TIME BUDGET STUDY AND TOTAL EXPOSURE ASSESSMENT TO AIR POLLUTANTS OF HONG KONG POPULATION

TU YOU, EDWARD

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A dissertation submitted for the Degree of Doctor of Philosophy

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Tu You, Edward (Name of student)

ABSTRACT

Abstract of thesis entitled: TIME BUDGET STUDY AND TOTAL EXPOSURE ASSESSMENT TO AIR POLLUTANTS OF HONG KONG POPULATION

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During the last twenty years, Hong Kong continuously upgraded herself to become a leading world commercial and financial centre. Increasing affluence of the society at large always led to a raise in the expectations about the quality of the life as well as the environment. The high population density, the scarcity of land sources, the crowded city traffic, and etc, made the population more and more proximate to the high levels of air pollution. The deterioration of the environment had the potential to endanger the health of the Hong Kong population. Of paramount importance is the total amount of pollutants an individual would expose.

Accordingly, this study intended to evaluate the time budget and total exposure of the Hong Kong population to air pollutants. The study composes of two major parts. The first part was to determine the daily activity pattern of Hong Kong population. The second part was to determine the air pollutant concentrations in different individual microenvironments.

In order to reveal the time activity pattern of Hong Kong population, a customarily made survey protocol was developed and was found to be quite successful. The survey was conducted continuously for about 6 months, with 400 questionnaires successfully collected through telephone interviews. The information collected from the questionnaires was analyzed and the time budget of Hong Kong people was obtained. Meanwhile, the major pollutant concentrations, like carbon monoxide, nitrogen oxides and respirable suspended particulate, were measured in a number of selected microenvironments. Even though carbon dioxide is not considered as air pollutant, it was also used as an indicator for ventilation effectiveness.

The results of this study revealed that Hong Kong people spent over 89% of their daily time indoors. The pollutant concentrations were found to be extremely high in pubs, restaurants and enclosed transits. Although the pollutant levels were not particularly high at home of most Hong Kong people, the long time span at home might also cause adverse health effect to human being. The significance of this study is that the results could help inform the policy makers of necessary actions that needed to be taken in order to reduce the health risk of the total population.

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1 INTRODUCTION

In this chapter, the objectives and the significance of this study will be discussed after a brief introduction on the background for exposure assessment.

1.1 Background

During the last few decades, Hong Kong continuously upgraded herself to become one of the leading world commercial and financial centers. Increasing affluence of the society at large always led to a raise in the expectations about the quality of the life as well as the environment.

The high population density coupled with the scarcity of land sources and the crowded city traffic made the population more and more proximate to the high level of air pollution. Deterioration of the environment had the potential to endanger the health of the population. Therefore, it is necessary to estimate the health risk of Hong Kong population caused by air pollution.

1.1.1 Risk assessment model

A central goal of environmental regulatory programs is to protect public health and welfare from the adverse effects of environmental pollutants. Public health generally refers to human populations, while public welfare refers to nonhuman components, e.g., ecological systems (Ott, 1982). In the context of this study, only the risks to public health are concerned, and the target of this study is people.

To reduce the risk of environmental pollutants to human health, a relationship between the source of a pollutant and its effects must be developed. If risk is to be assessed accurately, then all sources of the pollutant must be included. The sources should not only be limited to traditional ones (smoke stacks, sewage outfalls, toxic waste sites, etc.), but should also include nontraditional sources (building materials, consumer products, etc.) as well.

Establishing the links for a particular target and a particular pollutant requires knowledge on five fundamental components that may be viewed as links in a chain – from source to effect – comprising the complete risk model (Ott, 1985), which is shown in Figure 1.1.

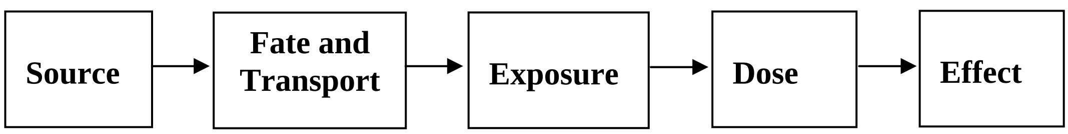


Figure 1.1 **Components of a conceptual risk model that relates the source of environmental pollution to ultimate effects of the pollutant on the pollution**

Such a link is called a “route of exposure”. In the risk model, each component is sequentially dependent on the one preceding it. That is, the quantities output from one component will become the input into the next component. Therefore, if information on one component of the model is lacking, it is impossible to fully characterize the relationship between the sources of the pollutants and the resulting effects; hence, the effect of the source control on risk reduction cannot be determined.

Despite the importance of each of the five components in determining the public health risk associated with environmental pollution, current development of the scientific knowledge on all five components has not been the same. Usually, environmental pollutions came to the attention of public officials because traditional pollutant sources, such as smoke stack plumes or leaking toxic waste drums, had caused much concern. The obviousness of such traditional sources had caused an overemphasis on the source component of the complete risk model. Consequently, a great body of knowledge existed for the nature of traditional sources, and most of the existing legislations dealt with the regulation of such sources, regardless of their relative contribution to overall risk. On the other hand, nontraditional sources, which could release pollutants that reached people by nontraditional routes of exposure, for example, consumer products emitting pollutants in the home, often received relatively little attention.

Once a traditional source of environmental pollution was known and identified, interests often focused on the manner in which the pollutant moved through the environment — its fate and transport — until it was ultimately converted to other chemicals or reaches humans. The fate and transport component had received considerable research attention. The traditional field of meteorology had developed a number of atmospheric dispersion models, and other fields had developed models for the movement of pollutants through streams, ground water, soil, and the food chain (Ott, 1982). In nearly all cases, the fate and transport research had dealt with traditional routes of exposure, tracing the movement of pollutants through geophysical carrier media, while nontraditional routes of exposure (for example, in a home, office, or other microenvironments) often had been overlooked (Ott 1990). Total human exposure approach reversed the focus, working backwards from the receptor toward the source.

As with the first two components of the whole risk model, the effects of pollutants on humans also have been received considerable research attention. Numerous studies related various exposure and doses to identifiable effects on animals and humans, as could be seen in any of the published air quality criteria documents (US EPA, 1982). Unfortunately, our knowledge on two important components of the risk model — exposure and dose — was relatively limited for most pollutants and for human populations. In this study, the exposure estimation was a major part to complement the lacking information of risk assessment model.

1.1.2 Air quality and human health

Although the concept of indoor air quality (IAQ) was relatively new, problems related to poor indoor air quality had existed ever since human beings started building shelters to protect themselves from the harshness of the natural environment.

In the past, resources and attentions had been focused on controlling ambient air pollution. The development of intense research interest for indoor air quality only emerged in the late 1970s, in particular for preventing the occurrence of occupational diseases in the industrial workplaces. Since then, there had been growing public concern about the impact of indoor pollutants in non-industrial buildings.

Indoor air quality (IAQ) has become an important issue in the concern of healthy life. Given that most people in developed countries spent more than eighty per cent of their daily times indoors, indoor air pollutants might influence the human health more than the ambient air.

There were several reasons that had aggravated the indoor air problem in the post-war era. One of the reasons could be attributed to the increasing demand for indoor spaces in conjunction with the decreasing supply of traditional building material giving rise to the use of new synthetic building materials. New material composites had also been used for their fire-retarding characteristics. However, not much consideration was given to the health effect of fugitive chemical emissions and respirable particulates associated with these new, non-traditional building materials until long after these materials were used.

Another reason could be seen in the fact that buildings were sealed for the purpose of energy conservation in response to the energy crisis in the early 1970s. New heating, ventilation and air conditioning (HVAC) systems were designed and installed with much less outdoor air makeup. Synthetic technology was applied to meet the changes in the insulation requirements. As a result, modern buildings have always been tighter in construction than before, with less infiltration of outdoor air and exfiltration of indoor air.

Still one more reason was that new technologies, including photocopying machines, computer workstations, electro-photographic colour reproduction equipment and high-end printers producing hundreds of pages per minute, were massively introduced into offices as an immediate response to the technology boom. In case the places were poorly ventilated, the installation of these equipment and machines could aggravate indoor air quality problems. Nowadays, indoor air quality had become an important issue that was concerned by building services engineers and building occupants as well.

Definition of indoor air quality

ASHRAE (ASHRAE Standard 62-1989R, “Ventilation for acceptable indoor air quality”) defined acceptable indoor air quality as: air in an occupied space towards which a substantial majority of occupants expressed no dissatisfaction and in which there were not likely to be known contaminants at concentrations leading to exposures that posed a significant healthy risk. Acceptable perceived indoor air quality was defined as air in an occupied space towards which a substantial majority of occupants expressed no dissatisfaction on the basis of odor and sensory irritation. Acceptable perceived air quality was necessary, but not sufficient, to meet this standard's definition of acceptable indoor air quality.

World Health Organization (WHO) recommended that unwanted odorous compounds should not be present in a concentration exceeding the ED50 detection threshold (ED50 stands for the 50th percentile effect dose) for non-industrial indoor environment.

Factors influencing indoor air quality

The overall quality of indoor air is influenced by thermal acceptability and air contaminants. Factors affecting thermal acceptability include temperature, humidity, and air movement. Common air contaminants include: airborne particles, volatile organic compounds, formaldehyde, radon, combustion gases, ozone, respiratory products and body odors, micro-organisms, asbestos, and tobacco smoke.

1.1.3 Total human exposure assessment

The total human exposure concept seeks to provide the missing component in the full risk assessment model: estimates of the total exposures of the population to environmental pollutants, with known accuracy and precision.

The human exposure to a pollutant can be defined as the event when a person comes into contact with a pollutant of a certain concentration during a certain period of time (Ott 1982). The amount of exposure is the product of concentration and time. Exposure assessments try to answer the question: which populations and under what circumstances may expose to a pollutant level exceeding the recommended threshold? Together with information from epidemiology studies, it is able to ascertain the health risk associated with the pollutants in the environment.

History had recorded numerous instances of human exposure to toxic agents in occupational and community settings (Paul 1990). Systematic analysis of occupational exposure and health response began in the 20th century. Currently, threshold limit values (TLVs) are available from the American Conference of Governmental Industrial Hygienists (ACGIH, 1996) for more than 600 chemicals, as personal exposure limits (PEL), the federal standards promulgated by the occupational Safety and Health Administration (OSHA) in the United States. In recent decades the exposure of air pollution to population has been receiving greater concern.

Historically, environmental regulatory programs measured pollutants only in geophysical carrier media (e.g., outdoor air, stream, soil) rather than the actual exposures of the population. A gap has always been identified to be existed between the observed levels in geophysical carrier media and the concentrations with which people actually come into contact. In this study, human exposure to various air pollutants was estimated through a method made use of the pollutant concentrations as well as the total time exposed to the pollutants.

1.2 Objectives of the study

There is much concern in Hong Kong about people's exposure to pollutants, especially the indoor air pollutants. Whilst the indoor pollutant levels are one of the major interests of building services engineers, the exposure to such pollutants must be set against the overall exposure level. Although exposure itself is not a direct health risk indicator, the adverse health risk effects associated with the pollutants found in the environment can be determined based on the total exposure assessments and epidemiological studies.

This study endeavored to determine the exposure of the general population to air pollution. The contribution of various microenvironments and pathways to the integrated exposure were compared, and sub-groups of the general population were identified for relatively high exposure. The objectives of this study were to:

i) quantify how Hong Kong people spent their time and their activities in a 24-hour period in order to establish time budgets for exposure assessments;

ii) measure the key pollutants including carbon monoxide, nitrogen oxides, respirable suspended particulate and carbon dioxide in the major microenvironment that affecting human health;

iii) preliminarily estimate the total exposure of Hong Kong population to air pollutants in accordance with the results of time budget survey and microenvironment study;

iv) calculate the exposure through theoretical approach, and get detailed exposure profiles using both non-parametric and parametric approaches.

1.3 Scope of work

The concept of total exposure assessment takes into account the daily activities or time budgets of the population. People are exposed to different types of pollutants with different concentrations at different times and in different locations during their daily activities. Therefore, the total exposure study was divided into two major parts. The first part related to the survey work required revealing the time budgets of the Hong Kong population, i.e., their daily activity patterns. The second part was on the measurement of air pollutants in various individual microenvironments.

One of the critical information needed for total exposure assessment was the detailed data on time budget of surveyed population, since this determined the duration, frequency and intensity of exposure times. To obtain the necessary data, a telephone questionnaire survey was used to collect the information of the time budget of Hong Kong population.

For the telephone survey, a random sampling methodology was developed using the Hong Kong residential telephone directories. An appropriate sampling size was employed for this study so as to ensure the expecting precision and deviation. In order to ensure the randomness in sample selection, a set of telephone numbers was randomly drawn from the residential telephone directories. A customarily designed questionnaire was developed to suit the format of the telephone interview.

The second major part was on the microenvironment study. A microenvironment can be defined as a location with homogeneous pollutant concentration that a person occupied for some finite period of time.

People spend their times on many different microenvironments everyday. In some microenvironments, people will be exposed to high pollutant concentration levels. In some, they will be exposed to lower pollutant concentration levels. In this study, the types of microenvironments that had large effects to the total exposure of people were chosen for more detailed studies. Two important issues were addressed in the microenvironment study:

1) How much time people spent on a particular microenvironment?
2) Did people have chance to be exposed to severe air pollution in a particular microenvironment?

1.4 Structures of the thesis

The followings lay out the basic framework of this thesis:

Chapter 1 **Introduction**

The introduction of the background information and objectives of the whole study were given.

Chapter 2 **Literature Review**

A literature reviews were carried on for the preparation of the study.

Chapter 3: **Methodology**

Detailed methodology of this study was discussed. Different methods of exposure assessment were compared, and the most suitable method for Hong Kong situation was chosen.

Chapter 4: **Time Budget Survey**

The time budget of Hong Kong population had been analyzed and daily activity patterns of Hong Kong people had been obtained.

Chapter 5: **Microenvironment Study**

Methodologies and data on site measurements used for revealing the pollutant levels in various microenvironments were discussed. Three typical microenvironments were chosen to carry out detailed analysis.

Chapter 6: **Total Exposure Assessment**

The total exposure of Hong Kong people to various air pollutants had been calculated based on the results of time budget survey and microenvironment studies.

Chapter 7**:** **Uncertainty Analysis**

The types of uncertainties were discussed and uncertainties that occurred in this study were analyzed.

Chapter 8: **Conclusions and Recommendations**

Some conclusions on total human exposure assessment of Hong Kong people to various air pollutants were drawn. In this last Chapter, some suggestions are proposed to improve the environmental regulatory program in Hong Kong.

1.5 Significance and value

Exposure assessment plays a key role in evaluating the health risks of human being to air pollution. Accurate exposure assessment is a pre-requisite for epidemiological studies as well as occupational hygiene. In this study, the total exposure of the Hong Kong population to some air pollutants was assessed. It was anticipated that the results of this study could benefit the society in many ways.

First of all, the statistical and sampling protocol developed in this study could lay a foundation for future large-scale population survey related to exposure assessment. The information from the daily time budgets of people was also useful to people involved in urban planning and socioeconomic issues. Also the results of the study were expected to assist policy makers in long term environmental planning regarding the methodology of the control strategies for environmental protection in Hong Kong.

Finally, the exposure assessments could be helpful in identifying the relative contribution of different pollutant sources to overall pollutant exposure, trends in exposure, as well as the effectiveness of control strategies.

2 LITERATURE REVIEW

The health risk of people posed by air pollutants is continuously increasing. However, the issue on how to quantify the adverse health effect caused by air pollutants still poses a difficult problem.

The quality of air to which an individual is exposed may be defined qualitatively by descriptors such as odor perceived by the individual, or quantitatively by the relative concentrations of the various components of the air. In this chapter, the concept of indoor air quality will be introduced before the major air pollutants and their adverse health effects are reviewed. The basic exposure concept and exposure assessment protocols will be introduced in this chapter after the current indoor and outdoor air quality standards or criteria have been examined.

2.1 Indoor air quality

In the last 20 years, emission controls have been quite effective in improving outdoor air quality. However, epidemiological studies have not been able to show that the improved outdoor air quality has generated a similar improvement in the health of the general public (Ott 1982). One of the reasons is that people nowadays tend to spend more and more time indoors where air quality is quite different from outdoors. Also, buildings are designed and built tighter to conserve energy. In view of reduction of ventilation rate, the increase use of synthetic furnishings and building materials, as well as the introduction of new production processes, it can be found that the indoor air quality problem is already looming on the horizon that will have a major impact on human health and productivity of workers. That is the reason why more and more interests are placed on the study of indoor air quality. In this research, the effect of indoor air pollutant to human exposure is concerned.

As described previously, indoor air quality may be defined either qualitatively by descriptors such as odor perceived by individuals, or quantitatively by the concentrations of various components in the air. Types of indoor environment involve: industrial and occupational environment, residential environment, office building environment and public building environment (e.g. schools, hospitals, theatres, hotels and so on). However, indoor air quality in the industrial environment is significantly different from the others and is handled mainly by the occupational exposure standards. Thus, the commonly said indoor air quality will just concern indoor air quality in residences, office buildings and public buildings.

There are many factors that affect indoor air quality, e.g. outdoor air quality, indoor sources of pollutants, pollution depletion mechanisms (deposition and chemical decay), meteorological factors (affecting air exchange), permeability of structure (affecting air exchange), ventilation measures (affecting air exchange) and so on (Ott 1985, 1986). The following simple mass balance model shows how the indoor concentration of a given pollutant affects quantitatively by the principal influencing factors.

$$\frac{dC_i}{dt} = aC_0 - aC_i - DC_i + S \Rightarrow C_i = \frac{aC_0 + S}{a + D}$$

Where C_i is indoor concentration, C_o is outdoor concentration, a is air exchange rate, D is pollutant decay rate, and S is indoor source strength per unit volume.

In general, the concept of indoor air quality composes of both the quantitative and qualitative descriptions. The issues addressed include: types of pollutants and their levels of concentration, indoor sources, distribution of pollutants within buildings, emission rates of pollutants to the indoor source, relationship between indoor and outdoor environment and so on. To establish an indoor air quality standard, human exposure to pollutants and the relationship between the thresholds of certain pollutants to human health should also be determined. Furthermore, we have to determine the causes of complaints about indoor air quality from occupants and make improvements to the indoor environment.

2.2 Indoor air pollutants and human health effects

Since indoor air may cause significant effect to the health of human being, it is necessary to identify the major indoor air pollutants and their health effect to human being. Environmental pollution can be defined as energy or waste materials that are discharged into the environment where they can cause damage to human health. Some indoor air pollutants may come from controlled outside air intake and uncontrolled infiltration of building structures. Yet, the major pollutants usually come from internal sources, such as people and their activities within the buildings.

Pollutants may reach people in different ways, e.g., through water, air, food or man-made products. The effects of indoor air pollutants on human health are complicated. As indoor environment embraces many different types of environments, the scopes of health impacts considered should include people of different ages, genders and occupations. Sometimes, the concentrations of indoor air pollutants may go up to such alarming levels that the long-term exposure to such a poor indoor air quality environment will lead to serious adverse impacts on human health. Unfortunately, the thresholds of some potential pollutants to human health are still unknown. There are many types of indoor air pollutants, and only the major ones and their health impacts are briefly discussed below.

Carbon Monoxide

Carbon monoxide is produced primarily by incomplete combustion, but it also occurs as a byproduct of tobacco smoking. The health impacts are primarily related to its ability to combine with hemoglobin and to reduce the oxygen-carrying capacity of bloodstream. For short-term exposures, it will have no observable effects when its concentrations maintain below 50 $\mu g/m^3$. Noticeable physiological effects (i.e. slight headache, lassitude and so on) will occur in the range 200-500 $\mu g/m^3$. However, for long-term exposures (10 hours or more), the concentrations for the same effects become 15 $\mu g/m^3$ and 80-200 $\mu g/m^3$ (USEPA 1982).

Carbon Dioxide

Carbon dioxide is a natural constituent of the atmosphere. The major indoor sources are combustion and respiration. For an adult, the production rate is 20 l/min. Small amount of carbon dioxide is produced from tobacco smoking. The respiratory system compensates naturally in ordinary individuals for carbon dioxide concentration for up to 2-3%. However, such a high concentration is unlikely to occur in building. Staying in an environment with high carbon dioxide concentration level will make people feel tired due to the lack of oxygen. Carbon dioxide presents no serious health hazard in itself, but because of its ubiquity and relative ease of measurement, it is often used as an indicator for general indoor air quality within buildings.

Nitrogen Oxide

The oxide of nitrogen, often collectively referred to NO_x that can be most commonly found in indoor air, is nitrogen dioxide. The potential health impacts of nitrogen dioxide include the irritation to respiratory system, the increase of susceptibility to respiratory infection and the impairment of lung development.

Concentration level exceeding 200 $\mu g/m^3$ is likely to lead to death and respiratory irritation has been noted at 10 $\mu g/m^3$ (USEPA 1982b).

Respirable Suspended Particulates

Respirable suspended particulates refer to particulates with diameters less then 10 μm. They can cause respiratory illness and reduce lung function. The main danger to health is likely occurring where the natural lung clearance mechanisms are impaired by some diseases. Small particles can absorb gaseous pollutants and, by deposition within the lungs, can apply a concentrated dose to local areas of tissue. Particles can act synergistically to enhance the effects of other pollutants such as sulphur dioxide.

Radon

Radon is a gas, which is formed as a radioactive decay product of radium. Radium and its parent uranium are widely distributed in the earth's crust and are present in nearly all soils and in building products derived from them. Radon has a half-life of approximately 3.5 days and decays through a series of daughter products to a relatively stable isotope of lead. Inhalation of short-lived radon daughters is one of the most important sources of radiation exposure.

Formaldehyde

Formaldehyde is a colorless gas with a wide range of possible source within buildings. Common sources include paper products, floor coverings, carpet backing, as well as combustion and tobacco smoking. Formaldehyde is a severe irritant to eyes and the upper respiratory tracts. The threshold for eye irritation may be as low as 0.01 ppm.

The health impacts of indoor air pollutants on human depend on the toxicity and stability of the pollutants. Some pollutants such as O_3 and SO_2 may be absorbed by or act on the surfaces of walls, floors, and furniture. The dose and exposure time are also main factors that for the health impacts. The sensitivity of people is different from each other. The integrated effects of different kinds of pollutants make it even harder to decide the threshold value of each individual pollutant. All these factors determine the threshold of the pollutants.

2.3 Indoor and outdoor air pollutants standards

2.3.1 Ambient air quality standards

The guidelines published by the World Health Organization (WHO 1987) for air quality aim to provide a basis for protecting public health from adverse effects of air pollution and for elimination or reduction of pollutants that are known or likely to be hazardous to human health (WHO, 1986). The guidelines are intended to provide background information and guidance to governments for making risk management decisions, in particular, for planning control strategies and setting national or local standards. Generally, the recommended limits are intended to cover the whole population, which include both infants and elderly. WHO's recommended limits are purely health-based since only scientific but not economic evidences are considered. Thus, the limits recommended should not be regarded as standards themselves. When setting up standards, the threshold values recommended in the guidelines should be considered in the context of prevailing exposure levels and environmental, social, economic and cultural conditions. Under certain circumstances, there may be valid reasons to pursue strategies that will result in pollutant concentrations above or below the recommended value. As the guidelines define the lowest concentration at which adverse effects will be observed, it will give conservative estimates for setting up primary air quality standards.

In the United States, the Environmental Protection Agency (EPA) had developed the National Ambient Air Quality Standards (NAAQS). National primary ambient air quality standards define levels of air quality which are judged by the administrator as necessary, with an adequate margin of safety, to protect the health of the public. The primary air quality standards are designed to assume very low risk from continuous exposures and to protect even the most sensitive groups of the population against the air pollution, such as the new-borns, the elderly and the seriously ill. The national secondary ambient air quality standards define levels of air quality, which are judged by the administrator as necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

The Hong Kong Government had also issued a set of Air Quality Objectives for seven major air pollutants since 1995 (HK EPD, 1995). The objectives formulated were generally in line with requirements of international standards and also did include the impacts of the pollutants on public health.

2.3.2 Occupational air quality standards

Occupational standards have generally developed for the industrial workplace where pollutants are generally associated with production processes. The workforce is assumed to comprise healthy fit adults. As expected, the level set in industrial environment is much higher than that in the ambient air standards. Nonetheless, these standards apply to long-term exposures, typically eight hours per day, five days per week, for a "working lifetime". The occupational standards give the limits of health risk but do not consider the comfort of workers.

<u>ACGIH TLVs</u>

American Conference of Government Industrial Hygienists has developed the Threshold Limit Values (TLVs) for chemical substances and physical agents and Biological Exposure Indices (BELs) as guidelines to assist in the control of health hazards (ACGIH, 1996). Threshold limits are based on the best available information from industrial experience from experimental human and animal studies.

NIOSH/OSHA

The National Institute for Occupational Safety and Health (NIOSH) of the United States provides recommendations for safety and health standards in the workspace. The recommendations are then transmitted to the Occupational Safety and Health Administration (OSHA, 1992).

