspected.
- By the equation 5.4, the concentration of CO_2 at the fourth tier was 527 ppm (0.95g/m^3) and the flow rate of outdoor air system was changed to 10.4 m^3/s.

In the fourth tier inside the office space, under these mentioned conditions, the effective dilution margin of the outdoor air for dilution purpose was reduced to (1000-527) ppm, i.e. 473 ppm.

If the conditions remained the same, the designed outdoor air quantity would have to be increased by 1.057 times to compensate the above degradation. In this case, the multiplier was 1.057. This new quantity would then have the same dilution capability of supplying the original amount at 500 ppm dilution margin.

The Four-tier diagnosis scheme has the advantage of considering each type of degradation of the outdoor air at each geographical tier. It is clear on what to avoid on the degradation of outdoor air in a new design. Appropriate multiplying factor to increase the base outdoor air quantity can be applied if a certain kind of degradation in a certain tier cannot be avoided. In any building investigation, any possible degradation of outdoor air in the outdoor air system can follow this Four-tier scheme. If the flow and concentration parameters can be found during the investigation, the required replenishment of the outdoor air quantity can be found.

5.9 Summary and Conclusions

The four-tier scheme is able to describe any fresh air system with reference to exoteric structure. It enables the quantification of the different kinds of degradations of outdoor air. Four-tier diagnosis scheme is an effective protocol for walkthrough inspection on IAQ survey to quantify and evaluate the effect of degradation on the whole outdoor air path. The concept of dilution margin is an approach to measure the deficiencies in outdoor air flow rate. This concept also points out that the ASHRAE procedures only takes into account indoor pollutant sources in space level, that is, the fourth tier in the context of the Four-tier diagnosis scheme. Fanger pointed out that the systems were also sources of pollutants. However, problems may arise in any part of the system through pre-contamination, short circuit and by-pass.

CHAPTER 6 : INDOOR POLLUTANT INVENTORY

6.1 Introduction

Impact of indoor air quality caused by building material emissions is mostly associated to radon radiation and volatile organic compounds (VOCs). Radon gas and its decay products are radioactive in nature. They belong to the series of Uranium and Thorium. Elements of the series are easily found in the earth's crust. Heavy exposure on radon and its decay products may increase the risk of contracting lung cancer. Bare concrete, bricks, tiles, and granite slabs are the earth-based materials which are massively used in construction and furnishing. During the outbreak of energy crisis from 70's, buildings have been constructed tighter than ever. For the purpose of energy saving in air-conditioned space, recirculation of room air is designed at higher proportions. The obvious consequence is that pollutants accumulate indoors. The Hong Kong Environmental Protection Department has reported 5% of residential buildings and 10% of non-residential buildings exceeding the action level of 200 Bq m^{-3} (Pang and Pun, 1994). Concentrations of indoor Rn-222 are believed to be contributed by earth-based building materials. The radon emanation rates of local building materials have been studied by Tso and her colleagues (1994). They made use of gamma spectrometry to investigate the radioactive properties of building materials, including radionuclide contents and Rn-222 emanation rates. They reported that indoor Rn-222 in high-rise buildings of Hong Kong was due to the concrete used. Further study by the same team concluded that ventilation to indoor was an effective mean in controlling indoor radon concentration (Leung et al, 1998).

The VOCs emitted from furniture and synthesized building materials are serious indoor pollutants because of their abundance in variety and toxicity, difficulties in measurement and removal, as well as control. Various materials like wood-based, urea-formaldehyde-based, and polymeric-based substances are common in use. Yu and Crump (1998) reviewed VOCs emissions from furniture in buildings. They reported that Sick Building Syndrome (SBS) was mainly caused by sources of VOCs from polymeric materials, wet painting, coating, and solvents. They suggested that labeling schemes of VOCs emission and database should be developed to support choices for low emission products. Other work contributed by Jones (1999), he summarized the impacts of VOCs on health. Over exposure on VOCs might have the problems on central nervous system, aches of head and throat, eyes irritating, respiratory disease, and unpleasant of mucous membrane. Both the works of Yu and Jones confirmed that VOCs emissions were important issues for consideration to avoid SBS.

Pollutant emission evaluated by chamber test is a powerful tool. Chao et al (1977), Cosma et al (2001), and Keller et al (2001) made use of chamber tests to investigate the properties of radon emission and diffusion rates on earth-based materials. Their studies provided a protocol to measure the emission rates of earth-based materials. Guo et al (2002) and Afshari et al (2003) developed an excellent chamber test in quantifying VOCs emissions. However, effective emission rates of pollutants in indoor space are difficult to evaluate from chamber test results due to the complicated air flow and venting in buildings. Hence, a protocol for on site, especially in existing buildings is of utmost essential in management of indoor air quality.

To facilitate the management of indoor air quality, this chapter proposes the concept of pollutant inventory. This is the data base of the equivalent emission rates of pollutants inside buildings. These equivalent emission rates are evaluated from the build up and decay profiles of the targeted pollutants in conjunction with radon gas which is naturally emitted from the earth-based building materials. The specific production rate represents the ensemble of all attribute sources of the interested pollutant contributing to a zone in the building.

6.2 Information of the Sampled Room

A conference room was selected in the development of the protocol for the pollutant inventor. The room was located on the 15th floor of an 18-storey building which was a six years old construction. The thermal and indoor air quality comfort was served by a constant air volume (CAV) air conditioning system. The area of the room was 14.7 m^2 covered with carpet. The ceiling was of aluminum type light-coating boards. The headroom was 2.46 m. Three walls of the room were fully walled by metal sheet coated partitions, while the other wall was a full height glass panel. There were eight chairs and one wooden table (2m×1m) in the room. Other furniture includes two wooden bookshelves (1m×0.35m×1m/each). No window was in the room.

During the measurement, the door was closed and no occupant was allowed in the room. The air conditioning system was scheduled to be off at night and was turned on in the morning of next day. Indoor/outdoor radon concentrations were measured by two solid state radon detectors Rad-7 [Durridge Company Inc., USA]. The logging intervals of the detectors were set at 30 minutes. Concentrations of TVOC were measured by Bruel

& Kjaer Multi-gas Analyzer 1302 [Bruel & Kjaer, Denmark]. The analyzer was calibrated using toluene as a reference gas by the manufacturer.

6.3 Protocol for Determining Pollutant Inventory

6.3.1 General Equation

Based on the mass balancing, the rate of change of pollutant-*j* concentration is given by Equation (6.1):

$$\frac{dC_j}{dt} = \frac{\sum_k^p \left[(E_k)_j (A_k)_j\right]}{V} + \frac{q}{V}\left[(C_j)_o - (C_j)\right] - (\lambda_j + R_j) C_j \qquad \text{(Eq. 6.1)}$$

where C_j is the concentration of pollutant-*j* at time t; the air flow across the sampled room is denoted by q; the emission rate of material-*k* for pollutant-*j* is E_k; the exposed area of material-*k* for pollutant-*j* is A_k; the natural decay loss of pollutant-*j* in space is λ_j; the reaction loss of pollutant-*j* in space is R_j; and the control volume of the room is V. Here, *j* is the subscript of Rn-222, and TVOC.

If the initial concentration, $(C_j)_i$, of the pollutant-*j* is determined, the solution of Equation (6.1) is written as:

$$C_j = \left[(C_j)_i - (C_j)_\infty\right] e^{-\left(\lambda_j + R_j + \frac{q}{V}\right)t} + (C_j)_\infty \qquad \text{(Eq. 6.2)}$$

where

$$(C_j)_\infty = \frac{q(C_j)_o + \sum_k^p \left[(E_k)_j (A_k)_j\right]}{V\left(\lambda_j + R_j + \frac{q}{V}\right)} \qquad \text{(Eq. 6.3)}$$

6.3.2 Determination of the Sampled Room Air Change Rates

The air change rate of the room plays a main role in determining the specific production rates of the pollutants and couples with the loss of the pollutants. Considering the chemical inertness and radioactive properties of Rn-222, the gas can be taken as tracer to quantify the air change rate of the room. It takes the benefits of the zero value of reaction loss R_{Rn-222} and the known value of decay loss, $7.55 \times 10^{-3} h^{-1}$. The air change rate is therefore given by Equation (6.4).

$$\frac{q}{V} = \left[L_{Rn-222} - 7.55 \times 10^{-3}\right]\left(h^{-1}\right) \qquad \text{(Eq. 6.4)}$$

The value of $\left(L_j\right)_{RL}$ is the absolute value of the exponential index in Equation (6.2), which is determined by the least squares fitting. The approach is described in Tung et al (2006).

6.3.3 Determination of the Specific Production Φ_j and Resultant Loss Rates $\left(L_j\right)_{RL}$ of Pollutants

Concentrations of indoor pollutants are linked to the operation of the ventilation system. In off mode, the ventilation rate of the room behaves as a chamber with small leakage rate. It allows the pollutants to grow gradually. The growing rate is dependent on the value of $\left(L_j\right)_{RL}$ and time elapsed. By rearranging Equation (6.3), the values of Φ_j and $\left(L_j\right)_{RL}$ are expressed as the followings:

$$\Phi_j = \frac{\sum_k^p \left[\left(E_k\right)_j \left(A_k\right)_j\right]}{V} = \left[\left(L_j\right)_{RL}\left(C_j\right)_\infty - \frac{q}{V}\left(C_j\right)_o\right] \qquad \text{(Eq. 6.5)}$$

$$\left(L_j\right)_{RL} = \left(\lambda_j + R_j + \frac{q}{V}\right) \quad \text{(Eq. 6.6)}$$

The magnitude of q/V is given by Equation (6.4). Value of $\left(L_j\right)_{RL}$ for pollutant-*j* is easily obtained by the same curve fitting technique, as described in previous section. To examine the consistency of the result, the decay profiles recorded at system on mode are used to verify the values of Φ_j. The values of Φ_j can be taken as constant within a short period of time while the extreme short life pollutants are not included in the measurement.

6.4 Results and Discussions

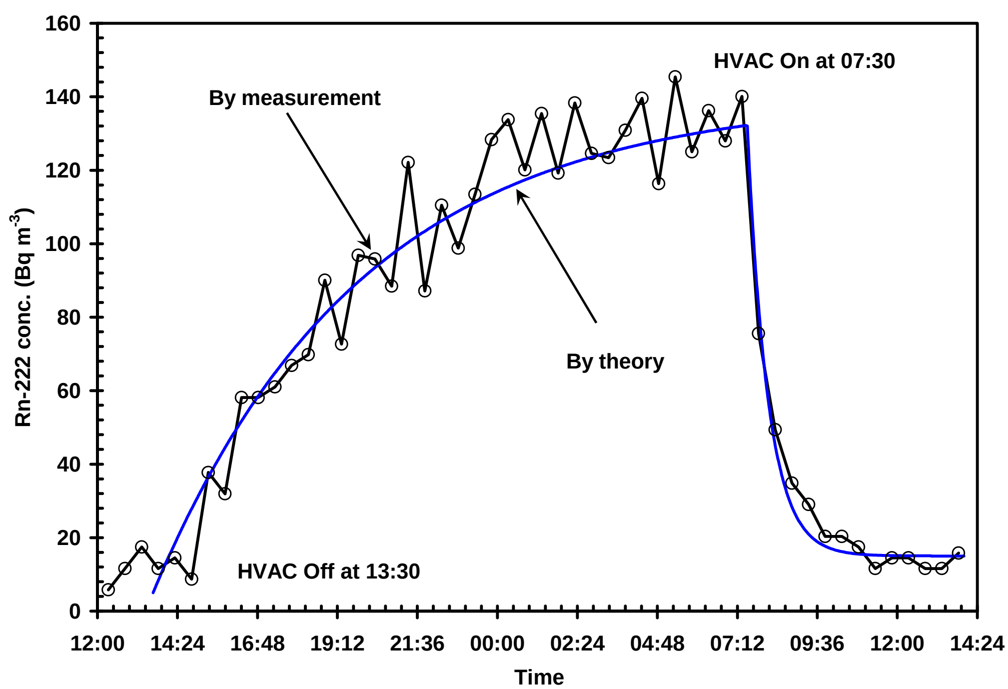
6.4.1 Specific Production Rate of Rn-222 of the Sampled Room

The results of measurements of mean outdoor concentrations, air change rates, chemical loss, natural decay loss, and specific production rates are summarized in Table 6.1. The profile of Rn-222 is shown in Figure 6.1. From the figure, it is observed that the concentrations of radon gas follow the operation status of the ventilation system. It increases during system off mode starting at 13:30 and decreases during system on mode at 07:30 in next morning. The specific Rn-222 production rates obtained for system off and on modes are 21.9 and 19.5 Bq m^{-3} h^{-1} respectively to give a mean of 20.7 Bq m^{-3} h^{-1} with a standard deviation of 1.7 Bq m^{-3} h^{-1} (8.2 %). Value of Φ_{Rn-222} obtained at off mode agrees with the on mode as shown in Table 6.1. This consistency of Φ_{Rn-222} is explained as follows. The total amount of Ra-226 (parent of Rn-222) in the sampled site is almost constant since the half life of the element is more than 1600 years. The loss rate of Ra-226 is insignificant as the element can constantly produce Rn-222. The production rate of the Rn-222 is a function of its exposed area and emission rate. These factors are not varied since the earth-based materials used in the room are not renewed or replaced.

Table 6.1 Results of Measurements at Two Operation Modes

Pollutant	Operation Mode	Outdoor conc.	Steady state conc.	Air change rate	Chemical loss and natural decay	Resultant loss	Specific production rate
Rn-222	Closed	3 ($Bq\ m^{-3}$)	140 ($Bq\ m^{-3}$)	0.15 (h^{-1})	0.00755 (h^{-1})	0.16 (h^{-1})	21.92 ($Bq\ m^{-3}\ h^{-1}$)
	Open	2.8 ($Bq\ m^{-3}$)	15 ($Bq\ m^{-3}$)	1.59 (h^{-1})	0.00755 (h^{-1})	1.60 (h^{-1})	19.54 ($Bq\ m^{-3}\ h^{-1}$)
TVOC	Closed	2 ($mg\ m^{-3}$)	12.1 ($mg\ m^{-3}$)	0.15 (h^{-1})	0.02755 (h^{-1})	0.18 (h^{-1})	1.87 ($mg\ m^{-3}\ h^{-1}$)
	Open	5 ($mg\ m^{-3}$)	6.28 ($mg\ m^{-3}$)	1.59 (h^{-1})	0.01755 (h^{-1})	1.61 (h^{-1})	2.15 ($mg\ m^{-3}\ h^{-1}$)

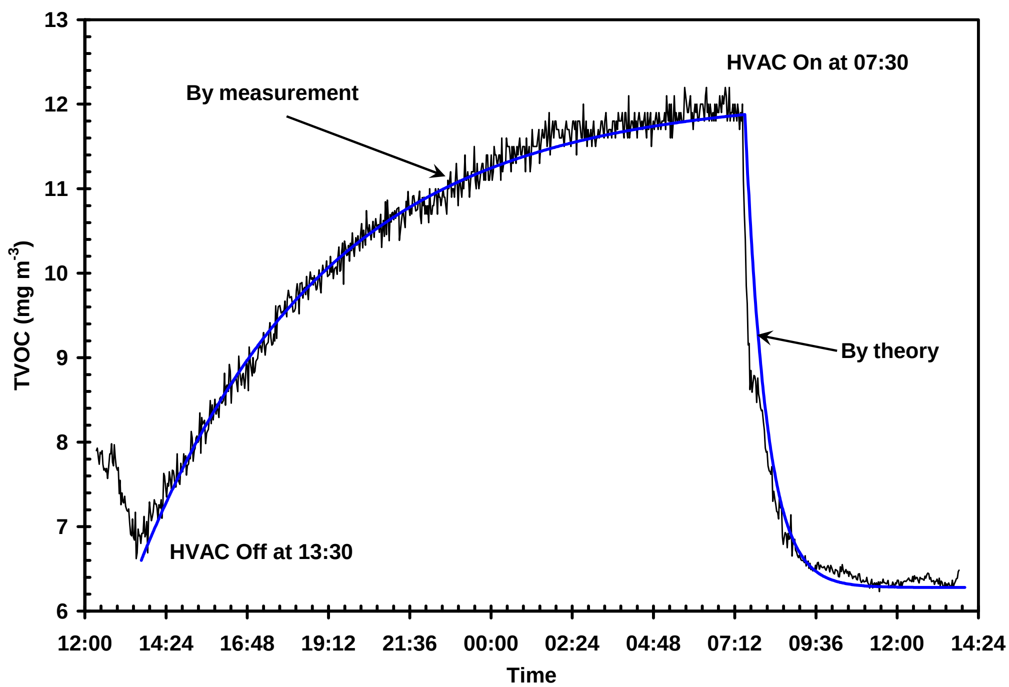
Figure 6.1 Sampled Room Rn-222 Concentration Profile at Closed/Open Modes



6.4.2 Specific Production Rate of TVOC of the Sampled Room

The profiles of TVOC measured at the two ventilation modes are shown in Figure 6.2. The specific TVOC production rates yielded at off and on modes are 1.9 and 2.1 mg m^{-3} h^{-1}, respectively. The mean is 2.0 mg m^{-3} h^{-1} and the standard deviation is 0.2 mg m^{-3} h^{-1} (9.7 %). The outdoor TVOC during off mode is 2 mg m^{-3} and that at on mode is 5 mg m^{-3}. Higher outdoor TVOC at on mode is influenced by the maintenance activities of painting and water proofing in the day time.

Figure 6.2 Sampled Room TVOC Concentration Profile at Closed/Open Modes



6.4.3 Indoor Pollutant Concentration and Exposure for Indoor Air Quality Management

When the specific production rate, decay loss, and chemical loss of the pollutant are fixed, the concentrations of the pollutant only varies with the outdoor level, elapsed time, and the air change rate of the building. The rapid changes found at the initial states of off mode and on mode. The air change rate in the room is an essential factor to control the concentrations of indoor pollutants. The rate of change of concentrations during off mode (accumulation) and on mode (decay) is proportional to the factor of resultant loss as given by Equation (6.7).

$$\frac{dC}{dt} = \left[(C_j)_\infty - (C_j)_i\right]\left[\left(R_j + \lambda_j + \frac{q}{V}\right)\right]e^{-\left(R_j+\lambda_j+\frac{q}{V}\right)t} \qquad \text{(Eq. 6.7)}$$

Equation (6.7) describes the model for the rate of change of concentrations of the pollutants. When the parameters are known, the profile can be predicted. It renders an indoor air quality management plan possible. As shown in Figures 6.3 and 6.4, for the radon "inventory" found in this room, the simulation shows that 0.4, 0.9 and 2.6 hours to reduce Rn-222 to the expected control level of 70 Bq/m^3 with air change rates of 2, 1 and 0.5 h^{-1} respectively, taking the mean outdoor radon concentration of 3 Bq/m^3. Similarly, when the TVOC "inventory" found in this room, the simulation shows that if the air change rate is less than 0.5 h^{-1}, the TVOC is not able to keep at 6 mg/m^3, taking the mean outdoor TVOC concentration of 3.5 mg/m^3. Alternatively, this concentration can be controlled within 0.8 and 2.4 hours with air change rates of 2 and 1 h^{-1} respectively. The simulated profile reveals that the decision of the air change rate is also dependent on the time to reach the set point, which is limited by the total exposure. This is a vital consideration for an optimum indoor air quality management strategy.

Figure 6.3 Sampled Room Rn-222 Concentration Profiles Simulated at Three Different Air Change Rates

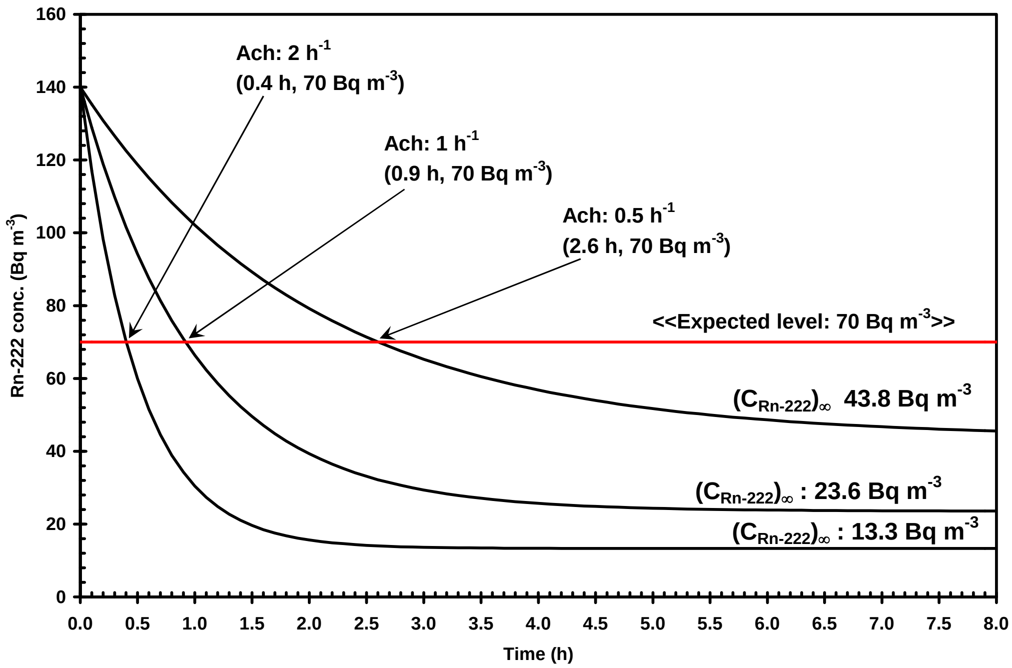
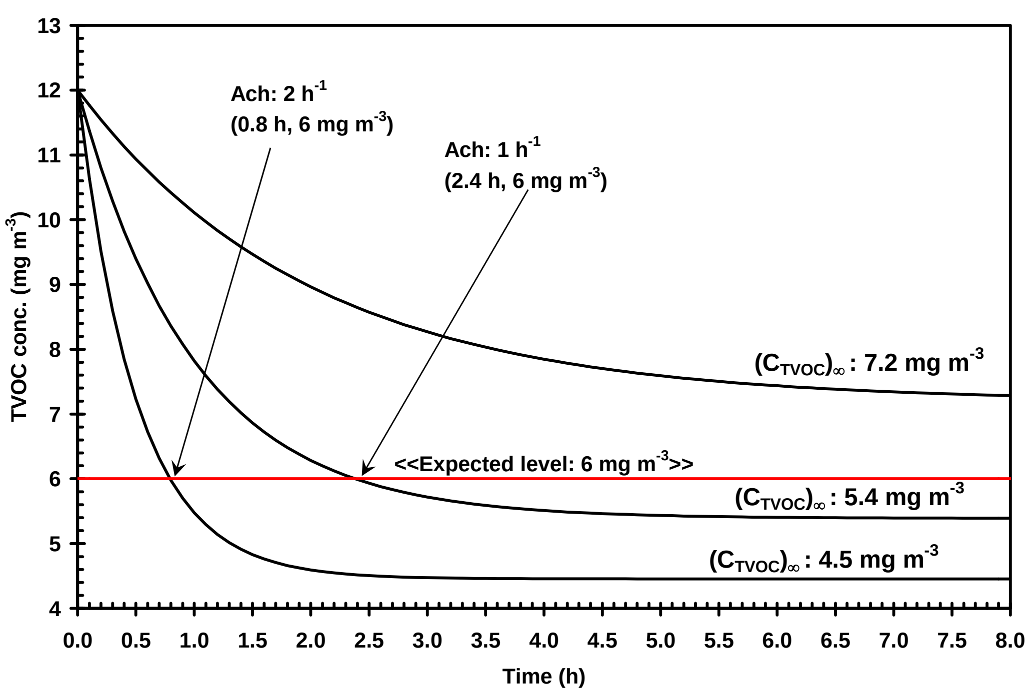


Figure 6.4 Sampled Room TVOC Concentration Profiles Simulated at Three Different Air Change Rates



6.5 Summary and Conclusions

The concept of "Indoor Pollutant Inventory" gives the IAQ managers a data base for a more appropriate strategy for managing the selection and quantifying of building materials and ventilation rates during normal operation. The "Pollutant Inventory" helps to keep track of IAQ deterioration, cap the minimum ventilation rate for demand ventilation control, ventilation requirements during temporary overloading of indoor pollutants and any extraordinary activity of a building in use.

This chapter presents a methodology which can simultaneously quantify the specific pollutant production rate and the resultant loss of the multi pollutants for an air conditioned building. The method is used as a tool in establishing a database of pollutants. A specific term "indoor pollutant inventory" is introduced because it plays a main role in air quality (IAQ) management. Pollutant inventory records the equivalent emissions of pollutants from sources in a building, for which the pollutants are required to be controlled at or below accepted levels. The same protocol is applicable to all other indoor pollutants including formaldehyde, gaseous pollutants, and likewise. It has a big advantage of independence of the sources as it measures the result of the ensemble.

The specific production rate Φ_j of pollutant-*j* is defined as its production rate normalized by the control volume of sampled room. The resultant loss $(L_j)_{RL}$ of pollutant-*j* is defined as the sum of its natural decay λ_j, reaction loss R_j, and ventilation loss (q/v). Two common indoor pollutants of Radon-222 (Rn-222) and Total Volatile Organic Compounds (TVOC) are selected to verify the methodology. During validating the method, the air conditioned system in an office was scheduled to shut down overnight followed by supply mode in the next morning. Two systematic pollutant curves corresponding to the build up and decay of the pollutants were recorded. These curves were used to quantify the values of Φ_j and $(L_j)_{RL}$. The values of Φ_j and $(L_j)_{RL}$ obtained from two different modes were mutually agreed to each other. Described in this chapter, pollutant of Rn-222 emitted from earth-based building materials is used as a tracer gas to determine the ventilation rates of the sampled room. Emission rates of other pollutants are then determined. The mean specific production rates of Rn-222 and TVOC were measured to be 20.7 Bq m^{-3} h^{-1} and 2.0 mg m^{-3} h^{-1} accordingly, while the sum of chemical and natural losses were 0.0076 and 0.0226 h^{-1}, respectively. Based on the results, the concentration profiles of the pollutants at three selected air change rates were simulated.

CHAPTER 7 : SAMPLING PROTOCOL ON INDOOR AIR QUALITY MEASUREMENT

7.1 Introduction

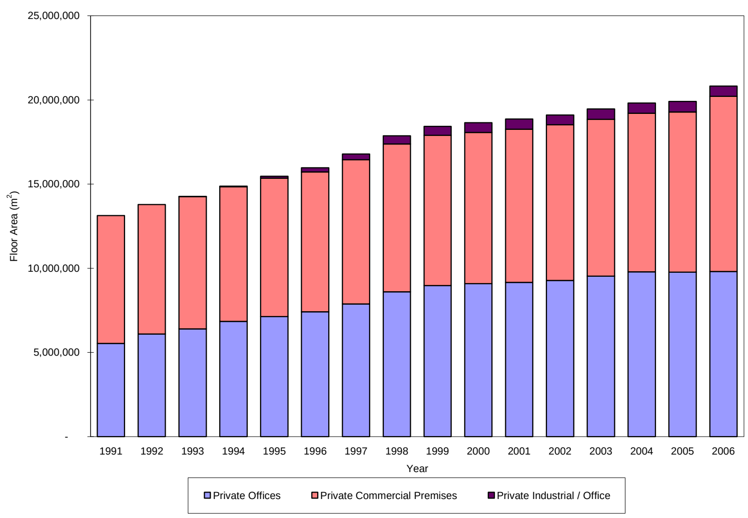
The Environmental Protection Department conducted a territory-wide indoor air quality survey in Hong Kong. The report released in 1997 confirmed that one-third of the sampled buildings were classified as sick buildings. Many of the causes could be attributed to unacceptable indoor air quality. In response to this, the Indoor Air Quality Management Group distributed a 'Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places' for public consultation and then launched in September 2003 together with 'A Guide on Indoor Air Quality Certification Scheme for Offices and Public Places'. It includes an IAQ certification scheme. The scheme is required to sample air at each location for nine IAQ parameters and three thermal comfort parameters. As discussed in Chapter 1, the cost of IAQ sampling for all air-conditioned buildings in Hong Kong to achieve the requirement of Certification Scheme of GN is extremely huge. Cost-effective and practical approach for IAQ sampling is needed for building owners or managers to sample their buildings and look for acceptable IAQ. This chapter describes a review of IAQ sampling in buildings and the development of a protocol of effective sampling based on statistical sampling principles.

7.2 Total Floor Area of Office Buildings and Commercial Premises

Hong Kong is one of the most densely cities in the world. In the 2006 Population Census, Hong Kong population was 6.9 million people who were crowded on about

1,100 square kilometres. Due to the limitation of land and the high population, most of buildings are high-rise in order to compile the development of society. As a metropolitan city in the world, Hong Kong has a large number of high-rise office buildings and commercial premises. For the sub-tropical region, most of the day in Hong Kong is hot and humid even in wintertime. Almost all of the office buildings and commercial premises are air-conditioned. Figure 7.1 shows the stock of Hong Kong private office buildings and commercial premises from 1991 to 2006. The total stock of floor areas of these buildings has steadily increased and many major developments will be completed in recent years. Therefore, a huge number of air-conditioned buildings are required to undergo the IAQ certification scheme if enforced control is executed.

Figure 7.1 Stock of Hong Kong Private Offices, Commercial Premises and Industrial/Office Buildings



The total stock of floor area of private offices, commercial premises and industrial/office buildings in 2006 was about 20,821,100 square metres. Based on the requirement of GN (Table 1.3), the minimum number of sampling point is 1,200 square metres per point. The total number of sampling point required for the Certification

Scheme is then calculated as around 17,350. The market value of the cost for sampling one point, according to a number of sources is HK$4,000. Therefore, the total cost to building owners for initial IAQ sampling for all private air-conditioned office buildings and commercial premises is HK$69.4 million. The actual cost could be higher, as the total numbers of the sampling point that required to be tested is well over 17,350. These costs would eventually be built into the costs borne by the society at large. With an average of 30 sampling points for one building, it is doubtful that all the building owners would be willing to spend HK$120,000 only for initial sampling of one building and adopt the scheme on a voluntary basis.

7.3 Industry on IAQ Sampling

The huge sums of money involved will surely stimulate new consultancy business for IAQ measurements. Taking into account of the total number of sampling point required for the Certification Scheme is 17,350. Except Saturday and Sunday (i.e. around 261 days of year), the minimum number of point required to sample per day is about 67. Taking the same basic reference numbers, there has to be adequate resources to cover 17,350 points per annum, or around 67 sampling points per working day. It would require 67 measurement teams each equipped with measuring instruments for IAQ parameters. The estimated annual expenditure of one set of measuring instrument for all 12 IAQ parameters is about HK$ 1 million. Therefore, HK$ 67 million expenditure is estimated for sampling IAQ per year for all Hong Kong air-conditioned buildings and commercial premises. It is clearly a huge resource requirement for IAQ sampling industry.

However, such business is very attractive to suppliers. It seems inevitable that, with the overwhelming workload for all concerned, the quality of survey and assessment will decline. EPD intends to control the quality by tightening up the quality of the 'authorised samplers' and laboratories. However, neither EPD nor any government department has any plan to invest in the regulatory process. It leads to concern that the good intentions of the Certification Scheme and GN will not be met, and instead end up with rather worthless certificates bought for millions of dollars.

7.4 Development of Pragmatic Sampling Protocol

Based on the previous discussion, it is possible that the GN will not be very successful as a voluntary scheme. However, there is pressure to regulate IAQ, this together with the market forces towards more sustainable buildings and high standard of indoor environment. Therefore, a more pragmatic protocol for managing the IAQ in air-conditioned buildings is desirable. This protocol should help building owners to optimise expenditure to obtain meaningful certification and lower IAQ risks.

7.5 Rationale of Sampling Protocol

For the purpose of enhancing our quality of life, air-conditioned buildings have been introduced since 1960s. Since that, the quality of air has seemed to be improved for thermal comfort issues. However, energy crisis happened in 1970s let the incoming rate of outdoor air supply for purpose of dilution turn down. Moreover, the tighter construction techniques are being used for reducing the heat transfer for energy savings. 'Build tight, ventilate right' is being an axiom for building construction industry. On the other hand, many new building materials are being used with unknown pollutant emission. Consequently, we spend most of our lives in indoor environment where air quality is quite different and often much worse than that outdoors because the concentration of the contaminants inside the building may rise to unwanted levels and have deleterious health effects to the occupants if either i) inadequate outdoor 'clean' air for dilution, ii) ineffective or under-designed ventilation or iii) too much indoor pollutant loads. For effective and economical determination of indoor air quality inside building, five principles of protocol for IAQ sampling have been developed.

Designing of IAQ sampling protocol requires systematic thinking. This thinking should address what pollutants to sample and what instruments to use. Further considerations include how many locations to sample within a given building and how long to sample. GN provides valuable information for consideration on the above issues. However, the sampling protocol should be reasonable and practicable which can be fully supported by the society and the resource. Therefore, the rationale of sampling protocol should have thoroughly and logistic consideration. Before planning to qualify the IAQ situation inside a targeted building, full understanding what parameters would affect the IAQ in that building is needed. Many factors affect indoor air quality and all of them may require to be dealt with initial planning. These factors have been discussed by Yocom (1991) and including the following:

- outdoor air quality
- indoor generation of pollutants
- pollution depletion mechanisms
- meteorological factors

- permeability of structure
- ventilation measures

Attention should also be given to identifying other measurable factors that modify indoor concentrations such as air exchange. A hastily developed design could very well lead to results of little practical significance or, worse, to erroneous and misleading findings. Thus good design requires a considerable amount of thought and effort.

7.6 Pragmatic Protocol on Sampling IAQ

The pragmatic protocol on sampling IAQ, which is based on the mentioned rationales, can provide hindsight in the management of IAQ. Adopting the parameters in the GN for IAQ sampling the pragmatic cost-effective protocol is based on several principles:

Principle 1 – a rationale of determining the population of measurement points;

Principle 2 – a rationale of determining the number of sampling points;

Principle 3 – a rationale of reducing the number of sampling parameters in each sampling point;

Principle 4 – a rationale of reducing the amount of sampling time for each parameter in each sampling point;

Principle 5 – a rationale of choosing alterative instrumentation.

7.6.1 Principle 1 – Determination of Population of Measurement Points

The target of indoor air quality surveys is to determine if the occupants inside the building are subjected to deleterious heath or comfort effects. To determine indoor air quality in a building, the obviously safe solution is to monitor all IAQ parameters for continuous period of time in every corner of occupied areas simultaneously. Unfortunately, such procedure would be prohibitively expensive, and thus, it is not an appropriate approach. Limiting the number of sampling points and length of the sampling period is a requirement if widespread IAQ surveys are to be conducted on statutory control. To limit the number of sampling points, a logical criterion is necessary. Randomly placed sensors or area determination may not be appropriate and lack of scientific rationales because there would be no guarantee that the highest risk zones would be identified. To obtain such a criterion, the rationale of zoning principle for IAQ sampling has to be thoroughly examined.

For effective studying the indoor air quality inside a building, the initial step is to define an IAQ zone. In principle, the definition of an IAQ zone may be described as parameters including pollutant concentration are uniform within a tolerance band. An IAQ zone may be a general open-plan office with uniform distribution of building material, in-house activity, ventilation system and served with the same unity of outdoor air system. As different zones of a building can have different environments, it is important to characterize the key issues of indoor pollutant sources associated with each zone, in particular of those which may cause potential risks on health as well as comfort.

For identifying the different zones, preliminary investigation including walkthrough inspection is an extremely crucial issue. Preliminary investigation involves study of complaint records, occupancy interviews, operation and maintenance schedule of HVAC system and identification of building characteristics. These characteristics include age and building materials, contents such as appliances and furnishings, outdoor air and air distribution system, occupant practices such as use of appliances, and potential interferents. Moreover, the habits of occupants and type of business with respect to indoor locations are of particular concern for IAQ studies because zone selection is strictly tied to occupancy patterns and indoor pollutant loads.