HSE Guidelines

The United Kingdom Health & Safety Executive (HSE) gives details of occupational limits, which should be used for the purposes of determining the adequacy of control of exposure by inhalation to substances hazardous to human health (HSE, 1996).

OELs of the Hong Kong Labor Department

The Labor Department in Hong Kong has set the Occupational Exposure Limits (OELs) for chemical substances in the work environment, which is based on the American Conference of Government Industrial Hygienists Threshold Limit Values (ACGIH TLVs). It aims to provide references in the form of occupational exposure limits to determine the adequacy of the control measures for some chemical substances, which are commonly found in industrial environment. The exposure of workers should not exceed the OELs such that they can be protected from the adverse health effect. The OELs has considered the absorption of chemicals by inhalation only and is only valid when significant absorption does not occur.

2.4 Exposure assessment

2.4.1 Basic concept of exposure and exposure assessment

The basic concepts used in exposure assessments were developed in the early 1980s by Duan (1982) and Ott (1982). Their introduction of the term human exposure (more simply exposure) emphasizes that the human being is the most important receptor of pollutants in the environment. Ott (1982) elaborated a system of definitions for the term exposure and defined exposure as an event that occurs when a person comes in contact with the pollutant. This is a definition of an instantaneous contact between a person i (or a group of persons), and a pollutant with concentration c at a particular time t. This definition refers to a contact with a pollutant, but it is not necessary that the person inhales or ingests the pollutant. When the duration of exposure is also taken into consideration, the result is an integrated exposure, calculated by integrating the concentration over time *t*. More easily understood is the term average exposure since it can be calculated by dividing the integrated exposure by the specified time.

The definitions of exposure described above refer to levels of pollutants in the ambient media. However, once the pollutant has crossed a physical boundary (e.g. skin), the concept of dose is used (Ott, 1982). Dose is the amount of material absorbed or deposited in the body for an interval of time. Dose can be determined as internal dose or as a biologically effective dose (NRC, 1991). When data on exposure values are available, an intake (also called `potential dose which assumes total absorption of the contaminant (NRC, 1991), can be calculated by multiplying the integrated exposure with the volume of air exchanged in the lung per specified time. Average intake (in analogy to average exposure) or dose rate can be deduced by dividing intake by time.

A comprehensive exposure assessment is part of a risk assessment that evaluates the relationship between the source of a pollutant and its health effect (Ott, 1990). The link between a pollutant emission and a particular target in the body consists of a sequence of events (Lioy, 1990), and describes the route of a contaminant from its source into the body. In general, this scheme is valid for all environmental media (water, air, food). Air pollutants are dispersed ubiquitously, and contact between the target organ (airway system) of a human and the pollutant takes place continuously. In the comprehensive concept of total exposure assessment (Ott, 1990; Lioy, 1990), all routes into the body have to be considered: contact with soil, water, food and air.

Conceptual approaches to measuring exposure can be classified according to their potential agreement with a perfectly precise personal exposure measurement (Lioy, 1995). Personal exposure measurement obviously reflects the individuals' exposure levels best, whereas qualitative methods provide less precise estimates.

Representative epidemiological studies have to include a large number of study individuals from the general population. Collecting exposure data from all these individuals is an expensive undertaking, so that a geographical clustering of the population is often used. In such studies, exposure data are collected by a central monitor and attributed to the residents of the cities in question. On the other hand, collecting exposure data on an individual level has the advantage of assessing frequency distributions in order to reveal whether part of the population is exposed to levels much higher or lower than the average level (Sexton and Ryan, 1988). Krzyzanowski (1997) stressed other key elements of exposure assessment, such as representative sampling, the control of confounding factors (factors which are related to the exposure and the health variable) and the appropriate averaging time. An additional difficulty in an exposure assessment for air pollutants is related to the fact that pollutants are present as mixtures. Therefore assessment of exposure has to rely on measurements of markers in these mixtures (Leaderer et al., 1993). Markers, also called indicators, should be unique to the mixture's sources; they should be readily detectable in air at low concentrations and present in a consistent ratio to other components (Leaderer, 1993). Examples of such indicators are NO_2, O_3, airborne particles, metabolites in biological specimens, or variables obtained from questionnaires.

In this study, the major focus was on the air inhalation pathway only, although ingestion or dermal exposure routes may be quite relevant for some pollutants, such as lead, which contaminate either settled dust or residential indoor surfaces. The definitions of key terms are provided in Table 2-1 (NRC, 1991).

Table 2-1 Definitions of terms

Term	**Definition**
Exposure	An event that occurs when there is contact at a boundary between a human and the environment with a contaminant of a specific concentration for an interval of time.
Total Exposure	Accounts for all exposure a personal has to specific contaminant, regardless of environmental medium or route of entry (inhalation, ingestion and dermal absorption).
Dose	The amount of a contaminant that is absorbed or deposited in the body of exposed organism for and increment of time, usually from a single medium.
Internal dose	Refers to the amount of the environmental contaminant absorbed in body tissue over a given time of interacting with an organ's membrane surface.
Biologically effective dose	The amount of a deposited or absorbed contaminant or its metabolites that has interacted with a target site over a given period so as to alter a physiological function.

National Research Council (NRC) & Committee on Advances in Assessing Human Exposure to Airborne Pollutants 1991

2.4.2 Significance of exposure assessment

Exposure assessment plays a key role in evaluating the risks of air pollution. Accurate exposure assessment is a pre-requisite for epidemiological studies and, as one of the critical elements of risk assessment, provides information on individual or population patterns of exposure to indoor and outdoor pollutants (Özkaynak, 1999).

In evaluating risks of air pollution, both the shape of the distribution of exposures and the exposures at the highest end are of special interest. The shape and measures of central tendency – i.e. mean and median – provide an indication of overall population risk level. The upper end of the distribution comprises those individuals or groups of individuals in a population who are potentially at greatest risk. It is important to determine the source, transport, concentration and behavioral factors that may lead to substantially greater exposures for those at the higher end of exposure distribution. The United States Environmental Protection Agency recognized this potential in its exposure assessment guidelines (USEPA, 1992). Consequently, exposure assessment for air pollutants characterizes the sources of variation in population exposures by such factors as location and time of day and from the differing pollutant concentrations in various indoor and outdoor environments.

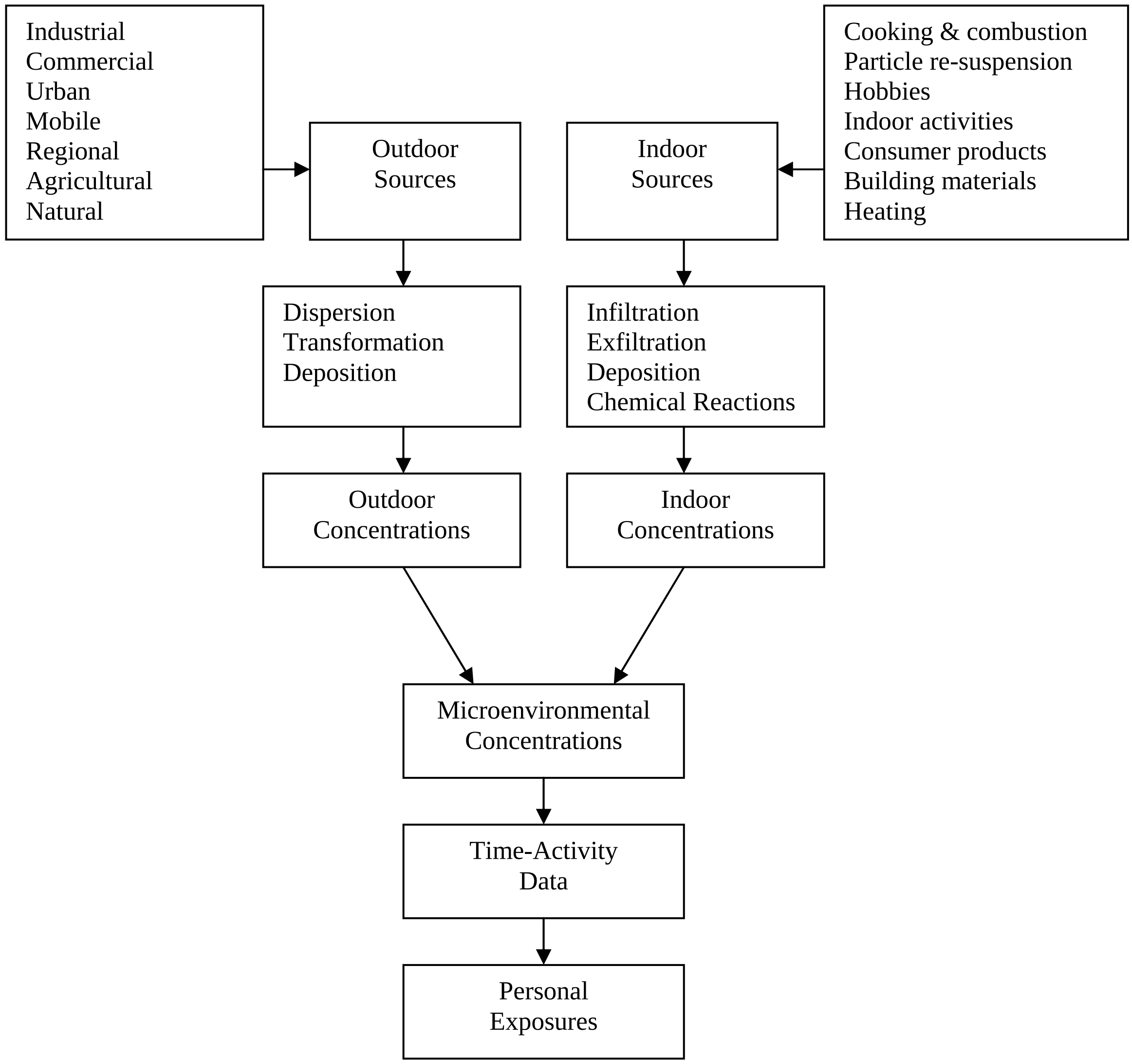


Figure 2-1 **Sources and factors influencing indoor, outdoor and personal exposures to air pollutants**

2.4.3 Exposure assessment procedures

As illustrated in Figure 2-1, exposure assessment begins with identification of key sources of selected pollutants and their emission rates into the air. Outdoors, a variety of stationary, mobile (i.e. vehicles) and area sources contribute to emissions of gaseous and particulate pollutants. Similarly, in the indoor environment, household cooking and heating sources, building materials, consumer products and human activities result in intermittent or continuous emissions of many classes of pollutants, including carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM) and biological agents. All of these sources, either indoors or outdoors, contribute to air pollution concentrations in the various microenvironments where people spend time during the daily course of their activities. The term "exposure" refers to length of contact with the pollutant (in the case of air pollutants, this is predominantly inhalation) during a specified time period (hours, day, months, etc). Thus, exposure to ambient air pollution refers to contact with pollutant concentrations that an individual encounters during time spent outdoors as well as to contact with outdoor pollution that may have penetrated indoors. Any assessment of exposure needs to take into account the fact that concentrations may vary both spatially and temporally depending on the location and the characteristics of the ambient sources.

Pollutants from outdoor sources can also penetrate indoors, and indoor microenvironments may be a significant locus of exposure to outdoor pollutants.

One key step in exposure assessment is, therefore, to predict (i.e. model) or directly measure the geographic and time profile of the pollution concentrations in the study region of interest. Various air pollution dispersion models can be used to predict concentrations of air pollutants both in urban and suburban environments using information on characteristics of the sources in the area and the associated emission rates of the pollutants. These models allow determination of fate and transport of the pollutants in the environment and provide concentration values at different receptor points, i.e. locations in the assessment area. Alternatively, indoor or outdoor fixed location monitoring can be conducted to obtain information on pollutant concentration profiles, and to derive empirical relationships between source emissions and microenvironmental concentrations.

Since the definition of exposure includes human presence and contact during the course of a selected time period, exposure assessment also involves the identification of the locations where individuals spend time and the amount of time spent in each of these locations. The term microenvironment refers to a location (e.g. outdoors near home, commuting, walking, indoors at home, indoors at work, school or shopping mall) in which the concentration is spatially uniform during the time spent in the microenvironment, even though the concentration may vary over time. In the microenvironmental model of exposure, personal exposures are estimated by the combination of pollutant concentrations in selected microenvironments, with the fraction of time spent in each of these microenvironments.

Thus, knowledge of where people are and what they are doing during the course of a typical workday or weekend is essential for determining personal exposures. Moreover, time-activity profiles of different population subgroups (e.g. the elderly, the adults and the teenagers) can also vary substantially. Time-activity diaries from a representative general population and certain subgroups had also been collected by various survey techniques, including direct diary entries and telephone-based 24-hr recall diaries.

2.4.5 Approaches of exposure assessment

Personal exposure measurements can be performed directly or indirectly (Ott, 1982). Under the direct approach exposure levels are determined on an individual basis (by using a personal sampler or a biological marker); under the indirect approach exposure levels are either measured stationary or determined by models (Ott, 1982; Lioy, 1995). The choice of a particular approach depends on a number of method inherent characterizations, such as sensitivity, precision, accuracy, selectivity and detection limit. Besides, cost and applicability are also important factors.

Passive samplers are the most widespread and easily used devices employed in personal sampling in direct approach. Passive samplers rely on the principle of the passive diffusion of a gas, and the concentration in air can be calculated according to Fick's law of diffusion (Palmes et al., 1976). The samplers are simple for personal sampling as they are light, do not need electricity, and can be easily fixed to outer clothing. They exist as tubes or small personal badges. Passive samplers can also be used to take stationary measurements in outdoor and indoor settings. The most established method is the passive sampler for NO_2 (Palmes et al., 1976; Yanagisawa and Nishimura, 1982; Hangartner, 1990). The sampling time is usually from a few days up to one week, depending on concentration. Passive samplers also exist for CO, SO_2, VOCs, O_3, formaldehyde and ammonia (Lee et al., 1992; McConnaughey et al., 1985; Shields and Weschler, 1987; Weschler et al., 1990; Koutrakis et al., 1993; Monn and Hangartner, 1990). Brown (1993) reviewed state-of-the-art passive samplers for ambient monitoring. The precision of NO_2 tubes was quite good; the error was within a range of 5-10%. For example, in the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), the coefficient of determination between the continuous monitors and passive samplers ranged between 0.69 and 0.93. On average, concentrations of duplicates were within 5%. The problem for passive devices is, however, the lack of accuracy, i.e. the agreement with a reference method. The O_3 tube (Monn and Hangartner, 1990; Hangartner et al., 1996), for example, had acceptable precision (variation <5-10%) but the agreement with a continuous monitor was not always very good.

Real-time personal monitors for gases are also available, but the detection limit is often too high, so that their use is limited to occupational settings only. A personal monitor for CO has also been shown to be practical in ambient conditions (Ott et al., 1986; Jantunen, 1998).

Personal monitors for particles exist with different cut-offs and size fractions, such as $PM_{2.5}$, PM_{10} or multistage samplers (analysis by gravimetric, collection of particles on filters). Real-time monitors, based on the principle of light scattering provide particle numbers in a volume of air. A real-time personal sampler also exists for the detection of combustion aerosols, using the principle of a photoemission aerosol sensor (Burtscher and Siegmann, 1993, 1994). The detection signal is related to levels of ultra fine combustion particles <1 μm.

The strength of direct approach is that it can measure exposure directly. Provided that the measurement devices are accurate, it is likely to give the most accurate exposure value for the period of time over which the measurement is taken. It is often expensive, however, and measurement devices and techniques do not currently exist for all chemicals. This method may also require assumptions to be made concerning the relationship between short-term sampling and long-term exposures, if appropriate. This method is also not source-specific, a limitation when particular sources will need to be addressed by risk managers.

Utilizing indirect approach, the assessor attempts to determine the concentration of pollutant in a medium or location and link this information with the time that individuals or populations contact the pollutant. Usually, the pollutant concentration and the time of contact are characterized separately. Pollutant concentration can be estimated by using appropriate microenvironmental models. In daily life, people move around and thus are exposed to various levels of pollutants in various locations. Duan (1982) introduced the term microenvironment, which is defined as a chunk of air space with homogeneous pollutant concentration. Such microenvironment can either represent outdoor location (e.g. in front of the home) or indoor location (bedroom, kitchen, etc.). Mage (1985) defined microenvironment as a volume in space, during a specific time interval, during which the variance of concentration within the volume is significantly less than the variance between that microenvironment and its surrounding microenvironments.

Selective measurements in microenvironments and a time-activity/time-budget questionnaire are used for the estimation of personally encountered pollution levels, calculated as integrated dose or concentration in a cubic meter of air. Different emission sources contribute to pollution levels in different microenvironments. The time fraction spent in each microenvironment allows calculation of integral personal exposure levels (i.e. the sum of exposure in all microenvironments). Such approaches are based on easy-to-use and reliable time-activity diaries.

Since it is demanding and expensive to obtain refined data of dozens of microenvironments in large-scale epidemiological surveys, the most practically feasible approach is to use group- microenvironments, where similar microenvironments are aggregated into microenvironment types (e.g. indoor and outdoor microenvironments). Stock et al. (1985) used personal-activity profiles and household characteristics to partition the locations into seven broad microenvironments. Three of them were indoors, two outdoors and two in transportation modes.

Questionnaires are important tools for assessing exposure. They can be used to identify contact with emission sources and frequencies of contacts with potential sources (e.g. in a household) (Lebowitz et al., 1989). This is especially important for the identification of contacts to indoor sources which do not reflect the same mixtures than outdoor sources (e.g. NO_2 from gas cooking, $PM_{2.5}$ from tobacco smoke). Questionnaires had been used to obtain data on time-budget and time-activity patterns (e.g. Kunzli et al, 1997). They have also been used to assess the perception of traffic near the home, representing a surrogate for the traffic intensity, and hence pollution levels in air. The most important advantage offered by questionnaire survey is their low cost.

One of the strengths of the indirect approach is that it is usually the least expensive method. Also, it is particularly suited for analysis of the risk consequences of proposed actions. It is both a strength and a weakness of indirect approach that the evaluation can be performed with little data. In this study, indirect approach is applied to estimate the human exposure and the detailed methodology will be discussed in the next chapter.

WHO approach

Personal exposure assessments are performed either directly or indirectly. In the direct approach exposure levels are determined for an individual by using

a personal sampler;

a biological marker, and

dermal contact.

Whereas, in the indirect approach, exposure levels are either measured stationary or determined by models, which involves

ambient measurements;

use of microenvironments; and

models and questionnaires.

Direct measurements

i) Personal sampling

It works on the principle of the passive diffusion of a gas and the concentration in air. Personal monitors are fixed to outer clothing of the samplers, who then complete a diary such that their time, location and physical activities are recorded. This allows estimating their ventilation rate and pollutant intake by inhalation, which can then by summing up the dietary intakes to create their total intake for the study period.

ii) Biological markers

Biological markers of exposure are considered measures of internal dose; they can be collected from breath, urine, hair, nails, nasal lavage or from blood. The advantage of the use of a biological marker is that exposure is integrated over time and that all exposure pathways are included. However, in order to assess the usability of a biological marker, it is important to know its half-lie in the body and its temporal variability.

iii) Dermal contact

Contamination of the skin leading to uptake may arise in many different ways, which leads to the needs of dermal exposure assessment. The conceptual model stresses the difference in mass in compartment and transport of mass between compartments. The identified compartments are source, air, outer and inner clothing layer and skin layer. The measurement methods of dermal contact involved the use of skin patches, wipes, adhesive tape, etc. in order to obtain the skin sample.

However, there are a number of fundamental problems possessed with dermal exposure assessment, which include:

Skin stripping cannot recover what has already penetrated to skin tissue. Adherence of contaminants to patch sampler and real skin fifers – the amount on the patch sampler does not represent the amount actually present for uptake on the skin.

Patch samplers sample over small areas and therefore errors can occur when results have to be extrapolated to the whole exposed area.

Indirect measurement

In this type of study, the targets of analysis are populations or groups of people rather than individuals as in the direct approach.

i) Ambient Measurements

Ambient monitoring networks have been established all over Europe and the USA by national institutions or local councils. They are equipped with on-line monitors providing continuous data with sufficient time resolution. Thus, the accuracy and precision of these monitors is generally good, but running such a network is expensive, especially with the implementation of quality assurance and quality control procedures.

ii) Microenvironments

The concept of microenvironment has been used to define an area across which the concentration of an air pollutant is assumed to be homogeneous. Depending on the characteristics of the media and the pollutant, a description of the actual activity is also required to understand exposure. Therefore, with selective measurements in the microenvironments and a time-activity data/questionnaires, the total average exposure can be defined.

iii) Future models and questionnaires

Questionnaires are important tools for assessing exposure. They can be used to identify contact with emission sources and frequencies of contacts with potential sources. They also obtain data on time activity pattern and are essential assessing long-term exposure to pollutants. The biggest advantage of questionnaires is their low cost, but there are also potential limitations which would be discusses in the later section.

The US EPA approach

EPA's exposure assessment methods are summarized as in the following:

i) Point of contact measurement

This is the same as direct approach where personal monitors are carried by samplers.

ii) Scenario evaluation

This is similar to the indirect approach as the assessor characterizes the chemical concentration and the time of contact separately. Chemical concentration is accomplished by measuring, modeling, or using existing data on concentrations, whereas the point of contact is done by survey statistics or activity diaries.

iii) Reconstruction of internal dose

Reconstruction of dose relies on measuring internal body indicators after exposure and intake and uptake have already occurred, and using these measurements to back-calculate dose.

Basically, the approaches of exposure assessment between the two organizations (WHO and US EPA) are the same, but the main difference is on the type of measurement being used - direct and indirect methods. Direct method measures the individual dose by using the measured data directly. On the contrary, indirect method needs to reconstruct the measured data before they can be used to predict the amount and concentration of dose before intake.

Exposure Modeling

Exposure modeling is a kind of indirect measurements. Mathematical models use system of equations to quantify and explain the relationship between air-pollutant exposure and important variables, for example, the emission rates from contaminant sources. The models can estimate exposures in situations where direct measurements are unavailable.

The models are derived from assumptions and approximations. It permits complex physical-chemical-behavioral problems to be represented by mathematical formulations. However, many of the currently used models have their own strengths and weakness, no model addresses the entire range of indoor problems and issues.

The models can be classified into two board categories (US NRC, 1991b): those that predict exposure (in units of concentration multiplied by time) and those that predict concentration (in units of mass per volume). The capabilities and functions of nine indoor exposure and concentration models are compared in Table 2-2.

Exposure models include:

i) National ambient air quality standards exposure model (NEM)
ii) Personal air quality model (PAQM)
iii) Regional human exposure model (REHEX)
iv) Simulation of Human activity and pollutant exposure model (SHAPE)

Concentration models include:

i) Macromodel for assessing residential concentrations of combustions generated pollutants (MACROMODEL)
ii) Indoor air quality model personal computer version (IAQPC)
iii) CONTAM
iv) Indoor air quality model (IAQ)
v) California Institute of Technology indoor model (CIT)

Exposure models avoid extensive environmental or personal measurement programs and it can provide estimates of population exposures that are based on small numbers of representative measurement. However, they have not been adequately validated. For example, the average exposure values of simulation of human air pollution exposure model (SHAPE) are well predicted but also show substantial discrepancies in the tails of the distribution.

One cause of inaccuracy in exposure modeling is failure to obtain measurement data on an appropriate time scale. Sampling and analysis are suggested to cover sufficient time for concentrations to be reasonably estimated for a full year, if they are to be served as reliable inputs to exposure models.

Concentration models are used extensively to estimate outdoor or indoor contaminant concentration at specific sites. Though they cannot estimate exposure directly, the output of the models can be combined with the data and information on human time-activity patterns to estimate the exposure value.

These models use physical, chemical and statistical methods to address the contaminant source release, dispersion, reaction and deposition. It can be further categorized into source-emission models, dispersion models and receptor models.

Emission models depend on the source and type of contaminant releases. Accurate estimation of emissions from point, area, and volume sources are very important to achieve accurate quantification of ambient concentration. However, monitoring of non-point source is one of the limitations of this model. A number of attempts have been made over the last decade to develop monitoring techniques or vapor and particulate emissions from pits, ponds and lagoons and fugitive emissions from chemical process equipment. Also losses from large open ponds and pits are more difficult to quantify and have caused difficulty in validation of emission models.

In the dispersion model, the atmospheric dispersion combined with the source emission rate to predict the concentrations of the contaminants at the receptor site. New developments in dispersion models have improved prediction of the average and time-varying concentrations to which individuals are exposed.

Receptor models used data on contaminants at a specific site identify the sources of contaminants. They are not predictive but can be used to validate predictive dispersion models.

Table 2-2   Comparison between direct and indirect method for exposure assessment

Direct method	**Indirect method**
Exposure is measured directly	The least expensive method
It gives the most accurate exposure value for the period of time over which the measurement was taken	Particularly suited to analysis of the risk consequences of proposed actions
Overall study cost is high	Assumptions have to be made which induces error
Measurement devices and techniques do not currently exist for all chemicals	People may give incorrect information on questionnaires and diaries

2.5 Summary

Monitoring indoor air and identifying the indoor air problem are the first steps in controlling the health risk of human being. The review of adverse health effect, which caused by air pollutant, can be helpful in choosing the major air pollutant to monitor. Current indoor and outdoor air quality standards can be used as indicators for the basis of evaluation of the indoor air quality. The exposure assessment in this study is based on the knowledge of the literature reviewed.

3 METHODOLOGY

Study of human exposure to the harmful air pollutants is helpful to protect people from potential risks. In this chapter, the concept of indoor air exposure assessment will be introduced before different assessment approaches and models are compared. Besides, the methodologies adopted for this study will also be discussed.

3.1 Contents of indoor air exposure assessment

Introduction and basic concepts

The National Research Council (NRC 1991) of the U.S. described human exposure to a contaminant as an event consisting of contact with a specific contaminant concentration at a boundary between the human and the environment (e.g., lung or skin) for a specific interval. Total exposure was determined by multiplying concentration by exposure time.

The process of a chemical entering the body involves three basic steps (USEPA 1992):

i) human comes into contact with, or is exposed to, a chemical in the air, water, food and soil;

ii) an amount of the chemical crosses a boundary from outside to inside the body, through intake (e.g., inhalation or ingestion) or uptake (e.g., absorption through the skin), and subsequently is absorbed and becomes available at biologically significant sites; and

iii) an amount of chemical reaches a target site and results in an adverse effect.

The EPA's guidelines for exposure assessment (USEPA 1992) identified five principal components of a typical exposure assessment:

i) Sources and pollutants --- The pollutants and their relevant sources in the environment must be identified, including production, use, disposal and environmental pathways.

ii) Exposure pathways and environmental fate --- The way in which the pollutant reaches the exposed individual or population (i.e., the receptor), including the movement through and any changes in the environment, must be determined and analyzed.

iii) Measured or estimated concentrations --- The environmental concentrations of the substance that are available for exposure must be determined based on measured data, use of mathematical models, or both.

iv) Exposed population --- Populations, particularly sensitive populations, that are potentially exposed by various routes of interest must be identified.

v) Integrated exposure analysis --- The integrated exposure analysis generally combines the estimation of environmental concentrations with the description of the exposed population to yield exposure profiles. For many analyses, the results should be considered in conjunction with the geographical distribution of the human or environmental populations.

Identifying pollutants and sources

The US EPA grouped indoor air pollutants of concern into several broad categories, environmental tobacco smoke (ETS), radon and radon daughters, biological contaminants, volatile organic compounds (VOCs), formaldehyde, polycyclic organic compounds, pesticides, asbestos, combustion products, particulate matter. Since the relationships between the contaminants and their sources can be complex and a single contaminant can come from several sources, some of the categories may overlap.

Determination of the pollutants and the sources in the indoor environment requires knowledge of the building, the building occupants and the surrounding sources of pollutants. Building location, design, operation, maintenance, age and other factors can substantially affect the concentrations of pollutants. Meanwhile, occupants can generate pollutants and bring these pollutants into a building. Pollutants in the ambient air and in the water and soil can enter buildings and even be concentrated in some situations.

Pollutants and sources strengths in a building often are determined through direct measurement. Models are also used to identify pollutants and sources when direct measurement if technically or economically infeasible.

Determining exposure pathways and environmental fate

The magnitude of human exposure to a contaminant depends on the concentration of the contaminant, how the person comes into contact with the contaminant, and the time of exposure. Outdoor exposure pathways can be complex and involve varieties of contaminants, contaminant sources, and transport media, points of contact and exposure routes. Indoor exposure pathways are generally less complicated, often involve fewer transport media, points of contact, and exposure routes. Typically pathways of the substances to which indoor populations exposed are infiltration of contaminated outdoor environment, contaminants brought indoors from the outside by the occupants, volatilization and evaporation of chemical from indoor sources, emissions from indoor equipment, and personal activities such as cooking, cleaning and smoking, and many others.

Measuring or estimating indoor contaminant concentrations

Likewise, indoor contaminant concentrations can be measured or estimated in a similar way as outdoor contaminant concentrations. Indoor pollutant concentrations can be measured by using fixed or portable monitors and by testing the equipment or materials being suspected of contributing to the indoor air pollutant concentration of concern.

Direct measurements can be taken by using personal monitors and by determining the presence of biological markers in the exposed population. Indirect measurement methods often are preferred for estimating exposure because they can be used to reasonably describe an individual's exposure and are generally less costly.

Identifying exposed populations

Identification of the exposed population can be relatively simple if the objective is to evaluate a limited number of microenvironments or a limited number of exposed persons. However, it can certainly increase the difficulty if the task is to evaluate a large exposed population having activities in numerous microenvironments. In a simple case, a building investigation may be required and the building occupants may be surveyed using questionnaires or through personal interview. Larger scale regional investigations, on the other hand, may need to use census data or statistical methods to identify persons for questionnaire survey.

Integrating exposure assessment

Estimating exposure is generally an integrated process using measured, modeled and gathered data. In an individual exposure model, microenvironmental contaminant concentrations are measured or modeled and time–activity patterns are used to estimate the time spent in each microevironment. Total exposure then is determined by summing the products of concentration and time for all of the microenvironments in which individual spent time. In a population exposure model, the microenvironment concentrations are combined with individual activity patterns and the results are usually extrapolated to a larger population.

Survey research techniques are used to obtain detailed, specific data on the physical properties of the examined microenvironments and population exposure and movement into and out of the microenvironments. Surveys usually require gathering of personal information through questionnaires or personal diaries.

Uncertainty in exposure characterization

Uncertainties in exposure assessment can arise from: (1) variations in methods or models used; (2) variations in inputs to those methods and models; (3) imprecise knowledge of the underlying science; and (4) natural variability (Patrick, 1992). A detailed discussion of the uncertainties associated with the exposure assessment will be shown in Chapter 7.

3.2 Methodology adopted for this study

In this study, the indirect approach was used to estimate the total human exposure. Exposure assessment was divided into two major parts. The first part was the time budget survey with an objective to determine the daily activity pattern of

Hong Kong population. The second part was microenvironment study with an objective to determine the concentration of air pollutant in different individual microenvironments. The total exposure could then be estimated based on the obtained data.

One of the critical information needed for total exposure assessment was the detailed data on time budget of surveyed population, since this determined the duration, frequency and intensity of exposure times. To obtain the necessary data, a telephone questionnaire survey was used to collect the information of the time budget of Hong Kong population.

For the telephone survey, a random sampling methodology was developed using the Hong Kong residential telephone directories, and a reasonable sampling size was determined so as to ensure the expecting precision and deviation. In order to ensure randomness in the sample selection, the telephone numbers were randomly drawn from the residential telephone directories. A questionnaire was developed to facilitate the process of telephone interview.

The second major part was on the microenvironment study. A microenvironment could be defined as a location with homogeneous pollutant concentration that a person occupied for some finite period of time.

In this study, eight major microenvironments were chosen for site measurements. Portable indoor air monitors were used to measure the indoor pollutant levels.

The average concentrations of the major microenvironments were obtained from our own survey measurements, while the concentrations of the remaining microenvironments were obtained from the measurement data reported in various open literatures. The results of time budget survey and microenvironment study will be discussed in the next two chapters.

4 TIME BUDGET SURVEY

Time budget survey is one of the major parts of total exposure assessment. In this chapter, the methodology employed for the telephone survey will be introduced, before the analysis of the collected information of the time budget and daily activity pattern of the Hong Kong population is discussed.

4.1 Introduction

According to the definition of exposure mentioned in the previous Chapters, one of the critical information needed for total exposure assessment is the detailed time budget and human activity patterns data for the examined population.

A reasonable scale of survey was needed to collect the information of human daily activity pattern. Telephone interview survey was used in this study, because it was relatively less expensive than face-to-face interview and could be expected to get higher response rate than mailed questionnaire survey.

The objective of the survey was to obtain the time budget information of Hong Kong population. In order to obtain necessary time budget information of almost seven million residents living in Hong Kong, a predetermined number of samples were drawn randomly. Telephone interview was chosen to collect the time budget information. A detailed schedule of telephone survey was formulated before the survey began. A questionnaire was designed to facilitate the collection of the time budget information via telephone interview. The procedures adopted by this survey will be discussed in details in this chapter. The results of the survey were used to estimate the total exposure of the Hong Kong population in Chapter 6.

4.2 Methodology

Generally speaking, the objective of statistics is to make inferences about a population from information contained in a sample. The inference might be in the form of an estimate of a population parameter, such as mean, total, or proportion, with a bound on the error estimation.

Each observation or item taken from the population contained a certain amount of information about the population parameter. Too little information prevented the experimenter from making good estimates, while too much information resulted in a waste of resources. The design of the survey and the sampling size determined the quantity of information in the sample pertinent to a population parameter. The quality of information was determined by accurate measurements, which could be enhanced by proper methods of data collection and good questionnaire construction.

4.2.1 Survey design

A statistical estimation required that randomness be built into the sampling design so that properties of the population could be assessed probabilistically. Random sampling from a finite population meant the items included in the sample were selected from the population so that every possible sample of the same size had an equal chance of being chosen. The simple random sampling procedure was used in this study.

Even though many methods of data collection, like personal interview, telephone interview and self-administered mailed questionnaire, were available for sample surveys, telephone interview was chosen in the study to collect the time budget information of Hong Kong population. This is because telephone interview usually requires less resource and can obtain higher response rate with acceptable information accuracy. The advantages and disadvantages of three different types of data collection methods are shown in Table 4.1.

Table 4.1 Advantages and disadvantages of three methods of data collection

Data collection method	Personal interview	Telephone interview	Mailed questionnaire
Time cost	High	low	Medium
Money cost	High	low	Medium
Response rate	High	medium	Low
Interviewer training	High	medium	Low
Accuracy of information	High	medium	Medium

4.2.2 Sampling size

In the planning of a sampling survey, a major issue needed to be addressed is to determine the sampling size. A larger sampling size might cost too much, while a smaller sampling size might incur a big error. The size for a sample was determined by confidence intervals for the population means μ and the population proportion of successes p. The formula below has frequently been used for determining the appropriate sampling size for a simple random, non-overlapping sampling method. (Shi L. M., Crowston W. B. et al, 1992).

$$n = \frac{Nt^2 p(1-p)}{N\Delta^2 + t^2 p(1-p)}$$

Where: n — sampling size

N — whole population

t — probability of normal distribution

p — proportion of success

Δ — tolerance of error

In this study, the confidence level was assigned to 0.95, with a probability t of 1.96. The value of p was assigned as 0.5, so that the product of p·(1-p) had the highest value than when any other value was used for p. The tolerance of error was 0.05. With a population of 7 millions in Hong Kong, the sampling size was determined to be 399.

4.2.3 Questionnaire design

The questionnaire was designed in a manner so as to facilitate the easy collection of the time spending pattern of the Hong Kong people via telephone lines. The questions should be clear and easy to answer. And the time needed to complete the questionnaire was restricted to less than fifteen minutes.

The questionnaire adopted was divided into two parts. Part 1 comprised 14 questions covering the basic socio-economic characteristics of the respondents, i.e. sex, age, address, education and occupation. Part 2 comprised the 24-hr recalled diary covering various activities on a typical day during weekdays (Monday-Friday) and weekends (Saturday and Sunday) respectively. The questionnaire was designed to record the activity and the location of respondent in a time span, using up to 9 major activities and 20 major microenvironments. An example of questionnaire is shown in Appendix 1.

4.2.4 Telephone survey

A random population survey sample was drawn from the 1998 Residential Telephone Directory in Hong Kong, with a typical day recalled questionnaire survey used for recording time diaries of surveyed subjects. In order to ensure the randomness in selecting the samples of the survey, a computer program had been developed to create a set of random numbers, so as to determine the extracted pages, columns and lines inside the Hong Kong residential telephone directories.

From around 600,000 residential telephone numbers, about 2000 individual telephone numbers had been selected. The response rate was about 20%. The daily activity information of around 400 samples was obtained after the completion of survey.

The telephone survey was conducted from 20:00 to 22:00 each day during the survey period. During that time period, most of Hong Kong people were expected to have returned home after work and could have some spare times to respond to the telephone survey. The time required for each survey was limited to about fifteen minutes to prevent the participants from becoming impatient. At the beginning of each interview, the surveyor explained the reason and significance of the survey clearly and asked for the support and cooperation of the respondents. Leading questions or attitudes were avoided to reduce the bias to the result. Languages used in telephone survey were Cantonese and English. Unfortunately, a few telephone numbers that had not been registered in the directory and about 5% of Hong Kong people who speak other languages were omitted in the survey.

4.3 Results and discussions

Prior to the detailed data analysis, an arithmetic time check had been performed so as to ensure that the total time spent reported by individual respondent was not substantially different from a total of 24 hours (a day). Samples would be rejected in case the reported totals were significantly more or less than 24 hours. The result of the telephone survey had then been collected and analyzed. Time budget and daily activity pattern of Hong Kong population had been obtained.

It was found that time budget and activity pattern could be influenced by many factors, i.e. age, gender, occupation. For example, the elder and the youngster group might spend more time indoors at home, while the adult group might spend more time in office buildings and other public places. Different subgroups of population with different time budget might have different exposure to air pollution.

4.3.1 Representativeness of the survey

Telephone interviews were successfully administered to 396 participants, and the socio-economic characteristics of the participants are listed in Table 4.2. In all participants, about half of the respondents were males. 10% of respondents were full time students. 78% were employed, in which 59.5% were office workers and 10.5% were non-office workers. About 15% were smokers with 7% consumed more than 20 cigarettes per day.

Table 4.2 Socio-economic status and demographic characteristics of respondents

	Subgroup	Number	Percentage (%)	Note
Gender	Female	181	45.71	
	Male	215	54.29	
Age (year)	<14	14	3.5	
	15-24	85	21.5	
	25-34	123	31.1	
	35-44	91	23.0	
	45-54	42	10.6	
	55-64	23	5.8	
	65-74	15	3.8	
	>75	3	0.8	
Education Background*	Non-educated	5	1.26	
	Primary school	35	8.84	
	Secondary school	164	41.41	
	University/college	92	23.23	
Occupation	Office workers	235	59.44	Working in office environments for more than 5 hrs per day
	Non-office workers	81	20.45	Working in office for less than 5 hrs per day
	Unemployed /housewife	40	10.10	
Smoking Habit	Heavy smoker	28	7.07	More than 20 cigarettes per day
	Light smoker	35	8.84	Less than 20 cigarettes per day
	Non-smoker	333	84.09	

Cooking fuel	Town gas	363	91.67
	LPG	28	7.07
	Kerosene	5	1.26
Total		396	100

* 100 respondents are not classified under any education background categories since they were under age of 25 and had not finished the schooling yet

The representativeness of the survey could be tested by comparing the age distributions of the participants and Hong Kong population. It is shown in Figure 4.1.

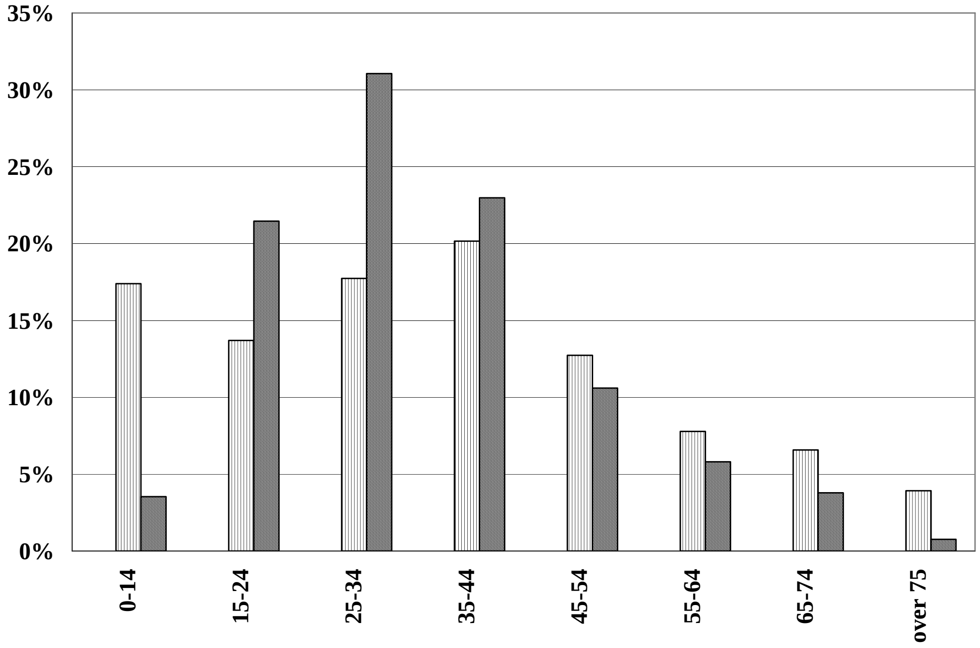


Figure 4.1 **Age distributions of the survey participants and Hong Kong population**

In Figure 4.1, the left column refers to the age distribution of Hong Kong population (Hong Kong Census 1998), while the right column refers to the age distribution of the participants of the survey. It was found that the proportion of teenager of survey participants was much less than that of Hong Kong population. The proportion of people between 15 to 35 years old of the survey participants was high. This was possibly due to the limitation of telephone interview. For most of the children could not answer the questions of the interview independently, little valid questionnaires responses from children were obtained. However, the general age distribution of survey participants could be compared with that of Hong Kong population, and the survey was proved to be representative.

4.3.2 Time budget of Hong Kong population

Figure 4.2 shows that the surveyed subjects mainly engaged in nine primary activities: sleeping, working, eating, traveling, shopping, cooking, personal hygiene, outdoor activities and entertainment. The survey results showed that the total time spent in nine major activities was about 23.3 hr/day (97%). Figure 4.3 shows the major locations, indoor at home, indoor in public places, enclosed transits and outdoor, that Hong Kong people spent their daily time. The total amount of time that Hong Kong people spent in indoor environments added up to be more than 21.2 hr/day (89%).

Table 4.3 shows the time budget of Hong Kong people during weekdays and weekends. It was found that Hong Kong people spent more time at home, in enclosed transits and outdoors during weekends. On weekdays, more than 2.7 hr/day were spent in various public places, such as in office buildings and schools. Hong Kong people spent much time in restaurants everyday, especially during weekends (2.16 hr/day of the population). Hong Kong people lived a busy life and many people chose to have meals in restaurants. Perhaps, it was due to the reason that traditional Chinese food usually takes more time to cook and eat. Shopping, go to pub, watching movie in cinema were favorite entertainments of Hong Kong people.

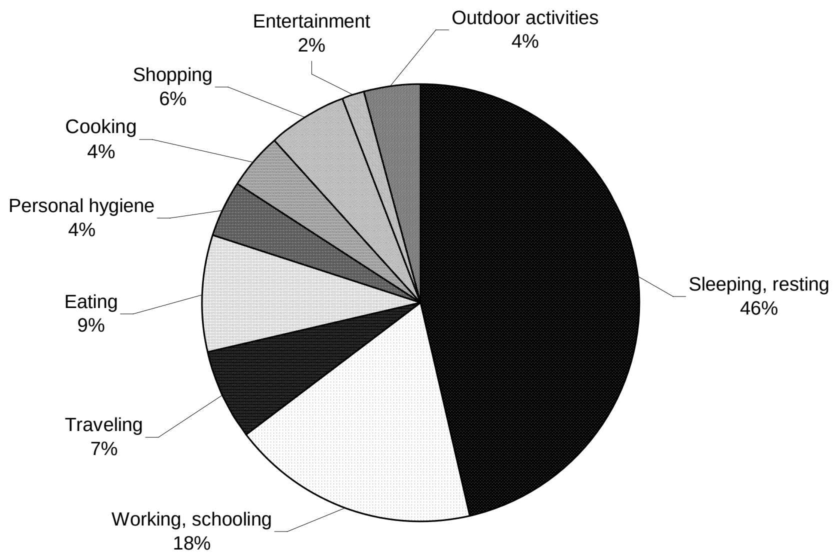


Figure 4.2 Percentage of time spent in major activities by Hong Kong people

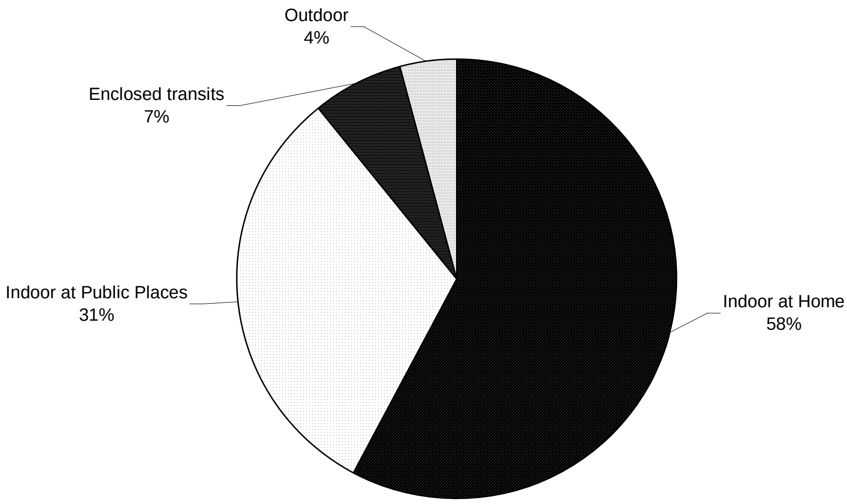


Figure 4.3 Percentage of time spent in major locations by Hong Kong people

Hong Kong people also spent much of their daily time on enclosed transits, especially on various public transit facilities. Bus and subway (MTR) were found to be the most preferred public transits by Hong Kong people. They spent over 0.7 hr/day in buses and 0.45 hr/day in MTR. Although the time spent outdoors was limited, Hong Kong people still hoped to spend more time outdoors during weekends.

According to the survey results, people in different age group might have different life styles and time budgets. Tables 4.4-4.6 show the time budget and daily activity patterns for three population subgroups, i.e. the youngster (6-18 years old), adult (18-60 years old), and elder (>60 years old), respectively.

Individuals from all three age groups, on average, spent more than 86% of their time indoors, 3-7% in enclosed transit, and 3-7% outdoor. Normal office workers (usually adults) in Hong Kong were used to work in office buildings, on average, 7.5 hours and 3.6 hours during weekdays and weekends respectively. It was much higher than people from the other two age groups. On the other hand, the youngsters spent more time (about 4.3 hr/day on weekdays) in school, and the elders spent more time at home (over 16.5 hr/day).

It was also found a heavy reliance of Hong Kong people took the public transport network to meet their daily commuting needs, with approximately 60% youngsters, 50% adults, and 33% elders spending time in buses; and 30% youngsters, 50% adults and 20% elders in subway (MTR) on a given day. In contrast, less than 20% of surveyed adults and 17% youngsters were commuted by private cars or taxi on weekdays or weekends. Heavy reliance on the public transport network was probably due to two main reasons: (i) the existence of an extensive and convenient transportation network in Hong Kong; and (ii) high operating and maintenance cost of possessing a car in Hong Kong. The elderly group was observed to spend less time in enclosed transits, while more time outdoor, than the other two age groups.

Data in Tables 4.4-4.6 not only indicate the length of time people exposed, but also the percentages of population who might be exposed in terms of percentage doer. For instance, results indicate that more youngsters (70% of youngest group) would visit restaurants than schools (60%) during weekdays. More adults (61.1% of adult group) would visit restaurants than offices (55.1%) during weekdays. More elders (70.8%) would visit shopping areas than restaurants (33.3%) during weekdays.