Thus, in the absence of guidelines and with a desire to limit the number of zones to be sampled, the anticipated mass balance for the indoor pollutant must be qualitatively conceptualized. The concentration of a contaminant in a space depends on the amount of contaminant generated within, and on the amount of air exchanged through the boundary of the space. Mathematically, when a contaminant is generated in a space which is assumed to be uniformly mixed, its concentration can be described by a mass balance equation (Keil, 2000). It is an expression of the law of conservation of mass on a given system. The law of conservation of mass states that mass is neither created nor destroyed in a process or non-nuclear chemical reaction. When chemical reactions occur in a system, strict application of the law of conservation of mass requires accounting for all of the mass in a system before and after a reaction.

When no reactions occur, a mass balance is a simple accounting of any chemical in the system. In words, a mass balance requires that the rate of chemical accumulation within any closed system is equal to the rate of mass into the system minus the rate of mass out of the system. The mass into the system can be divided into the mass into the system through the system boundaries and the mass generated inside the system. The general mass balance equation for a system is:

$Mass_{accumulated} = Mass_{generated} + Mass_{in} - Mass_{out}$

The rate of accumulation of mass of contaminant A in the air is written:

$$\frac{dmass}{dt} = V\frac{dC_{Aroom}}{dt}$$

where V = volume of air in the room

C_{Aroom} = uniform room concentration of A

t = time

The rate of contaminant mass leaving the room air has two components: the mass that leaves the room through the exhaust and the contaminant that leaves room air when it is adsorbed onto or absorbed into room surfaces (walls, floors, clothing, equipment). The latter is referred to as sink or 'nonventilatory' losses. The ventilatory loss can be described as:

$$-\frac{dmass}{dt} = QC_{Aroom}$$

Sinks are not well understood or characterized. Data indicate, however, that the rate of contaminant loss through sinks is proportional to the contaminant in the room. The proportionality constant, K_{sink}, is a property of the room that depends on the surfaces in the room, their area, and their affinity for the contaminant:

Mass removal rate via sinks = $K_{sink}\ C_{Aroom}$

where K_{sink} = rate constant for sink

So, the rate that pollutant mass is removed from the room air becomes:

$$-\frac{dmass}{dt} = QC_{Aroom} + K_{\text{sink}} C_{Aroom}$$

The generation term is designated as G_A and has dimensions of mass per unit time:

$$\text{Rate of Generation} = G_A\left(\frac{mass}{time}\right)$$

Finally, the rate of contaminant into the system through its boundaries is:

$$\frac{dmass}{dt} = QC_{Ain}$$

where C_{Ain} = the concentration of A in the incoming air

Combining the equations, we obtain the complete differential equation for air concentration in the well-mixed room:

$$V\frac{dC_{Aroom}}{dt} = G_A + QC_{Ain} - (QC_{Aroom} + K_{sink}\, C_{Aroom})$$

To summarize the above equation, the concentration of contaminant in a space is dependent on incoming air quality (C_{Ain}), pollutant inventory (C_{Aroom}, G_A) and ventilation (Q). IAQ has been described as the result of a complex relationship between the contamination sources in a building, the ventilation rate and outdoor air. Therefore, the major factors influencing IAQ in a building may be summarized as: (1) indoor pollutant inventory, that includes emissions from indoor contamination sources and materials in a building that change the concentrations of contaminants, (2) outdoor air system, and (3) ventilation effectiveness of air distribution system. Hence, using the above three issues to define IAQ zones is a scientific rationale as to determine the number of sample points.

For identifying the IAQ zones and understanding the existing IAQ situation in targeted building, walkthrough inspection in preliminary investigation is an effective way to achieve the purpose. A technique of walkthrough inspection is generally described in GN and 'Building Air Quality' by USEPA. Chapter 5 highlighted that the three types of degradation, i.e. pre-contamination, short-circuit and by-pass, by four-tier scheme for the outdoor air system in high-rise buildings can effectively be identified during walkthrough inspection. Over 80% of IAQ problems can be found out through walkthrough inspection according to the past experience.

In general, in air-conditioned indoor spaces, concentration of any pollutant is a function of three elements:

- quality of the ventilating air,
- distribution of the air, and
- emission characteristics of significant pollutants.

A sampling zone is then defined as a region of indoor space, whether it is confined by partitions providing a physical barrier to another zones, or a part of an open indoor space within which every physical location (preferably the workstations) has the same quality of ventilating air, the same distribution of the ventilating air and the same emission characteristics of all significant pollutants. Within a zone, the pollutant concentrations of a set of pollutants are expected to be unchanged within any location in the zone, within the accuracy of the measuring instruments used.

The air quality of the ventilating air is considered to be the same when the whole zone is served by the same airside system, including the fresh air supply system. Distribution of ventilating air is considered the same when the layout of the supply and return grilles, diffusers or registers gives a uniform circulation of the air within the zone. Emission characteristic of a pollutant will be the same if the pollutant sources are evenly distributed.

Air sampling zones can be defined by a trained operator doing an initial walkthrough survey of all air-conditioned spaces. The total number of zones forms the population of the representative air quality zones.

7.6.2 Principle 2 – Determination of Number of Sampling Points

Theoretically, the number of sampling point can be determined by the number of IAQ zone. However, statistical approach should be applied to determine the number of sampling point in the same type of IAQ zone for quality assurance. In the same type of IAQ zone, snapshot sampling is measured by randomly selection or area determination of GN during walkthrough inspection. Each of the locations must have the same chance of being sampled, at least approximately. The contaminant concentration is assumed to be normally distributed. For the formulas presented by Nagda et al. (1987), preliminary estimates of the arithmetic mean, $\bar{x}$, and standard deviation, S, are required. Once preliminary estimates of $\bar{x}$ and S have been made, the required sample size of the same

IAQ zone, N, can be approximated. The formula for sample size depends on the estimation goal. A typical estimation goal is to estimate the average pollutant levels under prescribed conditions with a stated degree of precision.

In the case of estimation goals, a common statement of desired precision is as follows: "We wish to have a 95 percent confidence that the average level for the pollutant under consideration can be estimated within +/- 10 percent of its true value for the chosen sampling conditions." The formula for the sample size necessary to meet this objective is as follows:

$$N = \frac{t_s^{\,2} S^2}{d^2} \qquad \text{(Eq. 7.1)}$$

where t_s = number of standard deviations (approximately 1.96) that account for the central 95 percent of the area under a normal curve

S = standard deviation for the variable to be estimated

d = the margin of error (i.e. 10 percent of the true value)

The value for t_s in the above expression varies with the confidence level of choice.

In some cases, practical considerations may prevent attainment of the desired sample size. However, budgetary or logistic constraints should also be an important issue for considering the number of sample point. In this case, monitoring can still be conducted but in recognition that errors associated with estimates or statistical tests will be higher than initially planned. However, if the desired sample size diverges substantially from that permitted by budgetary or logistic considerations, then the design may need to be altered. As a result, there could be greater house-to-house variations in monitoring results and a lower potential for explaining these variations.

If the zones within a building are viewed as the total population, once this is defined, the number of sampling points can be computed using classic statistical sampling theory. Determination of the number of sampling points is done using two procedures. The first procedure involves in grouping of similar zones into ‘categories’. When zones have the same three factors as defined in Principle 1, they will be grouped together to form ‘category’. In a given category, zones are expected to have similar pollutant profiles. For example, zones within a building where the activities are the same, such as typical offices with sedentary workers and non-smoking, served with typical air conditioning systems, and with the same pollutant inventories within the zones, can be grouped together to form a category .

The second procedure follows the definition of all the categories. The classic statistical sampling comes into effect the number of sampling points can be reduced to provide a more economical and viable monitoring schedule. Typically, the number of sampling points (N) in a category can be computed by the above equation (7.1).

$$N = \frac{t_s^{\,2} S^2}{d^2}$$

where t_s = number of standard deviations that account for the confidence level

S = standard deviation for the variable to be estimated

d = the margin of error (e.g. 10% of the mean value).

7.6.3 Principle 3 – Reduction of Number of Sampled Pollutants

A major component in determining indoor air pollution levels is often the outdoor concentration. Some of the materials initially in ambient air may be removed or destroyed on entering enclosed areas [Wadden and Scheff (1983)]. For example, environmental control systems such as air conditioning and makeup air ventilation filters may reduce the eventual contribution of pollutants like TSP, ambient ozone, nitrogen dioxide and carbon monoxide decays rapidly on a variety of air-entry surfaces. But outdoor levels always need to be considered when ventilation requirements are being determined to prevent unhealthful exposures.

It should be emphasized that indoor pollutant concentrations and their variation in time may also be influenced by the level of outdoor air pollution. Hence, it is necessary to have information about the quality of outdoor air if it is likely that it contains significant amounts of the pollutants studied. Nitrogen dioxide and respirable suspended particulates are the major pollutants of outdoor air in Hong Kong and these two parameters of all roadside stations did not comply with long-term (annual) air quality objectives. It is because the outdoor air quality is influenced by vehicular exhaust emission [Chan & Wu (1993), Chan et al. (1999, 2000)]. The polluted outdoor air reaches the indoor air with a certain time lag depending on the air exchange rate. Thus, care must be taken if short-term indoor measurements are carried out in the course of an episode of elevated pollution levels in outdoor air, not to assign elevated indoor concentrations erroneously to indoor sources when infiltration processes are the main cause.

If the level of contaminants in outdoor air exceeds that for minimum air quality standards, extraordinary measures beyond the scope of this text must be used. For the present discussion it will be presumed that outdoor air quality is satisfactory for dilution purposes.

The sources of indoor air pollution and the principal pollutants, grouped by outdoor and indoor origin, are summarized in Table 7.1. This is not a complete listing of all sources of indoor air pollutants, as there is continuous air exchange between indoors and outdoors, and most pollutants present in the outdoor air are also found indoors. Moreover, indoor sources may lead to an accumulation of some compounds that are rarely present in the ambient air.

Table 7.1 Typical sources of some pollutants grouped by origin [sourced from National Academy of Science (1981)]

Principal pollutants	**Sources, predominantly outdoor**
Sulfur oxides (gases, particles)	Fuel combustion, smelters
Ozone	Photochemical reactions
Pollens	Trees, grass, weeds, plants
Lead, manganese	Automobiles
Calcium, chlorine, silicon, cadmium	Suspension of soils or industrial emission
Organic substances	Petrochemical solvents, natural sources, vaporization of unburned fuels
Principal pollutants	**Sources both indoor and outdoor**
Nitric oxide, nitrogen dioxide	Fuel burning
Carbon monoxide	Fuel burning
Carbon dioxide	Metabolic activity, combustion

Particles	Environmental tobacco smoke, resuspension, condensation of vapours and combustion products
Water vapour	Biological activity, combustion, evaporation
Organic substances	Volatilization, combustion, paint, metabolic action, pesticides, insecticides, fungicides
Spores	Fungi, moulds
Principal pollutants	**Sources, predominantly indoor**
Radon	Underlying rock and soil, building construction materials (concrete, stone), water
Formaldehyde	Particle board, insulation, furnishings, environmental tobacco smoke
Asbestos, mineral, and synthetic fibrers	Fire-retardant, acoustics, thermal or electric insulation
Organic substances	Adhesives, solvents, cooking, cosmetics
Ammonia	Metabolic activity, cleaning products
Polycyclic hydrocarbons, arsenic, nicotine, acrolein, etc.	Environmental tobacco smoke
Mercury	Fungicides, paints, spills or breakage of mercury-containing products
Aerosols	Consumer products, house dust
Allergens	House dust, animal dander
Viable organisms	Infections

If proving that there are no potential of indoor pollutant sources which may emit the pollutant concentrations exceed the levels setting in the GN and the quality of outdoor air fulfill the GN criteria where the IAQ is purely a function of outdoor air quality, the parameters of sample could be reduced in the sampling or monitoring program.

On the other hand, regarding to the above principle 1, the concentration of the contaminant in a space in the well-mixed room:

$$V \frac{dC_{Aroom}}{dt} = G_A + QC_{Ain} - (QC_{Aroom} + K_{sink}\, C_{Aroom})$$

The concentration of contaminant in a space is dependent on incoming air quality (C_{Ain}), pollutant inventory (C_{Aroom}, G_A) and ventilation (Q). IAQ has been described as the result of a complex relationship between the contamination sources in a building, the ventilation rate and ventilating air. Therefore, if the contaminant has constant emission rate and its concentration profile has a known relationship between ventilation rate and is always under control. The parameters of sample could be reduced in the sampling or monitoring program if the emission of the parameters and ventilation are remaining constant all the time.

A problem with extensive air sampling is the potentially high cost of measurements. In most cases the indoor pollutants defined in the GN (Table 1.2) only exist in traces. To be confident in the air sampling, the lowest detectable limit should be one order below the prescribed level. Each pollutant has to be measured using a different technology, making comprehensive indoor air sampling very expensive. Therefore, it is possible to consider reducing the number of sampled pollutants. There are two ways that the number of sampled pollutants can be reduced:-

(a) If the pollutant comes from outdoor sources only, and if its concentration at the intake point is below the prescribed criteria at all times, this pollutant can be discounted. Vehicular borne pollutants, such as carbon monoxide and nitrogen oxides, are good examples.

(b) If the pollutant is known to have a constant emission rate, and if its profile relative to the ventilation rate is known and is under control at all times, this pollutant can be discounted. Radon gas, which is ubiquitous in Hong Kong buildings, is a good example.

7.6.4 Principle 4 – Reduction of Sampling Time for Each Pollutant in Each Sampling Zone

Indoor concentrations of air pollutants are influenced by outdoor levels, indoor sources, the rate of exchange between indoor and outdoor air, and the characteristics and furnishings of buildings. In addition, indoor concentrations of air pollutants are subject to geographical, seasonal and diurnal variations.

The variation with time of the concentration level of a pollutant in an indoor environment is well-known phenomenon. Parameters like the age of the building, the season, the time of the day, etc. all influence the result of an indoor air measurement. Therefore, it has to be considered carefully when such measurements are carried out.

It is clear that different results will be obtained under otherwise identical conditions. Furthermore, the occupants may contribute to the level of pollutants in one way or the other, e.g. through their various activities. Thus, the history of a room prior to and during sampling is of utmost importance and must be documented. Therefore, the signatures of the IAQ parameters especially those predominantly from indoors, like radon, carbon dioxide and TVOC, should be recorded at least once in order to determine the significant change of IAQ status in monitoring.

It is difficult to give a definite, but generally valid, recommendation for the time of sampling which could apply under all circumstances. However, daily profile of pollutants should be more or less the same if the indoor activities of the occupancy are similar. If the signature of IAQ parameters has already examined in the early stage (e.g. Testing & Commissioning stage) or after a major change in renovation or occupant density, the snapshot air pollutant sampling can be effectively used for determining the average 8-hour exposure. On the other hand, the signatures of some IAQ parameters such as carbon dioxide can provide an effective indicator of adequacy of ventilation.

Most air quality sampling is 8 hours continuously. The resources required for such measurements are significant burdens on IAQ management. The reduction of sampling time is based on the assumption that when a building enters into its routine operation that including the activities of the occupancy and the operation of ventilation system, the function of the zone or the pollutant inventory are ever changing, it is reasonable to assume that the pollution profiles of the target pollutants would remain similar with small changes of magnitude. When the pollutant profile has always known, a snapshot of measurement at any time can be used to determine the equivalent 8-hour exposure, and to check if any abnormal built up of the pollutant has occurred. This is particularly useful when availability of instrumentation is a problem.

7.6.5 Principle 5 – Choice of Alterative Instrumentation

In contrast to the situation encountered in outdoor air analysis where the concentrations of a number of pollutants are monitored continuously, indoor air pollution is not measured on a continuous basis in view of the large number of individual indoor spaces with different sources and pollution patterns. In general, it is also not possible to introduce bulky or noisy analytical equipment into indoor environments. As a first consequence of this situation, analysis of indoor pollutants is usually broken down into a sampling step which is performed on-site with relatively small, silent and inexpensive equipment, and a separation/identification step which is performed in the laboratory using complex instrumentation if necessary.

Concentration of pollutants may be distinct by different measuring principles. For example, for measuring respirable suspended particulates, the measuring principle of dusttrak is light scattering and the measuring principle of mini-vol sampler is size filtration. Selection of instrumentation plays a large role in affecting the acceptance of measured data. Since that, different measuring principles may come up with variation of measured results. Tung et al. (1999) mentioned the correlation between dusttrak and mini-vol sampler of sampling RSP. Chao et al. (2001) also mentioned the correlation relationship between different measuring principles of TVOC measured by TO-12 and PID method.

Even with a limited set of target pollutants for monitoring purposes, the demand for instrumentation can remain high. Since most pollutants in most zones will normally prevail in traces, the requirements in respect of precision and accuracy of instrumentation are particularly demanding.

If the simpler measuring instrument using in the sampling is different from the requirement mentioned in GN for some reasons, the calibration of this measuring instrument against the standard should be undertaken in order to prove that the measuring instrument is available for the sampling. Therefore, the cost of the resource for sampling can be reduced if the building management company has already had the instrument which is not specified by GN for sampling.

7.7 Case Study

For verification of the principles of sampling mentioned before, four case studies were conducted and summarized by IAQ site surveys among total 1022 locations which involved university campus, office buildings, shopping mall and commercial complex, conducted by the research project of the 4-year PolyU IAQ led by the Health and Safety Office, with the collaboration of Building Services Engineering Department, Civil and Structural Engineering Department and the Facilities Management Office of the The Hong Kong Polytechnic University and research project (ITS/133/0) supported by Innovation and Technology Fund (ITF) under Innovation and Technology Support Programme. The aim of the first case study was to demonstrate the zoning principle to determine the population of measurement points and number of the sampling points (principle 1 and 2). The second case study was to verify the possibility to reduce the number of sampled pollutants (principle 3). The third case study was to demonstrate the routine daily profile of the same location as to reduce the sampling time for each parameter in each sampling zone on the IAQ monitoring progress (principle 4). The last case study was to choose alterative instrumentation to carry out the IAQ monitoring progress (principle 5).

7.7.1 Case Study 1 – Verifying the Principle of Determining the Population of Measurement Points & the Number of Sampling Points (Principle 1 & 2)

An office building having 34 floors was investigated the IAQ situations. The total net floor area of this building is 40,960 square metres. Most activities of the tenant are routine office work. According to the GN launched by EPD, the numbers of sampling point are 35. Before sampling IAQ situations, walkthrough inspection was carried out. By the definition of zoning principle, the numbers of sampling point were identified by the determination of outdoor air system, indoor pollutant sources and air distribution system with addition to the statistical approach. Due to the building having only one outdoor air system and the uniformity of air distribution system, the main issue to determine the IAQ zone is based on the indoor pollutant sources. During the walkthrough inspection in preliminary investigation, instantaneous measurements of carbon dioxide, carbon monoxide, relative humidity and temperature (IAQ-Calc, TSI Model 8762), RSP (Dusttrak, TSI Model 8520) and TVOC (ppbRAE, RAE Systems Model PGM-7240) by hand-held instruments were also recorded in order to give out the real-time IAQ situation for helping to identify the number of zoning. Based on the sensation judgment by visual check and olfaction of well-trained site surveyor, 10 types of zoning were identified. Table 7.1 shows the types of zoning, and the average instantaneous values of CO_2, standard deviation of CO_2 and number of sampling points justified by the statistical approach.

Table 7.2 Summary Table of Types of Zoning, and the Average Instantaneous Values of CO_2, Standard Deviation of CO_2 and Number of Sampling Points justified by the Statistical Approach

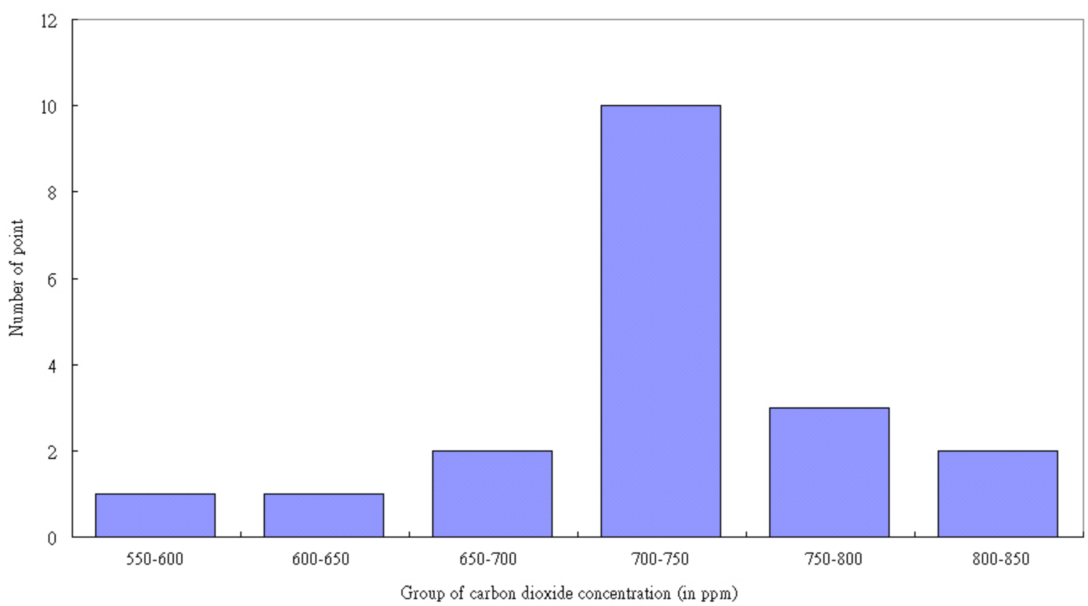
Type of IAQ zone	Type of activity / Company nature	Number of point by GN criteria	Average instantaneous readings of carbon dioxide during walkthrough inspection	Standard deviation of instantaneous CO_2 values	Recommended number of sampling point justified by zoning principle and statistical approach
1	Normal office	19	724	61.1	3
2	Publishing	2	843	38.5	1
3	Architect	2	852	123.2	2
4	Property Management	3	694	83.4	3
5	Shipping	1	785	-	1
6	Trading - Perfume	1	756	-	1
7	Trading – Leather bag	1	668	-	1
8	Trading – Wine	1	639	-	1
9	Smoking office	1	794	-	1
10	Crowded office	4	926	77.7	3
		35			17

Table 7.3 and Figure 7.2 show the instantaneous values of carbon dioxide and the CO_2 distribution at 19 locations of type 1 IAQ zone respectively. We found that the normal distribution of pattern was obtained and believed that the average values of the sampling point also obtained from intensive measurement (8-hour sampling according to GN) would be based on this normal distribution pattern of these populations.

Table 7.3 Instantaneous CO_2 Values during Walkthrough Inspection at 19 Locations of Type 1 IAQ Zone

Location	CO_2 value (ppm)	Location	CO_2 value (ppm)
1	728	11	638
2	812	12	552
3	715	13	716
4	708	14	798
5	726	15	725
6	824	16	682
7	762	17	727
8	683	18	751
9	748	19	717
10	742		

Figure 7.2 CO_2 Distribution at 19 Locations of Type 1 IAQ Zone



According to the principle 1 & 2, the recommended number of sampling point is 17. In order to verify the principle, 35 points were also sampled for 8 hours according to the GN requirement. The sampling results comparing the 17 points were shown in Table

7.4. Therefore, the number of sampling point can be effectively reduced from 35 to 17 points with regard to the rationale of IAQ zoning and statistical approach.

Table 7.4 Results of 35 and 17 Points of IAQ Sampling

	GN	IAQ zoning plus the statistical approach
No. of sampling point	35	17
Mean values	759	775
Range	552-1027	552-1027
Standard deviation	97.3	122.5

Other buildings studying on application of the principle of determining the population of measurement points and the number of sample points (Principle 1 & 2) for IAQ sampling are summarized in the following table.

Table 7.5 Summary Table of Types of Zoning, and the Average Instantaneous Values of CO_2, Standard Deviation of CO_2 and Number of Sampling Points justified by the Statistical Approach for the IAQ Studies at Commercial Complex

Type of IAQ zone	Type of activity / Company nature	Number of point by GN criteria	Average instantaneous readings of carbon dioxide during walkthrough inspection	Standard deviation of instantaneous CO_2 values	Recommended number of sampling point justified by zoning principle and statistical approach
(a) Building A of Commercial Complex at Tsim Sha Tsui					
1	Normal office	31	601.5	89.8	9
2	Office (new renovated)	11	672.5	56.9	3
3	Crowded office	2	881.5	111	2
No. of sampling point		44			14
Mean values		632			659
Range		447-960			533-960
Standard deviation		103.2			111.8
(b) Building B of Commercial Complex at Tsim Sha Tsui					
1	Normal office	38	634.2	83.9	7
2	Office (new renovated)	4	591	127.1	4

3	Crowded office	2	794	25.5	1
No. of sampling point		44			12
Mean values		638			630
Range		463-812			463-776
Standard deviation		92.5			93.4
(c) Building C of Commercial Complex at Tsim Sha Tsui					
1	Normal office	22	550.3	133.6	22
2	Office (new renovated)	12	580.5	127.9	12
3	Crowded office	7	906	136.5	7
No. of sampling point		41			41
Mean values		620			620
Range		369-1119			369-1119
Standard deviation		184.7			184.7
(d) Building D of Commercial Complex at Tsim Sha Tsui					
1	Normal office	36	564.9	97.4	12
2	Office (new renovated)	5	615.2	96.3	5
No. of sampling point		41			17
Mean values		571			586
Range		430-758			444-722
Standard deviation		97.5			85.9
(e) Building E of Commercial Complex at Tsim Sha Tsui					
1	Normal office	12	574.6	69.4	6
2	Office (new renovated)	19	582.5	110.4	14
3	Renovated office	7	646	127.3	7
4	Crowded office	3	821.7	75.3	3
No. of sampling point		41			30
Mean values		609			635
Range		376-881			449-881
Standard deviation		117.7			108.6

By applying the Principle 1 (Determining the population of measurement points) and Principle 2 (Determining the number of sampling points), the sampling IAQ for verifying the IAQ conditions inside buildings can be more rationalized than randomly sampling based on the total floor area. In general, the number of sampling point using these two principles could be reduced. However, the number of sampling point could not be reduced or even required more in some cases because of the necessity of sampling IAQ for providing the full picture or different situations of the IAQ conditions in the building.

7.7.2 Case Study 2 – Verifying the Principle of Reducing the Number of Sampled Pollutants (Principle 3)

For verifying the principle 3 of sampling protocols, integrated and continuous samplings were used to collect the eight indoor and outdoor airborne pollutants and comfort IAQ parameters for studying. This study was conducted from July 2001 to February 2002 and 54 office premises of the four buildings were researched. The IAQ parameters included carbon dioxide (CO_2), carbon monoxide (CO), respirable suspended particulate (RSP), nitrogen dioxide (NO_2), ozone (O_3), radon (Rn), relative humidity (RH) and temperature (Temp). Table 7.6 shows the target IAQ parameters, the types of measuring instrument and analyzing methods used in this study.

Table 7.6 Details of Measuring Instrument and Method for 8 IAQ Parameters in Case Study 2

IAQ parameters	Types of instrument	Analytical methods
Carbon dioxide (CO_2)	IAQ-CALC™ Indoor Air Quality Meters (TSI, Model 8762)	Dual-wavelength non-dispersive infrared
Carbon monoxide (CO)	IAQ-CALC™ Indoor Air Quality Meters (TSI, Model 8762)	Electro-chemical
Respirable suspended particulate (RSP)	Dusttrak™ Aerosol Monitor (TSI, Model 8520)	90^o light scattering
Nitrogen dioxide (NO_2)	Airbag (SKC) + Chemiluminescent Nitrogen Oxides Analyzer (Dasibi, Model: 2108)	Chemiluminescence detector
Ozone (O_3)	Ozone Monitor (Eco sensors, Model C-30ZX)	Heated metal oxide semiconductor
Radon (Rn)	Radon Monitor (Niton, Model Rad 7)	Solid state alpha detector
Relative humidity (RH)	IAQ-CALC™ Indoor Air Quality Meters (TSI, Model 8762)	Thin-film capacitive
Temperature	IAQ-CALC™ Indoor Air Quality Meters (TSI, Model 8762)	Thermistor

Criteria pollutants, CO, NO_2 and O_3 were measured in this study. The other IAQ parameters, CO_2, RSP, Rn and comfort parameters, temperature and RH were also monitored. Air samples in indoors were collected at the breathing level of sedentary occupants in normal office premises and air samples in outdoors were collected at the outdoor air intake of primary air handling unit. The indoor sampling locations were carefully selected and normally located at the occupied areas of open-plan offices without neighbours of indoor pollutant sources, such as photocopiers, printers, etc. The sampling duration of each location is 8-hour office time. The IAQ-CALC IAQ meter and dusttrak aerosol monitor were set to record the real-time data at 1-minute interval. The ozone monitor was measured with an external output. The output data was then recorded by a data logger (StowAway Volt) which was programmed to store 1-minute average values. For NO_2 sampling, air samples were collected by using pre-cleaned airbags with a portable sampling pump (SKC Inc.). Then the airbags were transported to the maintenance office of this buildings where stored the Chemiluminescent Nitrogen Oxides Analyzer for analyzing the NO_2 data.

For quality control and assurance measures, pre-flushed blank airbags were used for each sampling. The airbags and pumps were subject to pre-cleaning and pre-flushing to ensure that there is no contamination inside the sampling instrument. Before the air sampling was taken, the airbags were flushed by the compressed high purity grade of nitrogen gas ($N_2 \geq 99.995\%$) with quality certificate supplied by Hong Kong Oxygen. They were carefully located and sampled where to avoid the direct illumination of sunlight. After collection, the air samples were sent to the maintenance office for analysis. The airbags were analyzed within 15 minutes after sampling. The other instruments were calibrated regularly according to the relevant procedures mentioned on the manufacturer's maintenance manual or standards.

Table 7.7 Statistical Data of Indoor and Outdoor Ratio of Field Measurement

Building (locations)	F (29)			G (13)			H (6)			I (6)		
IAQ parameters	Indoor / Outdoor ratio			Indoor / Outdoor ratio			Indoor / Outdoor ratio			Indoor / Outdoor ratio		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Carbon dioxide (CO_2)	1.50	2.59	2.05	1.24	1.79	1.55	1.46	2.29	1.81	1.37	2.81	2.01
Carbon monoxide (CO)	0.00	0.58	0.08	0.00	0.007	0.001	0.00	0.025	0.004	0.00	0.044	0.007
Respirable suspended particulate (RSP)	0.04	0.31	0.11	0.11	0.91	0.27	0.13	0.65	0.26	0.23	0.55	0.35
Nitrogen dioxide (NO_2)	0.20	0.45	0.32	0.21	0.61	0.37	-	-	-	-	-	-
Ozone (O_3)	0.27	0.85	0.54	0.26	0.49	0.35	-	-	-	-	-	-
Radon (Rn)	1.44	10.32	3.58	2.73	8.27	4.78	5.76	53.00	17.76	1.92	14.03	6.49
Relative humidity (RH)	0.58	1.10	0.79	0.75	1.23	0.92	0.62	0.83	0.71	0.58	0.72	0.62
Temperature	0.89	1.37	1.13	0.81	0.95	0.88	0.74	0.97	0.86	0.72	0.86	0.81

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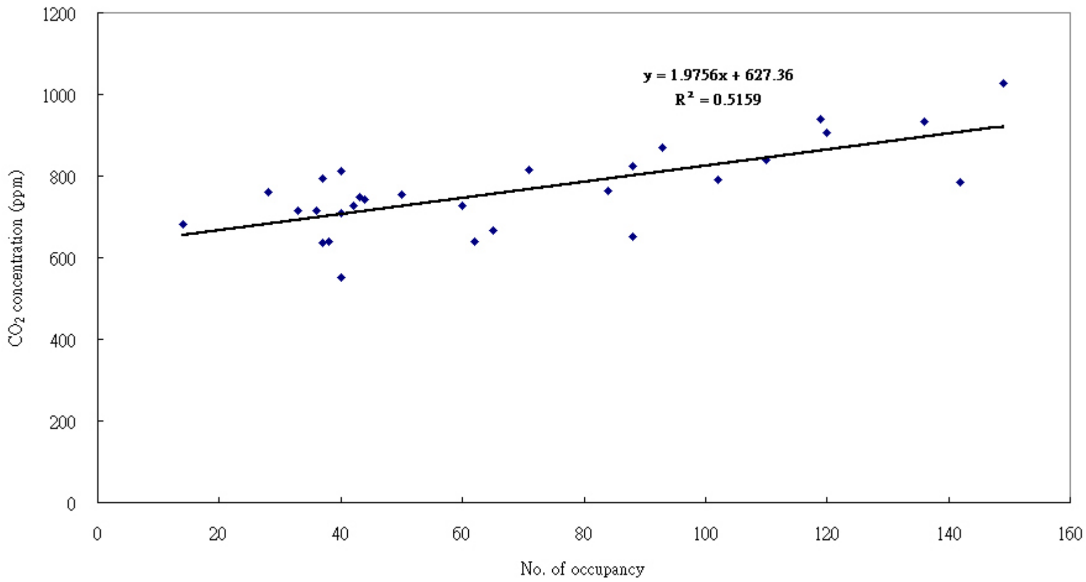
Table 7.7 summarizes the indoor and outdoor ratio of field measurements against 54 office premises among 4 buildings. The concentration of carbon dioxide inside office premise was mainly depended on the ventilation rate of outdoor air, ventilation effectiveness of air distribution system and number of occupancy and its density. The deviation of the number of occupancy in each floor was from around 40 to 200. If ventilation rate of outdoor air and ventilation effectiveness of air distribution system were approximate at different locations, rather high concentrations of carbon dioxide were recorded for most crowded offices. Figure 7.3 illustrates the good correlation between carbon dioxide and number of occupancy in office premises. For the two thermal comfort parameters, temperature and relative humidity, the average values of these parameters during the sampling period were recorded from 19.3 to 24.3^{o}C and from 38.9 to 71.3%. According to the design specification of this building, the design room temperature in office area is 20^{o}C in winter and 23^{o}C in summer. Therefore, rather constant values of room temperature were recorded. However, slight changes of room temperature and relative humidity were subjected to the outdoor conditions.

Figure 7.3 Correlation of Carbon Dioxide and Number of Occupancy in Office Premises



During the field measurements, there was not any activities such as fuel burning, and no other indoor pollutant sources highly emitted carbon monoxide, nitrogen dioxide, and ozone. The indoor concentrations of these three IAQ parameters were mainly depended on the outdoor concentration. According to Table 7.7, the indoor/outdoor ratio of carbon monoxide recorded within a range from 0 to 0.58. For nitrogen dioxide and ozone, the indoor/outdoor ratios were recorded from 0.2 to 0.61 and from 0.26 to 0.85 respectively. The correlation graphs of indoor and outdoor concentrations of carbon monoxide, nitrogen dioxide and ozone for Building F are shown in Figure 7.4, 7.5 and 7.6 respectively. They illustrate good correlations between indoor and outdoor concentrations.

Figure 7.4 Correlation of Indoor and Outdoor Carbon Monoxide Concentration

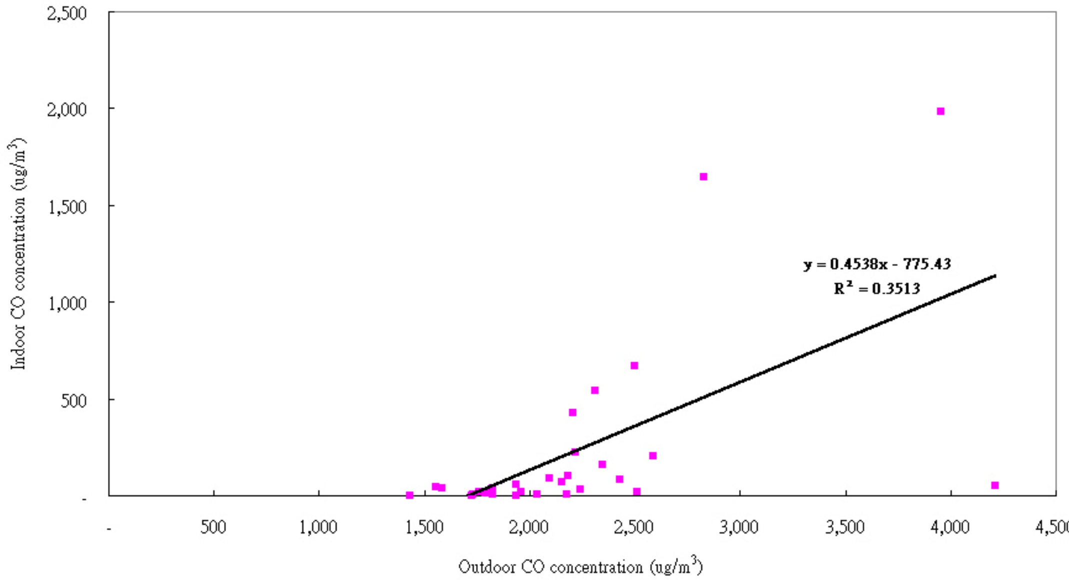


Figure 7.5 Correlation of Indoor and Outdoor Nitrogen Dioxide Concentration

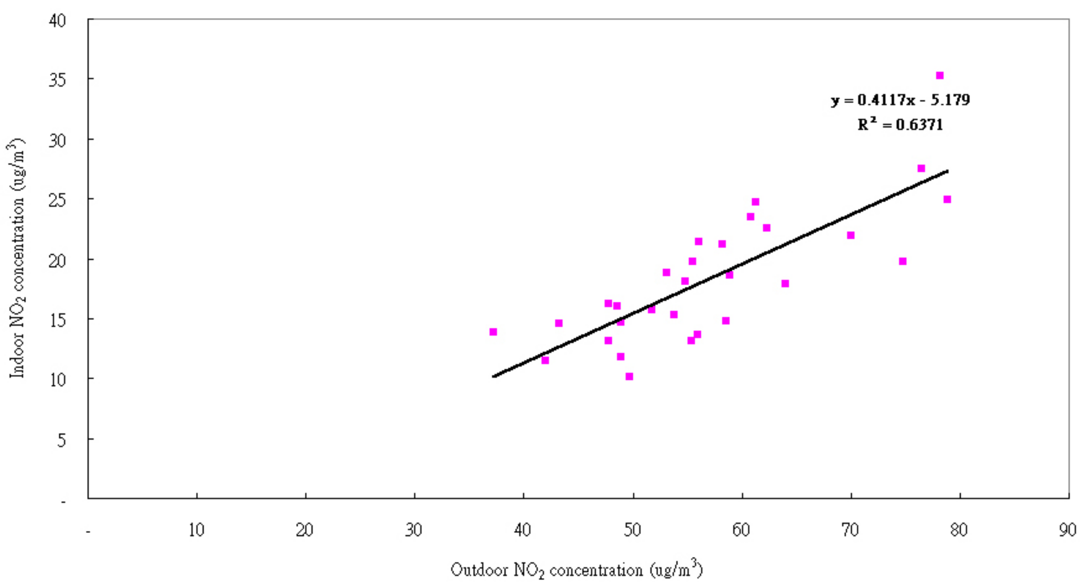
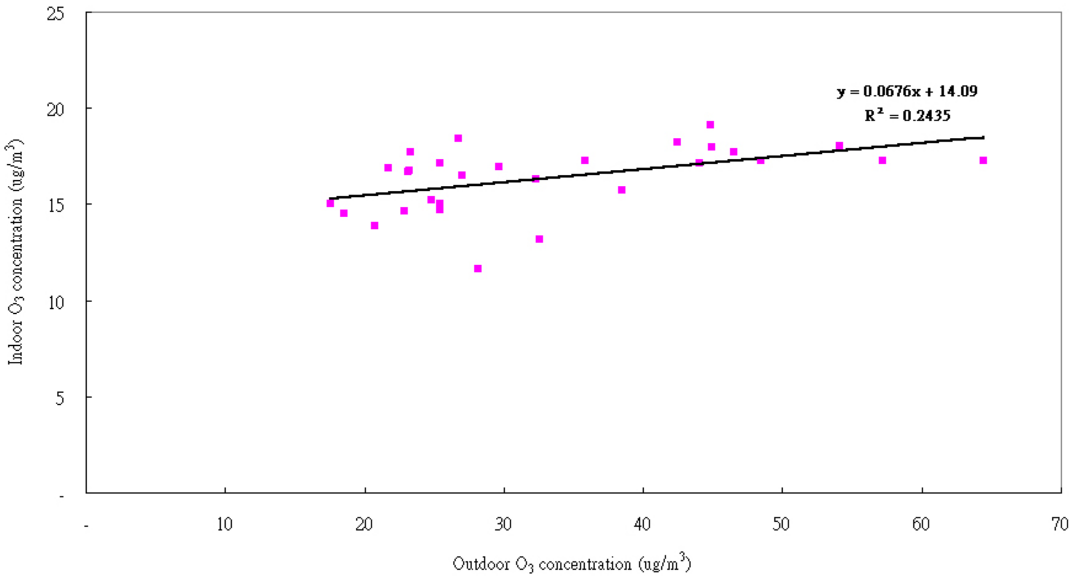


Figure 7.6 Correlation of Indoor and Outdoor Ozone Concentration



Through this case study, we believed that the indoor concentrations of carbon monoxide, nitrogen dioxide and ozone were mainly contributed by the outdoor air in this building. The relationship of indoor and outdoor concentrations of carbon monoxide, nitrogen dioxide and ozone were studied as to verify that the indoor concentration of IAQ parameters is dominated by the outdoor concentration of the related parameter if there is no high potential pollutant found indoors.

7.7.3 Case Study 3 – Verifying the Principle of Reducing the Sampling Time for Each Pollutant in Each Sampling Zone (Principle 4)

For verifying the principle 4 of sampling protocols, intensive measurements of four IAQ parameters were designed for 24-hour continuous sampling in office premise located on 29/F in Building A and 8-hour continuous sampling in office premise located on 22/F in Building B. This studies were conducted between August and December 2001. The four IAQ parameters included carbon dioxide (CO_2), respirable suspended particulates (RSP), radon (Rn), and total volatile organic compounds (TVOC) which are normally sourced from indoors. Table 7.8 shows the target IAQ parameters, the types of measuring instrument and analyzing methods used in this study.

Table 7.8 Details of Measuring Instrument and Method for 4 IAQ Parameters in Case Study 3

IAQ parameters	Types of instrument	Analytical methods
Carbon dioxide (CO_2)	IAQ-CALC™ Indoor Air Quality Meters (TSI, Model 8762)	Dual-wavelength non-dispersive infrared
Respirable suspended particulate (RSP)	Dusttrak™ Aerosol Monitor (TSI, Model 8520)	90^o light scattering
Radon (Rn)	Radon Monitor (Niton, Model Rad 7)	Solid state alpha detector
Total volatile organic compounds (TVOC)	ppbRAE Monitor (RAE Systems, Model PGM-7240)	Photo-ionization sensor with super bright 10.6eV

Criteria pollutants, CO_2, RSP, Rn and TVOC were measured in these studies. The sampling duration of the same location was 4-day 24-hour continuous in Building A and 2-day 8-hour continuous in Building B respectively. The IAQ-CALC IAQ meter, dusttrak aerosol monitor and ppbRAE monitor were set to record the average values at 5-minute interval. The radon monitor was set to record the real-time data at 30-minute interval. For quality control and assurance measures, all instruments were calibrated regularly according to the relevant procedures mentioned on the manufacturer's maintenance manual or standards.

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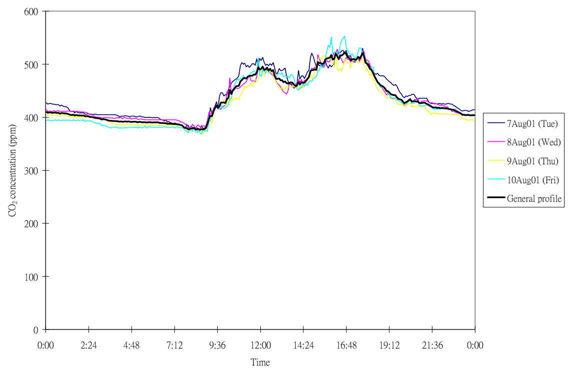
Table 7.9 summarizes the statistical values of 24-hour measurement of the four IAQ parameters for four days (from Tuesday to Friday) at the same location of office premise in Building A and 8-hour measurement for two days in Building B.

Table 7.9 Statistical Data of Field Measurement

Building			A				B	
IAQ parameters	Unit	Statistical value	Day 1	Day 2	Day 3	Day 4	Day 1	Day 2
Carbon dioxide (CO_2)	ppm	Minimum	375	378	369	369	584	561
		Maximum	530	528	517	553	740	732
		Average	443.2	435.8	427.4	431.4	669.2	651.4
		SD	43.7	40.6	41.6	48.9	35.8	41.5
Respirable suspended particulates (RSP)	$\mu g/m^3$	Minimum	16	14	13	11	16	19
		Maximum	38	39	34	29	40	39
		Average	24.0	21.6	21.2	16.5	23.5	24.7
		SD	5.9	5.0	6.3	3.9	3.2	3.0
Radon (Rn)	Bq/m^3	Minimum	8.8	14.6	8.8	17.5	23.5	23.5
		Maximum	146.2	140.3	155.0	146.2	174.0	181.9
		Average	59.4	64.0	62.6	60.4	90.9	91.9
		SD	39.1	42.3	43.3	40.4	48.1	50.7
Total volatile organic compounds (TVOC)	$\mu g/m^3$	Minimum	438	431	454	448	602	620
		Maximum	546	519	535	530	1281	1054
		Average	491.4	473.3	490.4	497.7	817.0	772.3
		SD	31.6	28.2	21.7	27.0	101.1	62.0

During the measurement periods, the activities of the office were more or less the same. The occupancy hour of these two office premise is normally from 9:00 a.m. to 5:30 p.m. on every Weekday and from 9:00 a.m. to 1:00 p.m. on every Saturday. The outdoor air is supplied by the fresh air fans and primary air units which are located on Mechanical Floor respectively. The fresh air supply fans or primary air units are operated from 8:00 a.m. to 9:00 p.m. on every Monday to Saturday. The figures of 24-hour and 8-hour daily profile of carbon dioxide, RSP, radon and TVOC in the two office premises are shown on the Figure 7.7 to Figure 7.10 respectively.

Figure 7.7 Signature of Daily Profile of Carbon Dioxide Concentration



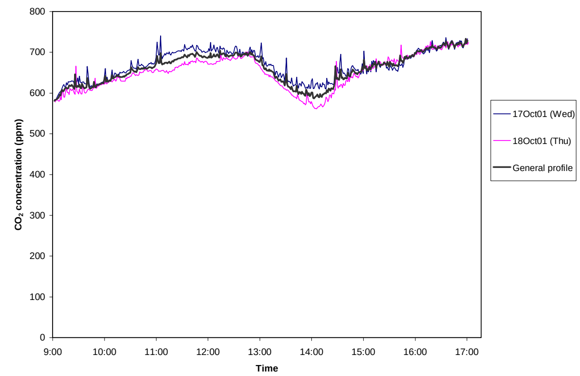
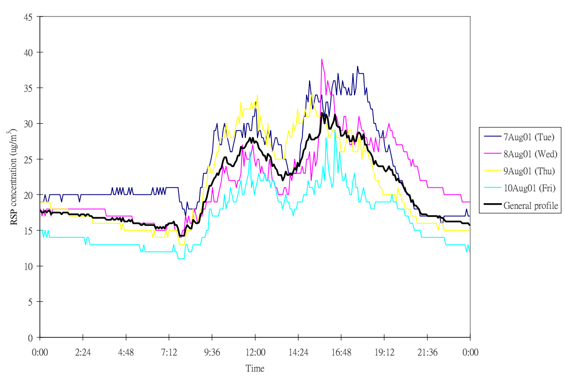


Figure 7.8 Signature of Daily Profile of RSP Concentration



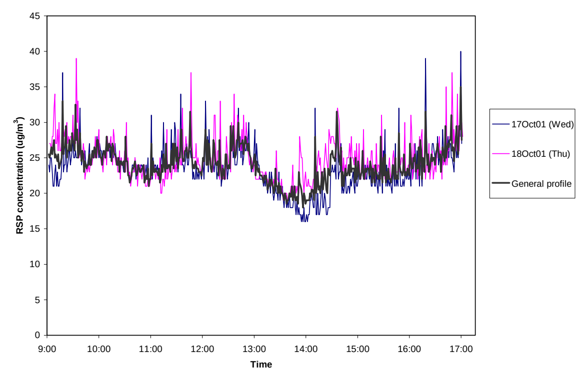


Figure 7.9 Signature of Daily Profile of Radon Concentration

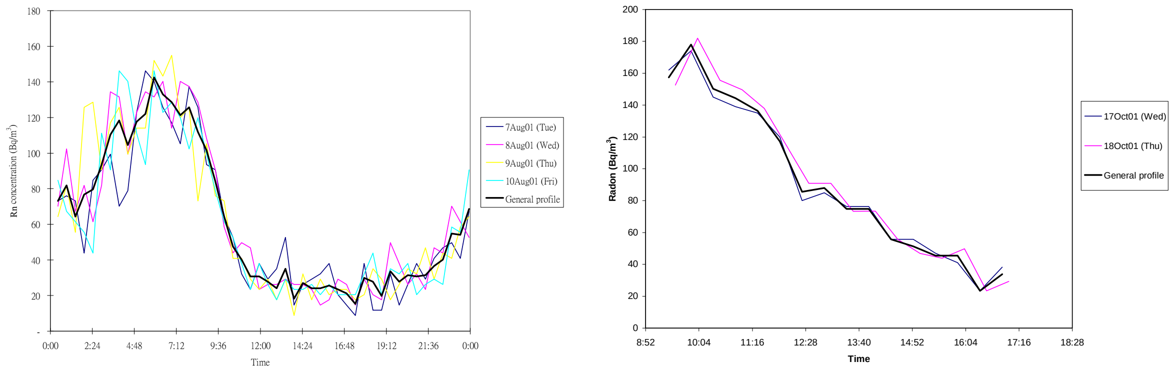
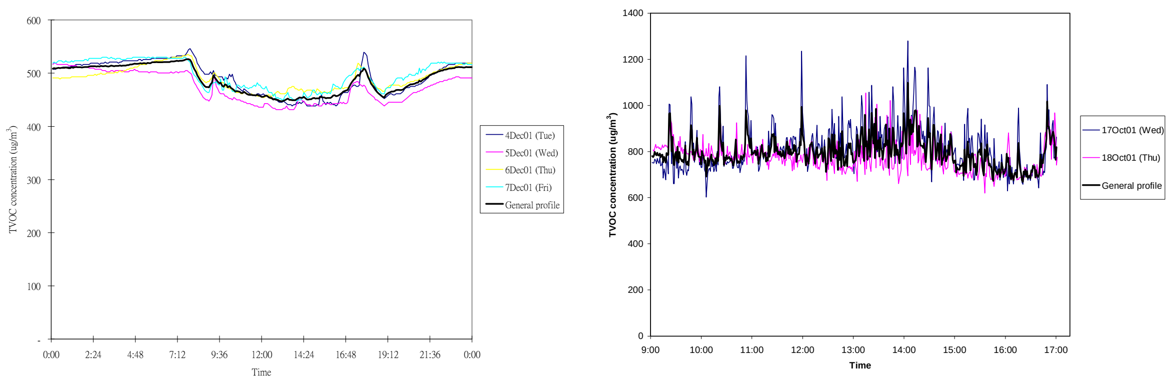


Figure 7.10 Signature of Daily Profile of TVOC Concentration



When the signatures of the indoor pollutants were identified, snapshot checking of monitoring program can be carried out on the maintenance schedule more effectively and economically. When the snapshot reading of the indoor pollutant in the inspection time was recorded, the expected total exposure of the indoor pollutant can be roughly calculated. However, special attention should be paid or the principle cannot be applied when the significant changes of outdoor air conditions, indoor pollutant sources, occupancy activities and densities. Recalibration of the signature of the indoor pollutant profile should be done if the situation of the indoor or outdoor environment has greatly difference.

7.7.4 Case Study 4 – Verifying the Principle of Choosing Alterative Instrumentation (Principle 5)

For verifying the principle 5 of sampling protocols, a new alterative instrumentation, Total Dust Collector (TDC) for measuring total suspended particulates (TSP) was introduced by the following rationale.

During the operation and maintenance for building systems, the difficulties in performance evaluation as brought by design can be classified into two types:

- Inadequate or unsuitable instrumentation: either there is insufficient instrument for performance assessment, or there is a lack of proper calibration, or that the instrument is installed at unsuitable locations creating a large error.
- Measurements requiring sophisticated procedures: some measurements such as assessment of thermal comfort or ventilation effectiveness require a sophisticated set up of measurement systems. During commissioning, an evaluation of the performance with higher accuracy is required. At the other times, the system performance can be monitored by much easier and cheaper alternatives with a slight scarification of accuracy.

Continuous monitoring of the indoor pollutant levels in indoor is compulsory for IAQ management. As biological contaminants may cling to fine dust particles and become airborne. The indoor particulate is a good indicator on the performance of the filtration system and a log of the dust concentration will aid the building management in tracing Indoor Air Quality (IAQ) problems.

Some common dust monitoring instruments are listed in Table 7.10. The initial cost of the instruments is very expensive. As the initial and operation cost of the continuous monitoring device should be reasonable and practicable, an integrated dust collector, Total Dust Collector (TDC) was developed. TDC is combined by three main parts, sample collection inlet with filter, a box and a fan. The initial cost for TDC is about \$300 and the total weight is less than 1 kg (Figure 7.11). In this study, a comparison between the certify dust sampler instrument and TDC, and a long-term measurement was performed to determine the performance of the TDC.

Table 7.10 Summary of Some Common Used Dust Samplers / Monitors

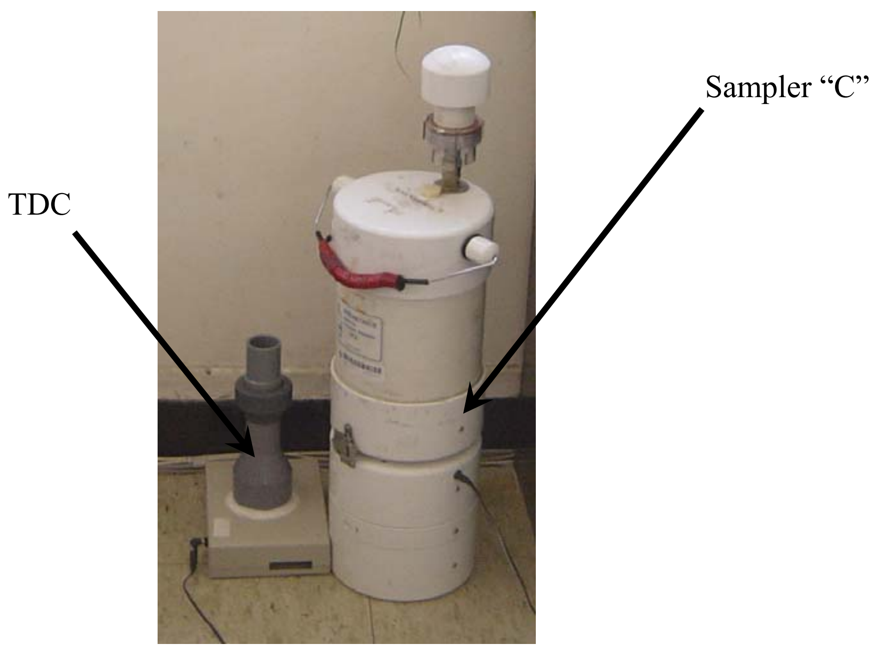
Principle of measurement	Sampler "A": Optical scattering	Sampler "B": Gravimetric	Sampler "C": Gravimetric	Sampler "D": Optical scattering
Type of sampling size	0.1 to 10 μm	> 2.5 μm	> 2.5 μm	0.3 to 20 μm
Weight	1.5 kg	0.3 kg	8 kg	1 kg
Size (cm)	22 x 15 x 9	8.2 x 7 x 5	16.5 O.D. x 50	12 x 20 x 5
Cost (HK\$)	About 35,000	About 40,000	About 30,000	About 35,000

Figure 7.11 Total Dust Collector (TDC)

- Comparison between the measurement with TDC and sampler “C”

Hong Kong Environmental Protection Department (HKEPD) specifies two measurement methods and principles of particulate level measurement in indoor. One is an integrated sampling technique and the other is an optical-scattering technique. For the integrated sampling technique, air is drawn by the sampler pump at a specified flow rate through a filter. The sample is collected on the filter and analyzed gravimetrically. Sampler “C” is one of the examples by this sampling technique (Figure 7.12). The design air flow rate of TDC and sampler “C” are 0.708 l/min and 5 l/min respectively. For the calibration of TDC, the particulate level between the sampler “C” and the new developed TDC was collected in six sites concurrently as the sampling principle of both samplers are same.

Figure 7.12 Sampler “C” and Total Dust Collector (TDC)



The temperature of the indoor environment during the sampling periods varied from 20°C to 25°C, and the relative humidity varied from 68.3% to 85%. The TSP level measured by TDC and sampler "C" varied from 62.1μg/m^3 to 137.6μg/m^3 and 55.7μg/m^3 to 116.5μg/m^3 respectively. The ratio of TSP level between TDC and sampler "C" varied from 1.1 to 1.4. The TSP levels for each measurement in different instruments are shown in Table 7.11.

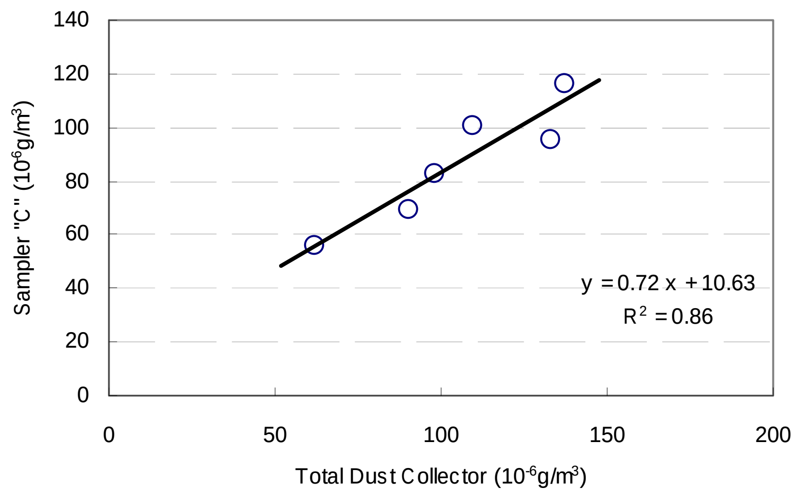
Table 7.11 Measured Result by TDC and Sampler "C"

Site No.	**Duration of Test**	**Monitoring TSP level by sampler " C" (μg/m^3) (A)**	**Monitoring TSP level by TDC (μg/m^3) (B)**	**Ratio of B to A**
1	24hrs15mins	95.2	133.4	1.4
2	36hrs31mins	116.5	137.6	1.2
3	31hrs29mins	100.5	109.5	1.1
4	39hrs34mins	55.7	62.1	1.1
5	27hrs54mins	82.6	98.1	1.2
6	29hrs24mins	69.4	90.3	1.3

Based on the measurements, the mean and standard deviation of TSP level measured by TDC were 105.17μg/m^3 and 28.3μg/m^3. The mean and standard deviation of TSP level measured by sampler "C" were 86.7μg/m^3 and 22.0μg/m^3 respectively.

The calibration curve of the TDC is shown on Figure 7.13. The performance of the TDC is well matched with the sampler "C". As the flow rate of the TDC is much smaller than sampler "C", therefore, the total weight of dust sample collected by TDC is not same.

Figure 7.13 Calibration Curve for the Total Dust Collector (TDC)



For managing IAQ in buildings, continuous monitoring of the indoor pollutant level in indoor is compulsory. However, continuous monitoring should be reasonable and practicable. As biological contaminants may cling to fine dust particles and become airborne. The indoor particulate is a good indicator on the performance of the filtration system and a log of the dust concentration will aid the building management in tracing Indoor Air Quality (IAQ) problems. Therefore, continuous monitoring of air particulate level in indoor is obligatory. Gravimetric and light-scattering principle instruments are commonly used to measure the particulate level in the indoor environment, but the initial cost is expensive. In this study, a simple and economic device, Total Dust Collector (TDC) was developed (initial cost of HK$300 with the total weight is less than 1 kg). The performance of the Total Dust Collector (TDC) was investigated by comparing with the certify dust sampler instrument and the calibration test was performed. It was found that the Total Dust Collector (TDC) is a precise and simple dust monitoring equipment.

For this case study, only total dust collector (TDC) was studied because it is custom-made product for this verification to demonstrate that the alternative instrumentation with adequate accuracy can be used for IAQ measurement for the aims of providing cost effective way for sampling or monitoring the indoor air conditions.

7.8 Justification with Cost Reduction on Pragmatic IAQ Sampling Protocol

In order to check for its effectiveness on cost reduction, the pragmatic IAQ sampling protocol was conducted in a Grade A office building as mentioned in previous case study (Section 7.7). The total floor area of this building is 40,960m^2. The minimum sampling points required by GN are therefore 35. However, when the principles 1 & 2 were applied for determining the number of sampling point, only 17 points were required to take sampling. By applying principle 3, only 9 parameters (temperature, relative humidity, air movement, CO_2, PM_{10}, HCHO, TVOC, Rn and bacteria) were required to measure for classifying the indoor air quality. The other 3 parameters (CO, NO_2 and O_3) which was mainly dominated by the outdoor concentration (that was much under any class of IAQ objectives) and there was also no high potential pollutants found indoors. The cost for measuring such parameters had then to be saved. Moreover, the manpower and time had been reduced by applying principle 4. In addition, the cost of instrumentation had also reduced by using alterative one when applying principle 5. The cost saving breakdown is shown in Table 7.12. By comparing the results, this protocol can reduce cost of the sampling as much as 66% with an equivalent representation. Also, when applying those principles, the cost of IAQ sampling can effectively reduce in terms of manpower, time and sampling resources.

Although the cost survey is too rough to produce any meaningful figures, the application of using the cost effective sampling protocol can also provide rationalized and practical ways to sample the indoor air conditions in an air-conditioned building.

Table 7.12 Cost Reduction Breakdown for Applying Pragmatic IAQ Sampling Protocol

	According to GN requirement	By Applying Pragmatic IAQ Sampling Protocol	Reduction
No. of Sample Taken	35	17	51.4%
Total Cost for measuring all 12 parameters (after applying principle 1 &2)	HK$4000 x 35 = HK$140,000	HK$4000 x 17 = HK$68,000	51.4%
Total Cost for measuring only 9 parameters (after applying principle 1, 2 & 3)		HK$3500 x 17 = HK59,500	57.5%
Total Cost for measuring only 9 parameters and reducing the measuring period (after applying principle 1-4)		HK$3000 x 17 = HK$51,000	63.6%
Total Cost for measuring only 9 parameters, reducing the measuring period and using alternative instrumentation (after applying principle 1-5)		HK$2800 x 17 = HK$47,600	**66.0%**

7.9 Site Surveys on IAQ Parameters Achieving GN Levels

Indoor air quality (IAQ) among different type of buildings was investigated for classifying the class of IAQ objectives based on Guidance Notes (GN) for the

Management of Indoor Air Quality in Offices and Public Places published by the Indoor Air Quality Management Group. The IAQ sampling was undertaken by sampling the representative locations and the measured values are then checked of compliance with guide values. The site surveys, conducted by the research project of the 4-year PolyU IAQ led by the Health and Safety Office, with the collaboration of Building Services Engineering Department, Civil and Structural Engineering Department and the Facilities Management Office of the The Hong Kong Polytechnic University and research project (ITS/133/0) supported by Innovation and Technology Fund (ITF) under Innovation and Technology Support Programme, carried out the IAQ sampling (total: 1022 locations) which involved university campus, office buildings and shopping mall. Table 7.13 shows the percentage of achievement of GN levels from the IAQ sampling among university campus, office buildings, shopping mall and comparing the site measurement by other surveyors in Hong Kong. The overall percentage of achievement of GN levels among 12 IAQ parameters is summarized in Table 7.14.

Table 7.13 Percentage of Achievement of GN Levels from IAQ Sampling

Parameter	University Campus (including auditorium, canteen, classroom, clinic, corridor, gym, kitchen, lab, library, office, photocopy room, plant room, security room, shop & store room) TOTAL: 434 locations				5 Grade A Buildings TOTAL: 54 locations				Shopping Mall TOTAL: 7 locations				Commercial Complex (10 office Buildings) TOTAL: 527 locations				Other survey studies in HK (20 buildings) TOTAL: 200 locations			
	N	E	G	F	N	E	G	F	N	E	G	F	N	E	G	F	N	E	G	F
CO_2	357	68.9%	13.2%	17.9%	53	77.4%	18.9%	3.8%	7	100%	0%	0%	526	89.0%	8.4%	2.7%	200	73%	15%	13%
CO	380	87.1%	12.9%	0%	53	100%	0%	0%	7	100%	0%	0%	527	99.4%	0.6%	0.0%	200	100%	0%	0%
PM_{10}	357	7.8%	87.1%	5.0%	59	66.1%	33.9%	0.0%	7	0%	100%	0%	527	0.0%	99.6%	0.4%	200	10%	78%	12%
NO_2	108	42.6%	57.4%	0%	39	100%	0%	0%	7	28.6%	71.4%	0%	-	-	-	-	200	100%	0%	0%
O_3	87	74.7%	25.3%	0%	41	100%	0%	0%	7	100%	0%	0%	-	-	-	-	200	100%	0%	0%
HCHO	59	76.3%	18.6%	5.1%	32	68.8%	31.3%	0%	7	100%	0%	0%	-	-	-	-	200	24%	70%	6%
TVOC	56	12.5%	23.2%	64.3%	46	0%	54.3%	45.7%	7	0%	0%	100%	451	36.8%	40.4%	22.8%	200	11%	21%	68%
Rn	68	95.6%	2.9%	1.5%	59	93.2%	3.4%	3.4%	7	100%	0%	0%	-	-	-	-	200	90%	7%	3%
Bacteria	93	76.3%	23.7%	0%	41	100%	0%	0%	7	71.4%	28.6%	0%	-	-	-	-	200	40%	49%	11%
Temp	355	82.8%	11.8%	5.4%	57	94.7%	5.3%	0%	7	100%	0%	0%	487	99.6%	0.0%	0.4%	200	100%	0%	0%
RH	336	93.8%	0.9%	5.4%	57	91.2%	1.8%	7.0%	7	100%	0%	0%	527	88.4%	7.6%	4.0%	200	100%	0%	0%
Air Movement	25	100%	0%	0%	49	85.7%	10.2%	4.1%	7	0%	0%	100%	-	-	-	-	200	100%	0%	0%

Legend: N = No. of sample taken; E = Excellent Class of IAQ Objectives; G = Good Class of IAQ Objectives; F = Fail to achieve Excellent or Good Class of IAQ Objectives

Table 7.14 Overall Percentage of Achievement of GN Levels among 12 IAQ Parameters

Parameters	No. of sample taken	Excellent	Good	Fail
CO_2	1143	79.4%	11.5%	9.1%
CO	1167	95.5%	4.5%	0.0%
PM_{10}	1150	7.6%	88.6%	3.8%
NO_2	354	81.1%	18.9%	0.0%
O_3	335	93.4%	6.6%	0.0%
HCHO	298	40.9%	54.0%	5.0%
TVOC	760	25.7%	34.5%	39.9%
Rn	334	91.9%	5.4%	2.7%
Bacteria	341	57.8%	35.8%	6.5%
Temp	1106	94.0%	4.1%	1.9%
RH	1127	92.3%	3.9%	3.8%
Air Movement	281	95.0%	1.8%	3.2%

7.10 Discussion on Sampled IAQ Parameters against GN Levels

Based on the site measurement among 1022 locations of office buildings, shopping mall and university campus, a review of the achievement of GN levels from 12 IAQ parameters are summarized as follows:

(a) Carbon Dioxide (CO_2)

Carbon dioxide is not a pollutant and will not adversely affect human health at concentrations up to 5,000 ppm or even higher. However, CO_2 is often used as a surrogate indicator for human bioeffluents. Unless the buildings are doing IAQ calibration, it should be noted that indoor concentrations of CO_2 are not always able to reflect overall IAQ conditions and do not necessarily mean the IAQ is acceptable even when the CO_2 concentration is low.

Carbon dioxide concentration in air-conditioning buildings depends on several factors, such as occupant density, ventilation effectiveness, quality and quantity of outdoor air supply. High CO_2 values always record in crowded office/classroom. If the number of occupancy is over the outdoor air design value, it is difficult to get an Excellent or Good level if the ventilation rate is not increased to satisfy the conditions.

To reduce the CO_2 level in buildings, outdoor air quantity can be increased but will cause a significant increase in energy consumption of MVAC systems and also increase the certain level of other parameters (e.g. PM_{10}) from outside. In addition, the location of outdoor air intake should be carefully chosen. Air-balance can be considered refining to achieve the actual loading of demand.

(b) Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2)

Carbon monoxide and nitrogen dioxide are common gas emitted during combustion process. In general, CO and NO_2 in buildings mainly come from outdoors (e.g. vehicle exhaust). Hong Kong Government has already implemented the legislative control on smoking bans in all indoor areas of workplaces, public places, restaurants, bars for all ages, and karaoke lounges since 1 January 2007. If no combustion process in the buildings, it is not difficult to achieve Excellent class if the outdoor air intake is away from busy road, carpark, kitchen or industrial exhaust.

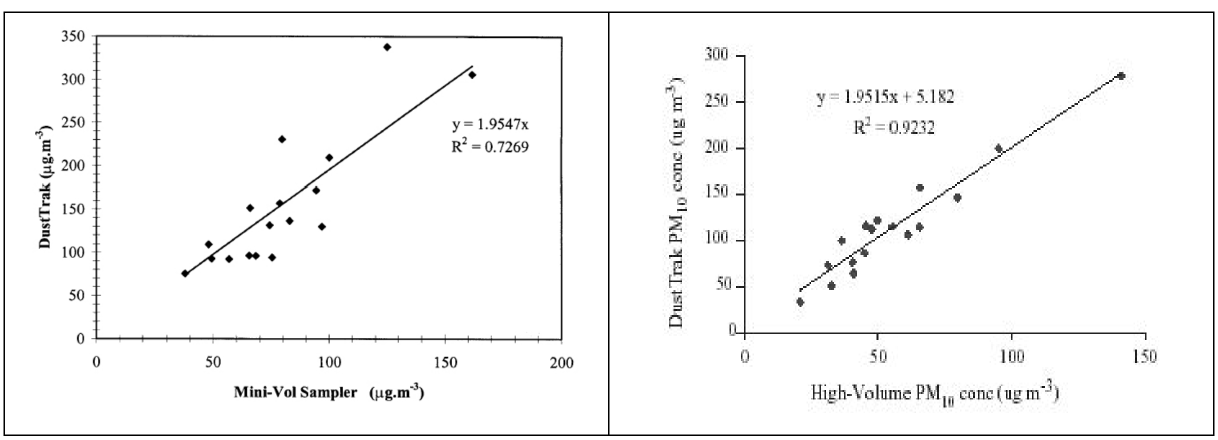
In the site measurement at university campus and shopping mall, these premises are located near busy road. Therefore, CO and NO_2 concentration at several locations measured could not achieve Excellent level, only achieve Good level.

(c) Respirable Suspended Particulates (PM_{10})

PM_{10} can come from indoor and outdoor sources (e.g. vehicular emission, people activity). If the buildings are leaky (especially in old buildings), the untreated air coming from infiltration can increase the indoor PM_{10} values. In addition, very high outdoor PM_{10} concentrations (about 120-190μg/m^3) are always measured in busy district and the average outdoor PM_{10} are usually recorded as 90-120μg/m^3. It is not difficult to achieve Good class if filtration system operated effectively but is difficult to achieve Excellent class because the PM_{10} are also contributed from indoor activity.