Table 4.3 Time budget of Hong Kong population during weekdays and weekends

Microenvironment	Weekday				Weekend			
	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})
Indoors at home								
Bedroom	8.00	98.99%	8.20	1-20	9.09	99.50%	9.14	3-20
Living/Dinning room	3.28	96.47%	3.40	0.5-10	4.27	95.20%	4.49	0.5-14.5
Kitchen	0.86	64.39%	1.33	0.1-7	1.03	69.19%	1.49	0.25-4
Bathroom	0.97	98.49%	0.98	0.25-4	1.08	98.99%	1.09	0.25-8
Others	0.11	3.79%	2.83	0.5-10	0.13	3.29%	4.02	0.5-13
Sub-total	13.22(55.08%)				15.60(65.00%)			
Indoors away from home								
Office building	4.12	48.48%	7.42	0.1-12	0.17	4.55%	3.45	1-9
School	1.15	20.70%	5.61	0.5-12	0.27	6.32%	4.20	1-12

Industrial plant	0.46	6.57%	6.96	0.5-10	0.04	0.76%	5.33	6-8
Shopping mall	1.04	48.99%	2.12	0.25-12	2.16	83.34%	2.57	0.5-12
Restaurant	0.84	60.35%	1.38	0.25-10	1.25	70.96%	1.76	0.5-5
Hospital	0.09	1.77%	4.93	0.5-9	0.01	0.75%	1.33	1-2
Hotel	0.01	0.50%	1.50	1-2	0.02	2.02%	1.23	0.3-3
Church	0.15	6.82%	2.21	0.5-15	0.43	13.89%	3.06	0.5-15
Cinema/Theater	0.11	6.82%	1.59	0.5-3	0.52	28.54%	1.82	0.1-4
Night Club/Bar	0.12	5.30%	2.26	0.5-6	0.31	13.64%	2.25	1-4
Indoor gym	0.11	9.09%	1.25	0.25-4	0.30	18.69%	1.59	0.25-4
Parking/Garage/Gas Station	0.04	3.03%	1.24	0.1-4	0.05	4.80%	1.05	0.2-5
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	8.23(34.29%)				5.51(22.96%)			
Enclosed Transit								
Private car/Taxi	0.11	11.11%	1.03	0.25-4	0.27	20.70%	1.34	0.33-4
Bus	0.79	61.61%	1.27	0.25-12	0.70	53.28%	1.27	0.2-10
Truck/Van	0.02	0.50%	4.50	1-8	0.01	0.50%	1.00	1

Train (KCR, LRT)	0.13	14.65%	0.88	0.1-2	0.15	17.17%	0.98	0.2-4
MTR (subway)	0.46	47.48%	0.96	0.2-8	0.47	48.23%	0.98	0.25-4
Tram	0.03	4.30%	0.72	0.1-2	0.02	3.28%	0.56	0.25-1
Airplane	0.02	1.77%	1.14	0.5-3	0.02	1.27%	1.20	1-2
Sub-total	1.56(6.50%)				1.64(6.83%)			
Outdoor								
Walking	0.86	79.54%	1.08	0.25-7.5	1.12	77.78%	1.44	0.05-7.5
Bicycle	0.00	0.08%	0.25	0.25	0.02	1.01%	2.00	1-4
Motorcycle	0.00	0.25%	1.00	1	0.01	0.75%	1.67	1-2
Others	0.05	0.50%	1.20	0.25-3	0.08	2.78%	2.00	0.25-8
Sub-total	0.91(3.79%)				1.24(5.17%)			
Total (approx)	23.92(100%)				23.99(100%)			

Table 4.4 Time budget of youngster (6-18 years old) during weekdays and weekends

Microenvironment	Weekday				Weekend			
	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})
Indoors at home								
Bedroom	8.63	100.00%	8.63	2-14	9.83	100.00%	9.83	4-14
Living/Dinning room	3.83	97.50%	3.92	1-9	4.01	95.00%	4.22	1-10
Kitchen	0.41	37.50%	1.02	0.25-3	0.31	62.50%	0.50	0.5
Bathroom	0.88	95.00%	0.92	0.5-2	1.03	100.00%	1.03	0.5-2
Others	0.05	2.50%	2.00	2.00	0.00	0.00%	0.00	N/A
Sub-total	13.78 (58%)				15.18(65.4%)			
Indoors away from home								
Office building	0.73	12.50%	5.80	1-10	0.00	0.00%	0.00	N/A
School	4.33	60.00%	7.21	6-10	0.20	5.00%	4.00	4

Industrial plant	0.48	7.50%	6.33	2-9	0.05	2.50%	2.00	2
Shopping mall	1.38	37.50%	3.67	0.5-10	1.80	82.50%	2.17	0.5-6
Restaurant	0.80	70.00%	1.14	0.5-4	0.71	52.50%	1.36	1-3
Hospital	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Hotel	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Church	0.00	0.00%	0.00	N/A	0.33	7.50%	4.33	2-6
Cinema/Theater	0.08	7.50%	1.00	0.5-2	0.95	52.50%	1.81	0.5-4
Night Club/Bar	0.18	5.00%	3.50	2-5	0.81	32.50%	2.50	0.5-5
Indoor gym	0.15	17.50%	0.86	0.5-1	0.65	37.50%	1.73	1-3
Parking/Garage/Gas Station	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	8.10(34.1%)				5.50(23.7%)			
Enclosed Transit								
Private car/Taxi	0.14	15.00%	0.96	0.25-2	0.16	17.50%	0.93	0.5-2
Bus	0.65	62.50%	1.04	0.25-3	0.71	62.50%	1.14	0.5-4
Truck/Van	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A

Train (KCR, LRT)	0.06	7.50%	0.83	0.5-1	0.25	25.00%	0.93	0.25-2
MTR (subway)	0.28	30.00%	0.92	0.5-3	0.28	37.50%	0.73	0.5-1.5
Tram	0.01	2.50%	0.50	0.5	0.03	5.00%	0.50	0.5
Airplane	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	1.15 (4.8%)				1.43(6.2%)			
Outdoor								
Walking	0.69	90.00%	0.77	0.25-2	1.05	82.50%	1.27	0.5-3
Bicycle	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Motorcycle	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Others	0.04	2.50%	1.50	1.5	0.08	2.50%	3.00	3
Sub-total	0.73(3.1%)				1.13(4.9%)			
Total (approx)	23.76(100%)				23.23(100%)			

Table 4.5 Time budget of adult (18-60 years old) during weekdays and weekends

Microenvironment	Weekday				Weekend			
	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})
Indoors at home								
Bedroom	7.92	98.80%	0.98	1-20	9.06	99.40%	9.11	3-20
Living/Dinning room	3.10	96.39%	3.22	0.5-10	4.20	95.18%	4.42	0.5-14.5
Kitchen	0.81	65.96%	1.23	0.1-7	1.01	67.77%	1.49	0.25-4
Bathroom	0.97	98.80%	0.98	0.25-4	1.08	98.80%	1.09	0.25-8
Others	0.12	4.22%	2.89	0.5-10	0.16	3.92%	4.02	0.5-13
Sub-total	12.92(55.5%)				15.50(63.5%)			
Indoors away from home								
Office building	4.13	55.12%	7.49	0.1-12	0.18	4.82%	3.63	1-9
School	0.84	17.17%	4.99	0.5-12	0.29	6.63%	4.32	1-12

Industrial plant	0.48	6.63%	7.18	0.5-10	0.04	0.60%	7.00	6-8
Shopping mall	0.94	48.80%	1.93	0.25-12	2.23	84.34%	2.63	0.5-12
Restaurant	0.86	61.14%	1.40	0.25-10	1.32	74.40%	1.78	0.5-5
Hospital	0.10	2.11%	4.93	0.5-9	0.01	0.90%	1.33	1-2
Hotel	0.01	0.60%	1.50	1-2	0.03	2.41%	1.23	0.3-3
Church	0.15	7.53%	2.03	0.5-15	0.43	15.06%	2.87	0.5-15
Cinema/Theater	0.12	6.93%	1.67	0.5-3	0.50	27.41%	1.83	0.1-4
Night Club/Bar	0.12	5.72%	2.13	0.5-6	0.26	12.05%	2.18	1-4
Indoor gym	0.12	8.73%	1.35	0.25-4	0.27	17.77%	1.55	0.25-4
Parking/Garage/Gas Station	0.04	3.61%	1.24	0.1-4	0.06	5.72%	1.05	0.2-5
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	7.92(34.0%)				5.62(23.4%)			
Enclosed Transit								
Private car/Taxi	0.11	10.84%	1.04	0.25-4	0.29	21.08%	1.38	0.33-4
Bus	0.80	63.55%	1.26	0.25-12	0.72	56.02%	1.29	0.2-10
Truck/Van	0.03	0.60%	4.50	1-8	0.01	0.60%	1.00	1

Train (KCR, LRT)	0.15	16.57%	0.88	0.1-2	0.16	15.96%	1.02	0.2-4
MTR (subway)	0.50	51.51%	0.97	0.2-8	0.52	52.41%	1.00	0.25-4
Tram	0.03	4.22%	0.66	0.1-2	0.02	3.31%	0.57	0.25-1
Airplane	0.02	2.11%	1.14	0.5-3	0.02	1.51%	1.20	1-2
Sub-total	1.64(7.04%)				1.74(7.2%)			
Outdoor								
Walking	0.78	78.01%	1.00	0.25-7.5	1.08	77.11%	1.40	0.05-7.5
Bicycle	0.00	0.10%	0.25	0.25	0.02	1.20%	2.00	1-4
Motorcycle	0.00	0.30%	1.00	1	0.02	0.90%	1.67	1-2
Others	0.02	0.30%	0.89	0.25-3	0.06	3.01%	1.90	0.25-8
Sub-total	0.80(3.4%)				1.18(4.9%)			
Total (approx)	23.28(100%)				24.04(100%)			

Table 4.6 Time budget of elderly (>60 years old) during weekdays and weekends

Microenvironment	Weekday				Weekend			
	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})	Population mean (hr d^{-1})	Percent doers	Doer mean (hr d^{-1})	Doer range (hr d^{-1})
Indoors at home								
Bedroom	8.13	100.00%	8.13	4-13	8.38	100.00%	8.38	6-13
Living/Dinning room	4.81	95.83%	5.02	1-12	5.60	95.83%	5.85	2-12.5
Kitchen	2.25	87.50%	2.57	0.5-6	2.52	100.00%	2.52	0.5-7
Bathroom	1.15	100.00%	1.15	0.5-2	1.15	100.00%	1.15	0.5-2
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	16.33(68.5%)				17.65(74.6%)			
Indoors away from home								
Office building	1.04	16.67%	6.25	2-9	0.17	8.33%	2.00	2
School	0.08	4.00%	2.00	2	0.08	4.17%	2.00	2

Industrial plant	0.17	4.17%	4.00	4	0.00	0.00%	0.00	N/A
Shopping mall	1.92	70.83%	2.56	0.5-4.5	1.73	70.83%	2.44	1-4.5
Restaurant	0.58	33.33%	1.75	0.5-3	1.08	54.17%	2.00	1-4
Hospital	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Hotel	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Church	0.38	8.33%	4.50	2-7	0.50	8.33%	6.00	6
Cinema/Theater	0.06	4.17%	1.50	1.5	0.06	4.17%	1.50	1.5
Night Club/Bar	0.00	0.00%	0.00	N/A	0.08	4.17%	2.00	2
Indoor gym	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Parking/Garage/Gas Station	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	4.23(17.7%)				3.71(15.7%)			
Enclosed Transit								
Private car/Taxi	0.08	8.33%	1.00	0.5-1.5	0.29	20.83%	1.40	1-2
Bus	0.75	33.33%	2.25	1-8	0.00	0.00%	0.00	N/A
Truck/Van	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A

Train (KCR, LRT)	0.00	0.00%	0.00	N/A	0.13	20.83%	0.60	0.5-1
MTR (subway)	0.13	20.83%	0.60	0.5-1	0.06	8.33%	0.75	0.5-1
Tram	0.10	8.33%	1.25	0.5-2	0.00	0.00%	0.00	N/A
Airplane	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	1.06(4.4%)				0.48(2.0%)			
Outdoor								
Walking	2.23	83.33%	2.68	0.5-6	1.83	79.17%	2.32	0.5-5
Bicycle	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Motorcycle	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Others	0.00	0.00%	0.00	N/A	0.00	0.00%	0.00	N/A
Sub-total	2.23(9.4%)				1.83(7.7%)			
Total (approx)	23.85(100%)				23.67(100%)			

4.3.3 Comparing time budget of people in Hong Kong and U.S.

Some U.S. researchers had also conducted a similar time budget survey in Los Angeles in California in 1992 (Jenkins et al, 1992), which was believed to be one of the pioneering surveys in this field. Accordingly, it would be valuable to compare the time budget of people in Hong Kong with that of U.S. by identifying similarities of the people in these two developed areas, and also the differences in characteristics due to the geographic, environmental, climatic, meteorological and historic specialties of Hong Kong and the special living style, cultural background of Hong Kong people.

Since Hong Kong and Los Angeles are both considered as economically developed areas, the time budget and daily activity pattern might have some similarities. On average, Hong Kong people spent 89% of their time indoors, 7% in enclosed transit, and 4% outdoor. This is similar to the time activity pattern of a Californian in US as shown in Table 4.7 (87% of time spent indoors, 7% in enclosed transit and 6% outdoor). This shows that the cultural differences between the people in Los Angeles and Hong Kong did not lead to any major differences in the total amount of time spent indoors. Although the average times spent indoors between these two nations were comparable, more detailed analysis showed significant differences in the average amount of time spent in specific locations.

People in Hong Kong spent 62 minutes less per day at home but 90 minutes more per day in indoor public places than people in US. It might be due to the smaller house area occupied by the people in Hong Kong people than those in Los Angles. Shopping malls, restaurants, pubs and bars were their favorite staying out places. The observed difference in activity patterns was probably due to the reason that Hong Kong people would prefer to stay inside the busy public places rather than their tiny and crowded apartments. On the other hand, the survey results showed that normal office workers in Hong Kong tend to have longer working hours than those in U.S. (320 minutes per day in Hong Kong in contrast with 275 minutes per day in US).

Data in Table 4.7 not only indicate the length of time people exposed, but also the percentages of the population who might be exposed in terms of percentage doer. For instance, results indicate that more Hong Kong people would visit shopping malls or restaurants (85.9% and 78.1% of the population respectively) than U.S. people (27.2% and 34.5% of the population respectively). More Hong Kong people (49.9% of population) worked in office buildings than those worked in Los Angeles (25.5% of population).

The total time spent in enclosed transits of the people in Hong Kong and Los Angeles was also comparable. On the average, the average total time spent by a Hong Kong adult commuters utilizing all modes of transport were 1.6 and 1.7 hour per day during weekdays and weekends respectively. This was approximately the same as the average time spent by daily commuters in other large metropolitan cities like Athens in Greece (Vellopoulou et al, 1998). Even though the average total time spent were approximately the same, Hong Kong people tended to use public transit facilities as a major commuting means, while the U.S. people used private cars.

Table 4.7 Time spent in various microenvironments of the people in HK and U.S.

Microenvironment	HK people				U.S. people			
	Population mean (min d^{-1})	Percent doers	Doer mean (min d^{-1})	Doer range (min d^{-1})	Population mean (min d^{-1})	Percent doers	Doer mean (min d^{-1})	Doer range (min d^{-1})
Indoors at home								
Bedroom	496	99.2	499	137-1200	524	95.9	546	5-1435
Living/Dinning room	212	97.4	217	8-686	196	80	246	1-1340
Kitchen	55	74.6	74	4-420	74	75.3	98	1-930
Bathroom	61	99.0	61	15-240	33	73.6	45	1-650
Others	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A
Sub-total	*831(57.7%)*				*893(62%)*			
Indoors away from home								
Office building	183	49.9	320	4-540	70	25.5	275	1-725
School	51	20.6	247	17-720	40	15.4	262	1-724

Industrial plant	21	6.7	309	22-532	35	8.9	393	4-750
Shopping mall	83	85.9	97	8-720	34	27.2	124	1-845
Restaurant	58	78.1	74	8-446	28	34.5	81	1-885
Hospital	4	2.1	193	22-386	14	8.0	181	4-840
Hotel	1	2.1	37	5-120	7	2.2	308	10-985
Church	2	2.3	78	10-160	6	4.7	135	5-395
Cinema/Theater	13	27.5	48	2-180	N/A	N/A	N/A	N/A
Night Club/Bar	11	15.9	67	8-300	8	4.6	174	5-825
Indoor gym	10	19.8	49	8-240	4	4.3	98	5-395
Parking/Garage/Gas Station	3	5.4	47	4-240	11	11.6	91	1-685
Others	N/A	N/A	N/A	N/A	102	N/A	N/A	N/A
Sub-total	*449(31.2%)*				*359(24.9%)*			
Enclosed Transit								
Private car/Taxi	7	15.4	46	8-180	73	74.2	99	1-585
Bus	46	69.9	65	5-686	4	3.4	114	5-1320
Truck/Van	2	0.8	140	17-343	18	17.5	102	2-785

Train (KCR, LRT)	8	19.0	38	4-120	1	0.9	123	5-395
MTR (subway)	28	61.2	46	4-352	N/A	N/A	N/A	N/A
Tram	2	5.7	31	4-103	N/A	N/A	N/A	N/A
Airplane	N/A	N/A	N/A	N/A	1	0.5	130	10-315
Sub-total	*96(6.7%)*				*97(6.7%)*			
Outdoor								
Working	56	86.9	64	8-450	10	26.4	38	1-360
Bicycle	0.3	1.3	29	11-68	1	3.1	41	5-160
Motorcycle	0.3	0.8	43	17-77	1	1.9	62	5-430
Others	3.4	3.5	102	12-272	74	N/A	N/A	N/A
Sub-total	*60(4.2%)*				*86(6.0%)*			
Total (approx)	*1436(100%)*				*1435(100%)*			

4.4 Summary

The time budget and daily activity pattern data of Hong Kong people were obtained through a well planned questionnaire survey. Telephone interview was successfully used to obtain the required information. Given that the results were obtained from a random sampling methodology, they were expected to representing the different population age groups in Hong Kong.

The results show that people of different age groups had different time budgets. Hong Kong people got a similar time budget to people in Los Angeles, even though there were differences in time spent in individual microenvironments.

The results also show that Hong Kong people spent about 89% of their daily time in indoors. The air quality and pollutant level of various indoor microenvironments might directly influence the health of Hong Kong people, and will be investigated by microenvironment study in Chapter 5. Based on the results of time budget survey and microenvironment study, the total exposure of Hong Kong people were estimated in Chapter 6.

5 MICROENVIRONMENT STUDIES

Microenvironment study is a significant part of indirect approach of exposure assessment in this research. As mentioned in the previous chapters, the concept of microenvironment is proposed to represent the indoor air conditions of different indoor environments. Together with the results of time budget survey, the total exposure could be estimated.

In this chapter, a number of major microenvironments that had potential health risk to human beings were chosen for detailed investigation. A microenvironment study protocol was developed to obtain the indoor pollutant levels in major microenvironments through site measurements.

5.1 Classification and characteristics of various microenvironments

Air contaminants may include gaseous pollutants, particulate, biological and organic compounds. Different kinds of air contaminants may have different sources of origins. Different types and concentration levels of air contaminants may exist in different types of microenvironments.

Based on the results of time budget survey, Hong Kong people spent about 89% of their daily time on various indoor microenvironments including home, in which about 60% of time spent on their homes everyday. Not only Hong Kong people stayed home for a long time, but also their houses were tiny and crowded. The lack of land resources in Hong Kong resulted in a high population density, and it was quite common that residents in Hong Kong lived in high-rise buildings within a small estate area. The indoor air quality had been extensively studied by many researchers in Hong Kong (Chao et al, 1998, Lee et al, 1999, Tu et al, 2003).

Hong Kong people visited restaurants and pubs frequently in their daily lives. These two types of microenvironments usually had many customers crowded in a limited space. Potential indoor pollutant sources, such as cooking gas, hot-pot stoves and smoking activities, were found everywhere. The pollutant concentration might increase to a dangerous level especially in case the fresh air intake was not enough (Chao et al, 1997, Chao et al, 2001, Lee et al, 2001, Tu et al, 2002, 2003).

Enclosed transits had limited space with high density of passengers. The results of time budget survey show that Hong Kong people took various public transit facilities (PTF) rather than private cars. Nowadays, several types of PTFs, such as public bus, MTR (Mass Transit Railway), KCR (Kowloon-Canton Railway), LRT (Light Railway Transit), ferry, tram, etc., were operating in Hong Kong. Air-conditioned PTFs had not provided enough fresh air to dilute the pollutants, and to prevent the accumulation of air pollutants that might lead to potential health risk to the passengers and PTFs staffs (Chan et al, 1999, Chan et al, 1998, Tu et al, 2003).

Therefore residential buildings, restaurants and pubs, public transit facilities were considered as significant microenvironments for further investigation. Site measurements were conducted with a strategically designed protocol in this study.

5.2 Site measurements in major microenvironments

As the microenvironments were used for estimating the total exposure of individuals, site measurements were carried out to obtain their indoor air contaminant concentrations. Exposures in residence, bus and restaurant were ranked the top three types of microenvironments that contributed significantly to the total exposure.

5.2.1 Protocol for site measurements

In this study, the average concentrations of the major microenvironments were obtained from our own survey measurements, while the concentrations of the remaining microenvironments were obtained from the measurement data reported in various open literatures. As far as the practicality of this study was concerned, the interests concentrate on the pollutant exposures that had significant health impact to human beings, from either chronic or acute point of view. The measured pollutants included carbon monoxide (CO), nitrogen dioxide (NO_2), and respiratory dust (PM_{10}). Although carbon dioxide (CO_2) is not considered as air pollutant, it was also measured in this study to indicate the ventilation efficiency in various microenvironments. Due to the limitation of time and equipment obtained, other pollutant such as VOCs, O_3 were not included in this study.

5.2.2 Instruments used in site measurements

A portable PM 7400 (MetroSonic, NY, USA) was used for simultaneously measuring the concentrations of CO, NO_2 and NO inside various microenvironments. Meanwhile, Dust trak 8520 (Dust Trak, Shoreview, Minn., USA) and Q-Trak 8551 (Q-Trak, Shoreview, Minn., USA) manufactured by TSI, are used to measure the PM_{10} and CO_2 concentrations respectively. The details of the operating principles, measuring ranges and accuracies of the equipment were given in Table 5.1. In order to assure the quality of the measuring data, all monitoring instruments were being calibrated prior to each site measurement by using reference gases.

Table 5.1 Equipment used in the site measurements

Model (Manufacturer)	Air Contaminant	Operating Principle	Resolution	Measuring Range	Accuracy
PM7400	CO	Electro-	1 ppm	0-1000 ppm	± 5%
(MetroSonic)	SO_2	chemical	0.1 ppm	0-100 ppm	± 5%
	NO_2		0.1 ppm	0-50 ppm	± 5%
	NO		1 ppm	0-200 ppm	± 5%

DustTrak 8520 (TSI)	PM_{10}	Laser scattering	0.001 mg/m^3	0.001-100mg/m^3	± 1%
Q-Trak 8551 (TSI)	CO	Electro-chemical	1 ppm	0-500 ppm	± 3%
	CO_2	NDIR	1 ppm	0-5000 ppm	± 3%
	Temp	Thermistor	0.1^{o}C	0-50^{o}C	± 0.6^{o}C
	RH	Thin-film capacitive	0.1% RH	5-95% RH	± 3% RH

5.3 Results and discussions

The average air pollutant concentrations inside various microenvironments in Hong Kong are summarized in Table 5.2. In total, twenty-two types of microenvironments investigated in this study had been grouped into four major categories, i.e. indoor at home, indoor away from home, enclosed transit, and outdoor. The current indoor and outdoor pollutant standards are shown in Tables 5.3 and 5.4 for reference.

As expected, both the indoor and ambient pollutant levels varied widely among different types of microenvironments. For instance, the NO_2 and PM_{10} concentrations at homes were much greater than those of offices because of the proximity of cooking fuel at residential premises. On the other hand, the CO concentrations were comparable between these two microenvironments. The NO_2, CO, and PM_{10} concentrations in restaurants and pubs were found to be at least from two to three times higher than those at homes. It was probably due to the presence of vast amount of cooking fuel and a large number of smokers inside the restaurants and pubs. On the contrary, shopping malls and outdoors had lower PM_{10} and NO_2 concentrations, but a greater CO concentration than residential premises. Higher CO concentrations in shopping malls and outdoors were probably due to their close proximity to traffic sources.