Using Dusttrak with light scattering technique usually gets a higher value than using gravimetric method that is a more appropriate one to measure the PM_{10} concentration. The correlated ratio between Dusttrak and Mini-Volume sampler of 1.95 [Tung et al (1999)] and the correlated ratio between Dusttrak and High-Volume sampler of 1.95 [LY Chan et al (2002)] has been mentioned in previous local studies. Figure 7.14 shows the correlation between Dusttrak and Mini-Volume Sampler [Tung et al (1999)] and also the correlation between Dusttrak and High-Volume Sampler [LY Chan et al (2002)].

Figure 7.14 Dusttrak and Mini-Vol Sampler Correlation [Tung et al (1999)] and Dusttrak and High-Vol Sampler Correlation [LY Chan et al (2002)]



For effectively reducing the PM_{10} concentration, filtration system with higher efficiency should be used. Moreover, outdoor air intake should be carefully located at the proper area with low risk of dusty.

(d) Ozone (O_3)

O_3 in buildings may come from outdoors and indoors. In airtight air-conditioned office buildings, outdoor ozone decay rapidly when passing through the air duct system. It is not difficult to achieve Excellent Class if local exhaust is used for heavy-duty office appliances that may emit ozone or outdoor O_3 concentration is not extremely high.

(e) Formaldehyde (HCHO)

HCHO mainly come from indoor sources (e.g. partition, furniture, renovation, etc.); Frequent renovation can be easily found in the office buildings and shopping malls, therefore the HCHO may record higher values if the renovated space is not purged before sampling. HCHO is difficult to control due to a variety of sources in indoor environment. However, it is not difficult to achieve Excellent or Good class if the building material using low HCHO emission and the renovated location is purged thoroughly.

(f) Total Volatile Organic Compounds (TVOC)

TVOC is found difficult to achieve Excellent/Good class as the following reasons:

- TVOC can come from indoor and outdoor sources (e.g. vehicular emission, building materials, partition, solvent, etc);

- high outdoor TVOC concentrations (about 600-1000μg/m^3) are always measured in busy district;
- the TVOC measuring instrument (ppbRAE) would get higher value if the RH is high and that instrument is not well-developed to get a steady value. It is because ppbRAE is designed to provide continuous total organic vapour exposure monitoring by using Photoionization Detector (PID) that humidity level can reduce the sensitivity of the PID since high concentrations of water molecules may block out some of the UV light. This well-known effect is called "quenching" and occurs with most existing photoionization detectors (RAEsystems, TN-102);

For effectively control the indoor TVOC levels, building materials should be selected with low VOC emission. In addition, the location of outdoor air intake should be carefully selected. The area has to be purged thoroughly after new renovation completed. Moreover, the ventilation path should be handled carefully if high TVOC concentration is found. In some cases, activated carbon filter is recommended to use to remove the VOC concentration.

(g) Radon (Rn)

Radon is colourless, odourless, and chemically inert, but radioactive. Radon is the radioactive decay products of radium, which exists in any earth-crust derived building materials. In high-rise buildings, concretes that have a high content of granite are the major indoor source. However, it is not difficult to achieve Excellent class if sufficient ventilation is provided.

(h) Airborne Bacteria

In general, bacteria can be originated from human body and MVAC components. Mould growth is common associated with poor humidity control. It is not difficult to achieve Excellent or Good class if they are well maintained and RH keep below 70%.

(i) Room Temperature, Relative Humidity and Air Movement

Room temperature, relative humidity and air movement are thermal comfort parameters in IAQ Objectives. It is not difficult to achieve Excellent Class if appropriate MVAC system is performed well.

7.11 Summary and Conclusions

By using sampling 12 IAQ parameters mentioned in GN, the resource in terms of equipment, labour and time may be consumed meaningless to justify what kinds of IAQ conditions in the indoor environment. By applying the five principles of sampling protocol for this study, the sampling size and time with appropriate rationale can be more representative to measure the IAQ parameters for classifying the levels of IAQ. In addition, if the IAQ parameters are found mainly coming from outdoors or sufficient ventilation can provide for diluting the IAQ parameters, some IAQ parameters can be reduced for sampling, like CO, NO_2, O_3 from outdoors or Rn in indoor environment.

The objective of the GN is to safeguard the occupant inside the office premise and public places and provide a sufficient quality of indoor air for the occupant. However, the resource of managing IAQ using in sampling would be too uneconomical that may let the building manager feel prohibitive on spending money to get possibly meaningless values of IAQ parameters. By using these five principles of sampling protocols, the quality of indoor air can also be sustained and these economical and effective approaches not only concern on the sampling, they also consider the rationale of the IAQ situation inside building and the carry-on IAQ monitoring and policy. In addition, over thousands of IAQ measured samples were analyzed to show the difficulty of the 12 parameters in IAQ Objectives in meeting the ‘good’ or ‘excellent’ level for providing full picture on common indoor air pollutants in buildings.

CHAPTER 8 : INDOOR AIR QUALITY MANAGEMENT

8.1 Introduction

This chapter introduces indoor air quality management against different stages which involve system commissioning, system and equipment evaluations during routine operation and maintenance on indoor air quality. In addition, the integrated electronic IAQ manager is developed to attain a full range of IAQ management skill.

8.2 Indoor Air Pollutant Calibration in Buildings

Metabolic carbon dioxide (CO_2) is always used as a surrogate indicator for indoor air quality. ASHRAE Standard 62 has mentioned that maintaining a steady-state CO_2 concentration in a space no greater than about 700 ppm above outdoor air levels will indicate that a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents (body odor). ASTM Standard D6245 is a standard guide for using indoor carbon dioxide concentrations to evaluate indoor air quality and ventilation. However, acceptable indoor air quality is defined as 'air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction' by ASHRAE Standard 62. Therefore, IAQ not only involves comfort for satisfaction but also health concern. Since CO_2 has evolved as an indicator for body odour, it should be related more to comfort and satisfaction, rather than to heath. This following section discusses using carbon dioxide as an indicator of

IAQ and suggests how indoor CO_2 after IAQ calibration can be recommended to use as an indicator of IAQ with regards to health and comfort issues in buildings.

8.2.1 Carbon Dioxide as IAQ Indicator

In recent years, CO_2 of 1000ppm has been suggested as a maximum level in air-conditioned offices in relation to occupant health. "Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places" (GN) launched by Indoor Air Quality Management Group of Hong Kong has set 1000 ppm of CO_2 as "Good" Class which represents the IAQ that provides protection to the public at large including the young and the aged. GN also mentioned that CO_2 concentration is nonetheless important to IAQ management and is commonly adopted as a surrogate in measuring air freshness. The lower the concentration of CO_2 the fresher the air supply is likely to be. The inherent assumption is that if the fresh air ventilation is sufficient to dilute odours, it is also sufficient to dilute other pollutants to an acceptable level.

However, the two main issues should be considered CO_2 concentration is used as an indicator of health:

- using CO_2 concentrations as an indicator of human body odour is distinct from any health effects associated with the CO_2 itself. Many studies found that adverse health effects from elevated CO_2 have not been observed until the concentration reaches a value of 7000 ppm to 20000 ppm. The threshold limit value (TLV) issued by the ACGIH for CO_2 is currently 5000 ppm.

- In some indoor environments, there may be specific pollutants present, such that even if the CO_2 level is below 1000ppm, the concentration of the pollutants may still maintain at harmful level.

Using CO_2 as an IAQ indicator has been widely used, but it is limited in many occasions especially when major pollutants are not from human related activities. However, the CO_2 can be used as IAQ surrogate indicator after the building is 'calibrated'. The following sections can explain more details on this.

8.2.2 Calibration for Building Ventilation

While CO_2 concentrations can be an appropriate mean of characterizing the acceptability of a space in terms of body odour, they do not provide information on the control of contaminants from other indoor pollutant sources such as building materials, furnishings, occupant activities, or from outdoor sources. If a building is being 'calibrated' to an acceptable IAQ, metabolic CO_2 can also be used as a surrogate indicator for health. Based on the single zone ventilation model, the pollutant emission rate and the ventilation rate can be described as:

$$V_e \, dC_{(t)} = [\, G + Q\, C_o - Q\, C_{(t)}]\, dt$$

where G = instantaneous CO_2 generation rate of the occupants

Q = outdoor air supply rate into the indoor space

V_e = effective volume of the space

C_o = CO_2 concentration of the outdoor air

$C_{(t)}$ = CO_2 concentration of space air at time t

The general solution to the single zone ventilation model is:

$$C_{(t)} = \left(\frac{Q \cdot Co + G}{Q}\right)\left(1 - e^{-\frac{Q \cdot t}{Ve}}\right) + C(0) \cdot e^{-\frac{Q \cdot t}{Ve}}$$

Once the relationship between the emission rate G, of the target pollutant and the ventilation rate, Q is established and known, metabolic CO_2 can be used as a surrogate indicator for monitoring and control purposes. In a building where several pollutants coexist, the 'calibration' should be carried out by the pollutant inventory that has been described in the previous chapter. The ventilation rate can then be designed and operated at the minimum rate that can keep any target pollutant below the required concentration for 'healthy air', and metabolic carbon dioxide for 'comfortable air'. The metabolic CO_2 at this situation will then become a control level for monitoring both health and comfort.

A properly managed building should have a pollutant inventory, which is a record of pollutant sources embedded in the building materials, pollutants emitted from the indoor activities and housekeeping. Unfortunately, the design practice focuses on 'comfortable air' rather than 'healthy air'. Therefore, it is advisable to 'calibrate' a building once to confirm the healthiness of the indoor air.

The calibration procedure can be applied to both new and existing buildings. The time when detailed pollution measurements are made should not correspond to unusually high or low pollution periods.

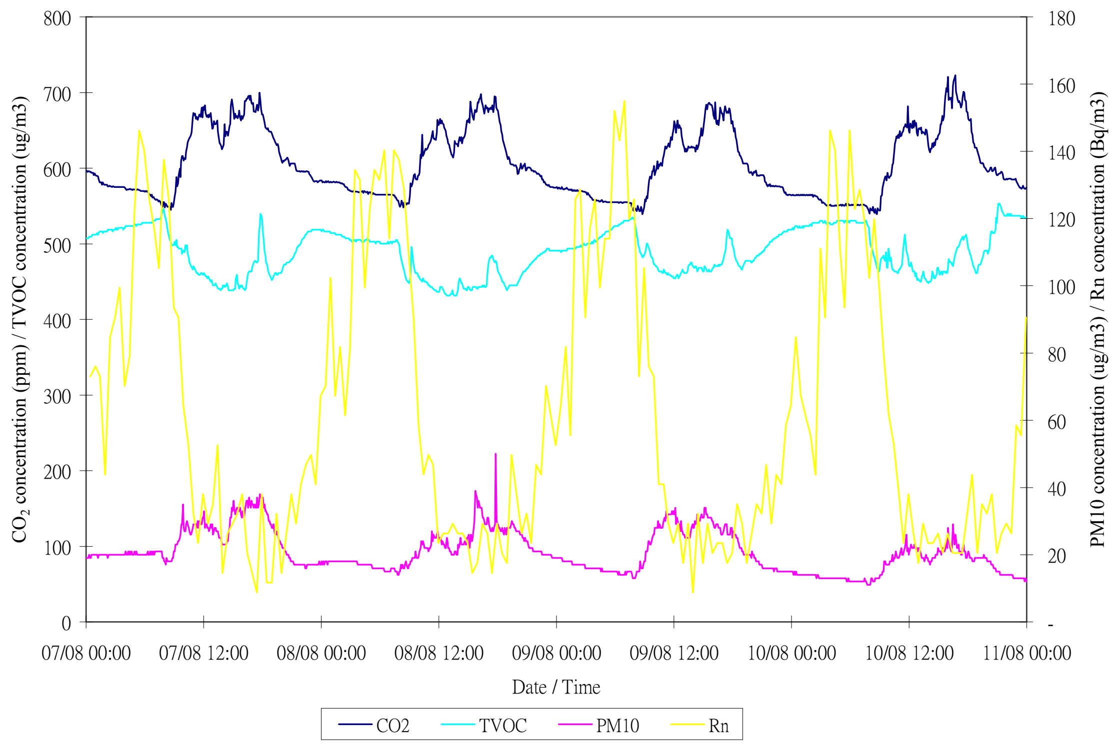
A single indoor air pollutant, typically CO_2 for office buildings, is used for continuous monitoring purpose. The concentration of other pollutants is calibrated against CO_2. As a result, the ventilation rate is used as an indicator instead. The ventilation rate and the concentration of typical indoor air pollutants are "calibrated" against steady-state operation modes of ventilation systems. The following section describes an example to identify whether the typical operation modes can control the concentration of pollutants within health limits. Although there is only one case study to demonstrate the acceptability for idea of calibration of building ventilation, it does show the concept of using this management skill for fine-tuning the ventilation rate under steady-state operation modes with acceptable concentration of indoor air pollutants.

8.2.3 IAQ Signature for Target Pollutants

Three indoor air pollutants: respirable suspended particulates (PM_{10}), total volatile organic compounds (TVOC) and radon were selected for the study. PM_{10} was monitored by light-scattering instrument Dust-Trak 8520. TVOC was monitored by photo-ionization detection instrument ppbRAE and radon concentration was monitored by RAD7 (from Niton electronics). CO_2 was measured by non-dispersive infrared analyzer (Solomat MP Surveyor Pro). All measuring parameters were continuous monitoring against normal working day (Tuesday to Friday).

The measurement was performed in a $120m^2$ office in a commercial building. The fan coil units are used to serve the office area. The instruments were placed at the middle of the room. Figure 8.1 shows the IAQ signature of four IAQ parameters in the room by plotting the concentration of IAQ parameters against time. The ventilation rate was measured by tracer gas decay measurement using CO_2. Infrared sensor was used for tracer gas concentration monitoring.

Figure 8.1 IAQ Signature for Target Pollutants



8.2.4 Results on Changing the Outdoor Air Rate

Comparing with the normal operation of system (i.e. air change rate is 4 ach), another four operating modes with different air change rate were established, as listed in Table 8.1. At each trial every operating mode was kept for 8 hours.

Table 8.1 Pollutant Concentration against Different Air Change Rate

Date / Time	8-hour average value				
	ACH	CO_2 (ppm)	TVOC ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	Rn (Bq/m^3)
7-Aug 09:00-17:00	4	653.40	459.37	29.01	37.09
8-Aug 09:00-17:00	4	641.17	444.86	24.39	34.90
9-Aug 09:00-17:00	4	634.69	468.07	28.55	32.16
10-Aug 09:00-17:00	4	645.09	468.77	20.36	32.89
Average for 7-Aug to 10-Aug		643.59	460.27	25.58	34.26
Standard deviation		7.82	11.13	4.05	2.22
14-Aug 09:00-17:00	1	976.31	620.57	23.22	90.79
15-Aug 09:00-17:00	2	825.13	578.45	25.93	69.65
16-Aug 09:00-17:00	3	702.34	510.28	26.77	48.56
17-Aug 09:00-17:00	5	618.71	428.17	29.98	25.18

8.2.5 Discussion on 'Building Calibration'

This section introduces the concept of "building calibration", which characterizes the air contaminants inside indoor spaces and addresses both health and comfort issues. It starts with a pollutant audit to identify the pollutant inventory. The relationship between the pollutant concentrations with ventilation rate and hence metabolic CO_2 can be calibrated. CO_2 can then be used as surrogate indicator for health as well as comfort. As a result, an awareness of the issue should enable building owners and occupants to undertake simple monitoring procedures in their premises to indicate prevailing IAQ. Building users can have a better understanding of contamination status in their surrounding living environment. The calibration process starts with identification of pollutant concentration profile in isolated condition and at different ventilation rates. With known pollutant profiles, the ventilation devices can be optimally operated to meet the prescribed pollutant concentration level.

From the results of Table 8.1, the 8-hour average value of TVOC could not fulfill the 'Good' class of IAQ objectives when the air change rate was 1. When the air change rate was kept at 2, the four IAQ parameters (CO_2, TVOC, PM_{10} and Rn) were at least maintained at 'Good' class of IAQ objectives. Therefore, the ventilation rate can be adjusted from 4 ach to 2 ach by means of this 'building calibration' for maintaining the IAQ condition in 'Good' class. As mentioned before, the concentration of CO_2 is related to fresh air supply under the steady state situation. So when the CO_2 level was found unreasonably higher than the recorded IAQ signature profile, the ventilation system may have failure to deliver fresh air for diluting other harmful pollutants. Metabolic CO_2 can be used as a surrogate indicator for monitoring and control purposes on indoor air quality after the building or the room is 'calibrated'. It is different from the function of CO which is proposed as a surrogate indicator for monitoring outdoor air quality due to the ease of measurement that discussed in Chapter 4.

In this particular study, increasing ventilation rate reduced the concentration of indoor generated pollutants. The optimal ventilation rate was determined based on the calibration results with consideration of the control on all the pollutants. These results provide a database for ventilation and indoor air quality management. The study illustrated how the indoor air pollutant is characterized through the building calibration exercise against the ventilation rate. Building operators can identify the best way to operate the ventilation system with reference to the pollutant inventory to provide acceptable IAQ to the occupants.

8.3 Geographical Information System (GIS) for IAQ Management

By reviewing all the building information related to indoor air quality, the geographic layouts of the building plans and the schematic diagrams of air distribution system highlights the important issues on fresh air system including all locations of outdoor air intake, routing of air distribution ductwork, capacities of system equipment, the potential risk of outdoor air degradation (like the locations of carpark, refuse chamber, toilet, etc), room features, building materials used, records of indoor air sampling and so on. By using such geographical information system, it can provide an effective collation of documentaries and air quality data base. The GIS technique can also utilize in IAQ management for inaugurating further elaboration in its application on other indoor built environment management, system and equipment managements.

8.4 IAQ Management by Data

Data management is a broad field of study, but essentially is the process of managing data as a resource that is valuable to building operators. Data Management Association (DAMA) states that data management is the process of developing data architectures, practices and procedures dealing with data and then executing these aspects on a regular basis. One of the important issues regarding data management is data mining. Data mining is a process in which large amounts of data are sifted through to show trends, relationships, and patterns. Data mining is a crucial component to data management because it exposes interesting information about the data being collected. It is important to note that data is primarily collected so it can be used to find these patterns, relationships and trends that can help the building operators to know the existing system performance. The operators can work from the beginning where data is collected to the end of the process where it is sifted through, analyzed and formatted where the building managers can then make quality decisions based upon it.

The methodology of DMAIC sourced by six sigma is introduced for IAQ management. Basic methodology of DMAIC consists of the following five steps:

- *Define* the process improvement goals that are consistent with customer demands and enterprise strategy.
- *Measure* the current process and collect relevant data for future comparison
- *Analyze* to verify relationship and causality of factors. Determine what the relationship is, and attempt to ensure that all factors have been considered.
- *Improve* or optimize the process based upon the analysis using techniques like Design of Experiments.
- *Control* to ensure that any variances are corrected before they result in defects. Set up pilot runs to establish process capability, transition to production and thereafter continuously measure the process and institute control mechanisms.

8.4.1 Example of Data Management on Particulates Matter (PM_{10}) Concentration in a University Campus

Air filters for removing particulate matter can be regarded as a standard component in air distribution systems. From the indoor air quality management point of view, air filters are selected according to the efficiency rating. Researches have been carried out on studying the efficiency of an air filter at various particle sizes, and eventually the ASHRAE standard 52.2 provides guidance on testing the particle size efficiencies. It facilitates the building management to select filters according to the characteristics of the loading dust. Despite this, the design of air handling system would also affect the level of PM_{10} contamination.

While mass balance model on indoor particulates is well-established to quantify the indoor suspended particulates level, it requires information on filter efficiency, outdoor particulates loading, the generation rate of indoor particulates due to occupant activity and other sources, rate of deposition to room surfaces and the rate of re-entrainment from surfaces. To quantify the latter three factors would be too difficult for building managers; thus, using this theoretical modeling approach to calculate the desired filter efficiency value, based on the desired indoor particulate concentration, would be too complicated from the management point of view.

In typical commercial buildings in Hong Kong, building managers usually specifies an efficiency value of some 80% - 90% during filter tendering process as a “standard practice”. Although such filter rating would be considerably high for general occupancy, this practice may not guarantee low indoor particulates concentration indoor if the dust loading and/or the infiltration rate is high. In another extreme the efficiency of the filter would be over-specified if the dust loading is actually low.

In view of this, a monitoring program on indoor particulate concentration has been proposed to control indoor PM_{10} pollution rather then just relying on a standard efficiency value during filter tendering. The study was performed in a university campus to evaluate the performance of the air filtration system and to characterize the particulates inside the campus based on the data management.

8.4.2 Site Information

The study was performed in 128 selected teaching rooms and lecture theatres in the university campus. The rooms are widely spread across the campus site with 93,500 m^2 floor area. The total floor area of those selected rooms is about 9,800 m^2. All rooms are air-conditioned. The general teaching rooms are served by fan coil units (FCUs) with fresh air supply from central primary air units (PAUs). For most of these general teaching rooms, space air is recirculated to the fan coil units. This means particulates from indoor sources are captured mainly by the fan coil unit filters, with approximately 30% dust spot efficiency. The air flow of fan coil units can be adjusted manually at three levels: high, medium and low speed. Lecture theatres are served by individual air handling units (AHUs). All these air handling units deliver constant air volume flow. The outdoor air flow rate at the primary unit is fixed. Air filters with MERV14 rating (according to ASHRAE standard 52.2 - 1999) are specified by the building management for PAUs and AHUs. The equivalent dust-spot efficiency is approximately 90-95%, according to table 5.2 in ASHRAE standard 52.2 (1999). Washable extended surface filters are used in fan coil units and as a pre-filter in PAUs and AHUs. The dust spot efficiency is approximately 30%.

8.4.3 Site Measurement

Prior commencing the measurements, the number of sampling points was determined based on the guidelines of IAQ certification scheme in Hong Kong. There are total 12 sampling points with 8-hour average measurement required for a total floor area of 9,800 m^2. The selected 128 rooms are installed with their own filters (either washable filters or MERV14 filters) and have different dust loading characteristics. In addition, the rooms are served by 20 different fresh air intakes. From the filtration performance monitoring point of view, more sampling points are required. Taken into account of infiltration characteristics in each room, a single room was counted as one sampling point. In another word, 128 monitoring points are selected. These points are grouped into 20 zones, in which each zone is served by a single fresh air intake.

Since there is a large number of monitoring points; cross-sectional analysis approach was adopted instead of 8-hour average measurement. The 128 rooms were randomly visited throughout different period and different days, and the outdoor PM_{10} concentration was also recorded near the intakes in each visits. 5-minute average of PM_{10} was recorded repeatedly in each monitoring point throughout the half year of study. The operating condition in the room was also recorded. To minimize disturbance on normal teaching activities, the measurement was performed when the classroom is empty. To account for the effect of indoor occupant sources, a number of samples were obtained during class teaching.

Light-scattering equipment DustTrak model 8520 was used to measure particulates matter PM_{10}. The gravimetric equivalent was obtained by using the correction factor of 1.96, obtained from a previous study on campus performed by Tung et al. (1999). The corrected DustTrak readings were used to establish a PM_{10} concentration database, such that the building management can identify locations for enhancement work.

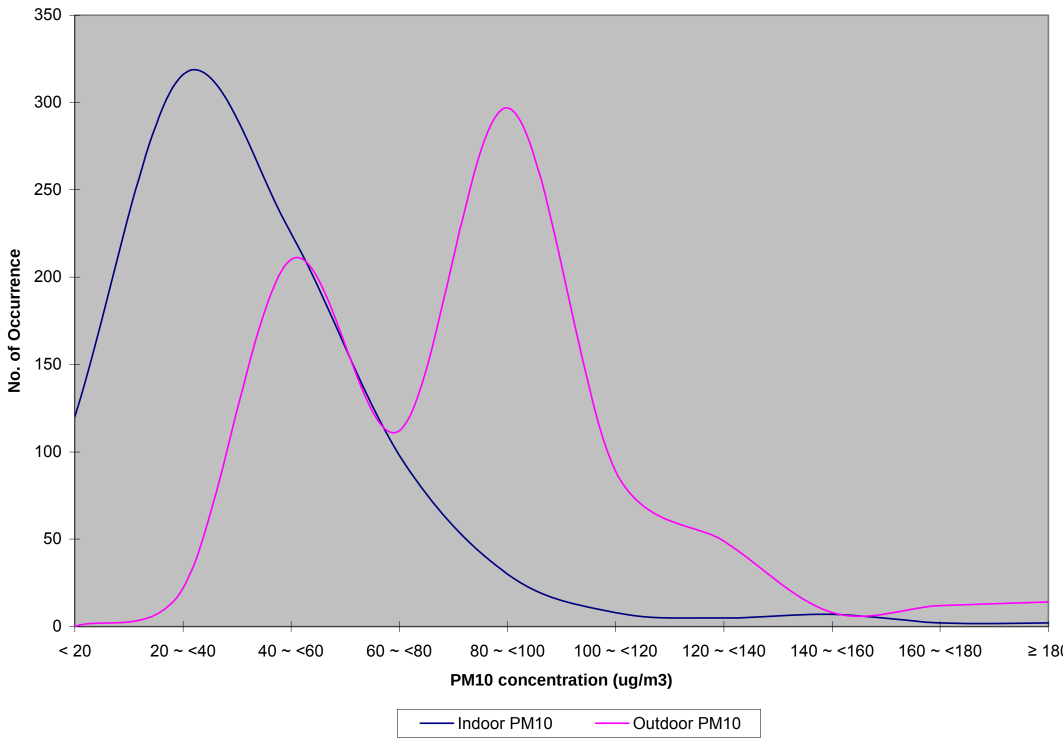
8.4.4 Results and Discussion

813 measurement data was obtained during the study. Table 8.2 and Figure 8.2 show the distribution of PM_{10} concentration. A 20μg/m^3 interval is adopted to allow comparison with the requirement in IAQ Certification Scheme [excellent class 20μg/m^3 and good class 180μg/m^3 or below].

Table 8.2 Table of Frequency Distribution of PM_{10} Data

Interval	Indoor			Outdoor		
	Frequency	Percentage	Cumulative	Frequency	Percentage	Cumulative
$PM_{10} < 20\mu g/m^3$	120	14.76%	14.76%	0	0.00%	0.00%
$20\mu g/m^3 \leq PM_{10} < 40\mu g/m^3$	316	38.87%	53.63%	22	2.71%	2.71%
$40\mu g/m^3 \leq PM_{10} < 60\mu g/m^3$	225	27.68%	81.30%	210	25.83%	28.54%
$60\mu g/m^3 \leq PM_{10} < 80\mu g/m^3$	98	12.05%	93.36%	112	13.78%	42.31%
$80\mu g/m^3 \leq PM_{10} < 100\mu g/m^3$	30	3.69%	97.05%	297	36.53%	78.84%
$100\mu g/m^3 \leq PM_{10} < 120\mu g/m^3$	8	0.98%	98.03%	89	10.95%	89.79%
$120\mu g/m^3 \leq PM_{10} < 140\mu g/m^3$	5	0.62%	98.65%	49	6.03%	95.82%
$140\mu g/m^3 \leq PM_{10} < 160\mu g/m^3$	7	0.86%	99.51%	8	0.98%	96.80%
$160\mu g/m^3 \leq PM_{10} < 180\mu g/m^3$	2	0.25%	99.75%	12	1.48%	98.28%
$180\mu g/m^3 \leq PM_{10}$	2	0.25%	100.00%	14	1.72%	100.00%

Figure 8.2 Frequency Distribution of PM_{10} Data

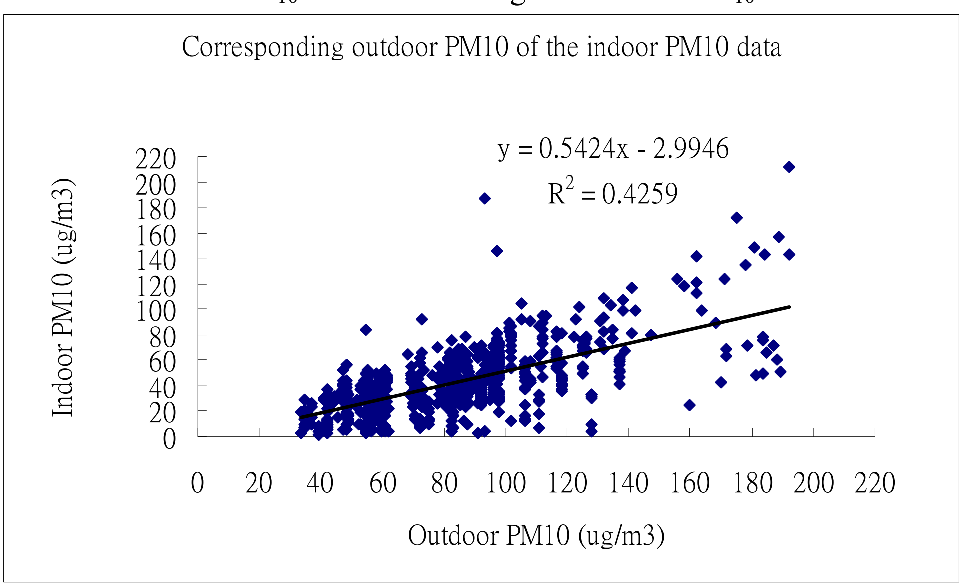


As an initial start of data analysis, this simple measurement helps building manager to have an initial understanding of PM_{10} levels throughout the campus based on the existing operation and maintenance. 99.75% of measured data is below 180µg/m^3. Only 14.76% of the measured data is below 20µg/m^3, the excellent class requirement. The major (38.87%) of the indoor PM_{10} concentration is the range between 20µg/m^3 to 40µg/m^3. For outdoor PM_{10} concentration, 98.28% of the measured points were within 180µg/m^3. The reduction in PM_{10} concentration from outdoor to indoor reflects that the air filtration system was functioning properly in capturing particulates. However, the system could not achieve an excellent level in terms of PM_{10} control by using the existing filtering system.

In order to identify the influencing factors on PM_{10} concentration characteristics, the large group of data is further analyzed according to the corresponding outdoor PM_{10} during the measurement (Figure 8.3), space description and the air-conditioning system design (Table 8.3), and the occupancy profile in the room (Table 8.4) in the latter sections.

Figure 8.3 plots the indoor PM_{10} concentration data against outdoor air. Indoor PM_{10} is plotted at the y-axis such that the slope of curve yields the indoor-to-outdoor ratio. Data for respirable particulates measured by Environmental Protection Department at the nearest outdoor monitoring station was compared. The maximum concentration in such database was 201μg/m^3 within the study period. To compare with, the maximum outdoor PM_{10} in our database is 192μg/m^3. This study had covered the worst outdoor PM_{10} contamination situation.

Figure 8.3 Outdoor PM_{10} Concentration against Indoor PM_{10} Concentration



Generally speaking, there is an increasing trend on indoor PM_{10} concentration when outdoor PM10 increase. Despite this, under a similar outdoor PM_{10} concentration, say 180μg/m^3, the indoor PM_{10} in various rooms is ranged between some 50 to 160μg/m^3. Space and system characteristic, together with the difference in occupancy, may explain. Table 8.4 describes the measured results in different classrooms, lecture theatres and computer centres. The corresponding air side system is also listed.

Indoor particulate concentration is used to indicate the filtration performance in different zones. Average indoor-to-outdoor ratio in the space is also presented to indicate the effect of the outdoor PM_{10}. Locations A to H are widely spread separately among the whole campus. Different building blocks within a same location are adjacent blocks. Take location F as an example, indoor corridor allows direct access from block 7 to block 8.

A minimum PM_{10} below 12μg/m^3 can be achieved in many student areas, except student computer centres and those with entrance door facing outdoor with FCU filters for space air filtration. For classroom at location E6 1/F, its door is facing outdoor but served with AHU and a 90% efficiency filter for space air filtration. Unlike other rooms with higher outdoor infiltration, the classrooms in that particular zone can maintain a very low minimum PM_{10} concentration and a relatively low indoor-to-outdoor ratio. While the maximum PM_{10} reaches some 60μg/m^3, with a corresponding outdoor PM_{10} of 110.7μg/m^3; a low average indoor-to-outdoor ratio in the zone means that AHU Constant Air Volume system design do perform better in terms of air filtration for rooms adjacent to outdoor.

Table 8.3 PM_{10} and Indoor–to-outdoor Ratios in Different Zones

Location ID	Block ID	Floor Level	Area of Rooms (range: m^2)	Min. PM10 ($\mu g/m^3$)	Max. PM10 ($\mu g/m^3$)	I/O ratio	FA Intake Level	System type (Filter efficiency)
A	1	2/F*	52 to 61	30.1	142.9	0.66	2/F	PAU (90%) + FCU (30%)
		3/F	22 to 91	11.7	81.6	0.58	3/F	PAU (90%) + FCU (30%)
		4/F	27 to 60	5.6	49.5	0.36	4/F	PAU (90%) + FCU (30%)
		5/F	27 to 42	7.1	59.2	0.35	5/F	PAU (90%) + FCU (30%)
		6/F	25 to 43	10.2	48.0	0.38	6/F	PAU (90%) + FCU (30%)

B	2	3/F	53 to 80	9.7	149.0	0.74	Roof above 7/F	PAU (90%) + FCU (30%)
		4/F	52	25.0	71.9	0.46	Roof above 7/F	PAU (90%) + FCU (30%)
		4/F@	52	90.3	211.7	1.38		
	3	4/F	798	29.1	186.7	0.5	Roof above 7/F	Computer Centre: PAU (90%) + FCU (30%)
C	4	2/F*	28 to 64	29.1	88.8	0.70	2/F	PAU (90%) + FCU (30%)
		1/F	40 to 64	32.1	103.7	0.79	1/F	PAU (90%) + FCU (30%)
D	5	3/F	74 to 219	29.6	69.9	0.57	Roof above 18/F	Computer Centre: PAU (90%) + FCU (30%)
		4/F	74 to 124	27.0	83.2	0.61	Roof above 18/F	Computer Centre: PAU (90%) + FCU (30%)
E	6	G/F*	150	4.6	33.7	0.29	1/F	Lecture Theatre: AHU (90%)
		1/F*	110	3.1	62.8	0.22	1/F	AHU (90%)

F	7	3/F	22 to 57	6.6	105.1	0.46	Roof above 9/F	Block: AHU (90%) + Classroom: FCU (30%)
	8	3/F	120	3.6	32.1	0.19	Roof above 9/F	Lecture Theatre Block 8: AHU (90%) + Individual: AHU (90%)
G	9	2/F*	146 to 261	6.1	71.9	0.33	2/F	Lecture Theatres: AHU (90%)
H	10	2/F**	54.4 to 114	10.7	69.4	0.39	2/F	PAU (90%) + FCU (30%)
		6/F	36 to 84	11.2	78.1	0.35	6/F	PAU (90%) + FCU (30%)

* Rooms with entrance door facing outdoor podium or ground level
** Classrooms with 4m headroom height. Lecture theaters also have higher headroom of approximately 4 to 5m. Computer centres and other space not specified (i.e. classrooms) have headroom height varied from 2.6m to 3m.
@ Classroom with exceptional high PM10. No significant cause can be identified in the space in this pilot study stage.
# PAU: Primary air unit: Only for outdoor air conditioning and filtration. Constant air volume.
AHU: Air handling unit (CAV): Room air and outdoor air is mixed, air conditioned and filtered.
FCU: Fan coil unit. Pretreated and filtered outdoor air is mixed with space air. Air volume can be selected manually by building occupants at three levels.

The PM_{10} concentration in location B is relatively high. A relatively high indoor-to-outdoor ratio is also observed, which means there is a relatively smaller difference between indoor and outdoor PM_{10}. In addition, the room is not suspected to suffer high infiltration since the entrance doors in these rooms are facing indoor corridors. As there is no significant sources observed during measurement; in this case, building management is advised to check the condition of air filters and also the air handling system. The effect of occupancy status and the speed of fan coil units can be observed in Table 8.4. Observed from the room at B2 3/F, low speed operation may result in higher indoor-to-outdoor ratio, but a maximum of 0.44 is also obtained under high speed. The effect of fan coil speed on PM_{10} is not clear. On the other hand, under similar outdoor PM_{10} concentration, more occupants would results in a higher PM_{10}, especially for rooms with higher outdoor infiltration (A1-2/F*). Compare with the effect of outdoor PM_{10}, although the increase in occupants would not significantly rise the PM_{10} to a level exceeds good class requirement; space air filtration should be enhanced. Lecture theatre in E6 with 90% efficiency filter for space air can maintain low indoor PM_{10} when if 26 persons were occupied.

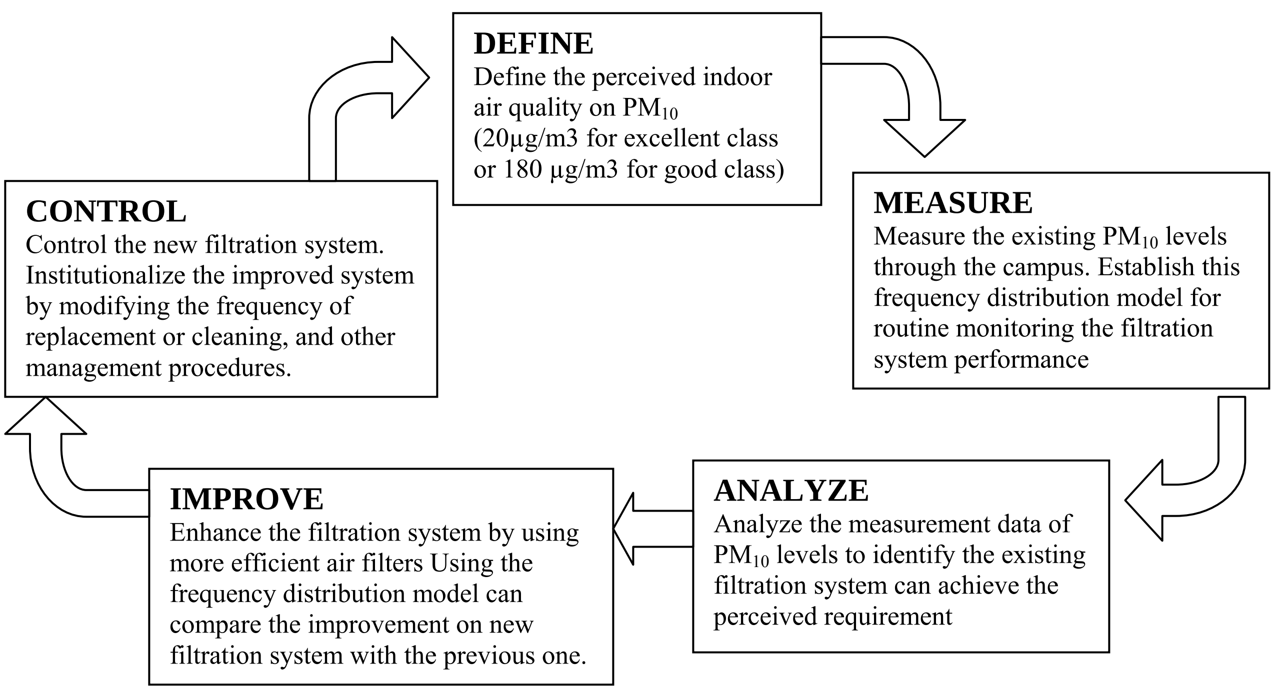
Table 8.4 Effect of Fan Coil Unit Speed and Occupancy on Indoor PM_{10}

Location ID	Block ID	Floor Level	Area of Room (m^2)	Space PM10 ($\mu g/m^3$)	Outdoor PM10 ($\mu g/m^3$)	I/O ratio	No. of Occupants	FCU speed (if applicable)
B	2	3/F	78.3	48.0	48.0	0.58	1	LOW
				37.8	37.8	0.43	1	LOW
				9.7	9.7	0.26	1	MED
				11.2	11.2	0.2	2	HI
				55.1	55.1	0.44	1	HI
A	1	2/F*	60.7	99.0	164.0	0.60	1	HI
				142.9	184.0	0.78	33	HI
A	1	3/F	41.7	42.9	91.8	0.47	1	LOW
				19.9	41.8	0.48	10	LOW
D	5	1/F	74.0	32.7	71.9	0.45	3	LOW
				64.3	68.4	0.94	22	LOW
E	6	1/F	110.0	8.7	71.9	0.12	1	N/A (CAV – AHU)
				14.3	75.0	0.19	26	

8.4.5 Discussion on IAQ Management by Data

The effect of filter efficiency on indoor particulates concentration can be established by air filtration models, taking the fraction of filtrated air to the total air entering the room, indoor source generation and the re-entrant of particulates from the surfaces brought-in by the occupants into account. However, this modeling approach which involves characterization of emission sources and the infiltration rate of the room could be tedious for building management personnel. This study reports an alternative approach of IAQ data management (Figure 8.4) to evaluate the effectiveness of air filtration system by sampling the particulate concentration in indoor space. By using the technique of management by data, the system performance against the routine operation and maintenance of filtration system can be obviously evaluated. Appropriate measures and controls can be taken by considering the perceived indoor air quality and budget control on system enhancement or frequency of filter replacement / cleaning.

Figure 8.4 DMAIC on IAQ Management on Evaluating Filtration System Performance



8.5 IAQ Solution by Using Equivalent Air Change Rate approach for Determination of Effectiveness of Air Purifier

As discussed in previous Chapter, in air-conditioned indoor spaces, concentration of any pollutant is a function of three elements: (a) quality of the ventilating air, (b) distribution of the air, and (c) emission characteristics of significant pollutants. The quality of indoor air is mainly determined by the quality of the ventilating air, air distribution and the indoor pollutant emission. Assuming the air distribution, indoor pollutant emission are constant and the quality of ventilating air is limited to the existing fresh air system, the concentration of any pollutant may be reduced by installing the air purifier to absorb the certain amount of the pollutant. In this present, there is no any standard evaluation approach to determine the performance of the air purifier. This study is to evaluate the performance effectiveness of such air cleaning equipment by using equivalent air change rate approach. The theory of this approach is based on the Olf approach [Fanger (1988)] to justify the satisfaction of human subjective response with or without using the air purifier.

The study was conducted in Dressing Room of Jockey Club Auditorium, which was located in the basement. Many complaints on odour problems in this room were reported. The premise is equipped with primary air handling unit (PAU) and fan coil unit (FCU) systems. The outdoor air supplied by the PAU via primary air ducts is connected with the mixing plenums of fan coil units. The cooled air is then supplied by these two fan coil units to the premise. In this study, two air purifiers were proposed to install for reducing the odour inside the room. The impact of human subjective responses on using air purifier was studied in order to evaluate the performance of air purifiers in the air-conditioned spaces.

8.5.1 Effect of Human Subjective Responses with and without Using Air Purifiers

An air purifier with photocatalyst technology was used to provide air cleaning function. This system applies photocatalytic boards and UV lamp for air disinfections. The maximum and minimum rated airflow rates are 420 and 60 m^3 per hour respectively. The recommended service space volume is 40 m^3. The measurements were conducted on 2 days. For the 2-day study, ten students were invited to survey the sensation of odour in five trials, which were without using air purifier, one air purifier and two air purifiers be used. Each trial for using air purifier was operated under full load ventilation mode. In addition, tracer gas decay measurements were also conducted for verifying the air change rate of the room against every trial.

8.5.2 Effect of Odour Sensation with Using Air Purifier

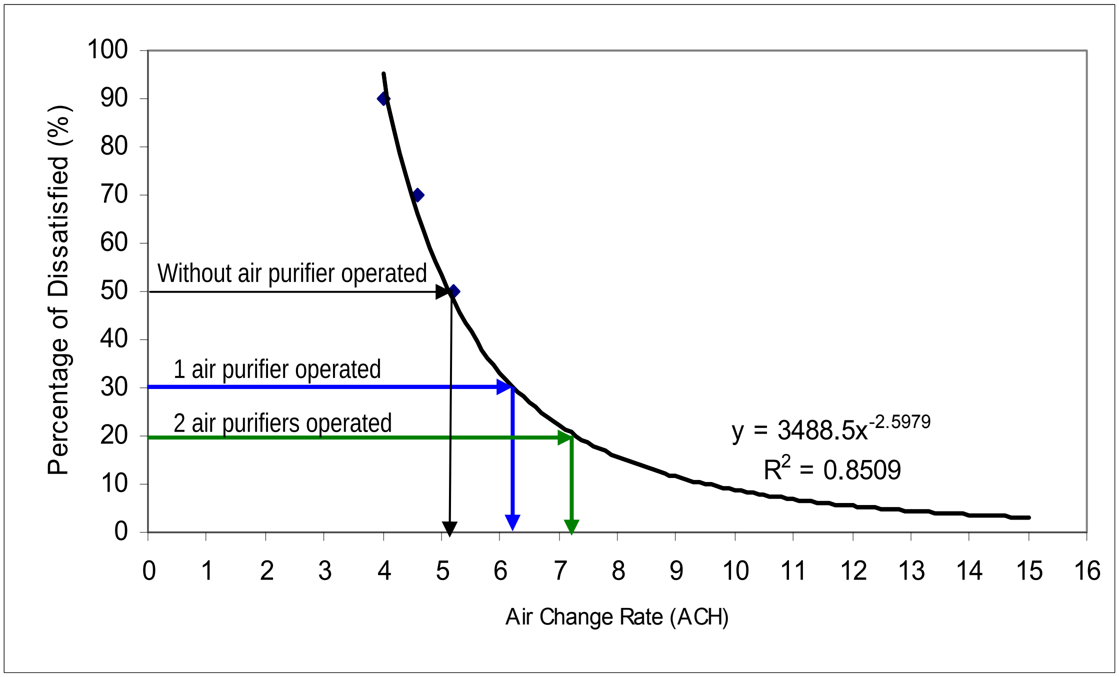
In the study, five measurements were carried out in dressing room. The percentage of satisfaction in each measurement was recorded. The results are shown in Table 8.5.

Table 8.5 Percentage of Satisfaction in Dressing Room

No. of Air Purifier be used	Damper Position	Vote	Accept	Percentage of Satisfied	Unaccepted	Percentage of Dissatisfied	Measured ACH	Equivalent ACH obtained by Figure 8.8
Without	20%	10	1	10%	9	90%	4	N/A
Without	50%	10	3	30%	7	70%	4.6	N/A
Without	100 %	10	5	50%	5	50%	5.2	N/A
One	100 %	10	7	70%	3	30%	5.2	6.2
Two	100 %	10	8	80%	2	20%	5.2	7.2

In the results, number of air purifier was affected the percentage of satisfaction. Higher percentage of satisfaction was achieved when more air purifiers are used. The results are shown in the Table 8.5 and Figure 8.5.

Figure 8.5 Equivalent ACH against Percentage of Dissatisfied

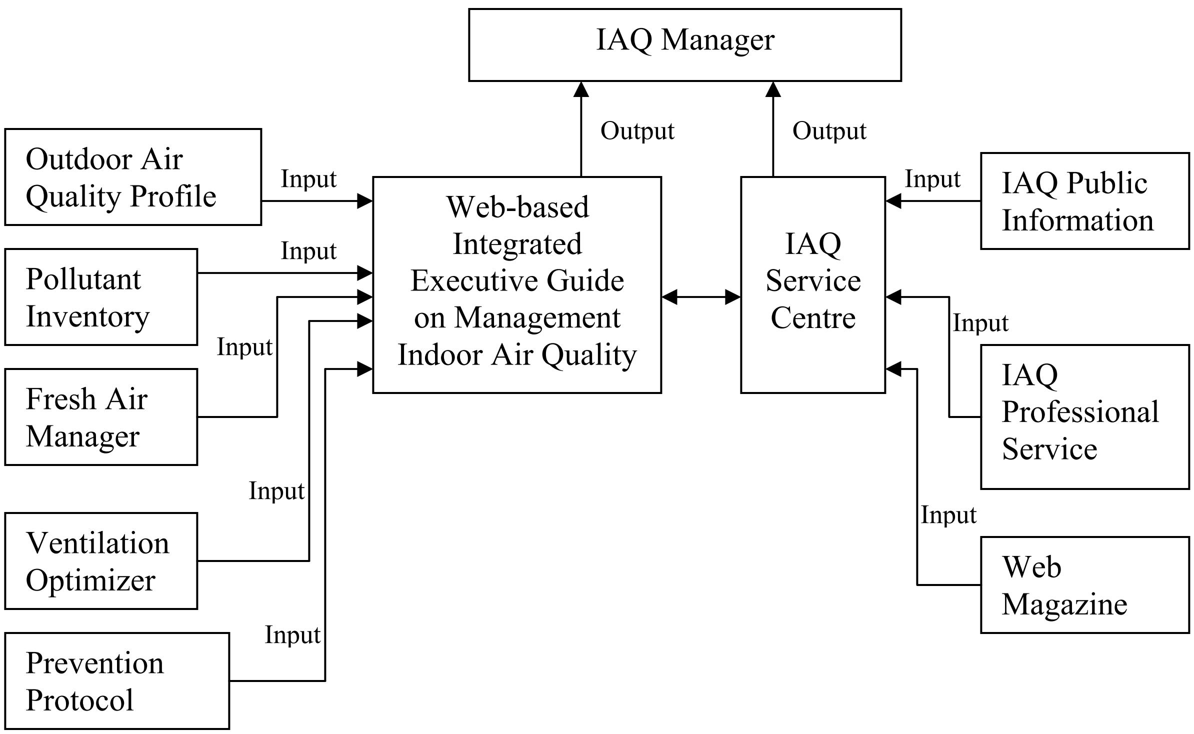


From Table 8.5, the percentage of satisfaction in using one air purifier was 70%, while that in using two air purifiers was 80%. Based on subjective responses as plotted in Figure 8.5, additional 1 ach was equivalent to install an air purifier at 70% satisfaction, while additional 2 ach was equivalent to install two air purifiers at 80% satisfaction. The result has evaluated the effect of human sensation by using air purifier. Therefore, the concept of equivalent air change rate approach based on subjective responses by human beings is introduced to evaluate the performance of air purifier.

8.6 Electronic IAQ Manager

Based on a full development of executive guide on IAQ management including design, operation and maintenance by formulating the previous chapters into a comprehensive useful tool for building industry, the integrated electronic IAQ Manager is developed as a web-based format to deliver the outputs from this research study with the following main features. The web structure of the electronic IAQ Manager is highlighted in Figure 8.6.

Figure 8.6 Web Structure of Electronic 'IAQ Manager'

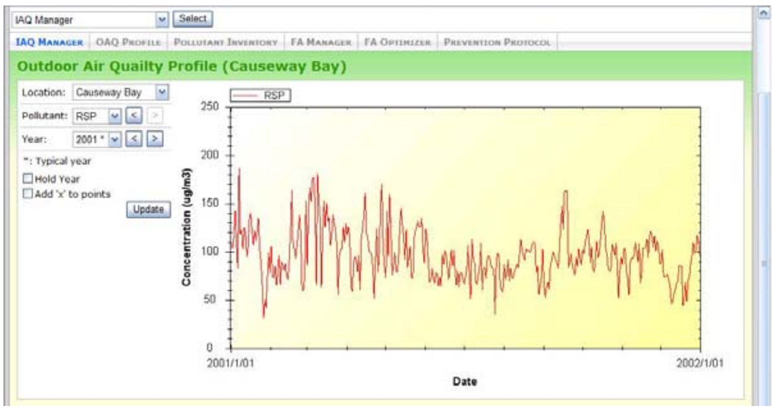


8.6.1 Web-based Integrated Executive Guide on Management Indoor Air Quality

(a) Outdoor Air Quality Profile

Comprehensive analyzed outdoor air quality data base with over 8.9 millions of data in 17 air monitoring stations (including 14 existing stations and 3 past stations) provides valuable information of total 23 years (from 1983 to 2005) on understanding the background of outdoor air pollutants among different district in Hong Kong. The web page of the ‘Outdoor Air Quality Profile’ is shown in Figure 8.7.

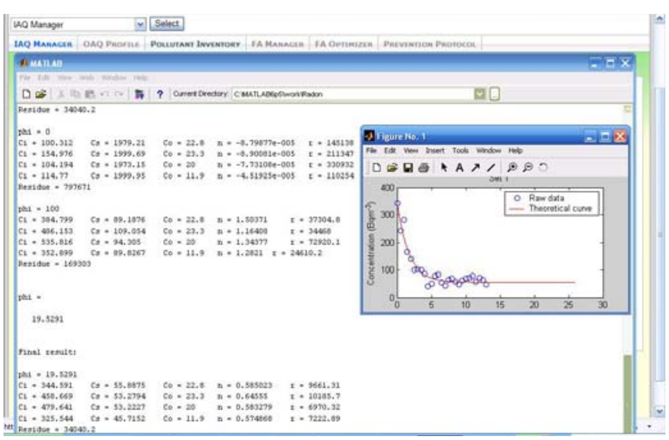
Figure 8.7 Web Page of ‘Outdoor Air Quality Profile’



(b) Pollutant Inventory

A minimum error optimizer by using the computational program is used for calculation of ‘indoor pollutant inventory’ for the determination of equivalent indoor pollutant load. The web page of the ‘Pollutant Inventory’ is shown in Figure 8.8.

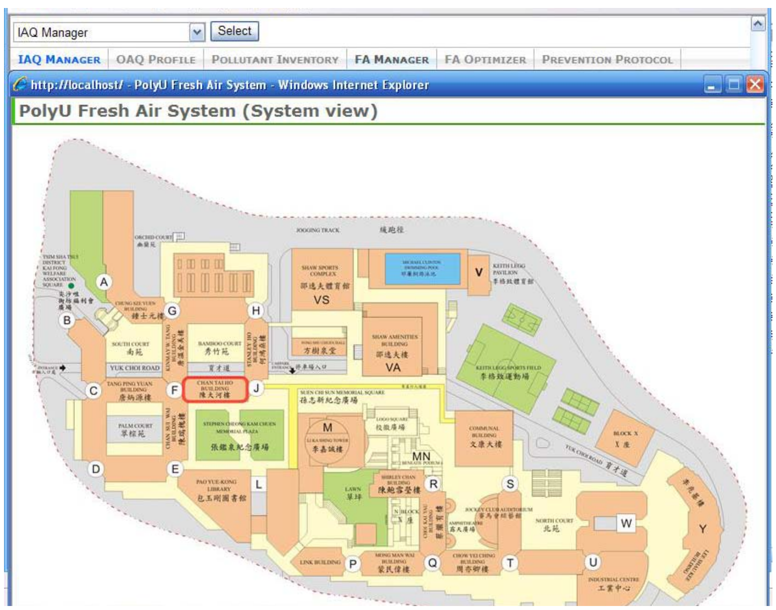
Figure 8.8 Web Page of ‘Pollutant Inventory’



(c) Fresh Air Manager

A geographic information system (GIS) based data base for fresh air system management is to determine fresh air intake location and identify the potential risk on outdoor air quality and quantity. The web page of the 'Fresh Air Manager' is shown in Figure 8.9.

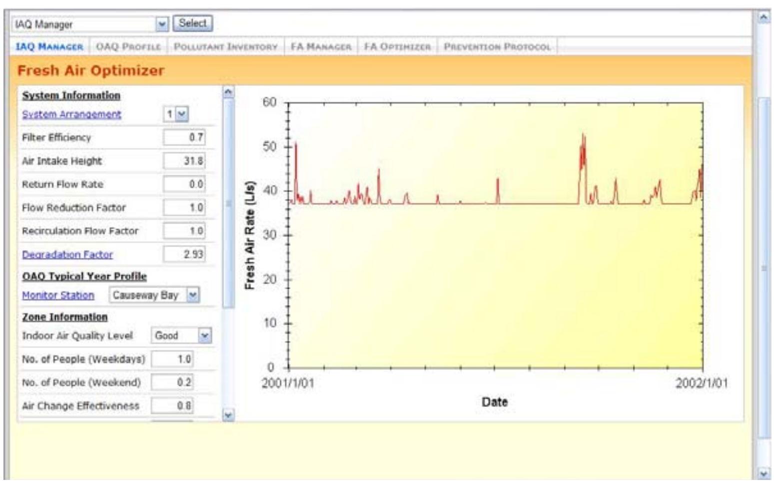
Figure 8.9 Web Page of 'Fresh Air Manager'



(d) Ventilation Optimizer

Ventilation optimizer is an analytic tool for optimizing outdoor air quantity for fresh air system design. By identifying what kinds of system design and fully compliance to any indoor air pollutant specification and supporting the good and excellent level of the GN, this electronic analyzer is used to determine the most optimum outdoor air quantity for continuous fresh air system operation by intensive utilization of the developed typical outdoor air pollutant profiles at 14 regions in Hong Kong and adopting ASHRAE 62.1-2007 Ventilation Rate Procedure and IAQ Procedure as well as Fanger's New IAQ Comfort Equation. In addition, a power law profile for the determination of outdoor air quality at outdoor air intake point and 'Four-Tier diagnosis scheme' for determining the overall fresh air quality degradation index which is a function of degradation due to pre-contamination, by-pass, short-circuiting and ventilation effectiveness are also considered for the optimum fresh air operation in building design. The web page of 'Ventilation Optimizer' is shown in Figure 8.10

Figure 8.10 Web Page of 'Ventilation Optimizer'



(e) Prevention Protocol

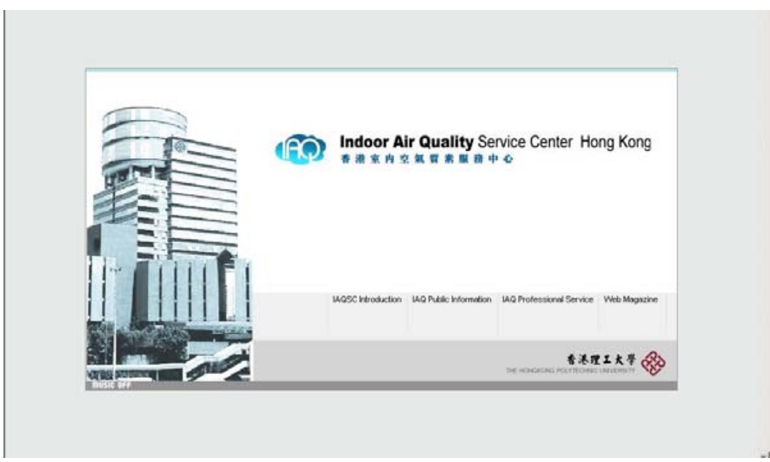
Prevention protocol provides intensive useful management protocol for prevention of communicable disease. The web page of 'Prevention Protocol' is shown in Figure 8.11

Figure 8.11 Web Page of 'Prevention Protocol'

8.6.2 Indoor Air Quality Service Centre

The informative Indoor Air Quality Service Centre is divided into three main web pages. The web page of 'Indoor Air Quality Service Centre' is shown in Figure 8.12.

Figure 8.12 Web Page of 'Indoor Air Quality Service Centre'



(a) IAQ Public Information

The IAQ Public Information section provides basic knowledge of IAQ and some new and innovative opinions from IAQ experts with the following issues:

- A data base of available recommendation from cognizant authorities including IAQ legislation and guidance;
- Comprehensive IAQ related news and information update;
- Education for managing acceptable indoor air quality for public and so on.

The web page of 'IAQ Public Information' is shown in Figure 8.13.

Figure 8.13 Web Page of 'IAQ Public Information'

(b) IAQ Professional Service

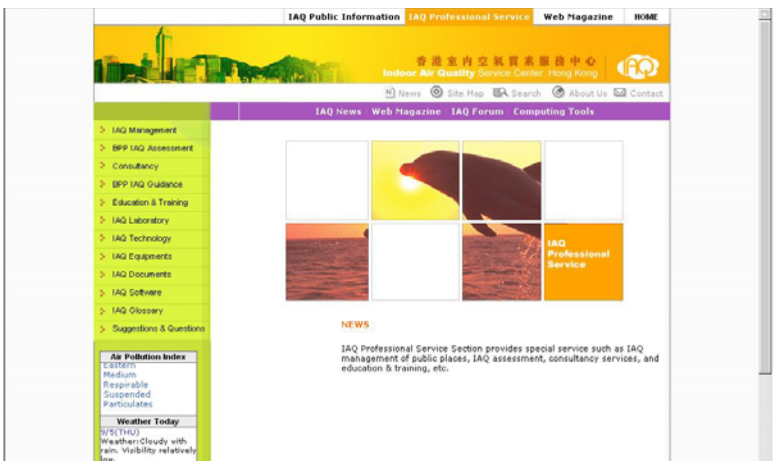
IAQ Professional Service section provides comprehensive management protocol for industry to highlight IAQ useful practices and skills with the following issues:

- Assessment tools for IAQ levels according to the GN;

- A simplified economical sampling protocol for the aims of monitoring indoor air quality;
- A building calibration model for the determination of capping the lowest turn down ratio of outdoor air
- Education and training tools for managing acceptable indoor air quality for professional and so on.

The web page of ‘IAQ Professional Service’ is shown in Figure 8.14.

Figure 8.14 Web Page of ‘IAQ Professional Service’



(c) Web Magazine

Web Magazine section provides online journal of Indoor Environment. The web page of ‘Web Magazine’ is shown in Figure 8.15.

Figure 8.15 Web Page of ‘Web Magazine’

8.6.3 Electronic Indoor Air Quality Management Platform

For managing indoor air quality in air-conditioning building effectively, electronic platform is an essential element for Building Management or Owner to establish a custom-made software interface by applying developed tools in Electronic IAQ Manager. To reflect the effectiveness of eIAQ manager, some buildings have tailor-made the Electronic Indoor Air Quality Management Platform to demonstrate the practicing experience on its use.

Figure 8.16 Home Page of ‘Electronic Indoor Air Quality Management Platform’ (MC6)

(a) Home Page of Electronic Indoor Air Quality Management Platform (MC6)

Electronic Indoor Air Quality Management Platform is developed for Millennium City 6 (MC6) to help the Building Owner handling the management of indoor air quality effectively. In this software tool, it is structured by the following contents:

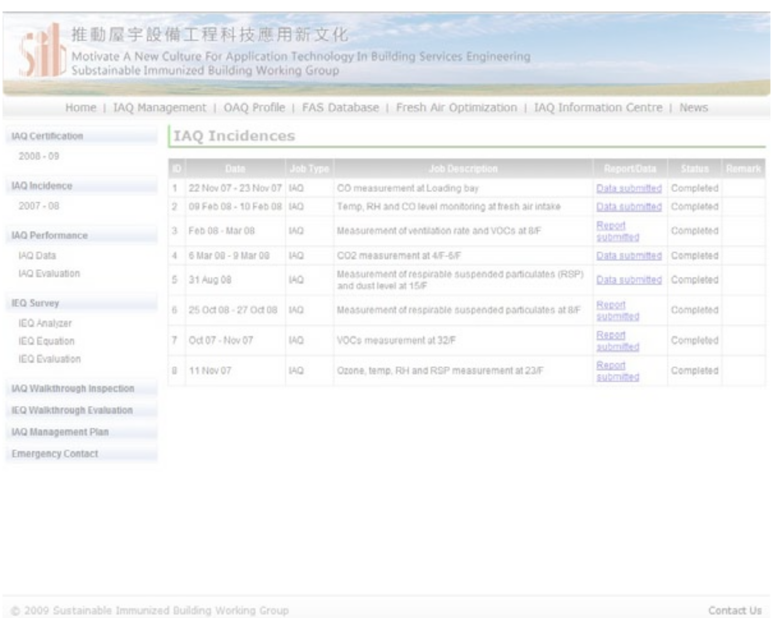
(b) Web Page of IAQ Management (MC6)

In this page, the content involves the following items:

- IAQ Certification: It is a page to show what class that the building is awarded according to the Indoor Air Quality Certification Scheme for Offices and Public Places issued by Indoor Air Quality Information Centre for identifying what kind of indoor air quality in this building.
- IAQ Incidence: It records all the incidence related to indoor air quality in this building which can make the Building Management / Owner chase back the indoor air quality problems in the building.
- IAQ Performance: It includes IAQ Data and IAQ Evaluation. IAQ Data is to record all the IAQ measurement data taken in the building for providing real data to evaluate the IAQ performance of the building. IAQ Evaluation is a list of summary table to present the detailed IAQ performance in the building.
- IEQ Survey: Besides concerning indoor air quality, other factors like thermal comfort, aural comfort, visual comfort also affect the indoor environment condition. IEQ Analyzer, IEQ Equation and IEQ Evaluation can help Building Management / Owner to understand the performance of indoor environment quality in the building.

- IAQ Walkthrough Inspection: By applying the Four-Tier Diagnosis Scheme mentioned in Chapter 5, the IAQ walkthrough survey protocol can analyze IAQ by identifying different processes of outdoor air entering the indoor environment.
- IEQ Walkthrough Evaluation: It provides a tool on evaluating the indoor environment quality during the walkthrough.
- IAQ Management Plan: By using the concept of the IAQ Management by Data mentioned in Section 8.4, the Building Management / Owner can apply the data management technique to evaluate operation and management strategies on fresh air handling equipment.
- Emergency Contact: It provides a contact list of professionals, consultants, contractors, suppliers or related parties to handle the indoor air problems in the building.

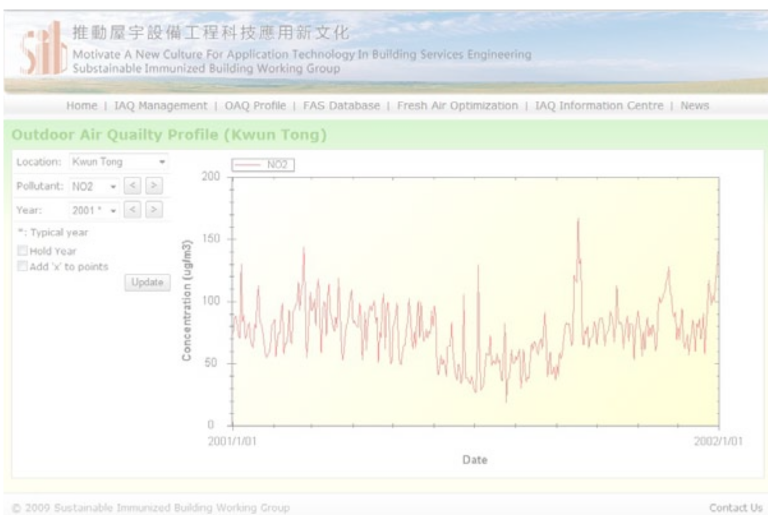
Figure 8.17 Web Page of 'IAQ Management' (MC6)



(c) Web Page of OAQ Profile (MC6)

In this page, it shows up the outdoor air quality profiles among different pollutants recorded in different monitoring stations and highlights the typical outdoor air quality year in different monitoring stations based on the output from Chapter 3 and 4. Building Management / Owner can select the nearest location of monitoring station from the building which can provide comprehensive information of outdoor air quality as base reference for designing, planning, operation, maintaining on fresh air system and equipment according to actual solid data from the past records.

Figure 8.18 Web Page of 'OAQ Profile' (MC6)



(d) Web Page of FAS Database (MC6)

In this page, the technique of Geographical Information System (GIS) mentioned in Section 8.3 is used for mapping all locations of the building to list out the recorded physical parameter, chemical parameter / bacteria, fresh air system arrangement and deign fresh air provision of the locations / floors which can comprehensively furnish the IAQ related information on the system, design and the recorded data.

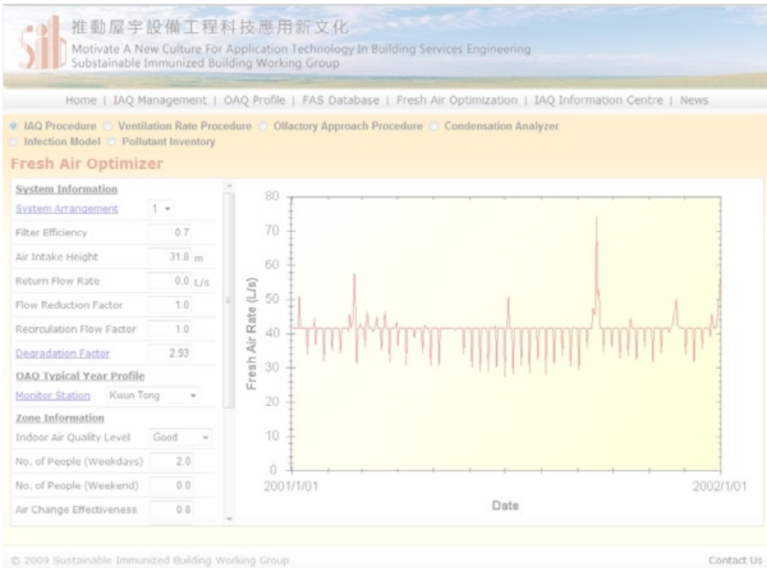
Figure 8.19 Web Page of ‘FAS Database’ (MC6)

(e) Web Page of Fresh Air Optimization (MC6)

In this page, the content involves the following items:

- IAQ Procedure: This page is used as a web calculator to calculate the required fresh air rate for the building by applying the output from the Typical Outdoor Air Quality Year developed in Chapter 4 as one of the parameter to evaluate the requirement of the fresh air into the building according to the ANSI/ASHRAE Standard 62.1-2007.

Figure 8.20 Web Page of ‘IAQ Procedure’ in ‘Fresh Air Optimization’ (MC6)



- Ventilation Rate Procedure: It is a web calculator to compute the minimum ventilation rate by selecting the occupancy category based on Table 6-1 Minimum Ventilation Rates in Breathing Zone mentioned in ANSI/ASHRAE Standard 62.1-2007.

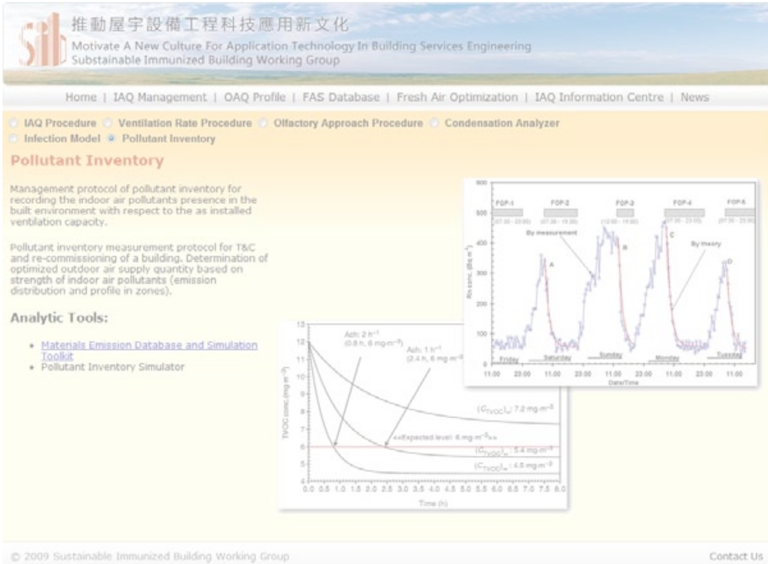
Figure 8.21 Web Page of ‘Ventilation Rate Procedure’ in ‘Fresh Air Optimization’ (MC6)

- Olfactory Approach Procedure: By applying Olfactory approach for ventilation design developed by Fanger, this page provides a calculator to evaluate the required ventilation rate by using this approach.

Figure 8.22 Web Page of ‘Olfactory Approach Procedure’ in ‘Fresh Air Optimization’ (MC6)

- Pollutant Inventory: Determination of optimized outdoor air supply quantity should be based on the strength of indoor air pollutants that are related to the emission distribution and profile in zones. By applying the principle of Indoor Pollutant Inventory mentioned in Chapter 6, Building Management / Owner can operate the fresh air system effectively to deliver the desirable indoor air quality with optimized outdoor air supply quantity.