Table 5.2 Summary of average air pollutant concentrations in various microenvironments in Hong Kong

Microenvironments	**Air Pollutants**			
	CO (μg/m^3)	**CO_2 (mg/m^3)**	**PM_{10} (μg/m^3)**	**NO_2 (μg/m^3)**
Indoor at home				
Residential building/home	943	1561.6	46.2	118
			(119.2[3])	
Indoor away from home				
Office building	854.3[1]	1883[1]	29.7[1]	18.9[1]
School	187	2416.1	117	0
Industrial plant	N/A	N/A	N/A	N/A
Restaurant	3750	2370	385	718
	(3344.9[1])	(2497.8[1])	(323[1])	(133[1])
Pub/Bar/Night club	9375	2797.2	810	108
Hospital	N/A	747.8	N/A	N/A
Hotel	3500	1620.5	85.6	21.4
Indoor gym.	750	1532.1	80[4]	44[4]
Shopping center	1660[1]	1870.2[1]	78[1]	63.64[1]
Car park/Garage	13750	1021.5	150[4]	356[4]

Cinema/Theatre	1696[1]	2675.4[1]	55[1]	66.1[1]
Enclosed Transit				
Bus/Minibus	3150	1574.3	137.5	1108
	(2375[2])			(794[2])
Truck/Van	3000	1794.6	120	990.7
Private car/Taxi	12625[2]	2356.2	95	1090[2]
Subway (MTR)	2475	2245	78	156
	(2178[1])	(4311.6[1])	(105[1])	(121[1])
Railway (KCR)	1150	1326	95	127
	(1250[2])			(219[2])
Ferry	645	830	85	61.6
	(750[2])			(147.6[2])
Tram	2500[2]	1528	117.4	772[2]
Outdoor	1136.2[5]	687.5	59[5]	62[5]

1 *HKEPD, Final report: Consultancy study for indoor air pollution in offices and public places in Hong Kong, 1997.*

2 *Chan, L. Y. et al, The effect of commuting microenvironment on commuter exposures to vehicular emission in Hong Kong, Atmos. Environ. 33: 1777-1787, 1999.*

3 *Lee, S.C. et al, Indoor and outdoor air quality investigation at six residential buildings in Hong Kong, Environ. Int. 25(4): 489-496, 1999.*

4 *Lee, S. C. et al., Indoor and outdoor air quality investigation at 14 public places in Hong Kong, Environ. Int. 25(4): 443-450, 1999.*

5 *HKEPD, Air Quality in Hong Kong, 1998.*

* *The concentrations shown without superscripts were measured by this study.*

Table 5.3 Hong Kong (ambient) air quality objectives

Pollutant	Concentration in $\mu g \cdot m^{-3}$ Averaging Time				
	1 hr	**8 hrs**	**24 hrs**	**3 mths**	**1 yr**
Sulphur Dioxide	800	---	350	---	80
Total Suspended Particulate	---	---	260	---	80
Respirable Suspended Particulate (PM10)	---	---	180	---	55
Nitrogen Dioxide	300	---	150	---	80
Carbon Monoxide	30,000	10,000	---	---	---
Photochemical Oxidants (ozone)	240	---	---	---	---
Lead	---	---	---	1.5	---

Table5.4 Recommended Indoor Air Quality Objectives for Office Buildings and Public Places in Hong Kong

Pollutant	Unit	**8 hrs average** (at 25°C and 101.325 kPa)		
		Level 1	**Level 2**	**Level 3 (OEL)**[h]
Carbon Dioxide (CO_2)	ppm	<800[a]	<1,000[f]	<5,000
	$mg \cdot m^{-3}$	<1,443	<1,803	<9,017
Carbon Monoxide (CO)	$\mu g \cdot m^{-3}$	<2,000[b]	<10,000[c,g]	<29,000
Respirable Suspended Particulate (RSP)	$\mu g \cdot m^{-3}$	<20[a]	<180[g]	---
Nitrogen Dioxide (NO_2)	$\mu g \cdot m^{-3}$	<40[c]	<150[g]	<5,600
Ozone (O_3)	$\mu g \cdot m^{-3}$	<50[b]	<120[c]	<200[k]
Formaldehyde (HCHO)	$\mu g \cdot m^{-3}$	<30b	<100c	<370[k]
Total Volatile Organic Compounds (TVOC)	$\mu g \cdot m^{-3}$	<200[b]	<600b	---
Radon	$Bq \cdot m^{-3}$	<150[l]	<200[b,d]	---
Airborne Bacteria	$cfu \cdot m^{-3}$	<500[e,i]	<1,000[e,i]	---
Room Temperature	ºC	20-25.5	<25.5	---
Relative Humidity	%	40-70	<70	---
Air Movement	$m \cdot s^{-1}$	<0.2	<0.3	---

a. *USEPA (1996), Maximum Allowable Air Concentration Standards for EPA Buildings*

b. *Finnish Society of Indoor Air Quality and Climate (1995), Classification of Indoor Climate, Construction and Finishing Materials*

c. *WHO (1996), Update and Revision of the Air Quality Guidelines for Europe*

d. *EPD (1995), Radon and You*

e. *ACGIH (1995), Air Sampling Instruments for Evaluation of Atmospheric Contaminants (100-1,000 cfu/m^3 =intermediate e.g. general indoor and outdoor concentrations)*

f. *ASHRAE 62-1989R (1996), Ventilation for Acceptable Indoor Air Quality (current status of the revised standards has been under "continuous maintenance" since July, 1997)*

g. *EPD (1987), Hong Kong Air Quality Objectives under the Air Pollution Control Ordinance (Cap. 3.11)*

h. *Labour Department (1998), A Reference Note on Occupational Exposure Limits (OEL) for Chemical Substances in the Work Environments*

i. *The exceedance of bacterial count does not necessarily imply health risk but serve as an indicator for further investigation*

j. *In some cases, it may not be practical to take 8-hour samples. In these circumstances, short-term sampling protocol should be used to demonstrate whether the level of air contaminants meet the IAQ Objectives. The short-term sampling should cover the worst case scenario.*

k. *Occupational Exposure Limit – Ceiling (OEL-c)*

l. *USEPA guidelines for new and existing residential premises*

In premises such as pubs, restaurants and schools, where there were considerable human occupancies, the average CO_2 levels were measured to be higher than 1000 ppm, which indicates inadequate ventilation. On the other hand, the CO and NO_2 concentrations encountered during commuting in enclosed transit were found to be greater than those encountered at home. Although ferries were classified under the category of enclosed transit, their concentration profiles were substantially different from the other types of enclosed transits, since the passengers inside the ferries were always exposed to ambient environment. Although the inside pollutant concentrations in private car or taxi were high, only 16% of Hong Kong people use them as commuting means. It was also found that the NO_2 concentration obtained through site measurement was much higher than the data obtained from HK EPD. It might be due to the lower resolution of the equipment used in the study. Therefore the NO_2 exposure was not calculated in the total exposure assessment.

5.3.1 Residential buildings

Indoor air quality at home should be under close scrutiny as Hong Kong citizens on average spent more than 13 hours at home everyday. It was strongly influenced by the ambient air quality, which was eventually determined by the emission quality from vehicle fleet (Chan and Wu, 1993; EPD, 1998; Chan et al, 1996). However, the external influence might be moderated by intermittent operation of air-conditioning systems. Apart from the predominant external influence, the presence of vast amount of indoor pollutant sources significantly influenced the indoor air quality at home. Nevertheless, monitoring of indoor air quality at residential premises mainly depended on individual voluntary action, as any public action would lead to an intrusion in individual's privacy right.

In this study, all the selected residential flats were air-conditioned. One limitation is that they could not represent all the housing types and areas. As the measurements were conducted in summer, future studies should be conducted to examine the different effects due to seasonal variations.

Table 5.5 Brief introduction of residential flats chosen to take IAQ measurements

Code	District	Floor	Area(m^2)	No. of occupant	Smoking habit	Cooking	Cooking Fuel	Air conditioning
1	Hong Kong Island	3	45	2	No	No	Town gas	Window style
2	Hong Kong Island	12	75	3	No	Yes	Town gas	Window style
3	Hong Kong Island	10	72	4	Yes	Yes	LPG	Split Unit
4	Kowloon peninsular	7	90	4	No	Yes	LPG	Window style
5	Kowloon peninsular	17	50	3	Yes	Yes	Town gas	Window style
6	Kowloon peninsular	5	55	4	No	No	Town gas	Window style
7	Kowloon peninsular	3	64	3	Yes	Yes	LPG	Window style
8	Kowloon peninsular	16	48	4	No	No	Town gas	Window style
9	Kowloon peninsular	14	56	6	No	No	Town gas	Split Unit
10	New Territory	14	70	2	No	Yes	Town gas	Window style
11	New Territory	2	72	2	No	Yes	LPG	Window style
12	New Territory	25	66	4	Yes	Yes	Town gas	Window style
13	New Territory	19	78	4	No	Yes	Town gas	Window style
14	New Territory	9	65	3	No	No	Town gas	Window style

Accordingly, the extent of abatement measures implemented depended mainly on individual health concern and personal favor.

High-rise building is one of the typical types of dwelling environment in Hong Kong. In this study, a total of 14 high-rise residential buildings were chosen for the site measurements, among which three were in Hong Kong Island, six were located in Kowloon Peninsular and five were located in New Territories. Table 5.5 shows the characteristics of the flats that examined in this study.

On average, two to six occupants were living in an examined flat. Most of the flats did install window type air-conditioners. Occupants within three examined flats had smoking habits. Town gas was used as the common cooking fuel by occupants in most of the examined flats.

Table 5.6 shows the air pollutant concentrations in the 14 selected residential flats. The indoor daily average concentrations of PM_{10} varied from 32.63 to 135.83 $\mu g \cdot m^{-3}$ with an average value of 62.17 $\mu g \cdot m^{-3}$ and a standard deviation of 28.38 $\mu g \cdot m^{-3}$. The corresponding outdoor daily average concentrations of PM_{10} varied from 29.52 to 140.44 $\mu g \cdot m^{-3}$, with an average value of 56.64 $\mu g \cdot m^{-3}$ and a standard deviation of 27.18 $\mu g \cdot m^{-3}$. Comparing with the requirements laid down in the general indoor air quality guideline, the indoor PM_{10} level measured could satisfy the requirement of Level 2, but was more than three times higher than that required by Level 1.

Table 5.6 **Pollutant concentrations in 14 dwelling flats**

PM_{10} concentration	**Unit**	**Average**	**Standard Deviation**	**Maximum**	**Minimum**
Indoor	$\mu g{\cdot}m^{-3}$	62.17	28.38	135.83	32.63
Outdoor	$\mu g{\cdot}m^{-3}$	56.64	27.18	140.44	29.52
I/O ratio		1.12	0.30	2.43	0.60
Other pollutant concentration	**Unit**	**Average**	**Standard Deviation**	**Maximum**	**Minimum**
CO indoor	$\mu g{\cdot}m^{-3}$	964.14	655.06	3788.57	0.00
NO_2 indoor	$\mu g{\cdot}m^{-3}$	67.68	33.20	155.27	18.78
CO_2 indoor	$mg{\cdot}m^{-3}$	959.02	484.18	2715.91	282.23

The indoor/outdoor ratio of PM_{10} concentration in fourteen residential buildings varied from 0.6 to 2.43. The average indoor/outdoor ratio was 1.12, with a standard deviation of 0.3. Figure 5.1 shows the distribution of PM_{10} indoor to outdoor ratios. It is noted that the outdoor air quality might have greater impact on the indoor air quality of residential buildings as most of the residential buildings were naturally ventilated. Figure 5.2 shows the inter-relationship between indoor and outdoor PM_{10} concentrations in the measured residential flats.

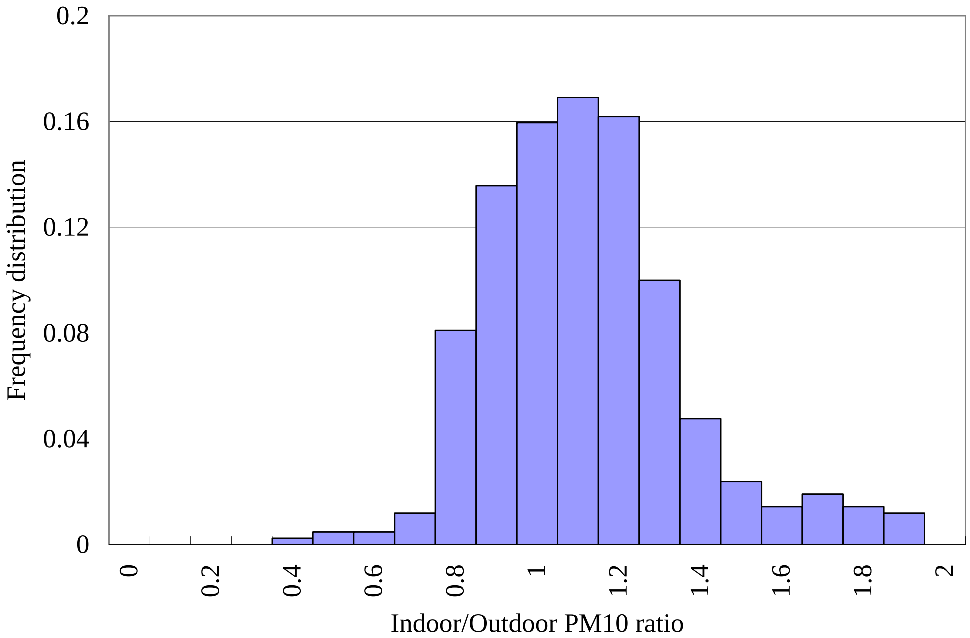


Figure 5.1 **Indoor/outdoor PM10 ratio distributions**

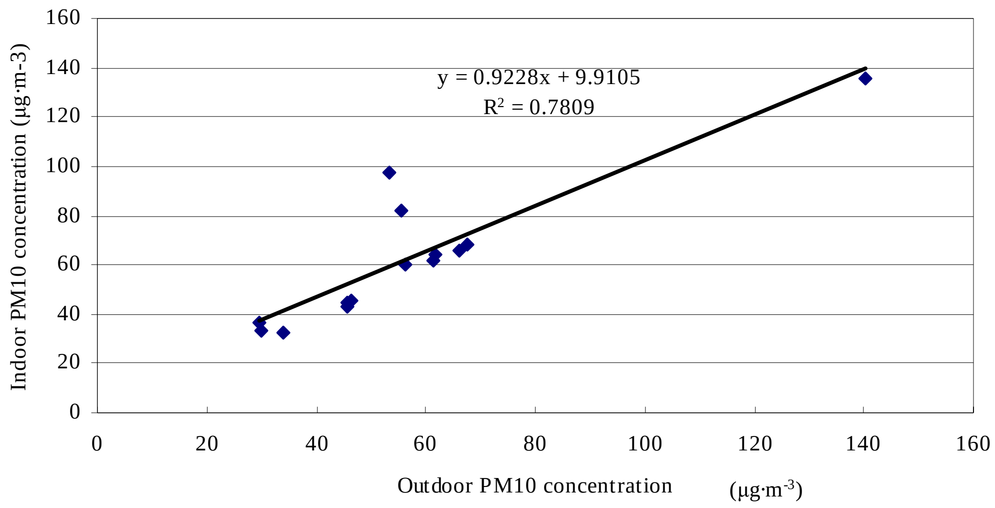


Figure 5.2 **Relationship of indoor/outdoor PM10 concentration (μg·m^{-3})**

The indoor PM_{10} levels were not only influenced by outdoor PM_{10} level, but also influenced by the occupant's conditions, such as people density in a flat, smoking habit of the occupants, cooking and cleaning activities, etc. A multiple regression model had been developed to determine the correlation among them:

$$C_{in} = \beta_0 + \beta_1 C_{out} + \beta_2 N + \beta_3 S + \beta_4 C$$

Where C_{in} refers to indoor PM_{10} concentration;

C_{out} refers to outdoor PM_{10} concentration;

N refers to people density (person/unit area) in the flat;

S refers to smoking habit of the flat occupants;

C refers to cooking activity of the flat occupants;

β, β_0 to β_4 refer to the constant and coefficients

The multiple regression model was formulated by using indoor PM_{10} concentrations as dependent variable, and the outdoor PM_{10} concentration, people density, smoking habit, cooking activity as independent variables. The final model was estimated by using SPSS software package. The resulting form was shown as follows:

$$C_{in} = 1.02 \cdot C_{out} + 0.80 \cdot N + 4.42 \cdot S + 11.28 \cdot C - 12.10 \qquad R^2 = 0.819$$

The adjusted R^2 value was used to check whether the estimated regression model was valid for representing the data. With a R^2 of 0.819, the model could be considered to fit the data reasonably well.

At the same time, F-test was used to test the significance of the model. Comparing the F statistic value (10.25) of the final regression model and the F identical value (assuming the significant level as 0.01, degree of freedom as 4 and 9), the validation of the final regression model was proved.

Comparing the values of standardized coefficients of the four independent variables in the multiple regression model, the influence of the independent variable on the dependent variable, could be identified. It was found that the standardized coefficient of outdoor PM_{10} concentrations was the largest, which implies that outdoor PM_{10} concentration had the greatest impact on the indoor PM_{10} concentration. Due to the natural ventilation, the outdoor air would have a significant impact on the indoor air directly. Window type air conditioners could supply fresh air and enhanced the indoor/outdoor air exchange rates. Cooking and smoking activity did have little effect on the indoor PM_{10} concentrations. That might be due to the lower frequency of cooking at home and small smoking population of Hong Kong.

The indoor CO concentrations were found from 0 to 3788.57 $\mu g \cdot m^{-3}$, with an average value at 964.14 $\mu g \cdot m^{-3}$ and a standard deviation at 655.06 $\mu g \cdot m^{-3}$. The indoor NO_2 concentrations varied between 18.75 and 155.27 $\mu g \cdot m^{-3}$, with average at 67.68 $\mu g \cdot m^{-3}$ and standard deviation at 33.20 $\mu g \cdot m^{-3}$. The average indoor CO and NO_2 levels could satisfy the requirement of the indoor air quality guideline, except in several flats. The reason of high CO and NO_2 concentrations might due to the high smoking and cooking activities. The lower indoor CO_2 concentrations were probably because of less cooking and smoking activities, and lower people densities.

5.3.2 Restaurants and pubs

Hong Kong people used to go to restaurants and pubs more frequently, and spent more time there than the people in other countries. Since the flats of most Hong Kong people were relative small, they usually spent much of their spare times in various public places and go home lately. This was particularly the case for the youngsters. The occupant density might rise to a high level in the restaurant especially during the meal time. Hong Kong people also liked to go to pub during evening after work.

Most of the restaurants located in the busy districts of the city and were closed to the city traffic. The ambient air might have direct influence on the indoor air. Although the government of Hong Kong SAR had showed an intention to impose an order to forbid smoking activities in restaurants, the policy could not practice in the near future due to the strong opposition from the business owners. Usually many Chinese restaurants in Hong Kong were operating from early morning to midnight. The cooking stoves were another major indoor pollutant source.

Therefore, 15 Chinese restaurants were chosen to monitor the indoor pollutant concentrations. In order to ensure that the results are representative, the selected restaurants located in different area of Hong Kong, of which 5 restaurants in Hong Kong Island, 6 in Kowloon Peninsular, 4 in New Territories. Site measurements were carried out from March 1998 to August 1998. The general characteristics of the restaurants are shown in Table 5.7.

Site measurements were conducted during lunch hour everyday during the survey period. The levels of respirable suspended particulate (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2) and carbon dioxide (CO_2) were monitored. The potential indoor pollutant sources, such as number of people, smoking people, cooking stoves, were also recorded for further analysis.

Figure 5.3 shows various pollutant concentrations within the 15 restaurants. The average CO concentration varied from 895 to 16763 $\mu g/m^3$. Only two restaurants exceeded the requirement of the indoor air quality guideline. The major sources of indoor CO were the cooking stoves and smoking. As all the restaurants located in the busy district, city traffic was the major outdoor source.

The average indoor NO_2 concentrations of the 15 restaurants varied from 56.6 to 1564.8 $\mu g/m^3$. Among them, 8 restaurants exceeded the requirement recommended by the guideline. The indoor and outdoor sources of NO_2 were similar to CO.

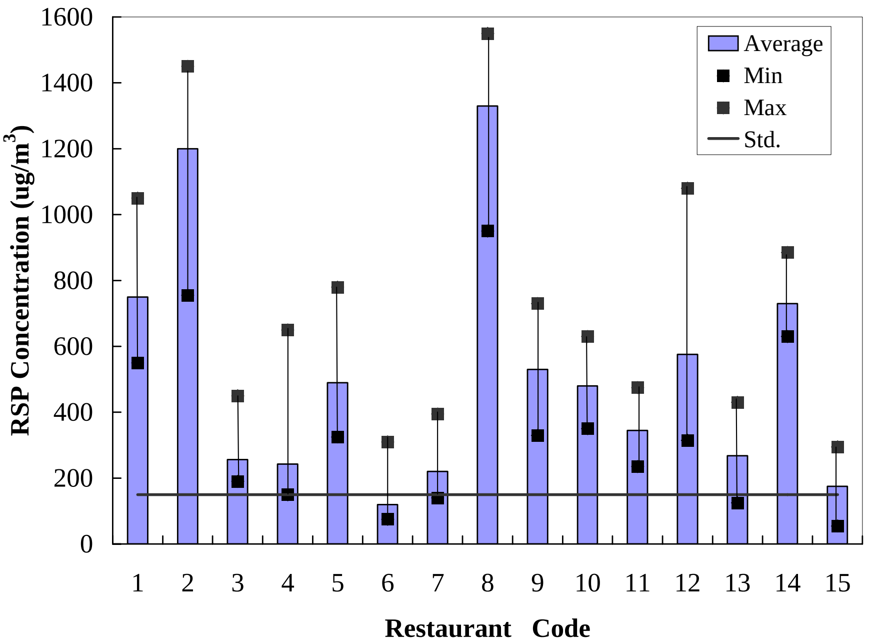
The average PM_{10} concentration varied from 120 to 1330 $\mu g/m^3$. Only 2 restaurants could satisfy the requirement of indoor air quality guideline. The major sources of PM_{10} were smoking and indoor activities of the occupants.

The measured indoor CO_2 concentrations ranged from 773 ppm to 1722 ppm. Only one of the 15 restaurants could satisfy the ASHRAE standard. The high people density and low ventilation rate might be due to the high CO_2 concentration.

Occupant density was another factor that might affect the pollutant concentration. ASHRAE standard for ventilation assumed that the people density in restaurant should be smaller than 0.7 person/m^2 (ASHRAE 62/1996). Table 5.7 shows that four restaurants could not meet the standard. Figure 5.4 shows the relationship between the concentrations of different occupant density. CO_2 concentration was found to have higher correlation with occupant density than the other pollutants. The higher CO_2 concentration might due to the lower ventilation efficiency as well as the higher occupant density.

Table 5.7 Brief description of the measured restaurants

Code	District	Surround environment	Area (m^2)	People density (m^{-2})	Indoor pollutant Sources
01	Kowloon peninsula	Commercial area	400	0.90	Smoking, Gas stove
02	Kowloon peninsula	Commercial area	200	0.85	Smoking, Gas stove
03	Kowloon peninsula	Commercial area	125	0.60	Smoking
04	Hong Kong Island	Commercial area	180	0.61	Smoking, Gas stove
05	Hong Kong Island	Commercial area	350	0.65	Smoking
06	New Territory	Commercial area	140	0.68	Smoking, Gas stove
07	Hong Kong Island	Commercial area	95	0.68	Smoking
08	Kowloon peninsula	Residential area	200	0.66	Smoking, Gas stove
09	Kowloon peninsula	Residential area	200	0.66	Smoking, Gas stove
10	Hong Kong Island	Residential area	120	0.80	Smoking, Gas stove
11	Kowloon peninsula	Residential area	420	0.65	Smoking
12	Hong Kong Island	Commercial area	170	0.85	Smoking, Gas stove
13	New Territories	Industrial Area	150	0.52	Smoking, Gas stove
14	New Territories	Residential area	170	0.55	Smoking
15	New Territories	Commercial area	320	0.60	Smoking, Gas stove



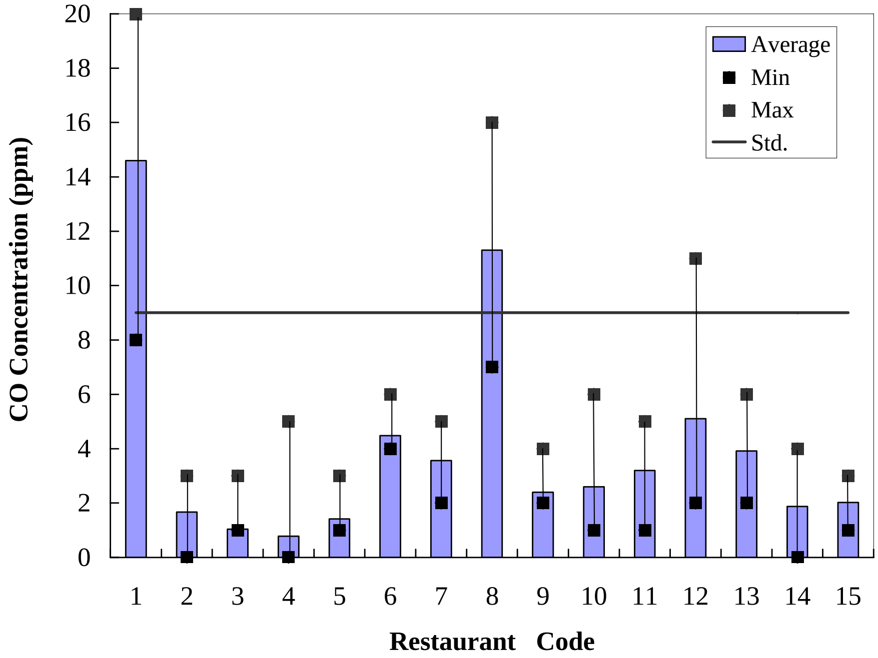
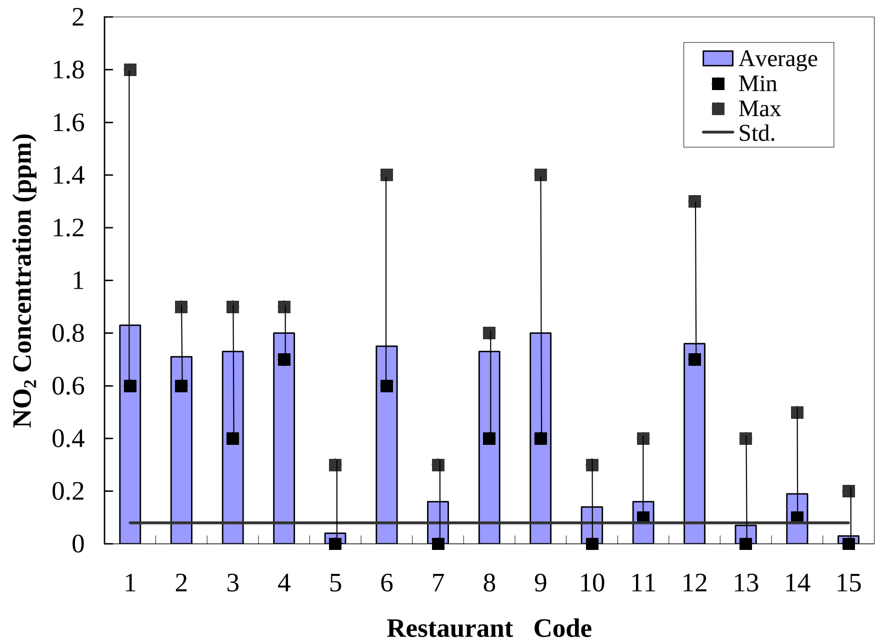