Figure 8.23 Web Page of ‘Pollutant Inventory’ in ‘Fresh Air Optimization’ (MC6)



(e) Web Page of IAQ Information Centre (MC6)

In this page, the content involves IAQ Codes / Document, IAQ Parameter, IAQ Laboratory, IAQ Reference, IAQ Objective, IAQ News and IAQ Web which can provide comprehensive information to Building Management / Owner to manage indoor air quality in the building.

Figure 8.24 Web Page of ‘IAQ Information Centre’ (MC6)

8.7 Summary and Conclusions

This chapter illustrates how 'building calibration' can help building operators to identify the best way to operate the ventilation system with reference to the pollutant inventory to provide acceptable IAQ to the occupants. In additional, the concept of 'Geographical Information System' for IAQ management can provide effective collation of documentaries and air quality data base. 'IAQ management by data' was introduced to demonstrate how the data management of pollutant concentration to help the building managers to understand the IAQ characteristics of pollutant in order to make decisions on defining the perceived indoor air quality against the management policies. 'Equivalent air change rate approach' also proposed to determine the performance evaluation of air cleaning equipment.

For integrating all the findings and outputs from this research study, electronic IAQ manager is constructed as a tool for 'Total IAQ Management and Solutions'

CHAPTER 9 : CONCLUSION

9.1 Enigma of the Guidance Notes

The drive for this study is the Hong Kong Government's initiation of an Indoor Air Quality Certification Scheme. The Scheme is in demand because of the awareness of the importance of acceptable air quality. Since the launch of the Scheme in 2003, only 35 places/buildings are awarded the 'Excellent' Class and 240 places/buildings are awarded the 'Good' Class up to March 2008. Unfortunately, not only the participation rate is low, the penetration rate according to a recent survey that conducted by The Social Sciences Research Centre of the University of Hong Kong, is low too. The Guidance Notes is considered to be enigma because of the down lying difficulties in a genuine compliance from the operation and maintenance point of view. It is an enigma also because healthy IAQ should be an ethical requirement but some of the approach is not appropriate.

Chapter 7 provides a more pragmatic approach of air sampling. This alternative sampling makes the location of measurement more representative by considering the three vital aspects of fresh air quality, pollutant inventory and ventilation pattern. Reduction of the number of sampling points can be ascertained using the statistical sampling approach for spaces are having similar conditions of the three aspects. For offices with similar conditions all through typical floors, the reduction of sampling points can be tremendously reduced by half. Further reduction of the sampling points can be exercised by distinguishing whether that the gaseous constituents of the 9 parameters are indoor or outdoor borne and limiting the outdoor borne parameters to sampling points at the fresh intake point. Samples for NO_2 and CO can be reduced to a large extent. This alternative sampling protocol can be further modified to a monitoring programme by limiting the sampling for CO_2 and particulates. This alternative sampling protocol was submitted to the HKEPD. The monitoring procedure was proposed in the draft of “Managing Air Quality in Air-Conditioned Public Transport Facilities”. The modified monitoring procedures for sampling CO_2 and particulates only has been adopted for IAQ Certificate renewal for four years before the full certificate expires.

In the same chapter, the analysis of the IAQ measured sample showed the order of difficulties of the 9 parameters in meeting the ‘good’ or ‘excellent’ level. In level of difficulty in compliance, they are: respirable suspended particulates, total volatile organic compounds, formaldehyde, bacteria, carbon dioxide.

9.2 Contradiction between IAQ Management Criteria and Ventilation Requirement for Acceptable IAQ

‘Solution to pollution is dilution’. If the outdoor air is clean, it is a pragmatic and practical rule to follow. The prescriptive Ventilation Rate Procedure and the performance based Indoor Air Quality Procedure in ASHRAE Standard 62.1-2007 are developed for such purpose. Before the GN, the IAQ management criteria was almost invariably be 1,000 ppm of CO_2 and the ventilation rate for buildings post 1989 (when ASHRAE 62-1989 firstly specified a more elaborate approach for design for ventilation system) was 10 litres/s/person, which was basically the prescriptive Ventilation Rate Procedure. Since the GN is launched, the IAQ management criteria has been mainly compliance to the ‘good’ or ‘excellent’ IAQ which is performance based. However, the ventilation rate is still the same. This paradoxical specification and the controversial ventilation requirement computation procedure would have been resolved by the performance based Indoor Air Quality

Procedure of the ASHRAE Standard 62. The apparent contradictory behavior of the engineers would not be difficult to apprehend if one realize the following problems:

i. outdoor air quality is not readily available in analyzable format;
ii. indoor air pollutant emission rate is generally not known;
iii. tools for evaluating the inevitable air quality degradation in fresh air distribution system is not available;
iv. design tools are not handy.

In this study, tremendous effort has been put into the research groundwork to support the development of a handy tool for engineers in the design of ventilation systems. Chapter 3 intelligently transforms the data base (over 8.9 millions of data) of the outdoor air pollutants from the 17 air monitoring stations (including 14 existing stations and 3 past stations) into an analyzable format. The outdoor air pollutant trends are found to correlate with governmental policies, social and financial incidences in Hong Kong. In Chapter 4, using the CIBSE approach, the first time in all similar studies, derives a set of typical year profiles of all recorded pollutants at these stations. These profiles integrate into a horizontal mapping of the outdoor air quality which is used for diluting the indoor pollutants. The first time in Hong Kong that the ventilation engineers have a comprehensive set of outdoor air quality annual profiles available for their designs. The same procedure can be used to derive outdoor air quality annual profiles in other countries such as in cities in the Mainland. It then provides a solution to solve problem (i) mentioned earlier.

Pollutant strength in the indoor environment is a great difficulty to the design engineers. Chapter 6 develops the concept of “pollutant inventory”. A zone model with minimum error in matching emission rate with ventilation ‘ON’ and ‘OFF’ is derived to quantify the emission rates of targeted pollutants. Radon is found to be a steady and reliable reference source in determining ventilation rates. This approach enables engineers to quantify accurately the ventilation rates in an indoor space and hence the ‘pollutant inventories’. These emission rates are termed ‘pollutant inventories’ because for the same building material in the same construction configuration used in the same building, the emission rates can be evaluated based on quantity based. Hence, it provides the information required for the source term in the ASHRAE IAQ Procedure for the management of ventilation rates. Problem (ii) mentioned in this section earlier is solved.

Chapter 5 enhances a Four-Tier Degradation Model first proposed by Chan (2000). Four-Tier Diagnosis Scheme is introduced as an effective protocol for walkthrough inspection on IAQ survey to quantify and evaluate the effect of degradation on the whole ventilating air path. It then provides useful tools to solve problem (iii) described earlier.

9.3 A Handy Tool for Engineers

The large outdoor air quality data forms a horizontal distribution of the outdoor air pollutants in Hong Kong. The power law (Chan 2000) gives the vertical profiles of the outdoor air pollutants from ground level to the fresh air intake. The four-tier diagnosis scheme provides the quality degradation from intake point to the discharge point of the outdoor air to the breathing zone. That completes the quality tracks of the ventilating air for IAQ management. Together with the pollutant inventory, an optimal ventilation quantity can be properly managed by the building executives. The IAQ sampling protocol developed in Chapter 7 monitors the IAQ at all time. More features can be implemented to facilitate the building executives in managing the IAQ including at times when communicable diseases peak.

The integrated electronic IAQ manager developed in Chapter 8 is a novel set up for the building executives. It not only embedded all the research outputs from this study, properly collated, but also embodied with a number of management features and tools. The essence is an IAQ Ventilation Optimizer which is a tool converted from the research outcomes. Other features include an express news of communicable disease aims to draw the alertness of the executives for appropriate protective actions. A 6-P approach is used to detail the Policy-Position Statement-Plans-Protocol-Process-Participation that the building undertakes. The electronic IAQ manager is linked to an IAQ web-site which provides the necessary IAQ information and laboratory technology. The IAQ web-site is developed when this project begins.

Geographical Information System technology is first time used in IAQ management if not building services management. This application of GIS technology is described in Chapter 8. This part of the electronic manager allows a visual aid in the form of photographs and drawings for more vivid management decisions to be made. Other features of the electronic manager are as shown in Chapter 8. It has been taken the candidate quite an effort in developing this electronic IAQ manager as an intelligent research element in this project that provide a solution on problem (iv) mentioned in previous Section.

9.4 Limitation of the Study

The course of this PhD study is memorable and that the candidate is very contended in completing the thesis. This is not a typical research work on a focus area, in this case, acceptable IAQ from the executive perspective. The candidate takes further effort in ‘narrowing the gap’ between research output and industrial application by converting the research results into a pragmatic tool, electronically collating all the information as a management guide to the building executives. The plan is ambitious. The work could nevertheless outweigh the scope of an academic study. However, pragmatism is the philosophy as the drive. Being pragmatic, the research objectives and directions could not be limited to fact finding of fundamental knowledge alone, but should be aimed at fulfilling the market demand and handy to the building managers. The project sometimes is perplexing. IAQ is a broad subject area. Acceptable IAQ pins down issues. Proper IAQ management is limited by the extensiveness of related science and technology, not to mention about the techniques required for generating tools. Nevertheless, for the safe, healthy and comfortable benefits to the building users, this project at last, focuses on its current context and produce a useful and constructive executive guide.

9.5 Recommendations for Further Study

9.5.1 Utilization of Analysis on Outdoor Air Quality Data

Apart from setting up ‘Typical Outdoor Air Quality Year’ mentioned in Chapter 4, more applications, like ‘Average Outdoor Day’, ‘Bad Outdoor Day’ or ‘Bad Outdoor Week’ can be considered for short-term IAQ guide.

9.5.2 Inventory for Different Kinds of Indoor Pollutant Sources

There are a wide range of pollutants in indoor environment. A framework detailing different kinds of indoor pollutant sources (e.g. different materials that emit VOCs, smoking, human activities, etc.) or even a simple database is recommended for further research and studies.

9.5.3 Electronic Platform for Building Services System Management

As indicated in last Section, time is the limit. Now, the electronic IAQ manager is developed as an electronic platform, being able to be hooked to other similar platforms for building services system management. Similarly, appropriate tools can also be hooked to the present platform as supplementary tools. Currently, in the same research team of the project supervisor, Professor Daniel W.T. Chan, has developed other similar electronic managers like Cooling Tower Managers is also found very useful in IAQ management because cooling towers are notorious of producing legionnella. This IAQ manager, together with the main electronic document platform and other system and equipment managers in electronic forms, have received very good feedback from the industry. Hence, further study should be carried out to produce a set of electronic managers and executive guides for the betterment of IAQ management.

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Appendix A Premises Awarded with IAQ Certificates (Up to 31 March 2008)

'Excellent Class' Certified Premises (Total 35 premises)

Name of building	Address	Certified location(s)
CLP Power Hong Kong Ltd.- Shatin Centre	6 On Lai Street, Shatin, New Territories, HK	14/F and 15/F Office Area
The Hong Kong Club Building	3A Chater Road, Central, Hong Kong	Office Zone 6/F to 22/F of Hong Kong Club Building
Gateway Apartments - Hampton Court	The Gateway, Harbour City, Tower 5, Kowloon, Hong Kong	Service Apartment (25/F to 39/F) Lift Lobby and Public Place
Gateway Apartments - Sutton Court	The Gateway, Harbour City, Tower 3, Kowloon, Hong Kong	Service Apartment (25/F to 39/F) Lift Lobby and Public Place
The Galleria	No.9 Queen's Road Central, Central, Hong Kong	Rm.1302, 13/F, The Galleria, No.9 Queen's Road Central, Central, Hong Kong
Bank of China Centre	11 Hoi Fai Road, Tai Kok Tsui, Kowloon	The whole building
Citibank Tower	50/F Citibank Tower, 3 Garden Road, Central, Hong Kong	50/F, Citibank Tower, 3 Garden Road, Central, Hong Kong
EMSD Headquarters	No. 3 Kai Shing Street, Kowloon, HK	Exhibition Gallery, Exhibition Path and Lecture Theatre
Cheung Kong Center	2 Queen's Road Central, Central, HK	7/F -70/F Common Areas
Two Exchange Square	8 Connaught Place, Central, Hong Kong	Office floors 5/F-49/F
Three Exchange Square	8 Connaught Place, Central, Hong Kong	Office floors 3/F-31/F
Gloucester Tower	Gloucester Tower, The Landmark, 15 Queen's Road Central, Hong Kong	Office floors 5/F-44/F
Edinburgh Tower	Edinburgh Tower, The Landmark, 15 Queen's Road Central, Hong Kong	Office floors 16/F-44/F
Three Bays	7 Stanley Beach Road, Stanley, Hong Kong	Club House
Cheung Kong Center	2 Queen's Road Central, Central, HK	3/F Common Area
Cheung Kong Center	2 Queen's Road Central, Central, HK	25/F
Cheung Kong Center	2 Queen's Road Central, Central, HK	10/F
Somerset House	12/F., North, Somerset House, Taikoo Place, 979 King's Road, Quarry Bay, HK	ISS Facility Services Ltd.
APEC Plaza	49 Hoi Yuen Road, Kwun Tong, Kowloon, Hong Kong	Main Lobby Area of First Floor
Hong Kong Institute of Education - Town Centre Campus	Level 2, Long Beach, 8 Hoi Fai Road, Tai Kok Tsui, Kowloon	Level 2
Dah Sing Financial Centre	108 Gloucester Road, Wanchai, Hong Kong	Common Area (Lobby and Corridor) of the Building
Bank of China Tower	No. 1, Garden Road, Central, Hong Kong	The whole building

Two International Finance Centre	8 Finance Street, Central, Hong Kong	Common Areas including all Lobbies
Cyberport 3	100 Cyberport Road, Hong Kong	Whole Building
Wai Fung Plaza	664 Nathan Road, Mongkok, Kowloon	Unit 703-706 Wai Fung Plaza, 664 Nathan Road, Mongkok, Kowloon
One Exchange Square	8 Connaught Place, Central, Hong Kong	4/F - 50/F Office Floors
Hongkong Electric Centre	44 Kennedy Road, Hong Kong	The Whole Building
HKPC Building	78 Tat Chee Avenue, Kowloon, Hong Kong	IAQ Information Centre
Club House, Forest Hill	Club House, Forest Hill, 31 Lo Fai Road, Tai Po, N.T.	Club House, Forest Hill
Baycrest	8 Hang Ming Street, Ma On Shan, N.T., H. K.	Club House
CITIC Tower	1 Tim Mei Avenue, Hong Kong	6/F-33/F Public Area
AIG Tower	1 Connaught Road Central, Hong Kong	AIG Tower (Whole Building)
ICBC Tower	3 Garden Road, Central, Hong Kong	3/F-40/F (Public Area)
Citibank Tower	3 Garden Road, Central, Hong Kong	3/F-50/F (Public Area)
The Lee Gardens	49/F & 50/F, The Lee Gardens, 33 Hysan Avenue, Causeway Bay, Hong Kong	Hysan Development Company Limited Head Office

‘Good Class’ Certified Premises
- Hong Kong (Total 94 premises)

Name of building	Address	Certified location(s)
Dragon Centre	23 Wun Sha Street, Tai Hang, Hong Kong	G/F & 2/F, H. K. Housing Society Regional Office
Wing Lung Bank Building	45 Des Voeux Road Central, Hong Kong	Whole Building
Hong Kong Convention Plaza Office Tower	Convention Plaza, 1 Harbour Road, Wanchai, HK	Common areas at Ground Floor G/F, 11/F- 50/F
Southorn Centre	130 Hennessy Road, Wanchai, Hong Kong	Celebrations Coordination Office, 4/F Southorn Centre
Southorn Centre	130 Hennessy Road, Wanchai, Hong Kong	Occupational Safety - Operations Division, Labour Department, 3/F, Southorn Centre
Haddon Court	41C Conduit Road, Central, Hong Kong	G/F Entrance Hall
Revenue Tower	5 Gloucester Road, Wanchai, Hong Kong	Environmental Protection Department's Offices at 33/F & 34/F (Part)
Alexandra House	18 Chater Road, Central, Hong Kong	Office Areas of Alexandra House
Hong Kong Convention & Exhibition Centre	G/F and M/F, Unit 17, 1 Expo Drive, Wanchai, Hong Kong	G/F and M/F, Unit 17, 1 Expo Drive, Wanchai, Hong Kong
Wu Chung House	31/F Queen's Road East, Wanchai, Hong Kong	31/F Queen's Road East, Wanchai, Hong Kong
K.K. Leung Building, The University of Hong Kong	Estates Office, The University of Hong Kong, Pokfulam Road, Hong Kong	LG1 Floor
Cornwall House	14/F, Cornwall House, Taikoo Place, 979 King's Road, Quarry Bay, Hong Kong	Office of the Licensing Authority, Home Affairs Department, 14/F Cornwall House
Bank of East Asia Harbour View Centre	56 Gloucester Road, Wanchai, Hong Kong	Main Lobby at G/F
Lippo Centre	89 Queensway, Admiralty, Hong Kong	Public Places of Whole Building
Fairmont House	8 Cotton Tree Drive, Central, Hong Kong	3/F Lobby
The Mayfair	1 May Road, Hong Kong	G/F.,3/F.,& 5/F.
Island West Transfer Station Administration Building	88 Victoria Road, Hong Kong	Whole Building
The Hong Kong and China Gas Headquarters Building	363 Java Road, North Point, Hong Kong	Office Areas on 20/F, 21/F, 22/F and 23/F
Dorset House	TaiKoo Place, 979 King's Road, Island East, HongKong	8/F - Whole Floor - Citigroup Office
Cheung Kong Center	2 Queen's Road Central, Central, HK	11th Floor
Cheung Kong Center	2 Queen's Road Central, Central, HK	G/F & UG/F - Lift Lobby
Cornwall House	Taikoo Place, 979 King's Road, Quarry Bay, Hong Kong	Social Welfare Department, 14/F Cornwall House
Tower II, Admiralty Center	18 Harcourt Road, Admiralty Centre, Admiralty, Hong Kong	Office Area on 4/F, Sun Hung Kai Securities Ltd

Wu Chung House	213 Queen's Road East, Wan Chai, Hong Kong	Innovation and Technology Commission, 20/F, Wu Chung House
AIA Building	1 Stubbs Road, Wanchai, Hong Kong	The Whole Building
Regence Royale	2 Bowen Road, Mid-level, Hong Kong	Common Areas of Regence Royale comprising Lobbies and Club House
Queensway Government Office	15/F, Queensway Government Offices, 66 Queensway, Hong Kong	15/F, Companies Registry
Ning Yeung Terrace Block A	78 Bonham Road, Hong Kong	Lobby at G/F
Ning Yeung Terrace Block B	78 Bonham Road, Hong Kong	Lobby at G/F
Far East Finance Centre	16 Harcourt Road, Admiralty, Hong Kong	Public Places of G/F & UG/F
Citibank Tower	Citibank Tower, Citibank Plaza, 3 Garden Road, H. K.	48/F Citibank Tower
Pacific Palisades	1 Braemar Hill Road, North Point, Hong Kong	Podium Level 6, Main Club House
248 Queen's Road East, Wanchai, Hong Kong	248 Queen's Road East, Wanchai, Hong Kong	Office of the Commissioner on Interception of Communications and Surveillance, Unit 1501, 15/F.
Revenue Tower	5 Gloucester Road, Wanchai, Hong Kong	46/F - Whole Floor - EPD Headquarter
Cosco Tower, Grand Millennium Plaza	183 Queen's Road Central, Hong Kong	Public Area of the Building
Lower Block, Grand Millennium Plaza	181 Queen's Road Central, Hong Kong	Public Area of the Building
Cheung Kong Center	2 Queen's Road Central, Central, HK	62/F
Cheung Kong Center	2 Queen's Road Central, Central, HK	30/F
148 Electric Road	148 Electric Road, North Point, Hong Kong	1/F Main Lobby
Convention Plaza Apartments	South West Tower, 1 Harbour Road, Wanchai, Hong Kong	B/F, G/F, 11/F-46/F (Common Area)
Ruttonjee House	11Duddell Street, Central, H. K.	Offices Floors LG/F-22/F
Dina House	3-11 Duddell Street, Cental	Office Floors LG/F-20/F
Wong Nai Chung Municipal Services Building	2 Yuk Sau Street, Happy Valley, Hong Kong	3/F., Wong Nai Chung Public Library
WWF Hong Kong	No. 1 Tramway Path, Central, Hong Kong	Whole Building
Park Towers	1 King's Road, North Point, Hong Kong	P1 Main Lobby
Quarry Bay Municipal Services Building	38 Quarry Bay Street, Quarry Bay, Hong Kong	4/F & 5/F Quarry Bay Public Library
Stanley Municipal Services Building	6 Stanley Market Street, Stanley, HK	Whole Building

Wu Chung House	Wu Chung House, 213 Queen's Road East, HK	Lift Lobbies & Common Corridors of 22/F,26/F,28/F,35/F,36/F & 38/F, Wu Chung House, 213 Queen's Road East, HK
Citicorp Centre	18 Whitfield Road, Hong Kong	Public Area (Lobbies - Main, 3/F, 7/F, 8/F, 16/F, 17/F, 24/F, 28/F, 30/F, 31/F, 32/F & 36/F)
Convention Plaza Shopping Arcade	Convention Plaza Shopping Arcade, 1 Harbour Road, Wanchai, Hong Kong	M/F and 3/F communal areas
Bank of America Tower	12 Harcourt Road, Hong Kong	Public Area (All Floors)
Guangdong Investment Tower	148 Connaught Road Central, Hong Kong	Whole building - Public Areas
Chong Hing Bank Centre	24 Des Voeux Road Central, H.K.	Whole Building-Chong Hing Bank Centre,24 Des Voeux Road Central, H.K.
Marina House	68 Hing Man Street, Shaukeiwan, Hong Kong	Public Area of Whole Building
Hong Kong Squash Centre	23 Cotton Tree Drive, HK	2009 East Asian Games (HK) Limited at 2/F & 3/F
Paradise Mall, Heng Fa Chuen	G/F, Central Commerical Block, Paradise Mall, Heng Fa Chuen	Public Area, Central Commerical Block
Paradise Mall, Heng Fa Chuen	East and West Commerical Blocks, Paradise Mall, Heng Fa Chuen	Public Area, East and West Commerical Blocks
Fairmont House	8 Cotton Tree Drive, Central, Hong Kong	Public Area
The Centrium	60 Wyndham Street, Central, Hong Kong	UG/F & 1/F - Entrance Hall
Southorn Centre	130 Hennessy Road, Wanchai, Hong Kong	EPD's Offices at 24/F. 25/F. 26/F. 27/F. & 28/F. , FPAHK's Offices at G/F. 8/F. 9/F. & 10/F.
Revenue Tower	5 Gloucester Road, Wanchai, Hong Kong	Environmental Protection Department's Offices at 2/F. 40/F. 45/F. 47/F & 48/F
Wanchai Environmental Resource Centre	221 Queen's Road East, Wanchai, Hong Kong	Whole Building
The Center	99 Queen's Road Central, Central, Hong Kong	All air conditioned indoor common area: B1-B3/F lift lobbies, 1/F shopping mall, Lobbies floor of UG/F, 6/F & 42/F, lift lobbies of 9 - 12/F, 16-18/F, 21-23/F, 25/F, 29/F, 31/F, 38-39/F, 43/F, 45/F, 48/F, 50/F, 52/F, 59-60/F, 67/F, 69/F, 72-73/F and 75-79/F, lift lobby and corridor of 15/F, 19/F, 20/F, 26-28/F, 30/F,32/F, 35-37/F, 46-47/F, 49/F, 51/F, 53/F, 55-58/F, 61-63/F, 65-66/F and 68/F

Immigration Tower	7 Gloucester Road, Wanchai, Hong Kong	Innovation and Technology Commission, 35 - 36/F., Immigration Tower
Hong Kong Squash Centre	23 Cotton Tree Drive, Central, Hong Kong	Squash Centre (G/F & 1/F) LCSD
Hong Kong Park Sport Centre	29 Cotton Tree Drive, Central, Hong Kong	The whole building with 3 floors LCSD
Shell Tower, Times Square	1 Matheson Street, Causeway Bay, Hong Kong	38/Fand Room 3903-3911 "The Coca-Cola Export Corporation"
Hong Kong Film Archive	50 Lei King Road, Sai Wan Ho, Hong Kong	Whole Building
Queensway Government Offices	66 Queensway, Hong Kong	Queensway Government Offices 10/F-15/F, 17/F-19/F, 21/F-22/F, 28/F-30/F, 42/F-46/F and Part area of 20/F, 23/F and 47/F
Times Square - Tower One	1 Matheson Street, Causeway Bay, Hong Kong	14/F- 46/F Office Floors
Times Square - Shell Tower	1 Matheson Street, Causeway Bay, Hong Kong	15/F-39/F Office Floors
Immigration Tower	7 Gloucester Road, Wan Chai, Hong Kong	1/F, Water Supplies Department Customer Enquiry Centre, Immigration Tower Wan Chai
One Capital Place	18 Luard Road, Wanchai	5/F-26/F Lift Lobbies
World Trade Centre	280 Gloucester Road, Causeway Bay, Hong Kong	28/F -30/F Hong Kong Housing Society H.O.
Queensway Government Offices	66 Queensway, Hong Kong	Office areas on 31/F and 33/F to 41/F
Jardine House	1 Connaught Place, Central, Hong Kong	2/F-49/F Office Floor
1063 King's Road	1063 King's Road, Quarry Bay	Common Areas from 6/F to 30/F
Arsenal House East Wing	1 Arsenal Street, Wanchai, Hong Kong	The Whole Building
Dorset House	TaiKoo Place, 979 King's Road, HongKong	7/F & 11/F Citibank Office
Admiralty Centre - Tower I	18 Harcourt Road, Hong Kong	Public Area of Tower I - (4-32/F Lobbies)
WORLD WIDE HOUSE	19 DES VOEUX ROAD CENTRAL HONG KONG	PUBLIC AREA OF OFFICE BUILDING (G/F, 4-27/F LOBBIES AND CORRIDORS)
World Wide House	19 Des Voeux Road Central, Hong Kong	Public Area of Shopping Mall (1/F-3/F Common Corridors)
Admiralty Centre - Tower II	18 Harcourt Road, Hong Kong	Public Area of Tower II - (4-26/F Lobbies)
Police College (New Teaching Block)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Whole Building of New Teaching Block
Police College (Mini Range)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Simulator Rooms of Mini Range
Police College (JPO Mess)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Whole Building
Police College (Upper & Lower Gymnasiums)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	Whole Upper & Lower Gymnasium

Police College (James Morrin Building)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	G/F and 2/F where equipped with Central MVAC System
Police College (Officer's Mess)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Whole Building of Officer's Mess
Police College (Indoor Range)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Waiting Hall and Control Room
Police College (Tactics Training Complex)	18 Ocean Park Road, Wong Chuk Hang, Aberdeen, HK	The Whole Building of Tactics Training Complex
Sino Favour Centre	1 On Yip Street, Chai Wan, Hong Kong	Public Places including all Lobbies
StarCrest	9 Star Street, Wan Chai, Hong Kong	Tower 1 Entrance Hall - G/F, & Tower 2- Entrance Hall - G/F.
Southorn Centre	130 Hennessy Road, Wanchai, Hong Kong	Environmental Protection Department's Office at 5/F.

- Kowloon (Total 74 premises)

Name of building	Address	Certified location(s)
Chinachem Golden Plaza	77 Mody Road, Tsim Sha Tsui East, Kowloon	Room 1207, 1209 & 1213, Chinachem Golden Plaza
One Mongkok Road Commercial Centre	1 Mongkok Road, Kowloon	16/F to 19/F, One Mongkok Road Commercial Centre
Stelux House	698 Prince Edward Road East, San Po Kong, Kowloon	Common area of whole building
Nan Fung Commercial Centre	19 Lam Lok Street, Kowloon Bay, Kowloon	Environmental Protection Department's Office at 5/F
Kowloon Government Offices	405, Nathan Road, Kowloon, Hong Kong	Mainland North Division (14/F, KGO), Drainage Services Department
Two Harbourfront	No 22 Tak Fung Street, Hung Hom, Kowloon, Hong Kong	Public Areas, G/F - 20/F, Two Harbourfront
KMB Headquarters	No. 9 Po Lun Street, Lai Chi Kok, Kowloon, HK	Office Accommodation and Common Area of Whole Building
Nos. 132-134, Block 19, Shek Kip Mei Estate	Nos. 132-134, Block 19, Shek Kip Mei Estate, Kowloon, HK	Shek Kip Mei Post Office
Hospital Authority Building	147B Argyle Street, Kowloon	Room G09 (Biomedical Engineering Services Section)
Hospital Authority Building	147B Argyle Street, Kowloon	Room 312 (Biomedical Engineering Services Section)
Gateway II - Tower Five in Harbour City	The Gateway, Harbour City, Tower Five, Kowloon, Hong Kong	Public Area of the Building from 6/F to 23/F
Gateway II - Tower Three in Harbour City	The Gateway, Harbour City, Tower Three, Kowloon, Hong Kong	Public Area of the Building from 6/F to 23/F
Gateway I - Tower Two in Harbour City	The Gateway, Harbour City, Tower Two, Kowloon, Hong Kong	Public Area of the Building from 5/F to 36/F
Gateway II - Tower Six in Harbour City	The Gateway, Harbour City, Tower Six, Kowloon, Hong Kong	Public Area of the Building from 5/F to 39/F

Gateway I - Tower One in Harbour City	The Gateway, Harbour City, Tower One, Kowloon, Hong Kong	Public Area of the Building from 5/F to 36/F
New Mandarin Plaza	14 Science Museum Road, Tsim Shu Tsui East, Kowloon	Public Area of the Tower A (4/F - 13/F) and Tower B (4/F - 13/F)
Hong Kong Sheng Kung Hui Nursing Home	6 Chun Yan Street, Wong Tai Sin, Kowloon	G/F General Office & G/F Public Lobby
Centenary Building	1 To Wah Road, Jordan, Kowloon	M/F (office portion only),1/F,2/F,3/F,R/F (covered portion)
West Wing Office Building	New World Centre, 20 Salisbury Road, Tsim Sha Tsui, Kowloon	Common areas from 4th to 15th floor
Shek Kip Mei Park Sports Centre	290 Nam Cheong Street, Sham Shui Po, Kowloon, Hong Kong	Whole Building, Leisure and Cultural Services Department
Lai Chi Kok Park Sports Centre	1 Lai Wan Road, Lai Chi Kok, Kowloon, Hong Kong	Whole Building
Festival Walk Office Tower	80 Tat Chee Avenue, Kowloon Tong, Hong Kong	L3 (Suite 310)
Grand View Garden - Commercial Block	185 Hammer Hill Road, Diamond Hill, Kowloon	G/F., Commercial Block, Grand View Garden
Concordia Plaza	1 Science Museum Road, Tsimshatsui East, Kln	Ground Floor and First Floor Lobby
Tai Kok Tsui Municipal Services Building	63 Fuk Tsun Street, Tai Kok Tsui, Kowloon, Hong Kong	3/F., Tai Kok Tsui Public Library
Tai Kok Tsui Municipal Services Building	63 Fuk Tsun Street, Tai Kok Tsui, Kowloon, Hong Kong	Offices on 5/F
Tai Kok Tsui Municipal Services Building	63 Fuk Tsun Street, Tai Kok Tsui, Kowloon, Hong Kong	6/F., Children Play Room
Tai Kok Tsui Municipal Services Building	63 Fuk Tsun Street, Tai Kok Tsui, Kowloon, Hong Kong	Arena on 7/F
Education Bureau Kowloon Tong Education Services Centre	19 Suffolk Road, Kowloon Tong, Kowloon	Whole Building (except Exhibition Gallery and Central Resources Centre at Podium Level)
Ocean Centre in Harbour City	No.5 Canton Road, Tsim Sha Tsui, Kowloon, Hong Kong	Public Area of the Building from 5/F to 17/F
Wharf T&T Centre in Harbour City	No.7 Canton Road, Tsim Sha Tsui, Kowloon, Hong Kong	Public Area of the Building from 3/F to 17/F
World Finance Centre - North Tower in Harbour City	No.19 Canton Road, Tsim Sha Tsui, Kowloon, Hong Kong	Public Area of the Building from 4/F to 17/F
World Commerce Centre in Harbour City	No.11 Canton Road, Tsim Sha Tsui, Kowloon, Hong Kong	Public Area of the Building from 3/F to 17/F
World Finance Centre - South Tower in Harbour City	No.17 Canton Road, Tsim Sha Tsui, Kowloon, Hong Kong	Public Area of the Building from 4/F to 17/F
Housing Authority Headquarters Block 3	80 Fat Kwong Street, Homantin, Kowloon	Whole Block
New World Centre	New World Centre, 20 Salisbury Road, Tsimshatsui, Kowloon, Hong Kong	Retail Areas at B2/F, B1/F, L0/F, L1/F, L2/F and L3/F
New World Apartments	24 Salisbury Road, Tsimshatsui, Kowloon, Hong Kong	Common areas from 4th to 19th floor

Jockey Club Auditorium	The Hong Kong Polytechnic University, Hung Hom, Hong Kong	Public Area and Office of Jockey Club Auditorium
Communal Building	The HK Polytechnic University, Hung Hom, Hong Kong	Canteens, restuarants, offices, multi purpose rooms and public areas
Li Ka Shing Tower	The HK Polytechnic University, Hung Hom, Hong Kong	Restaurants, offices and classrooms of the buiding
Shaw Amenities Building	The HK Polytechnic University, Hung Hom, Hong Kong	Whole Building
Cheung Sha Wan Ambulance Depot	7 Fat Tseung Street, Cheung Sha Wan, Kowloon, Hong Kong	G/F Office & 1/F Dormitory
Olympian City 2	18 Hoi Ting Road, West Kowloon, Hong Kong	Standard Chartered Bank (HK) Ltd. - Olympian City Branch Shop Nos. 135 & 136
Homantin Government Offices	88 Chung Hau Street, Homantin, Kowloon	The Whole Building
The Metropolis Tower	19/F The Metropolis Tower, 10 Metropolis Drive, Hunghom, Kowloon	CANON HONGKONG CO., LTD.
Tsim Tung Fire Station	1 Hong Chong Road, Tsim Sha Tsui East, Kowloon, Hong Kong	Four Floors (G/F, M/F, 1/F, 2/F) Fire Station Department
Tsim Tung Fire Services Headquarters Building	1 Hong Chong Road,Tsim Sha Tsui East, Kowloon	Twelve Floors (G/F to 11/F) Fire Services Department
Ho Man Tin Sports Centre	1 Chung Yee Street, Ho Man Tin, Kowloon Hong Kong	Whole Building with 3 numbers of floor
Ko Shan Theatre	77 Ko Shan Road, Hung Hom, Kowloon, Hong Kong	Whole Building with 2 numbers of floors
Argyle Centre Phase 1	688 Nathan Road, Mongkok, Kowloon	Public Area of 7/F-20/F Office Tower
Housing Authority Headquarters Block 1 and 2	33 Fat Kwong Street, Homantin, Kowloon	Whole Block
Mongkok Government Offices	30 Luen Wan Street, Mongkok, Kowloon	Building Department, 1/F., Mongkok Government Offices
Civil Engineering and Development Building	101 Princess Margaret Road, Homantin, Kowloon	Whole Building
One Harbourfront	No. 18 Tak Fung Street, Hung Hom, Kowloon, HK	Public areas, G/F - 21/F One Harbourfront
To Kwa Wan Preliminary Treatment Works	Sung Ping Street, To Kwa Wan, Kowloon	G/F Control Room, 1/F Office & Rest Room
New East Ocean Centre	14/F & 15/F., New East Ocean Centre, 9 Science Museum Road, TSTE, Kowloon	14/F & 15/F., Office Area, Shun Hing Electronic Trading Co., Ltd
Argyle Street Water Workshop Depot	G/F, 128 Sai Yee Street, Mong Kok, Kowloon	Water Supplies Department Customer Enquiry Centre, G/F 128 Sai Yee Street, Mong Kok
Tsim Sha Tsui Centre	66 Mody Road, Tsim Sha Tsui East, Kowloon	Common Areas of Whole Building
Enterprise Square Two	No.3, Sheung Yuet Road, Kowloon Bay, Kowloon	Common Areas of Whole Building
Empire Centre	68 Mody Road, Tsim Sha Tsui East, Kowloon	Common Areas from G/F to 12/F

Wong Tai Sin Community Centre	104 Ching Tak Street, Wong Tai Sin	3/F., Wong Tai Sin Community Centre, Family and Child Protective Services Unit (WTS/SK)
Enterprise Square	No.9, Sheung Yuet Road, Kowloon Bay, Kowloon	Common Areas of Whole Building
Argyle Street Water Workshop Depot	128 Sai Yee Street, Mongkok, Kowloon	G/F to 5/F, Water Supplies Department Mongkok Office
APB Centre	9 Sung Ping Street, Hunghom, Kowloon	Office areas on 4/F to 9/F
East Kowloon Polyclinic	160 Hammer Hill Road, Diamond Hill, Kowloon	East Kowloon Psychiatric Centre (Social Welfare Department), 1/F., East Kowloon Polyclinic
Enterprise Square Three	Enterprise Square Three Management Office, 3/F Enterprise Square Three, 39 Wang Chiu Road, Kowloon Bay	Common Areas of the Whole Building
The Metropolis Tower	The Metropolis Tower, 10 Metropolis Drive, Hunghom, Kowloon	L7 Entrance Hall
Shek Kip Mei Fire Station	380 Nam Cheong Street, Shek Kip Mei, Kowloon	1/F & 2/F All area equipped with Central MVAC System
Clubhouse at King's Park Villa	King's Park Villa, No.1 King's Park Rise, Homantin, Kowloon	Common Floor Area of Clubhouse
King Fu Building	Shop 6E, 36-60F Tak Man Street, Phase 4, Whampoa Estate, Hunghom	Priority Banking Centre
Stonecutters Island Sewage Treatment Works	Ngong Shung Road, Ngong Shuen Chau, Kowloon	Whole the Administration Building and 2/F., Control Centre of Main Pumping House
Cheung Sha Wan Government Offices	303 Cheung Sha Wan Road, Kowloon	5/F-7/F; 8/F (Half-floor); 9/F (Rm 906,907,907A) of the Cheung Sha Wan Government Offices
Peninsula Centre	9/F Peninsula Centre, 67 Mody Road, Tsim Sha Tsui East, Kowloon	9/F Office, Shun Hing Technology Co., Ltd
Cheung Sha Wan Government Offices	303 Cheung Sha Wan Road, Cheung Sha Wan, Kowloon	Environmental Protection Department's Offices at 8/F.

- New Territories (Total 72 premises)

Name of building	Address	Certified location(s)
Tsuen Wan Government Office	38 Sai Lau Kok Road, Tsuen Wan	25/F & 26/F, Tsuen Wan Government Offices, Civil Engineering & Development Department
Block A, Eastern Sea Industrial Building	29-39 Kwai Cheong Road, Kwai Chung	Fountain Set (Holdings) Ltd. Office at 6/F & 7/F
Passenger Terminal Building	Hong Kong International Airport, Lantau, Hong Kong	Central Concourse (Departure Concourse) Public Areas
Passenger Terminal Building	Hong Kong International Airport, Lantau, Hong Kong	East Hall Public Areas (Levels 6 & 7)

Tin Chak Shopping Centre	Rm 313, Tin Chak Shopping Centre, Tin Chak Estate, Tin Shui Wai	Tin Shui Wai North Public Library
Cathay Pacific Catering Services	11 Catering Road East, Hong Kong International Airport, Lantau, Hong Kong	Cathay Pacific Catering Services 1/F Office Area
Shatin Government Offices	1 Sheung Wo Che Road, Shatin, N. T.	Environmental Protection Department, 10/F, Shatin Government Offices
Shell Administrative Building	Sai Tso Wan Road, Tsing Yi Island, New Territories, Hong Kong	Office area at G/F, 4/F, 5/F and Training Room at 2/F
AsiaWorld - Expo	Hong Kong International Airport, Lantau, Hong Kong	Office
The Hong Kong University of Science and Technology	Clear Bay, Sai Kung, Kowloon	Lecture Theatures A-H and Computer Barns Rm 1101 & 4210
On Ting / Yau Oi Community Centre	4/F., On Ting / Yau Oi Community Centre, On Ting Estate, Tuen Mun, N.T.	Family and Child Protective Services Unit ?
King Fat House	G/F, King Fat House, Cheung Fat Estate, Tsing Yi, N.T.	Kwai Chung (South) Social Security Field Unit
Passenger Terminal Building	Hong Kong International Airport, Lantau, Hong Kong	Northwest Concourse, West Hall and Southwest Concourse (Departures Concourse) Public Areas
The HAECO Administratoin Building	80 South Perimeter Road, Hong Kong International Airport, Lantau, Hong Kong	Office Areas at 2/F, 3/F & 4/F, HAECO Administration Building
Tsuen Wan Town Hall	72 Tai Ho Road, Tsuen Wan, N. T.	The Whole Building
The KCRC West Rail Building	No. 23 Kam Ho Road, Kam Tin, N.T., H.K.	Whole Building
Yeung UK Road Municipal Services Building	45 Yeung Uk Road, Tsuen Wan, NT.	4/F & 5/F Yeung Uk Road Sports Centre
Hong Kong Institute of Education - Tai Po Campus	10 Lo Ping Road, Tai Po, N.T.	Block A,B,C,D,E
Administration Building - Chemical Waste Treatment Centre	51 Tsing Yi Road South, Tsing Yi, N.T.	Office areas on 1/F, 2/F, 3/F & 4/F
Modern Terminals Ltd. - Warehouse Building, Phase 1	Berth One, Kwai Chung, Hong Kong	12/F-Control Centre
Modern Terminals Ltd.-T9 Main Office Building	Terminal Nine South, Tsing Yi, New Territories	Whole Building
Modern Terminals Ltd. - Warehouse Building, Phase II	Berth One, Kwai Chung, Hong Kong	Rooftop Office
Modern Terminals Limited - T9 Workshop Building	Terminal Nine South, Tsing Yi, New Territories	2/F - EPD Office
SuperTerminal 1	North Office Block, SuperTerminal 1, Hong Kong International Airport, Hong Kong	1/F Customer Service Hall, 6/F Canteen, 3/F & 4/F Cargo Handling (Workstations) Areas

Landmark North	39 Lung Sum Avenue, Sheung Shui	Units 2001-2006, Sheung Shui Job Centre, Labour Department
AsiaWorld-Expo	Hong Kong International Airport, Lantau, Hong Kong	Hall 1,2,3,5,6,7,8,9,10&11
Lai King Fire Station	6 Wa Tai Road, Kwai Chung, N.T.	Whole Building
CLP Tuen Mun Depot	Tuen Mun Depot, 25 Tseng Choi Street, Tuen Mun, New Territories	1/F Office
Tai Po Community Centre	1/F, Tai Po Community Centre, No.2 Heung Sze Wui Street, Tai Po	Social Welfare Department - Tai Po (South) Integrated Family Service Centre
Centralised Science Laboratories Building of CUHK	Campus of the Chinese University of Hong Kong, Tai Po	Common Area
Sheung Shui Police Station	Sha Tau Kok Road, Lung Yeuk Tau, Fanling N.T.	G/F Report Room & Closed Area Permit Office, 1/F Briefing Room & 2/F Interview Room
Dragonair & CNAC (Group) Building	11 Tung Fai Road, HK Int'l Airport, Lantau Island, HK	Recreation area, cafeteria, passenger lift lobbies & corridor of the building
Cathay Pacific City	8 Scenic Road, Hong Kong International Airport, Lantau, Hong Kong	Cathay Pacific City
The Edge	9 Tong Chun Street, Tseng Kwan O	Shopping Area on G/F & Level 1
Sha Tin Marriage Registry (Sha Tin Town Hall)	1 Yuen Wo Road, Shatin, N.T.	G/F., Whole Area of Sha Tin Marriage Registry
Tseung Kwan O Sport Centre	9 Wan Lung Road, Tseung Kwan O, Sai Kung	Whole Building with 2 numbers of floors
Kwai Tsing Theatre	12 Hing Ning Road, Kwai Chung, New Territories	Whole Building with 3 numbers of floor
Sha Tin Town Hall	1 Yuen Wo Road, Shatin, N.T.	Whole Building (excluding the portion of STMR)
Tseung Kwan O Public Library	9 Wan Lung Road, Tseung Kwan O, Sai Kung	Whole Building with 2 numbers of floors
Tai Po Civic Centre	12 On Pong Road, Tai Po, New Territories	Whole Building with 2 numbers of floor
North District Town Hall	2 Lung Wan Street, Sheung Shui, New Territories	Whole Building
Yuen Long Theatre	9 Yuen Long Tai Yuk Road, New Territories	The Whole Building
Leisure and Cultural Services Headquarters	1-3 Pai Tau Street, Shatin, N.T.	Whole Building with 18 numbers of floor
Ha Tsuen Sewage Pumping Station	70 Ping Ha Road, HA Tsuen, Tin Shui Wai, N.T.	G/F., Whole Office Area, Administrative Block, Drainage Services Department
Sham Tseng Sewage Treatment Works	33 Sham Tsz Street, Tsing Lung Tau, Tsuen Wan,N.T.	1/F Whole Floor (Admin. Block) & 1/F (Control Room)
Tsuen Wan Government Offices	38 Sai Lau Kok Road, Tsuen Wan, New Territories	Environmental Protection Department's Offices at 7/F., 8/F., 9/F., and 10/F

Tuen Mun Government Offices	1 Tuen Hi Road, Tuen Mun, N.T.	Water Supplies Department Customer Enquiry Centre, 7/F Tuen Mun Government Offices, N.T.
Shatin Government Offices Building	1 Sheung Wo Che Road, Shatin, N. T.	Room 348, Water Supplies Department Customer Enquiry Centre, 3/F Shatin Government Offices Building
Tai Po Government Offices	1 Ting Kok Road, Tai Po, N.T.	Water Supplies Department Customer Enquiry Centre 4/F, Tai Po Government Offices
Back-up Air Traffic Control Complex	25 Chung Cheung Road, HKIA Lantau Island	Whole Building
Government Accommodations	Grand Regentville, 9 Wo Mun Street, Luen Wo Hui, Fanling, New Territories	Fanling Environmental Resource Centre at 2/F
Kwai Chung Fire Station	77-79 Hing Shing Road, Kwai Chung, N.T.	1/F & 2/F All area equipped with Central MVAC System
Administration Building	Administration Building, Black Point Power Station, Yung Long Road, Lung Kwu Tan, Tuen Mun, New Territories	2/F Office
Control Building	Control Building, Black Point Power Station, Yung Long Road, Lung Kwu Tan, Tuen Mun, New Territories	G/F, 1/F & 2/F Office
Hau Tak Shopping Centre	Hau Tak Shopping Centre, Tseung Kwan O, N. T.	Standard Chartered Bank (Hong Kong) Ltd. - Tseung Kwan O Branch Shop Nos. G37-40
Passenger Terminal Building	Hong Kong International Airport, Lantau, Hong Kong	North Concourse, South Concourse, Transfer Areas E1 & E2 (Arrivals Level) Public Areas
Siu Ho Wan Sewage Treatment Works	Cheung Tung Road, Siu Ho Wan, Lantau Island	Whole Block of Administrative Building and Control & Switch Room of Centrifuge Building
Maritime Square	33 Tsing King Road, Tsing Yi, N.T.	Public Area of Shopping Mall (G/F,1/F,2/F&3/F)
Yoo Hoo Tower	38-42 Kwai Fung Crescent, Kwai Fong, N.T.	8/F, 38-42 Kwai Fung Crescent, Yoo Hoo Tower, Kwai Fong, N.T. Hong Kong Post
The Lane	Level 1, The Lane, 15 Pui Shing Road, Hang Hau, Tseung Kwan O	Shopping Area on Level 1
Sha Tin Sewage Treatment Works (Laboratory Building)	1 Shui Chong Street, Ma Liu Shui, Sha Tin, N. T.	Whole Block of Laboratory Building
Sha Tin Sewage Treatment Works (Administration Building)	No.1 Shui Chong Street, Ma Liu Shui, Sha Tin, N.T.	Whole Block of Administration Building

Sha Tin Sewage Treatment Works (Mechanical Workshop Building)	No.1, Shui Chong Street, Ma Liu Shui, Sha Tin, N.T.	G/F & 1/F All Areas where equipped with Central MVAC System (including Office, Conference Room and Information Technology Support Centre)
CLP Sheung Shui Depot	16 Ka Fu Close, Sheung Shui, New Territories	1/F Main Block
Passenger Terminal Building	Hong Kong International Airport, Lantau, Hong Kong	Baggage Reclaim Hall Public Areas
Chinachem Tsuen Wan Plaza	455-457 Castle Peak Road, Tsuen Wan, N. T.	Environmental Protection Department's Offices at 6/F & 7/F
Terminal 1, Hong Kong International Airport	Hong Kong International Airport, Lantau, Hong Kong	Northwest Concourse, Southwest Concourse, Transfer Areas W1 & W2 (Arrivals Level) Public Areas
Terminal 1, Hong Kong International Airport	Hong Kong International Airport, Lantau, Hong Kong	Arrivals Central Concourse Public Areas
Air Traffic Control Complex and Tower	1 Control Tower Road, HKIA, Lantau Island	Whole Building
Terminal 1, Hong Kong International Airport	Hong Kong International Airport, Lantau, Hong Kong	Departures Hall Public Areas
Visitor Centre of Hong Kong Wetland Park	Wetland Park Road, Tin Shui Wai, New Territories, Hong Kong	Whole Building
Terminal 1, Hong Kong International Airport	Hong Kong International Airport, Lantau, Hong Kong	Arrivals Hall Public Areas

Appendix B Summary of Air Quality Objectives / Guidance (Indoor and Ambient) in Hong Kong and Worldwide

Parameters	Unit of Concentration	Hong Kong	Australia	Canada	China	Japan	South Korea	Singapore	Finland	UK	EU	WHO	USA						
													NIOSH	OSHA	ACGIH[11f]	NAAQS[11g]	NRC[11h]	AIHA[11i]	USEPA[11j]
CO2	ppm (STEL: 15-min average)	30000[1c]	30000[2c]							15000[8a]			30000[11a]	30000[11e]	30000				
	ppm (TWA: 1-hour average)	2500[1h], 3500[1i]																	
	ppm (TWA: 8-hour average)	800[1a], 1000[1b]						1000[7a]		5000[8a]									
	ppm (TWA: 8-hour working day; 5-day working week)	5000[1c]	5000[2c]											5000[11d], 10000[11e]	5000				
	ppm (TWA: 10-hour workday during 40-hour workweek)												5000[11a]						
	ppm (TWA: 24-hour average)				1000[4a]														
	ppm (IDLH)												40000[11c], 50000[11b]						
	ppm (Maximum values)								700[12a], 900[12b], 1200[12c]										
	ppm (Allowable air concentration levels)																		800
	ppm (Exposed over a lifetime)			3500[3a]															
	ppm					1000[5a]	1000[6a]												
CO	ug/m3 (TWA: 5-min average)	115000[1e,1f,1g]																	
	ug/m3 (TWA: 15-min average)									232000[8c]		100000[10a]							
	ug/m3 (TWA: 30-min average)											60000[10a]							
	ug/m3 (TWA: 1-hour average)	30000[1g,1k]		29000[3b]	10000[4a,4b,4c], 20000[4d]	23000[5b]	29000[6e]					30000[10a]				40000			
	ug/m3 (TWA: 8-hour average)	2000[1a], 10000[1b,1k]	10000[2a,2b]	12600[3b]			10000[6e]	10000[7a]		11600[8b], 35000[8c]	10000[9b]	10000[10a]				10000			
	ug/m3 (TWA: 8-hour working day; 5-day working week)	29000[1c]	34000[2c]											40000[11e], 55000[11d]	29000				
	ug/m3 (TWA: 10-hour workday during 40-hour workweek)												40000[11a]						
	ug/m3 (TWA: 24-hour average)				4000[4b,4c], 6000[4d]	11500[5b]													
	ug/m3 [Emergency Exposure Guidance Levels 10-min EEGL (NRC 1987)]																1718000		
	ug/m3 [Emergency Exposure Guidance Levels 30-min EEGL (NRC 1987)]																916000		
	ug/m3 [Emergency Exposure Guidance Levels 60-min EEGL (NRC 1987)]																458000		
	ug/m3 [Emergency Exposure Guidance Levels 24-hour EEGL (NRC 1987)]																57000		
	ug/m3 (Ceiling)												229000[11a]	229000[11e]					
	ug/m3 (IDLH)												1374000[11c], 1718000[11b]						
	ug/m3 (Allowable air concentration levels)																		10000
	ug/m3 (Maximum values)								2000[12a], 3000[12b], 8000[12c]										
	ug/m3					11500[5a]	11500[6b,6c], 28600[6d]												
PM10	ug/m3 (TWA: 1-hour average)					200[5b]													
	ug/m3 (TWA: 8-hour average)	20[1a], 180[1b]																	
	ug/m3 (TWA: 24-hour average)	180[1k]			50[4b], 150[4a,4c], 250[4d]	100[5b]	150[6e]			50[8b]	50[9a]	50[10e], 75[10d], 100[10c], 150[10b]				150			
	ug/m3 (TWA: 1-year average)	55[1k]			40[4b], 100[4c], 150[4d]		70[6e]				20[9a (by 1 Jan 2010)], 40[9a (by end of 2004)]	20[10e], 30[10d], 50[10c], 70[10b]							
	ug/m3 (Maximum values)								20[12a], 40[12b], 50[12c]										
	ug/m3					150[5a]	100[6c], 150[6b], 200[6d]	150[7a]											
NO2	ug/m3 (TWA: 5-min average)	1800[1e,1f,1g]																	
	ug/m3 (STEL: 15-min average)	9400[1c]	9400[2c]										1800[11a]	1800[11e]	9400				
	ug/m3 (TWA: 1-hour average)	300[1g,1k]	320[2a]	480[3b]	120[4b], 120[4c], 240[4a,4d]		282[6e]			287[8b]	200[9a]	200[10a]							
	ug/m3 (TWA: 8-hour average)	40[1a], 150[1b]																	
	ug/m3 (TWA: 8-hour working day; 5-day working week)	5600[1c]	5600[2c]												5600				
	ug/m3 (TWA: 24-hour average)	150[1k]			80[4b,4c], 120[4d]	75-113[5b]	150[6e]												
	ug/m3 (TWA: 1-year average)	80[1k]			40[4b], 40[4c], 80[4d]		94[6e]				40[9a]	40[10a]				100			
	ug/m3 (5-min EEL; Emergency Exposure Limits)																	65800	
	ug/m3 (15-min EEL; Emergency Exposure Limits)																	47000	
	ug/m3 (30-min EEL; Emergency Exposure Limits)																	37600	
	ug/m3 (60-min EEL; Emergency Exposure Limits)																	18800	
	ug/m3 [1-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																1880		
	ug/m3 [2-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																940		
	ug/m3 [4-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																470		
	ug/m3 [8-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																230		
	ug/m3 [16-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																110		
	ug/m3 [24-hour SPEGL; Shortterm Public Emergency Guidance Levels (NRC 1985)]																80		
	ug/m3 (Ceiling)													9000[11d]					
	ug/m3 (IDLH)												37600[11c], 94100[11b]						
	ug/m3 (Eposed over a lifetime)			100[3a]															
O3	ug/m3 (STEL: 15-min average)									400[8a]				600[11d]					
	ug/m3 (TWA: 1-hour average)	240[1k]	210[2a,2b]	240[3b]	120[4b], 160[4a,4c], 200[4d]	120[5b]	200[6e]									240			
	ug/m3 (TWA: 4-hour average)		170[2a,2b]																
	ug/m3 (TWA: 8-hour average)	50[1a], 120[1b]					120[6e]	100[7a]		100[8b]	120[9c]	100[10e], 120[10a], 160[10b], 240[10f]				160			
	ug/m3 (TWA: 8-hour workshift of a 40-hour workweek)													200[11d,11e]					
	ug/m3 (Ceiling - Heavy Work)	100[1c]																	
	ug/m3 (Ceiling - Moderate Work)	160[1c]																	
	ug/m3 (Ceiling - Light Work)	200[1c]																	
	ug/m3 (Ceiling)		200[2c]										200[11a]		200				
	ug/m3 [1-hour EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																1960		
	ug/m3 [24-hour EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																200		
	ug/m3 (IDLH)												9820[11c], 19630[11b]						
	ug/m3 (Maximum values)								20[12a], 50[12b], 80[12c]										
HCHO	ug/m3 (TWA: 5-min average)			120[3b]															
	ug/m3 (STEL: 15-min average)		2500[2c]							2500[8a]				2450[11d]					
	ug/m3 (TWA: 30-min average)											100[10a]							
	ug/m3 (TWA: 1-hour average)	98.1[1l]			100[4a]														
	ug/m3 (TWA: 8-hour average)	30[1a], 100[1b]						120[7a]		2500[8a]									
	ug/m3 (TWA: 8-hour working day; 5-day working week)		1200[2c]											920[11d]					
	ug/m3 (TWA: 10-hour workday during 40-hour workweek)												20[11a]						
	ug/m3 (Ceiling)	370[1c]	120[2b]										120[11a]		370				
	ug/m3 (IDLH)												24540[11c], 36810[11b]						
	ug/m3 (Allowable air concentration levels)																		20 + outside air concentration
	ug/m3 (Target level)			60[3a]															
	ug/m3 (Maximum values)								30[12a], 50[12b], 100[12c]										
	ug/m3						120[6a]												
TVOC	ug/m3 (TWA: 1-hour average)		500[2b]																
	ug/m3 (TWA: 8-hour average)	200[1a], 600[1b]			600[4a]														
	ug/m3 (allowable air concentration levels)																		200 + outside air concentration
	ug/m3 (Maximum values)								200[12a], 300[12b], 600[12c]										
	ppm							3 (refer to toluene)[7a]											
Rn	Bq/m3 (TWA: 8-hour average)	150[1a], 200[1b]																	
	Bq/m3 (TWA: 48-hour average)	100 [preferably; 1d], 200[1d]																	
	Bq/m3 (TWA: 1-year average)		200[2b]	800[3a]	400[4a]				200[12d], 400[12e,12f]										
	Bq/m3 (Maximum values)								100[12a,12b], 200[12c]										
Airborne Bacteria	cfu/m3 (TWA: 8-hour average)	500[1a], 1000[1b]																	
	cfu/m3				2500[4a]		800[6c]	500[7a]											

Room Temperature	oC (TWA: 8-hour average)	20 - < 25.5[1a], < 25.5[1b]																	
	oC	20 - 28[1j]	20-26[2d]			17-28[5a]		22.5-25.5[7a]											
	oC (summer)				22-28 (summer)[4a]				23-24[12a], 23-26[12b], 22-27[12c]										
	oC (winter)				16-24 (winter)[4a]				21-22[12a], 20-22[12b], 20-23[12c]										
Relative Humidity	% (TWA: 8-hour average)	40 - < 70[1a], < 70[1b]																	
	%	40 - 70[1j]				40-70[5a]		≤70[7a]	25-45[12a]										
	% (summer)			30-80[3b]	40-80[4a]														
	% (winter)			30-55[3b]	30-60[4a]														
Air Movement	m/s (TWA: 8-hour average)	< 0.2[1a], < 0.3[1b]																	
	m/s					0.5[5a]		≤0.25[7a]											
	m/s (summer)				0.3[4a]														
	m/s (winter)				0.2[4a]														
	m/s (summer, 24oC)								0.2[12a], 0.25[12b], 0.3[12c]										
	m/s (winter, 20oC)								0.13[12a], 0.16[12b], 0.19[12c]										
	m/s (winter, 21oC)								0.14[12a], 0.17[12b], 0.2[12c]										
SO2	ug/m3 (TWA: 5-min average)	1000[1e,1g]		1000[3b]															
	ug/m3 (TWA: 10-min average)		700[2a,2b]									500[10a,10e]							
	ug/m3 (STEL: 15-min average)		13000[2c]										13000[11a]	13000[11e]	13000				
	ug/m3 (TWA: 15-min average)									266[8b]									
	ug/m3 (TWA: 1-hour average)	800[1g,1k]	570[2a,2b]		150[4b], 500[4a,4c], 700[4d]	262[5b]	390[6e]				350[9a]								
	ug/m3 (TWA: 3-hour average)															1300			
	ug/m3 (TWA: 8-hour working day; 5-day working week)		5200[2c]											5000[11e], 13000[11d]	5200				
	ug/m3 (TWA: 10-hour workday during 40-hour workweek)												5000[11a]						
	ug/m3 (TWA: 24-hour average)	350[1k]			50[4b], 150[4c], 250[4d]	105[5b]	130[6e]				125[9a]	20[10e], 50[10c], 125[10a,10b]				370			
	ug/m3 (TWA: 1-year average)	80[1k]	60[2a,2b]		20[4b], 60[4c], 100[4d]		52[6e]					50[10a]				80			
	ug/m3 [10-min EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																78700		
	ug/m3 [30-min EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																52400		
	ug/m3 [60-min EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																26200		
	ug/m3 [24-hour EEGL, Emergency Exposure Guidance Levels (NRC 1984)]																13100		
	ug/m3 (IDLH)												262200[11b,11c]						
	ug/m3 (Exposed over a lifetime)			50[3a]															
TSP	ug/m3 (TWA: 24-hour average)	260[1k]			120[4b], 300[4c], 500[4d]														
	ug/m3 (TWA: 1-year average)	80[1k]	90[2a,2b]		80[4b], 200[4c], 300[4d]														
	ug/m3 (allowable air concentration levels)																		20
Pb	ug/m3 (TWA: 8-hour working day; 5-day working week)		150[2c]											50[11d]	150				
	ug/m3 (TWA: 10-hour workday during 40-hour workweek)												50[11a]						
	ug/m3 (TWA: 3-month average)	1.5[1k]	1.5[2a,2b]		1.5[4b,4c,4d]											1.5			
	ug/m3 (TWA: 1-year average)				1[4b,4c,4d]		0.5[6e]			0.25[8b]	0.5[9a]	0.5[10a]							
	ug/m3 (IDLH)												100000[11c], 400000[11b; Effective], 700000[11b]						
FSP (PM2.5)	ug/m3 (TWA: 1-hour average)			100[3b]															
	ug/m3 (24-hour average)											25[10e], 37.5[10d], 50[10c], 75[10b]				35			
	ug/m3 (1-year average)											10[10e], 15[10d], 25[10c], 35[10b]				15			
	ug/m3 (Exposed over a lifetime)			40[3a]															
Fungal	cfu/m3							500[7a]											

Reference:

Hong Kong	1a	'Excellent Class' (8-hour average) in IAQ Objectives for Office Buildings and Public Places: Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places by Indoor Air Quality Management Group, The Government of the Hong Kong Special Adminstrative Region (September 2003)
	1b	'Good Class' (8-hour average) in IAQ Objectives for Office Buildings and Public Places: Guidance Notes for the Management of Indoor Air Quality in Offices and Public Places by Indoor Air Quality Management Group, The Government of the Hong Kong Special Adminstrative Region (September 2003)
	1c	A Reference Note on Occupational Exposure Limits for Chemical Substances in the Work Environment by Occupational Safety and Health Branch, The Labour Department (October 1998)
	1d	'Control of Radon Concentration in New Buildings' (ProPECC PN 1/99): Practice Note for Professional Persons by Environmental Protection Department
	1e	Practice Note on Control of Air Pollution in Vehicle Tunnels by Air Services Group of Environmental Protection Department (November 1995)
	1f	'Control of Air Pollution in Car Parks' (ProPECC PN 2/96): Practice Note for Professional Persons by Environmental Protection Department
	1g	'Control of Air Pollution in Semi-Confined Public Transport Interchanges' (ProPECC PN 1/98): Practice Note for Professional Persons by Environmental Protection Department
	1h	'Level 1' (1-hour average): Practice Note for Managing Air Quality in Air-conditioned Public Transport Facilities - Buses (ProPECC PN 1/03) / Railways (ProPECC PN 2/03) by Environmental Protection Department (November 2003)
	1i	'Level 2' (1-hour average): Practice Note for Managing Air Quality in Air-conditioned Public Transport Facilities - Buses (ProPECC PN 1/03) / Railways (ProPECC PN 2/03) by Environmental Protection Department (November 2003)
	1j	Practice Note for Managing Air Quality in Air-conditioned Public Transport Facilities - Buses (ProPECC PN 1/03) / Railways (ProPECC PN 2/03) by Environmental Protection Department (November 2003)
	1k	Hong Kong (Ambient) Air Quality Objectives: 'Technical Memorandum for Specifying Air Quality Objectives for Hong Kong' Air Pollution Control Ordinance (Cap. 311)
	1l	'Technical Memorandum for Issuing Air Pollution Abatement Notices to Control Air Pollution from Stationary Polluting Processes: Air Pollution Control Ordinance (Cap. 311)
Australia	2a	Goals for Maximum Permissible Levels of Pollutants in Ambient Air: Ambient Air Quality Goals recommended by the National Health and Medical Research Council (Published in 1996; Rescinded on 19 Mar 2002)
	2b	Goals for Maximum Permissible Levels of Pollutants in Indoor Air: Interim National Indoor Air Quality Goals recommended by the National Health and Medical Research Council (Published in 1996; Rescinded on 19 Mar 2002)
	2c	Exposure standards for atmospheric contaminants in the occupational environment - Worksafe Australia (National Occupational Health and Safety Commission) [NOHSC:1003(May 1995)]
	2d	Comfort at Work, Fact Sheet #21, NOHSC Publication, website, 2003
Canada	3a	Acceptable Long-Term Exposure Range (ALTER) [Exposed over a lifetime]: Exposure Guidelines for Residential Indoor Air Quality by Health Canada [April 1987; Revised July 1989]
	3b	Acceptable Short-Term Exposure Range (ASTER): Exposure Guidelines for Residential Indoor Air Quality by Health Canada [April 1987; Revised July 1989]
	3c	Exposure Guidelines for Residential Indoor Air Quality by Health Canada [April 1987; Revised July 1989]
China	4a	Indoor Air Quality Standard, China Standard (GB/T 18883-2002)
	4b	Grade 1 of Concentration Limit: China's National Ambient Air Quality Standards (Standard No. GB3095-1996)
	4c	Grade 2 of Concentration Limit: China's National Ambient Air Quality Standards (Standard No. GB3095-1996)
	4d	Grade 3 of Concentration Limit: China's National Ambient Air Quality Standards (Standard No. GB3095-1996)
Japan	5a	The Law for Maintenance of Sanitation in Buildings in Japan
	5b	Environmental Quality Standards in Japan, Ministry of the Environment, Government of Japan
South Korea	6a	Indoor Air Quality Management Act (2004)
	6b	Indoor Air Quality Management Act (2004): Subway stations, underground markets, libraries, museums, galleries, funeral houses, saunas
	6c	Indoor Air Quality Management Act (2004): Medical centers, childcare centers, medical centers for elders, maternity recuperation centers
	6d	Indoor Air Quality Management Act (2004): Indoor parking lots
	6e	Environmental Quality Standards, Ministry of the Environment, Republic of Korea
Singapore	7a	Guidelines for Good Indoor Air Quality in Office Premises: Institute of Environmental Epidemiology, Ministry of the Environment (October 1996)
UK	8a	Workplace Exposre Limits (EH40/2005), Health and Safety Commission, The Control of Substances Hazardous to Health Regulations 2002
	8b	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland
EU	9a	First Air Quality Daughter Directive. Council Directive 1999/30/EC
	9b	Second Air Quality Daughter Directive. Council Directive 2000/69/EC
	9c	Air Quality Directive for Ozone. 2002/3/EC
WHO	10a	Air Quality Guidelines for Europe, Second edition: WHO Regional Publications, European Series, No. 91, World Health Organization 2000
	10b	WHO interim target 1 (IT-1): Air Quality Guidelines Global Update 2005, World Health Organization 2006
	10c	WHO interim target 2 (IT-2): Air Quality Guidelines Global Update 2005, World Health Organization 2006
	10d	WHO interim target 3 (IT-3): Air Quality Guidelines Global Update 2005, World Health Organization 2006
	10e	WHO air quality guidelines (AQG): Air Quality Guidelines Global Update 2005, World Health Organization 2006
	10f	High level: Air Quality Guidelines Global Update 2005, World Health Organization 2006
NIOSH	11a	Recommended exposure limits (RELs) [10-hour workday during a 40-hour workweek]: National Institute for Occupational Safety and Health
	11b	Immediately Dangerous to Life and Health [Original (SCP) IDLH]
	11c	Immediately Dangerous to Life and Health [Revised IDLH]
OSHA	11d	Permissible exposure limits (PELs) / Short-term exposure limit (STEL): Occupational Safety and Health Administration, Current
	11e	Permissible exposure limits (PELs) / Short-term exposure limit (STEL): Occupational Safety and Health Administration, 1989
ACGIH	11f	Threshold Limit Values (TLV): American Conference of Governmental Industrial Hygienists (1993/94)
NAAQS	11g	National Ambient Air Quality Standards (NAAQS) [2006]
NRC	11h	National Research Council
AIHA	11i	American Industrial Hygiene Association [1964]
USEPA	11j	Maximum Allowable Air Concentration Standards for EPA Buildings (1996)
Finland	12a	Individual Indoor Climate (S1): Classification of Indoor Climate 2000. Target values, design guidance and product requirements, Finnish Society of Indoor Air Quality and Climate
	12b	Good Indoor Climate (S2): Classification of Indoor Climate 2000. Target values, design guidance and product requirements, Finnish Society of Indoor Air Quality and Climate
	12c	Satisfactory Indoor Climate (S3): Classification of Indoor Climate 2000. Target values, design guidance and product requirements, Finnish Society of Indoor Air Quality and Climate
	12d	Radon concentration in the room air for new residences, the Ministry of Social Affairs and Health
	12e	Radon concentration in residences, the Ministry of Social Affairs and Health
	12f	Radon concentration in work places during working hours, the Ministry of Social Affairs and Health

Appendix C Environmental Legislation for Air Pollution Control in Hong Kong

Year	Legislation	Description of Control
1933	Summary Offences Ordinance (Cap. 228)	Provides for the control on dropping dirt in a public place, for example from trucks onto a public road.
1960	Public Health and Municipal Services Ordinance (Cap. 132)	Makes provision for urban services and public health, including control of nuisance caused by emissions of fumes.
1962	Building (Demolition Works) Regulations (Cap.123)	Regulates building demolition, including prevention of nuisance.
1972	Air Pollution Control (Furnaces, Oven and Chimneys) (Installation and Alteration) Regulations	Requires prior approval to ensure suitable design for the installation and alteration of furnaces, ovens and chimneys.
1974	Air Pollution Control (Dust and Grit Emission) Regulations	Stipulates the emission standards, assessment procedures and requirements for particulate emissions from stationary combustion sources.
1978	Shipping and Port Control Ordinance (Cap. 313)	Regulates and controls ports, vessels and navigation, including control of smoke emissions.
1983	Air Pollution Control Ordinance (Cap. 311)	Provides for the control of air pollution from stationary sources and motor vehicles. Also enables promulgation of regulations (as below).
	Air Pollution Control (Appeal Board) Regulations	Stipulates the procedures and run down of an appeal.
	Air Pollution Control (Smoke) Regulation	Restricts emission of dark smoke from stationary combustion sources.
1984	Road Traffic Ordinance (Cap. 374)	Regulates road traffic, vehicle and users of roads and related matters; includes provisions to limit pollution from vehicles.
	Road Traffic (Construction and Maintenance of Vehicles) Regulations	Specifies emission limits for in-service vehicles.
1987	Air Pollution Control (Specified Processes) Regulations	Provides the administrative framework for the licensing of Specified Processes.
1989	Ozone Layer Protection Ordinance (Cap. 403)	Gives effect to Hong Kong's international obligations under the 1985 Vienna Convention, the 1987 Montreal Protocol and any amendments to control the manufacture, import and export of ozone depleting substances.
1990	Air Pollution Control (Fuel Restriction) Regulations	Prohibits the use of high sulphur content solid and liquid fuel for commercial and industrial appliances. (In Shatin, only gaseous fuel is allowed except for the appliances used in construction sites or for emergency purposes.)
1992	Air Pollution Control (Vehicle Design Standards) (Emission) Regulations	Sets out the emission standards for newly registered vehicles.
1993	Air Pollution Control (Air Control Zones) (Declaration) (Consolidation) Order	Provides for consolidated declaration of Air Control Zones.
	Ozone Layer Protection (Products Containing Scheduled Substances) (Import Banning) Regulation	Prohibits the import of portable fire extinguishers containing halons from all countries and other controlled products from a country or place not a party to the Montreal Protocol unless the Authority considers that it complies with the requirements of the Protocol.