Figure 5.3 **Pollutant concentrations in 15 restaurants**



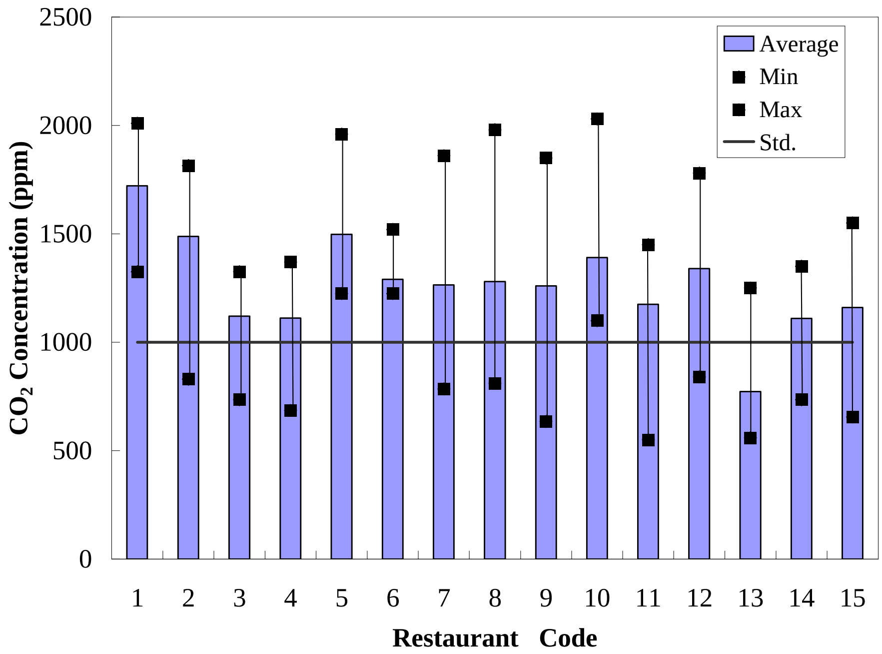
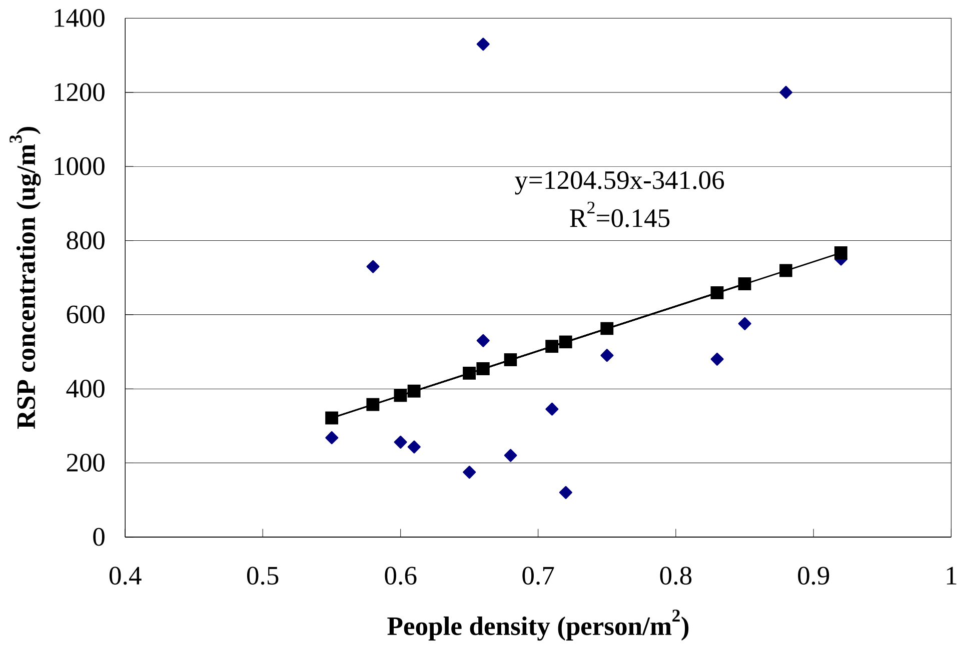


Figure 5.3 Pollutant concentrations in 15 restaurants



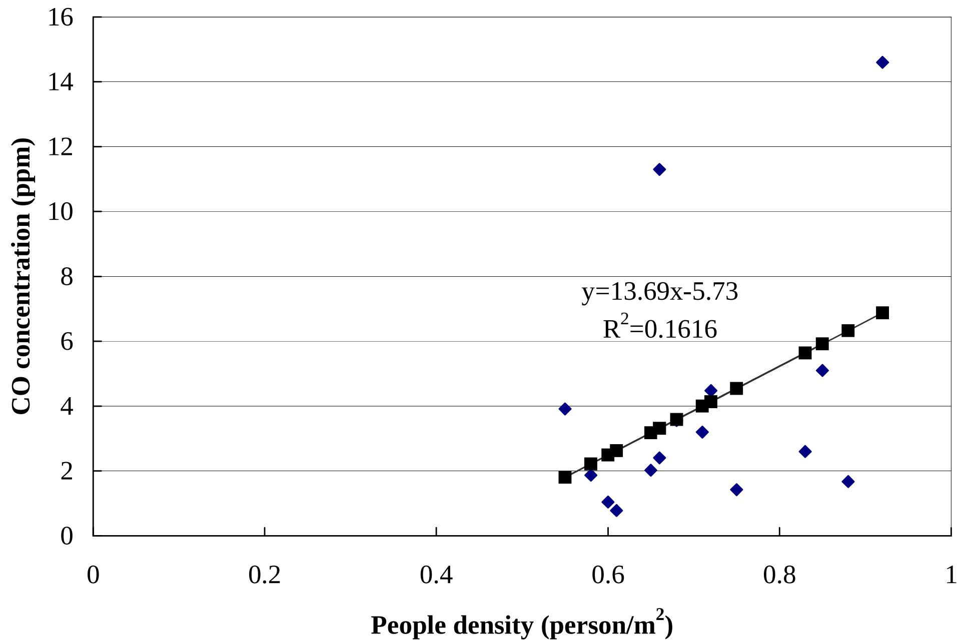
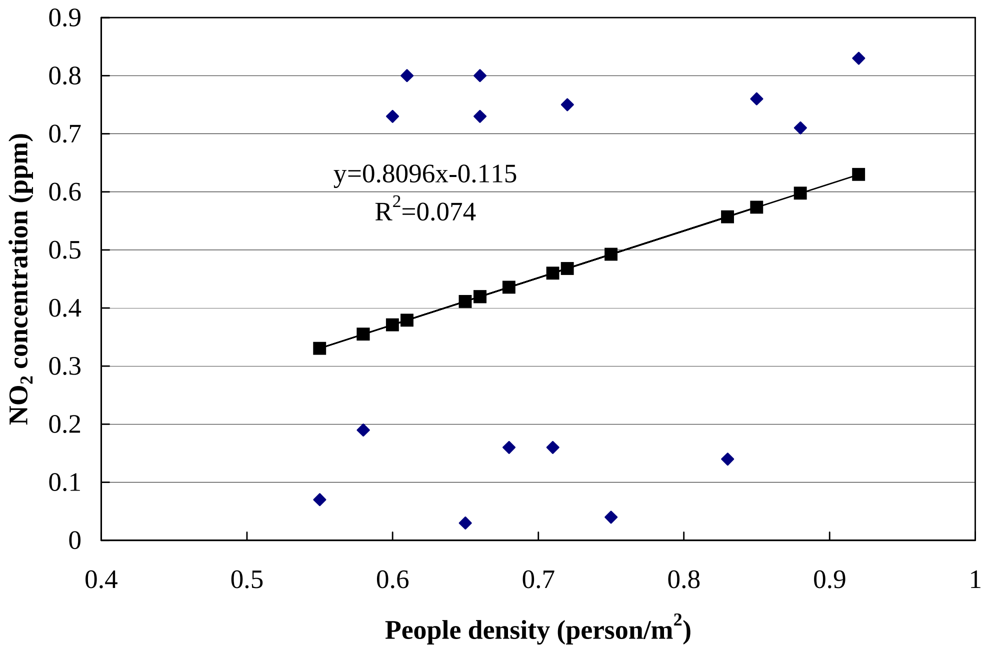


Figure 5.4 Relationship between pollutant concentration and people density



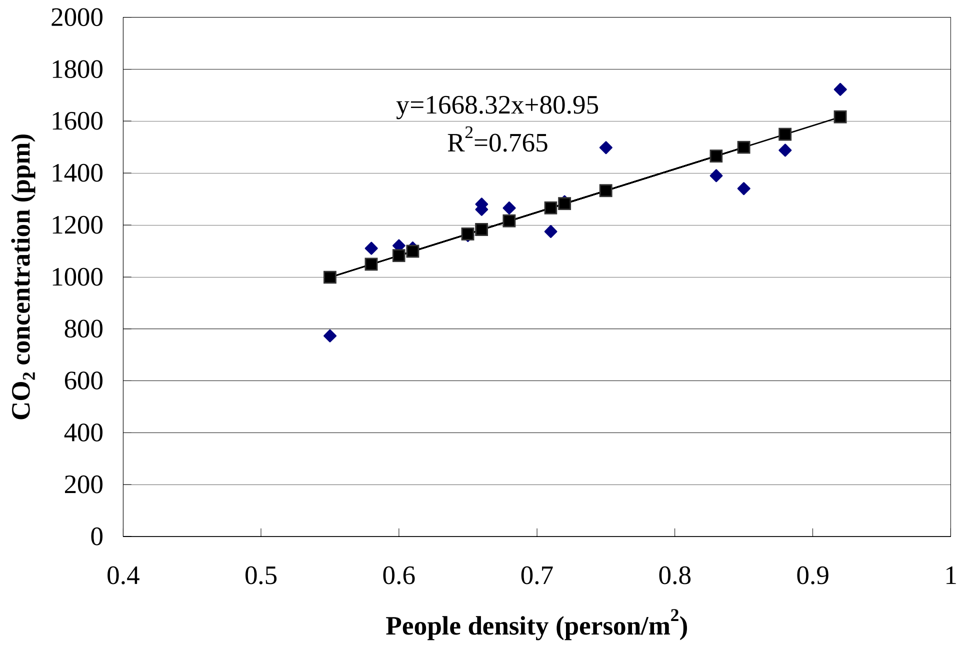


Figure 5.4 **Relationship between pollutant concentration and people density**

Site measurements were also conducted in 13 pubs and bars in Hong Kong. Table 5.8 shows the general characteristics of the selected pubs & bars with their indoor pollutant concentrations. All the measured pubs & bars were located in busy commercial areas of Hong Kong with heavy outdoor traffic.

The measured indoor PM_{10} concentrations varied from 286 to 2287 $\mu g/m^3$, with an average of 1016 $\mu g/m^3$. On the other hand, all the pubs and bars measured exceeded the requirement of the indoor air quality guidelines. This was probably due to indoor smoking and bad ventilation. The people density was also higher than the assumption laid down in ASHRAE standard. The average outdoor PM_{10} concentrations were acceptable; however, the concentrations of several sites exceeded the requirement of the ambient air quality objectives.

The average indoor CO concentration varied from 34.4 to 18360 $\mu g/m^3$, with an average value of 6196.5 $\mu g/m^3$. The indoor CO levels in pubs and bars were higher than most of the other public places due to heavy indoor smoking activities. Notwithstanding this, only 2 pubs exceeded the requirements of the guideline.

Table 5.8 Brief description of the measured pubs and bars and indoor pollutant concentrations

Code	District	Area (m^2)	People density (m^{-2})	Number of Smoker	Indoor PM10 ($\mu g/m^3$)	Outdoor PM10 ($\mu g/m^3$)	CO_2 (ppm)	CO ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)
01	Kowloon peninsula	400	0.31	11.5	2266	67	1790	11475.0	1067.4
02	Hong Kong Island	70	0.57	2	665	302	1141	8032.5	1335.5
03	Kowloon peninsula	80	0.57	4.3	2287	266	2067	18360.0	537.8
04	Kowloon peninsula	40	1.15	4	1345	179	1044	6885.0	1144.7
05	Kowloon peninsula	250	0.22	2.3	599	82	1256	3442.5	158.7
06	Kowloon peninsula	100	0.53	7	1151	92	1393	6885.0	1886.1
07	Hong Kong Island	60	0.53	3.7	680	113	1216	5737.5	421.9
08	Kowloon peninsula	30	0.53	1	286	77	688	3442.5	363.9
09	Kowloon peninsula	200	0.13	2.7	1299	87	677	34.4	18.8
10	Kowloon peninsula	70	0.23	1.9	1422	92	1104	6139.1	540.9
11	Kowloon peninsula	350	0.13	2.7	384	107	554	1400.0	114.5
12	Kowloon peninsula	400	0.08	2.7	312	266	543	3213.0	783.5
13	Hong Kong Island	80	0.13	2	516	67	828	4934.3	144.5
14	Hong Kong Island	150	0.20	7.3	890	48	2500	12571.4	2098.6
15	Kowloon peninsula	150	0.50	11.5	670	45	1920	17142.9	418.3
16	Kowloon peninsula	90	0.39	4.6	750	56	1050	4571.4	485.2
17	Hong Kong Island	180	0.27	4.8	240	38	840	7428.6	4068.3
18	Kowloon peninsula	75	0.53	1.3	1200	101	1110	4457.1	394.3
19	Hong Kong Island	65	0.48	8.5	1330	66	1160	5714.3	469.4
20	Hong Kong Island	170	0.47	2.5	530	60	1390	8032.5	1966.6

5.3.3 Enclosed transits

Four types of air-conditioned public transport facilities (PTFs), including public bus, MTR, KCR & LRT and ferry, were chosen for site measurements. General information in relation to various PTFs currently used in Hong Kong is shown in Table-5.9. Eight urban and suburban bus routes, all MTR, KCR and LRT lines, and three air-conditioned ferry lines were chosen for site measurements. Indoor air pollutant concentration measurements were conducted 91, 15, 15 and 24 times in public bus, MTR, KCR & LRT, ferry respectively. The average duration of measurement was from 0.2 to 1.5 hr for each journey.

Table 5.9 Brief introduction of the PTFs in Hong Kong [1,24]

Road Transport	**Registered vehicles**	**Average daily passengers**	**Notes**
Franchised buses	6,178	3,971,000	Five franchised bus companies
Public light buses	4,341	1,751,000	Green minibuses: 306 routes Red minibuses: No fixed routes
Taxis	18,026	1,311,000	Three types: Urban, New Territories and Lantau Island

Rail transport	**Length (km)**	**Average daily passengers**	**Notes**
Mass transit railway	77	2,196,000	Tsuen Wan, Kwun Tong, Island, Tung Chung lines and Airport express
Kowloon-Canton	34	737,000	new towns in the north-eastern New

railway			Territories
Light rail transit	32	361,000	north-western New Territories
Trams	16	237,000	Hong Kong Island

Harbor transport	**Vehicles**	**Average daily passengers**	**Notes**
Ferries	64	158,000	14 ferry operators provide 32 regular rates to outlying islands, Southwest New Territories and across the harbor

Table 5.10 shows the results from the site measurements. Comparing with the current indoor air quality guideline advocated in Hong Kong, the average concentrations of PM_{10}, CO and CO_2 were all within the acceptable levels. The PM_{10} and CO concentrations might exceed the standard only when bus was running in the cross-harbor tunnel or in serious city traffics.

From Table 5.10, it was found that the indoor PM_{10} concentration in bus was the highest among the four types of PTFs. The PM_{10} concentration in the MTR was the second highest. Although Hong Kong government had imposed strict policy to restrict the pollutant exhausting level, exhaust gas of different vehicles affected the air quality of the surrounding environment. Until the end of 2000, over 500,000 vehicles registered and about 268 vehicles were running in one kilometer of road in Hong Kong [1]. The air quality inside urban buses and MTR might be directly influenced by city traffic. Air pollution caused by traffic had little effects on KCR & LRT, and ferry, as they were operating in the suburban areas or on the sea.

Buses also had the highest indoor CO concentrations, while ferry and MTR were ranked the second and third positions respectively. Ferry had a high occupant density and almost kept closed during the whole trip. Although the ambient air was cleaner, insufficient ventilation might lead to the pollutant accumulations. The highest CO_2 concentration also indicated the lower ventilation efficiency of the ferry. KCR and LRT had relatively lower indoor PM_{10} and CO concentrations.

Table 5.10 Air pollutant concentrations in various PTFs

		PM10 concentration（$\mu g \cdot m^{-3}$）			
PTFs	**Samples**	**Mean**	**Std. Dev.**	**Min**	**Max**
Bus	91	124.6	87.88	16.0	490.0
MTR	15	78.0	29.78	47.6	143.8
KCR & LRT	15	58.6	14.15	39.4	89.5
Ferry	24	57.7	24.81	11.8	115.6
		CO concentration（$\mu g \cdot m^{-3}$）			
PTFs	**Samples**	**Mean**	**Std. Dev.**	**Min**	**Max**
Bus	91	3011.6	1620.4	0.0	9142.9
MTR	15	1462.9	765.7	685.7	3428.6
KCR&LRT	15	1226.7	578.7	457.1	2285.7
Ferry	24	2347.6	1902.8	800.0	10285.7
		CO_2 concentration（ppm）			
PTFs	**Samples**	**Mean**	**Std. Dev.**	**Min**	**Max**
Bus	91	1663.4	1133.70	353.0	4521.0

MTR	15	898.6	268.16	378.0	1448.0
KCR&LRT	15	692.7	175.41	437.0	1062.0
Ferry	24	1817.1	1468.08	226.0	4653.0

The pollutant concentrations of CO and NO_2 were generally observed to be high in enclosed transits due to the proximity of nearby vehicle exhaust. The short circuit emission from exhaust tail pipes of nearby vehicles intensified the pollutant concentrations inside the enclosed transit. In particular, significantly high pollutant concentrations were observed inside private car and taxi. In contrast, the PM_{10} levels inside the enclosed transits were not observed to be high as most of the transits were air-conditioned with filters installed for removing the PM_{10} generated from nearby car exhaust.

5.4 Summary

Outdoor

Despite there were several occurrences within a year that the particulate and NO_2 concentration levels of ambient air exceeded the air quality objective in Hong Kong (HKEPD, 1999), the annual average pollutant concentration levels were still lower than the annual standards. Generally, people in Hong Kong were still considered to be living in a relatively healthy environment.

Indoor at home

Comparing with the indoor air quality guideline of Hong Kong, the indoor PM10 level could satisfy the requirement of the Level 2, but was over 3 times higher than the requirement of the Level 1. The outdoor PM_{10} level could satisfy the requirements of the ambient air quality objectives.

The average indoor CO and NO_2 level could satisfy the requirement of the indoor air quality guideline, except in several flats. The reason of high CO and NO_2 concentrations might be due to the high smoking and cooking activities. The lower indoor CO_2 concentrations were because of the lower people density.

Indoor away from home

Despite a strong influence by ambient air, the pollutant concentrations in different indoor public places might vary according to the existence and the strength of pollutant sources; as well as the effectiveness of mechanical ventilation and air-conditioning systems.

For places like car park, high CO concentration level was expected. However, this might not call for an immediate concern for action, as only 3% of the total sampled subjects visited car parks on a given day.

The pollutant concentrations in restaurants, pubs and bars were shown to be among the highest in various microenvironments. The extremely high CO concentrations in pubs, bars, nightclubs and restaurants indicated the presence of vast number of smokers. Accordingly, the air quality inside restaurants should receive more government attention as more than 64% of surveyed subjects visited restaurants on a given day, with an average time span of 1.3 hour per day.

Meanwhile, the effectiveness of mechanical ventilation system also had a significant impact on the indoor pollutant concentration levels. Given source strength was constant, greater pollutant removal rates and smaller indoor pollutant concentrations would be obtained if indoor places were equipped with more effective ventilation or air-conditioning systems.

Nowadays, nearly all indoor public places including schools in Hong Kong were air-conditioned. Apart from providing improved thermal comfort, air-conditioning systems also helped to improve the indoor air quality by removing the indoor pollutants. The amount of pollutant removed depended directly on the effectiveness of air-conditioning systems, which could be revealed by observing the CO_2 concentrations inside different microenvironments. A CO_2 concentration level of higher than 1000 ppm could imply inadequate ventilation effectiveness. It could be seen from Table 4 that many public indoor places in Hong Kong, like restaurants, pubs, bars and nightclubs, were under ventilated with respect to number of occupants, smoking and cooking activities. Besides, heavy CO dominated car parks were also observed to be under ventilated, or have low ventilation effectiveness.

Enclosed transit

In general, a descending order of pollutant levels was observed for the enclosed transits in Hong Kong: private car, buses, minibuses, trams, subway and trains, and ferries. The results revealed were similar to those shown in a recent report submitted to the Environmental Protection Department in Hong Kong (HKPU, 2001). The pollutant concentration levels inside double-decker buses and mini-buses were observed to be lower than private cars as their venting positions were located at a higher level for taking in cleaner air at higher road levels. Subways and railways, which were usually positioned at a distance from the roadside, were less influenced by vehicular borne pollutants. Unlike other enclosed transits, ferries had a substantially low pollutant concentration as they were always exposed to ambient air away from polluted vehicle sources.

6 TOTAL EXPOSURE ASSESSMENT

In the previous two chapters, the methodologies adopted for obtaining the relevant information of time budget and data of indoor pollution level in major microenvironments were discussed. In this chapter, the total exposure of Hong Kong people was estimated through different approaches. The results of the exposure assessment were analyzed.

6.1 Introduction

The exposure of human being is always considered to be one of the significant indicators for estimating the health risk caused by pollutants.

Broadly speaking, two complementary conceptual approaches, namely the direct and indirect, have been devised for estimating the total exposure of human beings. The direct approach involves of direct measurements of exposure of the sampled population to pollutants of concern. Although the direct approach is valuable in determining exposures and sources of exposure for the specific population sampled, it needs to extrapolate the findings to a larger population segment. On the other hand, the indirect approach attempts to explore and understand the basic relationships between causative variables and resulting exposures, usually in particular microenvironments, through exposure modeling. In this study, the indirect approach was applied to estimate the exposure of Hong Kong people.

6.2 Estimating total exposure

6.2.1 Data description

The pollutant concentrations and the time duration that people spent on various microenvironments were independent of, and were obtained from the site measurements and telephone survey respectively.

The time budget data came from a citywide telephone survey in Hong Kong (Chau et al, 2002). The survey was conducted in the period between April and August 1998. A random population survey sample was drawn from the Hong Kong residential telephone directory, with a 7-day recalled questionnaire used for recording time diaries of the participants. Telephone interviews were successfully administered to 396 participants. The computed statistics of average daily time spent for all survey participants and for doers only in eight major microenvironments are given in Tables 6.1 and 6.2 respectively.

Table 6.1 Descriptive statistics of average daily time spent in 8 major microenvironments for all participants in corresponding microenvironments

Time for all people (hr)

Microenvironment	n	Mean	S.D.	Minimum	Maximum
Home	396	13.90	2.68	7.71	23.34
Office building	396	2.62	2.92	0.00	9.00
School	396	0.90	2.03	0.00	12.00
Shop	396	1.36	1.52	0.00	12.00
Restaurant	396	0.95	0.89	0.00	7.43
Pub & bar	396	0.17	0.57	0.00	5.00
Bus	396	0.76	0.94	0.00	11.43
MTR	396	0.46	0.59	0.00	5.86

Table 6.2 Descriptive statistics of average daily time spent in 8 major microenvironments for doers in corresponding microenvironment

Time for doers (hr)					
Microenvironment	**n**	**Mean**	**S.D.**	**Minimum**	**Maximum**
Home	396	13.90	2.68	7.71	23.34
Office building	194	5.34	1.69	0.07	9.00
School	87	4.08	2.42	0.29	12.00
Shop	341	1.58	1.53	0.14	12.00
Restaurant	310	1.22	0.84	0.14	7.43
Pub & bar	62	1.11	1.03	0.14	5.00
Bus	277	1.09	0.95	0.09	11.43
MTR	239	0.76	0.59	0.07	5.86

The average PM_{10} and CO concentrations in eight major microenvironments were obtained through site measurements. A PM7400 (MetroSonic, U.S.) portable gas monitor was used to monitor the CO concentration. A portable DustTrak 8520 manufactured by TSI (Shoreview, Minn., USA), was used to measure the PM_{10} concentration in the site measurements. The monitoring instrument was calibrated for quality assurance according to the requirements of the manufacturer before each site measurement. The average daily PM_{10} and CO concentrations in eight major microenvironments are given in Tables 6.3 and 6.4 respectively.

Table 6.3 Descriptive statistics of PM_{10} concentrations in 8 major microenvironments

		PM_{10} concentration ($\mu g \cdot m^{-3}$)			
Microenvironment	**n**	**Mean**	**S.D.**	**Minimum**	**Maximum**
Home	14	62.17	34.99	8.56	205.54
Office building	40	29.74	24.15	6.75	163.57
School	5	129.60	59.78	90.00	230.00
Shop	8	77.89	24.58	38.40	110.66
Restaurant	14	514.20	361.57	120.00	1330.00
Pub & bar	20	941.10	593.93	240.00	2287.00
Bus	91	124.56	87.88	16.00	490.00
MTR	15	78.00	29.78	47.58	143.76

Table 6.4 Descriptive statistics of CO concentrations in 8 major microenvironments

		CO concentration ($\mu g \cdot m^{-3}$)			
Microenvironment	**n**	**Mean**	**S.D.**	**Minimum**	**Maximum**
Home	14	964.14	655.06	0.00	3788.57
Office building	40	854.25	456.57	233.02	1958.91
School	3	1290.00	404.00	826.00	1563.00
Shop	8	1660.00	836.80	767.00	3181.00
Restaurant	14	4586.20	4466.70	895.05	16754.00
Pub & bar	20	6977.14	4722.91	34.29	18285.71
Bus	91	3011.62	1620.40	0.00	9142.86
MTR	15	1462.86	765.68	685.71	3428.57

Figure 6.1 shows the frequency density distribution histograms of the time that the survey participants spent on eight major microenvironments. Except for homes and restaurants, the typical histogram of time frequency density distribution for individual microenvironment was a mixed distribution. It consisted of two zones, which corresponded to two population sub-groups. In the histogram, the sub-group of non-doers (proportion *h*) was represented by tall bar on the left, while the sub-group of doers (proportion *1-h*) was represented by the asymmetrical distribution.

The time frequency density distribution for each microenvironment was proposed to fit a mixed distribution defined by a continuous uniform distribution for the non-doers and a Gamma distribution for the doers. The Gamma distribution form was validated by means of the Anderson-Darling statistics (D'Agostino, 1986). The Gamma PDF curves are also shown in the Figure 6.1.

Similar methods were also used to fit the Gamma distributions to the pollutant concentration data for other eight types of microenvironments. Figures 6.2 and 6.3 show the concentration frequency density distribution histograms and the fitted Gamma PDF curves of PM_{10} and CO for eight different types of microenvironments.

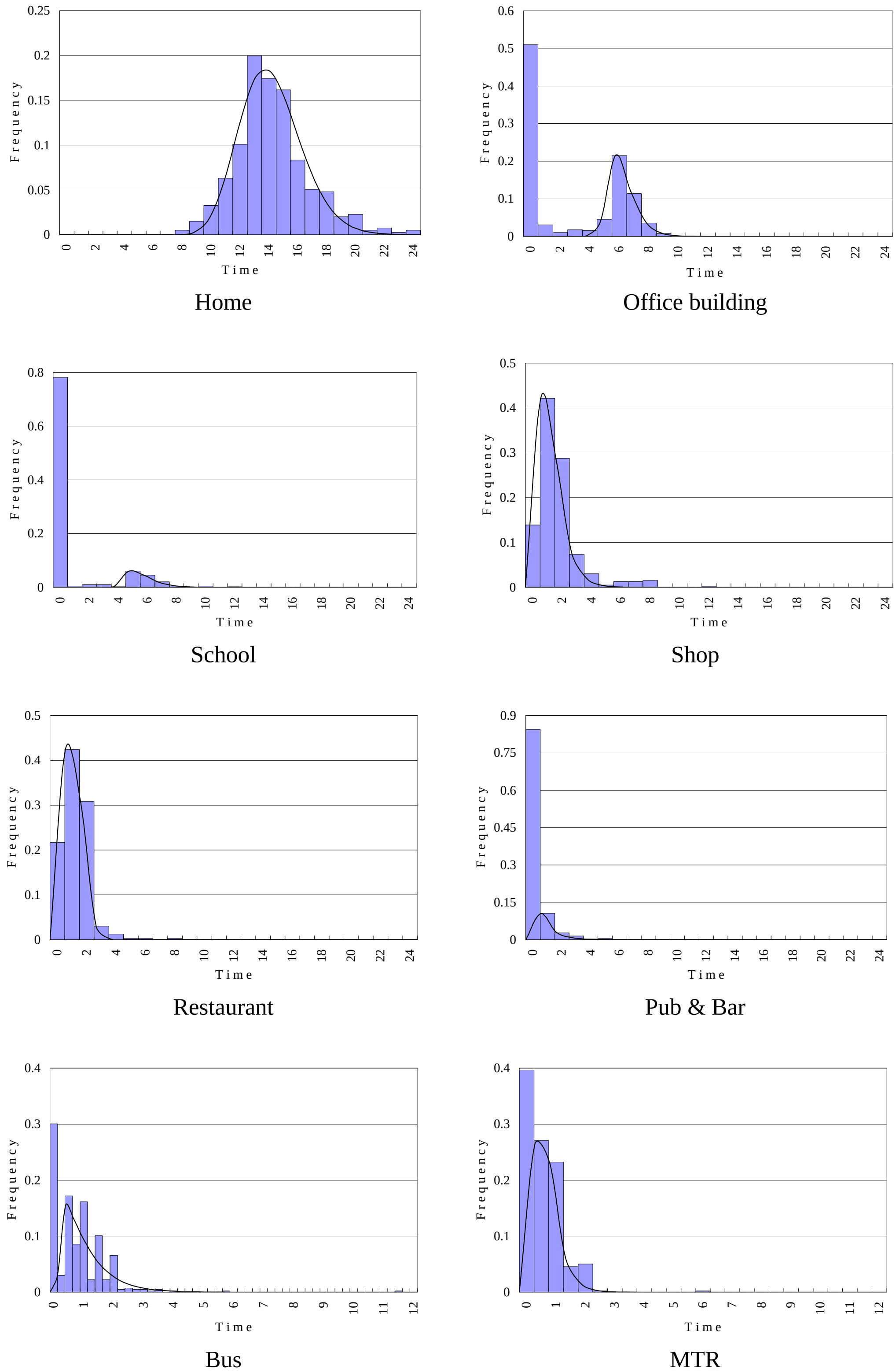


Figure 6.1 Histograms of time distribution and fitted Gamma curves in eight microenvironments

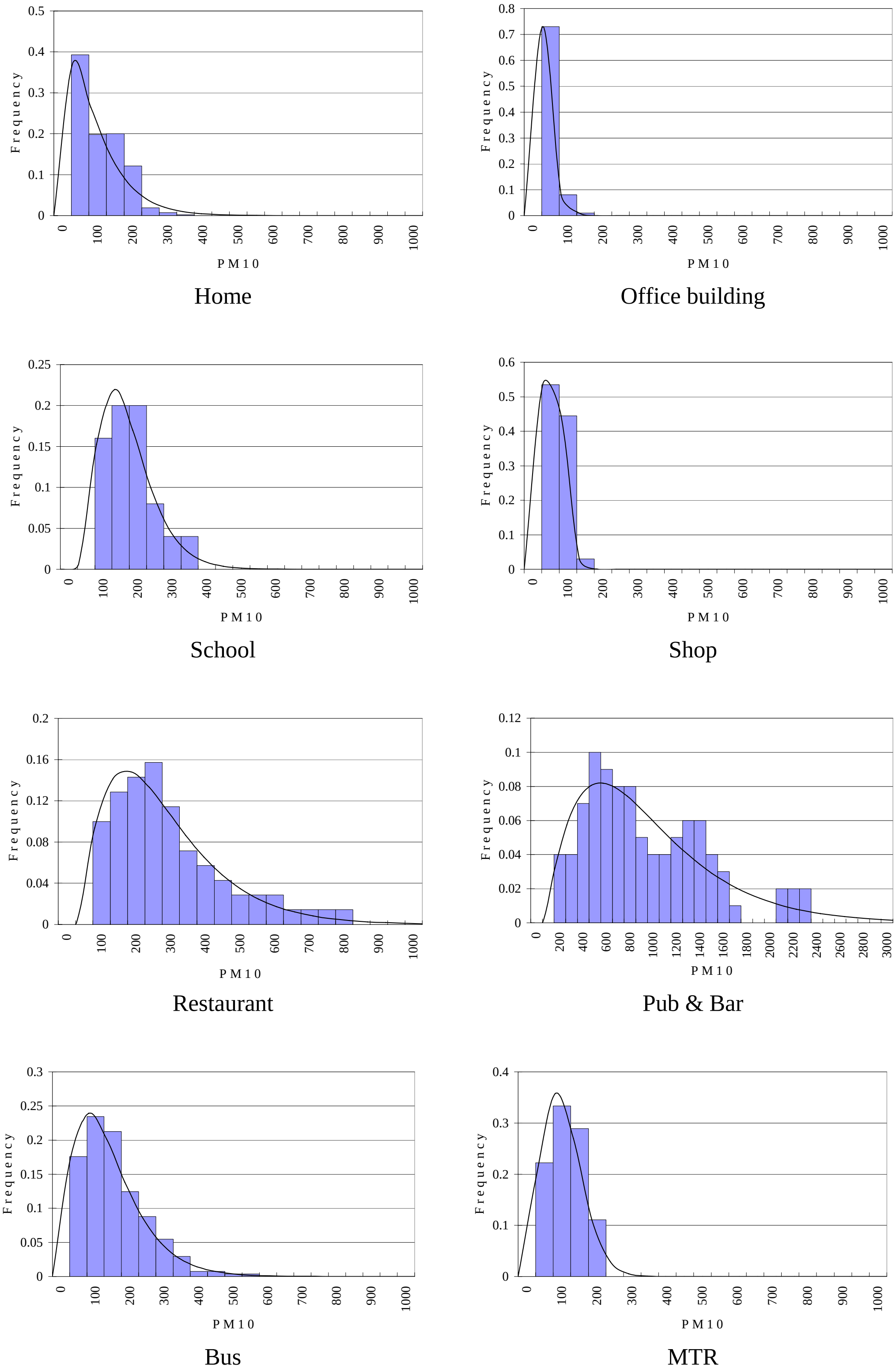


Figure 6.2 **Histograms of PM_{10} concentration distribution and fitted Gamma curves in eight microenvironments**

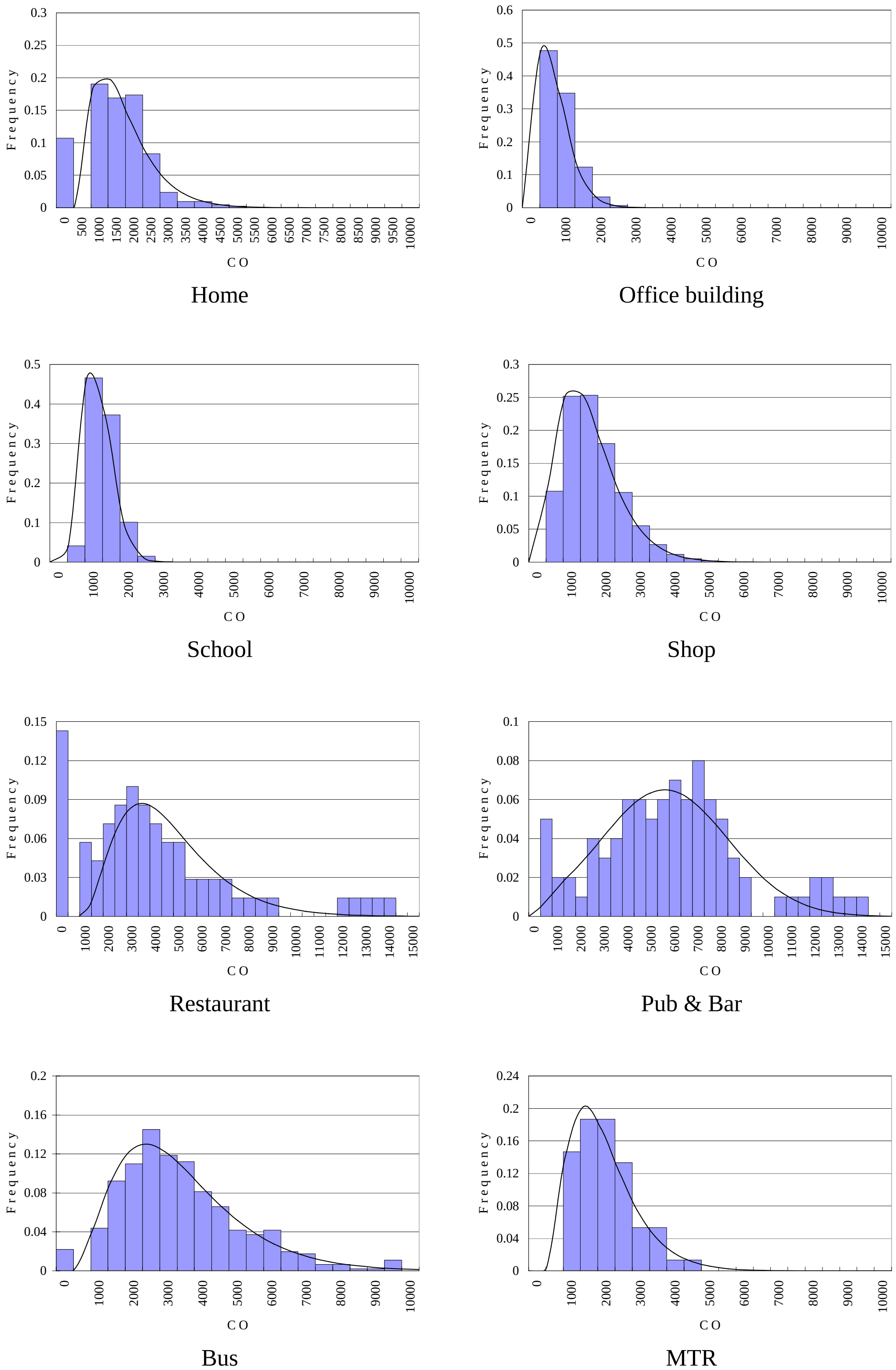


Figure 6.3 **Histograms of CO concentration distributions and fitted Gamma curves in eight microenvironments**

The Gamma PDF for a continuous random variable x defined in [0, +∞] was expressed as:

$$f(x, r, \lambda) = \frac{1}{\lambda^r \Gamma(r)} x^{(r-1)} e^{\frac{-x}{\lambda}}$$

Where r, λ, θ were the shape, scale and threshold parameters respectively, and $\Gamma(r)$ was the usual Euler's integral. The mean and variance of the Gamma distribution were connected to r and λ as follows:

$$E(x) = r\lambda \qquad V(x) = r\lambda^2$$

However, the threshold parameters were not studied in this study as it merely demarcated the lower position of the distribution of the doers to include the non-doers. The estimated parameters of the corresponding Gamma PDF for time and pollutant concentrations are given in Tables 6.5 and 6.6 respectively.

Table 6.5 **Parameters of the Gamma PDF fitted to the pollutant concentration data in eight microenvironments and parameters of the Gamma PDF fitted to the time data (only for doers)**

Microenvironment	**Parameters of the fitted Gamma pdf**			
	PM_{10}		**CO**	
	r	λ	r	λ
Home	3.895	15.964	4.913	219.799
Office building	1.517	19.611	3.501	244.022
School	7.180	18.050	10.196	126.524
Shop	10.042	7.757	3.935	421.828
Restaurant	2.410	213.570	1.667	2752.000
Pub & bar	2.766	340.243	1.454	4797.600

Bus	2.273	54.810	4.199	733.410
MTR	8.167	9.551	4.748	308.119

Table 6.6 **Parameters of the Gamma PDF fitted to the pollutant concentration data in eight microenvironments and parameters of the Gamma PDF fitted to the time data (only for doers)**

Microenvironment	**Parameters of the fitted Gamma pdf**	
	Time	
	R	λ
Home	30.551	0.455
Office building	5.210	1.072
School	1.977	2.063
Shop	1.758	0.899
Restaurant	2.785	0.437
Pub & bar	1.692	0.655
Bus	2.141	0.507
MTR	2.182	0.350

Meanwhile, a theoretical approach and Monte-Carlo simulation in non-parametric and parametric approaches were also used to estimate the pollutant exposure (Albert et al, 2002, Gauchi, 2002). Theoretical approach is the most simple and rapid way to obtain the average exposure of the population. Since then, it was also widely used by other researches. But the representativeness of the sample may affect the accuracy of the result. In this study, non-parametric and parametric approaches were used to compare the result of theoretical approach. The extra benefit of using parametric approach was to obtain the exposure profile of the population. The details will be described immediately next.

6.2.2 Theoretical Approach

The time budget distribution of Hong Kong population, which was obtained from a citywide survey, was independent of the pollutant concentration distributions for individual microenvironment constructed from site measurement data.

Continuous random variable E_p, which is the daily pollutant exposure of surveyed population p, is a function of random variable c_j and $t_{p,j}$, as shown in the following:

$$E_p = \sum_{j=1}^{k} c_j t_{p,j}$$

Where c_j, the average pollutant concentration in microenvironment j, $t_{p,j}$, the average daily time spent in microenvironment j of surveyed population p, are both continuous random variables.

Under the theoretical approach, an independent relationship between pollutant concentration c_j and time $t_{p,j}$, was assumed, with the mean of E_p being estimated by taking the mathematical expectation of the function.

$$E(E_p) = E(\sum_{j=1}^{k} c_j t_{p,j}) = \sum_{j=1}^{k} E(c_j)E(t_{p,j})$$

Therefore, an unbiased estimation of the mean of E_p was given by:

$$\hat{E}_p = \sum_{j=1}^{k} \bar{c}_j \bar{t}_{p,j}$$

Where $\bar{c}_j$ was the arithmetical mean of the available pollutant concentration data of microenvironment *j*, $\bar{t}_{p,j}$ was the arithmetical mean of the time spent in microenvironment *j* by the surveyed population *p*.

Assuming pollutant concentration was independently related to time, the variance of E_p could be expressed as:

$$V(E_p) = \sum_{j=1}^{k} V(c_j t_{p,j})$$

Where the variance of each product of two independent random variables was defined as:

$$V(c_j t_{p,j}) = V(c_j)V(t_{p,j}) + E(t_{p,j})^2 V(c_j) + E(c_j)^2 V(t_{p,j})$$

The results of theoretical approach for estimation of daily pollutant exposure are given in Tables 6.7 to 6.10.

Table 6.7 Daily PM_{10} exposure of all participants in eight microenvironments estimated through theoretical approach

Microenvironment	PM_{10} Exposure (μg hr m^{-3})	
	Mean	S.D.
Home	863.95	893.43
Office building	88.87	155.51
School	116.09	264.16
Shop	106.04	198.20

Restaurant	489.99	814.31
Pub & Bar	163.13	777.89
Bus	94.63	189.97
MTR (subway)	35.94	74.33
Total	1958.65	1497.09

Table 6.8 **Daily PM_{10} exposure of different population groups estimated through theoretical approach**

Population Group	PM_{10} Exposure (μg hr m^{-3})		
	Number	Mean	S.D.
All	396	1959.00	694.23
Female	181	1935.38	715.75
Male	215	1978.89	676.62
Youngster	40	2265.37	745.00
Adult	332	1940.71	689.66
Elder	24	1701.39	503.55
Student	34	2203.33	559.35
office worker	187	1835.01	533.77
non-office worker	135	2156.91	888.05
Employee	322	1969.97	720.84
unemployed	40	1663.04	443.79

Table 6.9 **Daily CO exposure of all participants in eight microenvironments estimated through theoretical approach**

Microenvironment	CO Exposure (μg hr m^{-3})	
	Mean	S.D.
Home	13397.4	2521.5
Office building	2552.6	2593.6
School	1155.5	2624.2
Shop	2259.3	2523.4
Restaurant	4370.3	4102.7
Pub & Bar	1209.4	3987.5
Bus	2287.9	2816.6
MTR (subway)	674.1	863.1
Total	27906.5	8231.0

Table 6.10 **Daily CO exposure of different population groups estimated through theoretical approach**

Population Group	CO Exposure (μg hr m^{-3})		
	Number	**Mean**	**S.D.**
All	396	27906.5	6186.1
Female	181	27692.9	6444.1
Male	215	28086.3	5969.5
youngster	40	29241.7	5985.0
Adult	332	27917.5	6175.2
Elder	24	25528.5	6219.6

student	34	27964.9	4943.3
office worker	187	27746.3	4422.8
non-office worker	135	28937.6	8260.0
Employee	322	28245.8	6337.4
Unemployed	40	25125.9	5240.2

6.2.3 Non-parametric approach

Non-parametric approach is a method of exposure assessment when time and pollutant concentration data are available. No PDF hypothesis was made either on the time or on the pollutant concentration data in every microenvironment.

Taking $c_{i(p),j}$ as the real pollutant concentration in microenvironment *j* contacted by an individual *i* of the survey participant *p*, $t_{i(p),j}$ as the daily time spent in microenvironment *j* by an individual *i* of the survey participants *p*, the estimated total pollutant exposure of individual *i* in the surveyed population *p* in *k* microenvironment could thus be written as:

$$\hat{E}_{i(p)}^{[NP]} = \sum_{j=1}^{k} c_{i(p),j} t_{i(p),j}$$

Since $c_{i(p),j}$ was unknown, it was therefore replaced by a random deviate $\tilde{c}_{i(p),j}$ drawn from the observed cumulative frequency of pollutant concentration in microenvironment *j*.

$$\hat{E}_{i(p)}^{[NP]} = \sum_{j=1}^{k} \tilde{c}_{i(p),j} t_{i(p),j}$$

Therefore, the mean of E_p could be estimated by:

$$\hat{E}_{S(p)}^{[NP]} = \frac{1}{n_p} \sum_{i=1}^{n_p} \frac{1}{n} \sum_{d=1}^{n} \left[\sum_{j=1}^{k} \tilde{c}_{i(p),j(d)} t_{i(p),j} \right]$$

Where:

n_p was the number of individuals in the surveyed population *p*,

n was the number of random deviates drawn from the observed cumulative frequency of pollutant concentration in microenvironment *j* for each individual,

$\tilde{c}_{i(p),j(d)}$ was the d^{th} pollutant concentration random deviate drown from the observed cumulative frequency of pollutant concentration in microenvironment *j* for individual *i* of the surveyed participants *p*,

$S_{(p)}$ was the simulation set of the nn_p outputs for the surveyed participants *p*.

The results of non-parametric approach for estimation of daily pollutant exposure are given in Tables 6.11 to 6.14.

Table 6.11 Daily PM_{10} exposure of eight microenvironments estimated through non-parametric approach

Microenvironment	PM_{10} Exposure ($\mu g\ hr\ m^{-3}$)				
	mean	SD	Median	95^{th} quartile	99^{th} quartile
Home	845.0	439.3	754.5	1637.0	2100.2
Office building	89.0	146.5	17.1	375.1	659.4
School	109.3	264.5	0.0	753.4	1172.3
Shop	109.1	138.1	71.0	349.1	800.3
Restaurant	473.9	512.7	331.4	1473.9	2040.7
Pub & Bar	172.0	644.2	0.0	871.4	3554.2
Bus	94.5	125.4	54.2	355.0	618.8
MTR (subway)	37.0	51.0	21.2	132.9	194.6
Total	1929.9	966.8	1721.5	3505.5	5810.2

Table 6.12 Daily PM_{10} exposure of different population group estimated through non-parametric approach

Population Group	PM_{10} Exposure (μg hr m^{-3})					
	N	mean	SD	Median	95^{th} quartile	99^{th} quartile
All	396	1929.88	966.76	1721.49	3505.49	5810.24
Female	181	1914.82	949.62	1681.51	3536.59	5560.36
Male	215	1942.55	982.98	1754.54	3341.42	5699.04
Youngster	40	2299.80	1021.73	2041.25	3973.46	5423.76
Adult	332	1912.98	962.70	1713.15	3336.84	5664.17
Elder	24	1547.06	740.41	1424.01	3305.32	3674.05
Student	34	2347.99	1004.75	2127.28	3664.31	5492.28
office worker	187	1828.79	813.54	1637.91	3091.91	4167.19
non-office worker	135	2064.05	1152.63	1837.65	3733.71	6118.10
Employee	322	1927.40	975.50	1721.50	3531.00	5703.90
Unemployed	40	1594.30	715.00	1476.20	3156.60	3454.20

Table 6.13 Daily CO exposure of all participants in eight microenvironments estimated through non-parametric approach

Microenvironment	CO Exposure (µg hr m^{-3})				
	mean	SD	Median	95th quartile	99th quartile
Home	13445.7	6807.5	12112.9	25075.3	35300.6
Office building	2567.2	3379.4	722.8	9035.3	14154.9
School	1171.6	2764.3	0.0	7838.7	12141.8
Shop	2345.6	3182.5	1395.1	7127.6	17757.9
Restaurant	4172.9	5215.5	2759.4	13004.5	20319.4
Pub & Bar	1026.4	4136.8	0.0	6382.4	16584.4
Bus	2264.2	2761.1	1351.7	7267.8	12582.2
MTR (subway)	677.7	1391.8	320.0	2393.4	3449.6
Total	27671.3	9920.2	26834.3	44721.6	57411.3

Table 6.14 Daily CO exposure of different population group estimated through non-parametric approach

Population Group	CO Exposure (μg hr m^{-3})					
	N	mean	SD	Median	95th quartile	99th quartile
All	396	27671.3	9920.2	26834.3	44721.6	57411.3
Female	181	27765.4	9938.5	26914.6	44373.2	55686.2
Male	215	27592.0	9927.4	26616.3	44723.1	57951.0
Youngster	40	28670.8	9122.3	26595.8	45010.4	50494.0
Adult	332	27846.7	10020.8	27005.0	44803.0	58337.6
Elder	24	23578.9	9176.9	23722.2	36071.4	39074.7
Student	34	27510.5	7824.7	26595.8	39697.4	45728.4
office worker	187	28297.6	9339.7	26914.6	44423.8	53655.0
non-office worker	135	27984.5	11094.2	27327.8	49061.1	58610.1
Employee	322	28166.3	10096.9	27005.0	44903.3	58482.4
Unemployed	40	23822.6	9411.3	23722.2	39928.4	43744.6

6.2.4 Parametric approach

Considering $\tilde{c}_{mj}$ as a random pollutant concentration drawn m times from the fitted Gamma CDF (cumulated density function) of microenvironment j with parameters given in Table 6.5, $\tilde{t}_{mj}$ as a random time drawn m times from the fitted mixed CDF of microenvironment j with parameters given in Table 6.4, the estimated simulation set S(with m elements) of pollutant exposure can be expressed as:

$$E_{S(m)} = \sum_{j=1}^{k} \tilde{c}_{mj} \tilde{t}_{mj}$$

The mean of the pollutant exposure over simulation set S could then be estimated by:

$$\overline{E}_S = \frac{1}{m} E_{S(m)}$$

For each simulation set S, when m=10,000, 10,000 outputs of pollutant exposure were obtained. Therefore, the mean, variance, quartile could be calculated. The results of Monte-Carlo simulation are given in Tables 6.15 to 6.18 and Figure 6.4.