1993 and 1994	Air Pollution Control (Specified Processes) (Specification of Required Particulars and Information) Order	Provides for the supply of information and specifications by owners of certain existing specified processes to the Air Pollution Control Authority.
1993, 1994 and 1996	Air Pollution Control (Specified Processes) (Removal of Exemption) Order	Removes the exemption granted to the owner of premises for conduct of certain specified processes.
1994	Air Pollution Control (Motor Vehicle Fuel) Regulation	Sets out the specifications of liquid motor vehicle fuel to be used in motor vehicles and prohibits the sale of leaded petrol.
	Ozone Layer Protection (Controlled Refrigerants) Regulation	Requires the conservation of controlled refrigerants used in large scale installations and motor vehicles.
1996	Air Pollution Control (Asbestos) (Administration) Regulation	Provides for the qualifications and fees for registration of asbestos consultants, contractors, supervisors and laboratories.
	Air Pollution Control (Open Burning) Regulation	Prohibits open burning of construction waste, tyres and cables for metal salvage, and controls other open burning activities by permit system.
1997	Air Pollution Control (Construction Dust) Regulation	Requires contractors to take dust reduction measures when construction work is being carried out.
1999	Air Pollution Control (Petrol Filling Stations) (Vapour Recovery) Regulation	Requires petrol dispensers and petrol storage tanks of petrol filling stations and petrol delivery vehicles to be equipped with effective vapour recovery systems and to observe good practice during petrol unloading and vehicle refuelling.
2001	Air Pollution Control (Dry-cleaning Machines) (Vapour Recovery) Regulation	Requires dry-cleaning machines using PCE as a dry-cleaning agent to be equipped with a vapour recovery system and to meet the stipulated emission standard.
2003	Air Pollution Control (Emission Reduction Devices for Vehicles) Regulation	Requires pre-Euro light diesel vehicles up to 4 tonnes to have emission reduction devices for licence renewal.

Appendix D Site Information of Fixed Network Monitoring Stations

Monitoring Station	Building (Address)	Area Type [described from EPD annual report]	Sampling Height (Above Principal Datum of H.K.)	Above Ground	Date Start Operation
A. Existing General Air Quality Monitoring Station					
Central/Western (CW)	Upper Level Police Station (1 High Street, Sai Ying Pun)	**Urban: Mixed residential/commercial** [2003-now] Urban: Residential [1983-2002]	78m	18m (4 floors)	Nov 1983
Eastern (EN)	Sai Wan Ho Fire Station (20 Wai Hang Street, Sai Wan Ho)	**Urban: Residential** [1999-now]	28m	**15m (4 floors)** [2002-now] 17.5m (4 floors) [1999-2001]	Jan 1999
Kwai Chung (KC)	Kwai Chung Police Station (999 Kwai Chung Road, Kwai Chung)	**Urban: Mixed residential/commercial/industrial** [1999-now]	19m	13m (2 floors)	Jan 1999
	Chen Zao Man College (1-5 Kwai Hop Street, Kwai Hing)	Urban: Mixed residential/commercial/industrial [1998] Industrial: Mixed industrial/residential [1994-97] Urban: Mixed residential/industrial [1988-93]	82m	25m (6 floors)	Jul 1988 [closed in Dec 1998]
Kwun Tong (KT)	City District Office (6 Tung Yan Street, Kwun Tong)	**Urban: Mixed residential/commercial/industrial** [1998-now] Industrial: Mixed Industrial/Residential [1997] Industrial: Industrial (to West) Residential (to East) Urban: Residential [1995-96] Industrial: Industrial (to West) Residential (to East) [1983-94]	34m	25m (6 floors)	Jul 1983
Sham Shui Po (SSP)	Police Station (37A Yen Chow Street, Sham Shui Po)	**Urban: Mixed residential/commercial** [1998-now] Urban: Mixed commercial/residential/industrial [1983-97]	21m	17m (4 floors)	Jul 1984

Appendix D Site Information of Fixed Network Monitoring Stations (continued)

Monitoring Station	Building (Address)	Area Type [described from EPD annual report]	Sampling Height (Above Principal Datum of H.K.)	Above Ground	Date Start Operation
A. Existing General Air Quality Monitoring Station (continued)					
Sha Tin (ST)	Sha Tin Govt. Secondary School (11-17 Man Lai Road, Tai Wai, Sha Tin)	**New Town: Residential** [1998-now] New Development: Mixed residential/industrial [1994-97] Urban: Mixed residential/industrial [1991-93]	27m	21m (5 floors)	Jul 1991
Tung Chung (TC)	Tung Chung Health Centre (6 Fu Tung Street, Tung Chung)	**New Town: Residential** [1999-now]	28m	21m (4 floors)	Apr 1999
Tap Mun (TM)	Tap Mun Police Station (Tap Mun)	**Background: Rural** [1998-now]	26m	11m (3 floors)	Apr 1998
Tai Po (TP)	Tai Po Govt. Office Bldg. (1 Ting Kok Road, Tai Po)	**New Town: Residential** [1998-now] New Development: Residential [1994-97] Urban: Residential [1990-93]	31m	25m (6 floors)	Feb 1990
Tsuen Wan (TW)	Princess Alexandra Community Centre (60 Tai Ho Road, Tsuen Wan)	**Mixed residential/commercial/industrial** [1998-now] Industrial: Mixed commercial/residential [1994-97] Urban: Mixed residential/industrial [1988-91, 93] Urban: Mixed commercial/residential [1992]	21m	17m (4 floors)	Aug 1988
Yuen Long (YL)	Yuen Long District Branch Offices Bldg. (269 Castle Peak Road, Yuen Long)	**New Town: Residential** [2002-now] New Town: Residential with fairly rapid development [1998-2001] New Development: Residential [1995-97]	31m	25m (6 floors)	Jul 1995

Appendix D Site Information of Fixed Network Monitoring Stations (continued)

Monitoring Station	Building (Address)	Area Type [described from EPD annual report]	Sampling Height (Above Principal Datum of H.K.)	Above Ground	Date Start Operation
B. Existing Roadside Air Quality Monitoring Station					
Causeway Bay (CB)	(1 Yee Woo Street, Causeway Bay)	**Urban Roadside: Busy commercial/residential area surrounded by many tall buildings** [2003-now] Urban Roadside: Busy commercial area surrounded by many tall buildings [1998-2002]	6.5m	**3m** [2001-now] 2m [1998-2000]	Jan 1998
	Police Station (152 Electric Road, Causeway Bay)	Urban: Commercial/Residential [1982-90]	18m	14m (3 floors)	Oct 1982 [closed in Jul 1990]
Central (CL)	Junction of Des Voeux Road Central and Charter Road, Central	**Urban Roadside: Busy commercial/financial area surrounded by many tall buildings** [1998-now]	8.5m	4.5m	Oct 1998
Mong Kok (MK)	Junction of Nathan Road and Lai Chi Kok Road	**Urban Roadside: Busy commercial/residential area surrounded by many tall buildings** [2002-now] Urban Roadside: Mixed residential/commercial area surrounded by some moderately tall buildings [2001]	8.5m	3m	Jan 2001
	Mong Kok Rd. Pumping Station (4E Mong Kok Road, Mong Kok)	Urban Roadside: Mixed residential/commercial area surrounded by some moderately tall buildings [1998-2000] Ground Level Monitoring Station [1991-97]	7m	2m (1 floor)	Apr 1991 [closed in Sep 2000]
C. Past General Air Quality Monitoring Station					
Tsim Sha Tsui (TST)	Empire Centre (68 Mody Rd, Tsim Sha Tsui East, Kowloon)	Urban: Commercial / Hotel [1982-93]	54m	50m (12 floors)	Mar 1982 [closed in Aug 1993]
Junk Bay (JB)	Haven of Hope Sanatorium (Nansen Bldg., Po Lam Rd., Junk Bay)	Rural: with some industrial [1981-93]	46m	13m (3 floors)	Jul 1981 [closed in Apr 1993]
Hong Kong South (HKS)	Pokfulam Fire Services Officers Married Qtr. (789 Pokfulam Rd., H.K.)	Urban: Residential [1989-93]	150m	90m (26 floors)	Sep 1989 [closed in Jul 1993]

Building Evaluation (Indoor Air Quality) Form

Indoor Air Quality Survey

Name of building 樓字名稱 : ____

Address of building 樓字地址 : ____

Completed by 填寫人 : ___________________________ Date 日期 : _____________________

Telephone no. 電話 : _____________________________ E-mail address 電郵 : ______________________

Please fill in the following information and it will be treated in confidence.
請填妥以下資料及這些資料將絕對保密。

Note : Please either give a tick (✓) to the square boxes or fill in blanks as indicated.
請在方格內劃上(✓)或在空格上填上適當的資料。

I. Building Information 樓字資料

1. Building function 樓字類型 : ☐ Office 寫字樓 ☐ Residential 住宅 ☐ Industrial 工業 ☐ Shopping Arcade 商場 ☐ Mixed-use 多用途 : _________________ ☐ Other 其他 : ______________________

2. Building age 樓字年齡 : _____________ (Opened from year 開業年份 : __________)

3. Building Owner 業主 : ____

4. Property Manager 物業管理 : ______________________________________

5. E & M maintenance 機電維修 : ____________________________________

6. No. of floor 樓層 : _____________

7. Total floor area (m^2) 總樓面面積 (平方米) : _______________

8. Any default of building facade ? 樓字外牆有沒有缺陷 ? ☐ Yes 有 ☐ No 無

   If "Yes", what is the default ? ____
   如"有",這缺陷是甚麼 ? ____

II. Outdoor Environmental Information 室外環境資料

1. Where is the building sited at ? 樓字置身在何處? ☐ Commercial area 商業區 ☐ Residential area 住宅區 ☐ Industrial area 工業區 ☐ Countryside 郊區 ☐ Other 其他 : __________________

2. Any outdoor air quality monitoring ? ☐ Yes 有 ☐ No 無
   有沒有對室外空氣質素進行監察?
   If "Yes", which pollutant(s) are being monitored ? ____
   如"有",監察的污染物是甚麼?

3. Any weather data monitoring ? ☐ Yes 有 ☐ No 無
   有沒有對室外天氣進行監察?
   If "Yes", which parameter(s) are being monitored ? ____
   如"有",監察的內容是甚麼?

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III. HVAC System Information 空調系統資料

A. Fresh Air System 鮮風系統

1. Description of system : ______________________________
   系統描述： ______________________________

A1. First Tier 第一段 [from outdoor air intake to front end equipment, e.g. PAU 由鮮風入口至前置鮮風設備]

1. Type of system : ______________________________
   系統種類：

2. Specification of front end equipment :
   鮮風系統設備之規格：

Item no. 編號	Location 位置	Location of fresh air intake 鮮風入口位置	Total flow rate 總風量	Power consumption 耗電功率	Delivery path 送風途徑	Type of filter used 過濾器類型	
						Pre-filter 前置過濾器	Filter 過濾器

3. Ducting of fresh air system : ☐ Direct ducting from outdoor air lourve to front end equipment
   鮮風系統風管佈置 鮮風管直接由外牆百頁連接到鮮風機組
   ☐ No direct ducting
   沒有直接風管連接

4. Any air control damper at this tier ? ☐ Yes 有 ☐ No 無
   在這一段,有沒有控制閥？
   Control principle / sequence : ______________________________
   控制原理 / 次序： ______________________________

5. Any other control which affect the flow rate of fresh air at this tier ? ☐ Yes 有 ☐ No 無
   在這一段,有沒有其他控制影響鮮風風量？
   What is the control ? ______________________________
   這控制是甚麼？
   Control principle / sequence : ______________________________
   控制原理 / 次序： ______________________________

6. Performance 表現： ☐ Acceptable 可接受 ☐ Unacceptable 不可接受
   Reason 理由： ______________________________

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A2. Second Tier 第二段 [Fresh air distribution duct from front end equipment to rear end equipment, e.g. AHU 送風系統由前置鮮風設備至後置鮮風設備之送風槽]

1. Type of system : ____
   系統種類:

2. Any air control damper at this tier ? ☐ Yes 有 ☐ No 無
   在這一段,有沒有控制閥?

   Control principle / sequence : ____

   控制原理/次序: ____

3. Any other control which affect the flow rate of fresh air at this tier ? ☐ Yes 有 ☐ No 無
   在這一段,有沒有其他控制影響鮮風風量?

   What is the control ? ____
   這控制是甚麼?

   Control principle / sequence : ____

   控制原理/次序: ____

4. Performance 表現: ☐ Acceptable 可接受 ☐ Unacceptable 不可接受

   Reason 理由: ____

   ____

A3. Third Tier 第三段 [from rear end equipment to occupied zone 由後置鮮風設備至用戶區]

1. Type of system : ____
   系統種類:

2. Specification of the rear end equipment :
   送風系統設備之規格:

Item no. 編號	Floor no. 樓層	Source of fresh air 鮮風來源	Flow rate 風量		Power consumption 耗電功率	Delivery path 送風途徑	Type of filter used 過濾器類型	
			Supply air 出風	Fresh air 鮮風			Pre-filter 前置過濾器	Filter 過濾器

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4. Ducting of A/C system : 送風系統風管
   - ☐ Direct ducting among fresh air duct, return air duct and rear end equipment 鮮風管及回風管直接連接到風機組
   - ☐ Room mixing, No direct air ducting to rear end equipment 風機房混風,沒有直接風管連接到風機組

5. Any air control damper at this tier ? 在這一段,有沒有控制閥? ☐ Yes 有 ☐ No 無

   Control principle / sequence : ____________________

   控制原理/次序: ____________________

6. Any other control which affect the flow rate of fresh air at this tier ? 在這一段,有沒有其他控制影響鮮風風量? ☐ Yes 有 ☐ No 無

   What is the control ? 這控制是甚麼? ____________________

   Control principle / sequence : ____________________

   控制原理/次序: ____________________

7. Performance 表現: ☐ Acceptable 可接受 ☐ Unacceptable 不可接受

   Reason 理由: ____________________

   ____

A4. Fourth Tier 第四段 [Occupied zone 用戶區]

1. Type of system : 系統種類: ____________________

2. Any air control damper at this tier ? 在這一段,有沒有控制閥? ☐ Yes 有 ☐ No 無

   Control principle / sequence : ____________________

   控制原理/次序: ____________________

3. Any other control which affect the flow rate of fresh air at this tier ? 在這一段,有沒有其他控制影響鮮風風量? ☐ Yes 有 ☐ No 無

   What is the control ? 這控制是甚麼? ____________________

   Control principle / sequence : ____________________

   控制原理/次序: ____________________

4. Performance 表現: ☐ Acceptable 可接受 ☐ Unacceptable 不可接受

   Reason 理由: ____________________

   ____

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B. Air side equipment

1. Specification of any other air side equipment (e.g. supply air fan, exhaust fan) :
其他送風系統設備(如:送風扇,排氣扇)之規格:

Item no. 編號	Floor no. 樓層	Purpose 用途	Flow rate 風量	Power consumption 耗電功率	Delivery path 送風途徑	Type of filter used 過濾器類型

C. Documentation 資料儲存

	Well documented 齊全	Incomplete 不齊全	No documented 沒有	Remark 備註
1. Design stage 設計階段				
- Contract drawing 合約圖紙	☐	☐	☐	________________
- Specification 規範	☐	☐	☐	________________
- Design intent 設計概念 (e.g. Number of people 設計人數, Design criteria 設計標準)	☐	☐	☐	________________
2. Completion stage 完成階段				
- As-fitted drawing 竣工圖紙	☐	☐	☐	________________
- T & C report 調試報告	☐	☐	☐	________________
- O & M manual 操作及維修手冊	☐	☐	☐	________________
3. Current stage 現階段				
- Tenant drawing 租戶竣工圖紙	☐	☐	☐	________________
- Tenant specification 租戶設計規範	☐	☐	☐	________________
- Tenant T & C report 租戶調試報告	☐	☐	☐	________________
- Tenant O&M manual 租戶操作及維修手冊	☐	☐	☐	________________

D. Operation 操作

1. Operation schedule for fresh air system :
鮮風系統操作時間表:

Summer Mode 夏季時間 : Monday – Friday 星期一至五 : ______________________
Saturday 星期六 : ______________________
Sunday 星期日 : ______________________

Winter Mode 冬季時間 : Monday – Friday 星期一至五 : ______________________
Saturday 星期六 : ______________________
Sunday 星期日 : ______________________

2. Operation Principle : ____
操作原理: ____
____

E. Maintenance 維修保養

1. Inspection & cleaning schedule 巡查及清潔時間表:

Equipment	Location	Inspection Frequency	Cleaning Frequency	Replacement Frequency
PAU				
AHU				
Fan coil unit				
Terminal unit				
Chiller				
Cooling tower				
Drain pan				
Heating & cooling coils				
Air Ductwork				
Diffuser				
Plantroom				

2. Any major system change or maintenance after completion ?
在工程完成後,有沒有重大系統修改或維修?

Date 日期	Description 內容	Purpose 目的	Location 範圍

3. Maintenance schedule related to IAQ :
有關室內空氣質素的維修保養:

Description 內容	Type of work 工作類型	Tool 用品	Frequency 頻率

E. Indoor Air Quality Monitoring 室內空氣質素監察

1. Any indoor air quality monitoring ? ☐ Yes 有 ☐ No 無
有沒有對室內空氣質素進行監察?
If "Yes", which pollutant(s) are being monitored ? ______________________________
如"有",監察的污染物是甚麼?

IV. Pollutant Inventory 污染物清單

A. Building material 樓宇用料

Description 內容	Any Material Safety Data Sheet? (Y/N) 有沒有物料安全資料? (有/無)	Pollutant Content 污染物內容	Emission rate 釋放率

B. Routine work (e.g. cleaning, pest control, O&M) 日常工作(如：清潔,滅蟲,維修保養)

Description 內容	Any Material Safety Data Sheet? (Y/N) 有沒有物料安全資料? (有/無)	Pollutant Content 污染物內容	Emission rate 釋放率

C. Occupant material 租戶用料

Description 內容	Any Material Safety Data Sheet? (Y/N) 有沒有物料安全資料? (有/無)	Pollutant Content 污染物內容	Emission rate 釋放率

D. Temporary work (e.g. renovation work) 臨時工作

Description 內容	Any Material Safety Data Sheet? (Y/N) 有沒有物料安全資料? (有/無)	Pollutant Content 污染物內容	Emission rate 釋放率

V. Occupancy Information 租戶資料

1. List of occupancy 租戶清單

Floor no. 樓層	Company name 公司名稱	Type of business 公司業務	Work activity 工作性質	Floor area 樓面面積	Population 公司人數	Working schedule 工作時間	Policy on smoking 吸煙政策

2. Complaint record (last one year) 投訴記錄(最近一年)

Floor no. 樓層	Thermal comfort 熱舒適	Noise 噪音	IAQ 室內空氣質素	Water damage 水破壞	System defect 系統故障	Others 其他	Total 總數

VI. Overall comment 整體評論

1. Overall Performance on IAQ 整體表現： ☐ Acceptable 可接受 ☐ Unacceptable 不可接受

2. Any subjective enhancement 建議： ____

____

3. Comment on the IAQ in this building :
對於這大樓之室內空氣質素意見：

____

____

4. Comment on the outdoor air quality around this building :
對於這大樓之室外環境空氣質素意見：

____

____

VII. Required document checklist 所需文件清單

1. Outdoor Environmental Information 室外環境資料

(a) Outdoor air quality monitoring record 室外空氣質素監察記錄	☐ Yes 有	☐ No 無
(b) Weather data monitoring record 室外天氣監察記錄	☐ Yes 有	☐ No 無

2. HVAC System Information 空調系統資料

(a) Original design intent 原設計資料	☐ Yes 有	☐ No 無
(b) Equipment schedule / Specification of air-side equipment (e.g. PAU, AHU, FCU, fan, filter) 送風系統之設備表 / 規格 (如：新風機，空氣處理機，風機盤管，風機，過濾器)	☐ Yes 有	☐ No 無
(c) Testing & commissioning report of air-side equipment 送風系統之調試報告	☐ Yes 有	☐ No 無
(d) Drawings 圖紙		
- HVAC schematic drawing (Air-side) 空調系統圖 (送風)	☐ Yes 有	☐ No 無
- HVAC system layout plan 空調系統平面佈置圖	☐ Yes 有	☐ No 無
- Furniture layout drawing 傢具平面佈置圖	☐ Yes 有	☐ No 無

3. Indoor Air Quality Monitoring Record 室內空氣質素監察記錄	☐ Yes 有	☐ No 無
4. Material Safety Data Sheet 物料安全資料	☐ Yes 有	☐ No 無
5. Complaint Record from Occupants 租戶投訴記錄	☐ Yes 有	☐ No 無

--- END ---
*** 結束 ***

Walkthrough Survey Form

Indoor Air Quality Survey

Name of building 樓宇名稱 : ____

Address of building 樓宇地址 : ____

Completed by 填寫人 : ________________________ Date 日期 : ____________________

Investigated by 檢查員 : ______________________________ Time 時間 : ____________________

All information will be marked by IAQ investigator(s) and treated in confidence.
所有資料將由室內空氣質素檢查員填寫及絕對保密。

Note : Please either give a tick (✓) to the square boxes or fill in blanks as indicated.
請在方格內劃上(✓)或在空格上填上適當的資料。

I. Authorities Measurement Record 有關政府部門量度紀錄

1. Weather data 天氣記錄 (from nearest station of Hong Kong Observatory 最近之香港天文台氣象站)

   Temperature 溫度 : ________________ Relative humidity 相對濕度 : ________________

   Wind direction 風向 : ________________ Wind speed 風速 : ________________

2. Air quality data 空氣質素 (from nearest station of Air Quality Monitoring Station 最近之空氣監察站)

   Sulphur dioxide 二氧化硫 : ________________ RSP 可吸入懸浮粒子 : ________________

   Nitrogen dioxide 二氧化氮 : ________________ Carbon monoxide 一氧化碳 : ________________

   Ozone 臭氧 : ________________

II. Outdoor Environmental Information 室外環境資料

1. Any significant of fresh air intake blockage due to surrounding environment ? ☐ Yes 有 ☐ No 無
   有沒有受到四周環境影響而造成阻塞鮮風之跡象?
   If "Yes", which type of blockage ? ☐ Building 樓宇 ☐ Mountain 山峰
   如"有",阻塞是由甚麼所產生? ☐ Plant 樹木 ☐ Other 其他 : ________________

2. Any outdoor potential pollutant hazard?
   室外潛在污染物的程度如何?

			Very much 非常				Not at all 完全沒有	Remark 備註
a.	Industrial pollutant	工業廢氣	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Vehicle exhaust	汽車廢氣	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
c.	Park / Planting	公園 / 樹木	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Loading dock	碼頭船塢	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Dumpster	垃圾場	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Parking facility	停車場	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
g.	Cooling tower	冷卻塔	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
h.	Construction site	建築地盤	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
i.	Re-entrained	廢氣回流	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
j.	Soil gas	土壤氣體	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
k.	Pesticides	殺蟲劑	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
l.	Noise	噪音	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
m.	Sewage water	污水	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
n.	Others (Please specify) : __________ 其他(請註明) : __________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

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3. Instantaneous measurement by hand-held instrument :
手提儀器之即時量度結果:

Instrument Name 儀器名稱	Serial No. 序號	Measured Location 量度地方	Measured Parameters 量度內容	Results 結果

4. Comment on outdoor environmental condition :
對於室外環境情況之意見:

____

____

____

III. HVAC System Information 空調系統資料

A. Fresh Air System 鮮風系統

A1. First Tier 第一段 [from outdoor air intake to front end equipment, e.g. PAU 由鮮風入口至前置鮮風設備]

1. Condition of fresh air plant room:
鮮風機房的情況:

			Very bad 非常差				Very good 非常好	Remark 備註
a.	Cleanliness	清潔程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________
b.	Odour	氣味程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________

			Very high 非常高				Very low 非常低	Remark 備註
c.	Standing water risk	污水積聚機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________
d.	By-pass risk	鮮風污染機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________
e.	Short-circuit risk	污氣回流機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________
f.	Other contamination risk (Please specify) 其他污染機會(請註明)							
	________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________
	________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	____________

2. Cleanliness condition of front end equipment:
鮮風機組清潔情況:

			Very bad 非常差				Very good 非常好	Not Applicable 不適用	Remark 備註
a.	Outdoor air lourve	外牆百頁	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
b.	Front end equipment	鮮風機	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
c.	Ductwork	風管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
d.	Filter	過濾器	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
e.	Condensate drip pan	水盤	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
f.	Coil	盤管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
g.	Dehumidifier	除濕器	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
h.	Insulation	保溫	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________

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i.	Pipework	水管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
j.	Valve	閥門	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
k.	Others (please specify): 其他(請註明):								
	____________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐		____________________
	____________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐		____________________

A2. Second Tier 第二段 [Fresh air distribution duct from front end equipment to rear end equipment, e.g. AHU 送風系統由前置鮮風設備至後置鮮風設備之送風槽]

1. Condition of air duct well? :
風管豎井的情況:

			Very bad 非常差				Very good 非常好	Remark 備註
a.	Cleanliness	清潔程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
b.	Odour	氣味程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________

			Very high 非常高				Very low 非常低	Remark 備註
c.	Standing water risk	污水積聚機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
d.	By-pass risk	鮮風污染機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
e.	Short-circuit risk	污氣回流機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
f.	Other contamination risk (Please specify) 其他污染機會(請註明)							
	__________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________

2. Cleanliness condition of air duct component:
風管清潔情況:

			Very bad 非常差				Very good 非常好	Not Applicable 不適用	Remark 備註
a.	Air duct	風管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
b.	Insulation	保溫	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
c.	Access panel	檢修門	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
d.	Control damper	控制閥	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
e.	Others (please specify): 其他(請註明):								
	____________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐		____________________
	____________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐		____________________

A3. Third Tier 第三段 [from rear end equipment to occupied zone 由後置鮮風設備至用戶區]

1. Condition of AHU plant room:
風機房的情況:

			Very bad 非常差				Very good 非常好	Remark 備註
a.	Cleanliness	清潔程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
b.	Odour	氣味程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________

			Very high 非常高				Very low 非常低	Remark 備註
c.	Standing water risk	污水積聚機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
d.	By-pass risk	鮮風污染機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________
e.	Short-circuit risk	污氣回流機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________

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f. Other contamination risk (Please specify)
其他污染機會(請註明)

____________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
____________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

2. Cleanliness condition of rear air equipment:
空氣處理機組清潔情況：

			Very bad 非常差				Very good 非常好	Not Applicable 不適用	Remark 備註
a.	Rear end equipment	風機	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
b.	Ductwork	風管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
c.	Filter	過濾器	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
d.	Condensate drip pan	水盤	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
e.	Coil	盤管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
f.	Dehumidifier	除濕器	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
g.	Insulation	保溫	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
h.	Pipework	水管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
i.	Valve	閥門	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
j	Fan coil unit	盤管風機	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
k.	VAV box	變風箱	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
l.	Access panel	檢修門	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________
m.	Diffuser	風咀	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	____________

n. Others (please specify) :
其他(請註明):

____________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________________
____________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	______________________

A4. Fourth Tier 第四段 [Occupied zone 用戶區]

1. Condition of surrounding of air distribution system :
送風系統周圍的情況：

			Very bad 非常差				Very good 非常好	Remark 備註
a.	Cleanliness	清潔程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Odour	氣味程度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

			Very high 非常高				Very low 非常低	Remark 備註
c.	Standing water risk	污水積聚機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	By-pass risk	鮮風污染機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Short-circuit risk	污氣回流機會	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

f. Other contamination risk (Please specify)
其他污染機會(請註明)

____________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

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2. Cleanliness condition of air distribution component:
送風系統設備清潔情況:

			Very bad 非常差				Very good 非常好	Not Applicable 不適用	Remark 備註
a.	Air duct	風管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
b.	Insulation	保溫	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
c.	Access panel	檢修門	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
d.	Control damper	控制閥	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
e.	Return air grille	風咀	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
f.	Occupied zone	用戶區	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	N/A ☐	________
g.	Others (please specify) : 其他(請註明):								
	________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________	
	________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________	

A5. Instantaneous measurement 即時量度

1. Instantaneous measurement by hand-held instrument :
手提儀器之即時量度結果:

Instrument Name 儀器名稱	Serial No. 序號	Measured Location 量度地方	Measured Parameters 量度內容	Results 結果

A6. Overall comment 整體評論

1. Overall Performance 整體表現: ☐ Acceptable 可接受 ☐ Unacceptable 不可接受
Reason 理由: ____
____

1. Any subjective enhancement 建議: ____
____

3. Comment on the fresh air system :
對於鮮風系統之意見:
____
____

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B. Other systems 其他系統

1. Any potential pollutant hazard risk of other parameter(s) which may affect the IAQ :
有沒有其他潛在污染物影響室內空氣質素?

			Very low 非常低				Very high 非常高	Remark 備註
a.	Exhaust	排風	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Floor drain	地漏	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
c.	Trap	隔氣	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Sump pit / Drainage tank	污水井	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Vent pipe	排氣管	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Grease tank	隔油池	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
g.	Other contamination source (Please specify) 其他污染源(請註明)							
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

IV. Occupancy Information 租戶資料

1. Any indoor potential pollutant hazard?
室內潛在污染物的程度如何?

		Not at all 完全沒有				Very much 非常	Remark 備註
a.	Office equipment 辦公室設備						
	- Photocopier / Laser printer 影印機/雷射打印機	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Supplies 日用品						
	- Cleaning agent 清潔劑	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	- Pest control 滅蟲劑	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	- Solvent 溶劑	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
c.	Microwave oven 微波爐	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Refrigerator 雪櫃	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Environmental smoke tabacoo 香煙	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Cosmetics 香水	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
g.	Stored refuse 垃圾	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
h.	Pesticides 殺蟲劑	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
i.	Food 食物	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
j.	Other contamination source (Please specify) 其他污染源(請注明)						
	______________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	______________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

2. Any sign of occupant dissatisfaction by observation?
觀察有沒有租客不滿意的表現?

		Not at all 完全沒有				Very much 非常	Remark 備註
a.	Uneven temperature 不平均溫度	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Persistent odours 持續的氣味	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

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c.	Drafts 氣流頗大	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Sensation of stuffiness 不流通	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Coolness / Hotness 頗冷/頗熱	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Others (Please specify) 其他(請註明)						
	______________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	______________________________	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

3. Any feeling during walk-through investigation?
在現場視察調查中,有沒有以下的感覺?

			Not at all 完全沒有			Very much 非常		Remark 備註
a.	Dusty	塵埃頗多	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Stuffy	不流通	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
c.	Stale	污濁	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Smelly	有味	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Draught	氣流頗大	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Crowd	擠迫	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
g.	Noisy	嘈雜	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
h.	Others (Please specify) 其他(請註明)							
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

4. Instantaneous measurement by hand-held instrument :
手提儀器之即時量度結果:

Instrument Name 儀器名稱	Serial No. 序號	Measured Location 量度地方	Measured Parameters 量度內容	Results 結果

5. Any comment on the IEQ performance :
對於室內環境質素的意見:

			Very good 非常好			Very bad 非常差		Remark 備註
a.	Indoor air quality	室內空氣質素	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
b.	Thermal comfort	熱舒適	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
c.	Visual comfort	視覺舒適	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
d.	Aural comfort	味覺舒適	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
e.	Working environment	工作環境	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
f.	Others (Please specify) 其他(請註明)							
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________
	______________________________		1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	________________

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6. Sketch a layout plan and locate the pollutant source(s) / air pattern / other IAQ-related issues.
繪畫平面圖,並顯示污染物來源/空氣流動式樣/其他關於室內空氣質素項目:

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V. Overall comment 總結

1. Preliminarily grading on IAQ : ____________________
   室內空氣質素評分:

2. Overall IAQ Performance 整體室內空氣質素表現:
   - ☐ Very Good 很好
   - ☐ Good 好
   - ☐ Fair 可以
   - ☐ Bad 差
   - ☐ Very Bad 極差

   Reason 理由: ____
   ____

3. Any subjective enhancement 建議: ____
   ____

--END OF SURVEY--
*** 調查結束 ***

Indoor Air Quality Evaluation Checklist

Indoor Air Quality Survey

Name of building 樓宇名稱 : ____

Address of building 樓宇地址 : ____

Completed by 填寫人 : __________________________ Date 日期 : ____________________

Telephone no. 電話 : ____________________________ E-mail address 電郵 : _____________________

Please fill in the following information and it will be treated in confidence.
請填妥以下資料及這些資料將絕對保密。

Note : Please either give a tick (✓) to the square boxes or fill in blanks as indicated.
請在方格內劃上(✓)或在空格上填上適當的資料。

I. Fresh Air System 鮮風系統

1. Specification of front end equipment :
鮮風系統設備之規格 :

Item no. 編號	Location 位置	Location of fresh air intake 鮮風入口位置	Total flow rate 總風量	Deliver to which floor 送風至那層

2. Operation schedule for fresh air system :
鮮風系統操作時間表 :

Summer Mode 夏季時間 : Monday – Friday 星期一至五 : ______________________
Saturday 星期六 : ______________________
Sunday 星期日 : ______________________

Winter Mode 冬季時間 : Monday – Friday 星期一至五 : ______________________
Saturday 星期六 : ______________________
Sunday 星期日 : ______________________

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Indoor Air Quality Evaluation Checklist
Indoor Air Quality Survey

II. Pollutant Inventory 污染物清單

1. Office Area 辦公室位置

Flat / Floor No. 單位 / 樓層	Cleanliness* 清潔程度	Odour* 氣味程度	Pollutant Content** 污染物內容															No. of occupancy 人數	Remarks 備註
			Carpet 地氈	Marble/ Granite 雲石/ 花崗石	Cigarette smoking 抽煙	Combustion device e.g. gas stoves and heaters 燃燒用品 如: 氣體爐, 加熱器	Photocopier/ Laser printer 影印機/雷射打印機	Other office equipment e.g. fax machine 其他辦公室設備 如: 傳真機	Electrostatic air cleaner 空氣清新機	Particle -board 粒子板	Paneling 嵌板	Plywood 夾板	Ceiling tile 天花板	Urea-formaldehyde foam insulation 尿素-甲醛泡沫絕緣材料	Household products e.g. solvents, adhesives 日常用品 如: 溶劑, 黏合劑	Plant / Flower 植物/ 花朵	Pesticide 殺蟲劑		

Remark: * - Please put "✓" for good condition; "O" for acceptable condition; "×" for bad condition 如是良好情況, 請填上"✓"; 如是可接受情況, 請填上"O" ;如是頗差情況, 請填上"×"

** - Please put "✓✓" for high amount; "✓" for average amount; "×" for no this item 如是高使用量, 請填上"✓✓"; 如是有使用, 請填上"✓" ;如是無使用, 請填上"×"

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III. Air Distribution System 送風系統

Flat / Floor No. 單位/樓層	Even distributed 平均分佈	By-pass risk of supply air 供風繞流機會	Short-circuit risk of foul air 污染空氣帶回用戶區機會	Blocked air path 通風系統被阻塞	Local device is installed e.g. local fan, heater, air-cleaner 個別設備安裝 如: 風扇, 暖爐, 空氣清新機	Remark 備註

Remark: Please put "✓" for having great chance of this item; "O" for having little chance of this item; "×" for having no chance of this item

備註: 如是有很大機會的, 請填上"✓"; 如是有一點機會的, 請填上"O"; 如是沒有機會的, 請填上"×"

--- END ---

*** 結束 ***