Table 6.15 Daily PM_{10} exposure of all participants in eight microenvironments estimated by parametric approach

Microenvironment	PM_{10} Exposure (μg hr m^{-3})				
	Mean	**S.D.**	**Median**	**95th quartile**	**99th quartile**
Home	843.5	461.1	754.9	1693.6	2274.7
Office building	79.6	138.9	0.0	350.9	567.4
School	120.4	318.70	0.0	778.7	1489.4
Shop	105.0	102.34	80.7	308.3	470.3
Restaurant	473.3	584.78	302.0	1622.3	2916.9
Pub & Bar	174.2	600.30	0.0	1325.8	3047.6
Bus	87.9	127.38	43.7	319.2	612.7
MTR(subway)	33.9	45.57	17.5	124.9	204.0
Total	1916.5	1003.5	1700.0	3978.0	5565.6

Table 6.16 Daily PM_{10} exposure of different population group estimated through parametric approach

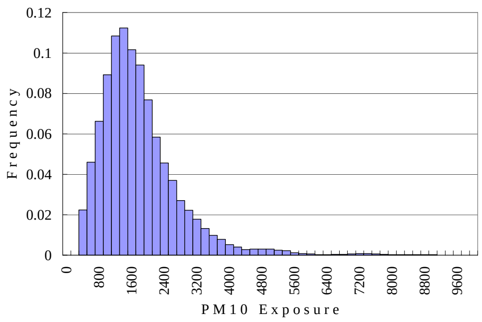
Population Group	PM_{10} Exposure (µg hr m^{-3})					
	N	mean	SD	Median	95^{th} quartile	99^{th} quartile
All	396	1916.5	1003.5	1700.0	3978.0	5565.5
Female	181	1917.3	1040.7	1722.5	3859.4	5492.2
Male	215	1981.9	996.6	1746.1	3925.8	5452.6
Youngster	40	2292.0	1112.0	2128.3	4264.2	6171.4
Adult	332	1933.0	982.6	1749.6	3941.9	5146.8
Elder	24	1660.1	890.3	1486.0	3403.7	4496.1
Student	34	2198.3	818.7	2089.6	3713.5	4892.4
office worker	187	1864.3	903.6	1698.0	3510.2	4901.2
non-office worker	135	2108.2	1117.4	1871.7	4138.2	5761.0
Employee	322	1982.7	1023.7	1762.9	4018.9	5488.4
Unemployed	40	1605.6	787.7	1467.4	3040.8	4040.9

Table 6.17 **Daily CO exposure of all participants in eight microenvironments estimated by parametric approach**

Microenvironment	**CO Exposure (µg hr m^{-3})**				
	Mean	**S.D.**	**Median**	**95th quartile**	**99th quartile**
Home	13745.3	6581.2	12765.0	25899.4	32923.1
Office building	2432.8	3344.4	779.0	9475.1	13565.1
School	1076.3	2882.8	0.0	7073.6	15032.4
Shop	2197.5	2463.4	1466.0	7310.1	11524.6
Restaurant	4459.1	4935.6	3094.5	14538.7	22609.9
Pub & Bar	1036.2	4345.5	0.0	6755.1	20238.1
Bus	2405.5	3049.8	1541.0	8646.7	14153.1
MTR(subway)	724.0	978.5	393.9	2668.0	4134.4
Total	28076.6	11560.3	26535.0	48895.1	63683.9

Table 6.18 Daily CO exposure of different population group estimated through parametric approach

Population Group	CO Exposure (µg hr m^{-3})					
	N	mean	SD	Median	95^{th} quartile	99^{th} quartile
All	396	28076.6	11560.3	26535.0	48895.1	63683.9
Female	181	28412.1	11349.5	27270.0	47520.5	60663.9
Male	215	27857.9	10847.6	26006.0	47876.5	58899.8
Youngster	40	29491.5	12109.7	27483.5	51739.3	70601.2
Adult	332	28255.6	11186.1	26615.5	46915.9	67499.0
Elder	24	25881.8	11152.4	24477.5	45467.8	59256.2
Student	34	28190.3	8625.6	27200.5	44009.0	52962.8
office worker	187	27850.7	9523.2	26864.0	43967.9	56310.0
non-office worker	135	28929.2	12963.8	26918.0	51988.9	70134.1
Employee	322	28331.8	11101.4	26238.0	49044.5	60359.4
Unemployed	40	24882.8	10591.8	23679.0	43549.6	55279.6



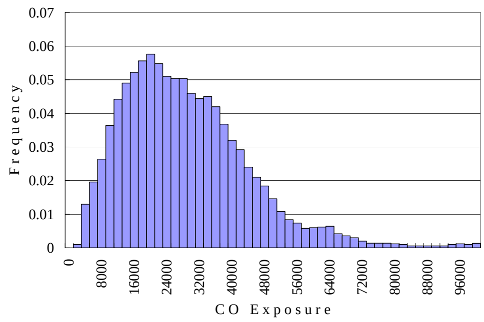


Figure 6.4 **PM_{10} and CO exposure through Monte-Carlo simulation**

6.3 Analysis and discussion

In Section 6.2, the daily exposures of PM10 and CO were estimated through three different approaches. The results of three approaches were compared below. Comparing with the results obtained by the theoretical method, the daily PM10 exposure was 1.47% less than those derived by non-parametric approach, while 2.15% less than those derived by parametric approach. The daily CO exposure was 0.84% less than those derived by non-parametric approach, while 0.61% more than those derived by the parametric approach, as compared with the results of theoretical method. Notwithstanding these minor deviations, the results from the three approaches were close.

Similar results of pollutant exposure estimation through the three different approaches showed the representativeness of the survey samples and the wide scope of site measurements in this study. Based on a well-organized survey and IAQ monitoring strategies, the theoretical approach is the simplest way to estimate the average exposure of the population. Parametric approach is invaluable when the profile of exposure is required.

In this study, not only the general exposure information but also the detailed exposure profile, such as the quantile and PDF of exposure, are expected. Therefore, using the parametric approach in exposure assessment will be a good solution. Thanks to the limited population and area of Hong Kong, it is not difficult to collect enough data for parametric approach.

6.3.1 Pollutant exposure in different microenvironments

The results of daily PM_{10} and CO exposures in eight major microenvironments, estimated by using the three approaches, are compared in Tables 6.19 and 6.20. The amount of daily PM_{10} exposure in homes, shops and restaurants were similar by the three approaches. It might be due to the reason that the majority of the Hong Kong population usually spent their time in these microenvironments everyday. For the other microenvironments, such as pub & bar; MTR; and school, only a proportion of population spent some time there. There were differences between the pollutant exposures obtained through parametric approach and theoretical approach.

6.3.2 Pollutant exposure of different subgroup of Hong Kong population

The total exposure could be varied for different subgroups of Hong Kong people. Males and females, the youngsters and oldsters, the office workers and non-office workers had different life styles. Thus, their daily activity patterns and time budgets were also different. The daily PM_{10} and CO exposures, obtained through three approaches, are again compared in the Tables 6.21 and 6.22 respectively. It was found that similar results were obtained from the three methods. The amount of exposure obtained by parametric approach of each subgroup of Hong Kong population varies within 3% when comparing with the theoretical approach. Only few data of non-parametric approach varied about 10% when comparing with the theoretical approach.

Table 6.19 Comparing daily PM_{10} exposures obtained through the three approaches in eight major microenvironments

Microenvironment	PM_{10} Exposure ($\mu g\ hr\ m^{-3}$)				
	Theoretical (A)	Non-parametric (B)	Difference from A (%)	Parametric (C)	Difference from A (%)
Home	863.95	845.0	-2.19%	843.5	-2.37%
Office building	88.87	89.0	0.15%	79.6	-10.43%
School	116.09	109.3	-5.85%	120.4	3.71%
Shop	106.04	109.1	2.89%	105.0	-0.98%
Restaurant	489.99	473.9	-3.28%	473.3	-3.41%
Pub & Bar	163.13	172.0	5.44%	174.2	6.79%
Bus	94.63	94.5	-0.14%	87.9	-7.11%
MTR(subway)	35.94	37.0	2.95%	33.9	-5.68%
Total	1958.65	1929.9	-1.47%	1916.5	-2.15%

Table 6.20 Comparing daily CO exposures obtained through the three approaches in eight major microenvironments

Microenvironment	CO Exposure ($\mu g\ hr\ m^{-3}$)				
	Theoretical (A)	Non-parametric (B)	Difference from A (%)	Parametric (C)	Difference from A (%)
Home	13397.4	13445.7	0.36%	13745.3	2.60%
Office building	2552.6	2567.2	0.57%	2432.8	-4.69%
School	1155.5	1171.6	1.39%	1076.3	-6.85%
Shop	2259.3	2345.6	3.82%	2197.5	-2.74%
Restaurant	4370.3	4172.9	-4.52%	4459.1	2.03%
Pub & Bar	1209.4	1026.4	-15.13%	1036.2	-14.32%
Bus	2287.9	2264.2	-1.04%	2405.5	5.14%
MTR(subway)	674.1	677.7	0.53%	724.0	7.40%
Total	27906.5	27671.3	-0.84%	28076.6	0.61%

Table 6.21 Comparing daily PM_{10} exposures obtained through the three approaches for different subgroups of Hong Kong Population

Population Group	PM10 Exposure (μg hr m^{-3})				
	Theoretical (A)	Non-parametric (B)	Difference from A (%)	Parametric (C)	Difference from A (%)
Female	1935.38	1914.82	-1.06%	1917.3	-0.93%
Male	1978.89	1942.55	-1.84%	1981.9	0.15%
Youngster	2265.37	2299.80	1.52%	2292.0	1.18%
Adult	1940.71	1912.98	-1.43%	1933.0	-0.40%
Elder	1701.39	1547.06	-9.07%	1660.1	-2.43%
Student	2203.33	2347.99	6.57%	2198.3	-0.23%
office worker	1835.01	1828.79	-0.34%	1864.3	1.60%
non-office worker	2156.91	2064.05	-4.31%	2108.2	-2.26%
Employee	1969.97	1927.40	-2.16%	1982.7	0.65%
Unemployed	1663.04	1594.30	-4.13%	1605.6	-3.45%

Table 6.22 Comparing daily CO exposures obtained through 3 approaches for different subgroup of Hong Kong Population

Population Group	CO Exposure (μg hr m^{-3})				
	Theoretical (A)	Non-parametric (B)	Difference from A (%)	Parametric (C)	Difference from A (%)
Female	27692.9	27765.4	0.26%	28412.1	2.60%
Male	28086.3	27592.0	-1.76%	27857.9	-0.81%
Youngster	29241.7	28670.8	-1.95%	29491.5	0.85%
Adult	27917.5	27846.7	-0.25%	28255.6	1.21%
Elder	25528.5	23578.9	-7.64%	25881.8	1.38%
Student	27964.9	27510.5	-1.62%	28190.3	0.81%
office worker	27746.3	28297.6	1.99%	27850.7	0.38%
non-office worker	28937.6	27984.5	-3.29%	28929.2	-0.03%
Employee	28245.8	28166.3	-0.28%	28331.8	0.30%
Unemployed	25125.9	23822.6	-5.19%	24882.8	-0.97%

Some interesting results were revealed when three subgroups were examined with respect to their total time spent in pubs & bars. Upon examining the impact of the time spent in pubs & bars on the pollutant exposures for three age groups, each group was further divided according to the time span in pubs & bars, i.e. 0.5 hr, 0.5-1hr, >1 hour. Figures 6.5 & 6.6 show the 24-hr total exposures for three age groups who had different time spans in pubs & bars.

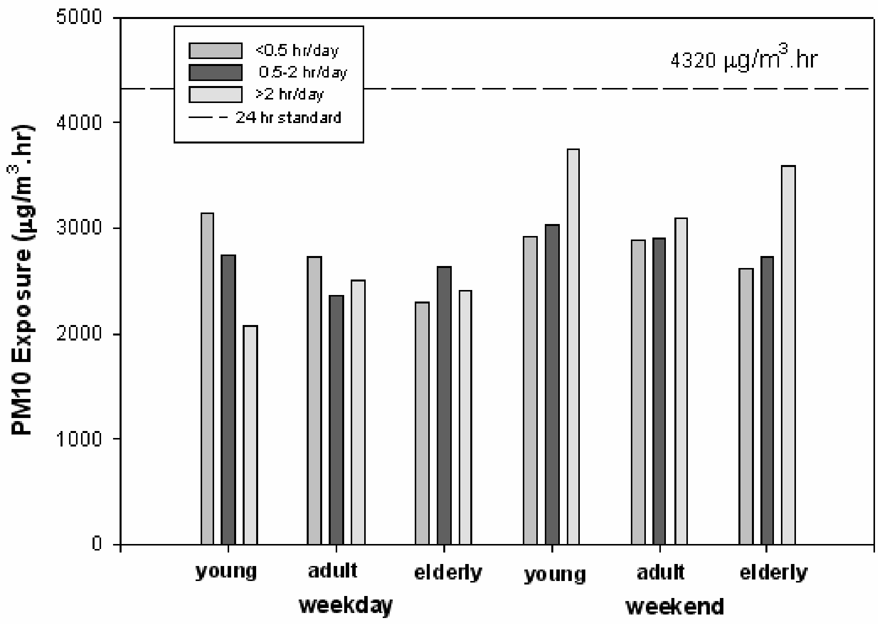


Figure 6.5 **The 24-hr PM_{10} exposure for different age groups with different daily time spent in pubs & bars**

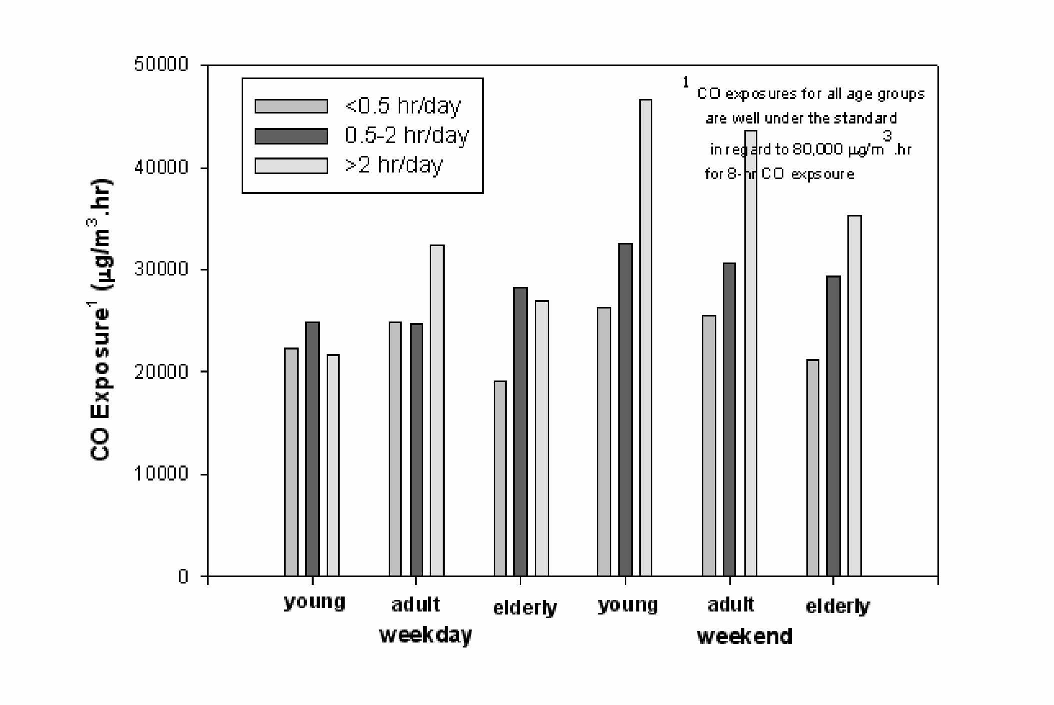


Figure 6.6 The 24-hr CO exposure for different age groups with different daily time spent in pubs & bars

Figure 6.5 shows that the 24-hr PM_{10} exposures for all groups were increasing with the amount of daily time spent in pubs & bars. Similarly, Figure 6.6 shows that the 24-hr CO exposures for all groups were also increasing with the amount of time spent there. Although the total 24-hr CO and PM_{10} exposures were determined to be lower than the 24-hr standards, the exposure levels of some subgroups were indeed very close to the alarming levels. The youngsters used to stay more than 1 hour in pubs and bars during weekends were the potentially high-risk group as their 24-hr PM_{10} exposures would reach the dangerous levels.

7 UNCERTAINTY ANALYSIS

Given that this exposure assessment study were based on a wide array of information sources and techniques, assumptions and inferences, uncertainties obviously arise that may eventually affect the results. In order to minimize the impact, a number of strategies had been introduced and they will be discussed in details in the following context.

7.1 Types of uncertainties

For this exposure assessment study, there are three major sources of uncertainties that may have potential impact on accuracy of the findings:

1. Uncertainties in relation to missing or incomplete information needed to fully define the exposure (scenario uncertainty)
2. Uncertainties in relation to characteristics of some parameters (parameter uncertainty)
3. Uncertainties in relation to gaps in scientific theory required for making predictions on the basis of causal inferences (model uncertainty)

In immediate next, each of these three types of uncertainties will be discussed together with the necessary strategies employed to minimize them.

7.2 Scenario uncertainties

Sources of scenario uncertainty include descriptive errors, aggregation errors, errors in professional judgment, and incomplete analysis. Descriptive errors include errors in information, such as the current producers of the pollutant and its industrial, commercial, and consumer uses. Information of this type was the foundation for the eventual development of exposure pathways, scenarios, exposed populations, and exposure estimates. In this study, the result of microenvironment study was used to represent the air pollution in the whole environment. Uncertainties may occur in this process and some of the risky microenvironments might be omitted.

Aggregation errors arise as a result of lumping approximations. For instance, assumptions made on homogeneity of populations, and spatial and temporal approximations (e.g. steady-state conditions) may lead to aggregation errors. In this study, the spatial and temporal variations of the pollutant concentration in a certain microenvironment had not been considered. In other words, the distribution profiles of pollutant concentrations inside all microenvironments were assumed to be homogeneous, which may have a profound impact on the accuracies of the subsequent developed exposure models.

Professional judgment adopts virtually every aspect of the exposure assessment process, from defining the appropriate exposure scenarios, to selecting the proper environmental fate models, to determining representative environmental conditions, etc. Unfortunately, errors in professional judgment also are a source of uncertainty.

7.3 Parameter uncertainties

Sources of parameter uncertainty may come from errors in measurement and sampling, errors due to data variability, and use of generic or surrogate data. Measurement errors can be random systematic, which may occur from imprecision in the measurement process. The types of equipment used for monitoring the indoor pollutant levels can also incur errors and uncertainties in measurement. In this study, this type of uncertainties had been minimized by calibrating different types of equipment in accordance with the guideline recommended by manufacturer each time before conducting the surveys.

Systematic error occurs whenever there is a bias or tendency away from the true value. Sampling errors may come from under-representation of the total population by the selected samples, as this may affect the accuracies of drawing an inference about the nature of the whole from survey measurements of a subset of the total population. Uncertainties obviously arise if the data do not represent the exposure scenario being analyzed.

In the time budget survey, the number of samples randomly drawn from the population was decided by the formula given in Chapter 4 to minimize the selection bias. However, uncertainty may occur during the process of randomly drawing participants of the survey. The randomness of participants was influenced by the constraints imposed by the formulation of the telephone directory. Certainly, this approach under-represents those individuals coming from families without fixed telephones. Also, this approach can lead to another type of response uncertainty. As adults usually answered the phone, this might lead to an under-representation of the number of children and elderly in our survey sample. Notwithstanding these limitations, the telephone survey was the only practical approach for obtaining the time budget of Hong Kong population given the available resources. To reduce the uncertainty occurred in the survey process in the future, more participants should be drawn from different age and gender groups for face-to-face interviews.

As the entire time budget survey was conducted in 1997, the activity pattern of the Hong Kong people today may be different from what had been obtained. Therefore, due care should be exercised in applying these results. It is suggested that more surveys study should be conducted so as to obtain the latest activity patterns of the Hong Kong population so that more updated information can be obtained and can also be used for comparing with those obtained five years ago.

Inability to characterize the inherent variability in environmental and exposure-related parameters is another major source of parameter uncertainties. For example, meteorological and hydrological conditions may vary seasonally at a given location, soil conditions can have large spatial variability, and human activity patterns can vary substantially depending on age, sex, and geographical location. In this study, the site measurements in different microenvironment were usually conducted within two or three months. Although the seasonal variation can also influence the result of microenvironment study, its effect was ignored due to the resource limitation. However, this type of uncertainty can only be reduced by conducting more site measurements in different seasons.

7.4 Model uncertainties

Modeling errors are due to simplified representations of reality being used in the model development. Even the most suitable model has been selected, problems may still arise on how well the model represents the real situation. This question is compounded by the overlap between modeling uncertainties and other uncertainties, e.g., natural variability in environmental inputs, representativeness of the modeling scenario, and aggregation errors.

In this study, indirect approach was used to estimate the pollutant exposure of Hong Kong population. Meanwhile, three different approaches: theoretical approach and Monte-Carlo simulation in non-parametric and parametric approaches were used to estimate the pollutant exposure so as to minimize the model uncertainties. Although the theoretical approach has the benefits of simplicity and rapidness, the issue of representativeness of the selected samples may affect the accuracy of the result. Through Monte-Carlo simulation, the original data were fitted into a smooth curve and become continuously. Then time and pollutant concentration data were randomly drawn from the cumulative distribution frequency of fitted curve and the exposure was calculated. This process repeated for thousands of times therefore the uncertainties caused by the original data was reduced. Although three approaches were used to calculate the total exposure of Hong Kong population and the result were compared in the previous chapter, the results can not be validated. It can only be fulfilled through comparison with the result of direct approach of the total exposure assessment, which will be the next step of work in the future.

7.5 Summary

Even though many different types of uncertainties exist, this study can only address some of them as a result of the resources and budget limitations. Accordingly, due care should be exercised in applying these findings.

8 CONCLUSIONS AND RECOMMANDATIONS

In this chapter, the major findings of the study are summarized. Although there are some limitations for this study, it is one of the pioneering studies for assessing the citywide exposure of Hong Kong people. The results can be a useful reference for the policy maker of Hong Kong government for the environmental protection in the future. It might also be useful as the foundation of further studies.

8.1 Findings from the time budget survey

Exposure assessment and risk management could only be fulfilled when the time budget or activity pattern were obtained through a large scale of survey in the target population. This kind of survey had already been conducted in the United States and other western countries. However, it was only a start in Hong Kong. In the last few decades, the environmental protection department had conducted several projects to estimate the citywide air pollutant levels. But fixed station could only supply the ambient air pollutant level. Since most of Hong Kong people spent much of their daily times indoors, the indoor pollutant levels affected the health of human being directly.

It was found that time budget and activity pattern could be influenced by many factors, i.e. age, gender, occupation. For example, the elder and the youngster group spent more time indoors at home, while the adult group spent more time in office buildings and other public places. Different subgroups of population with different time budget might have different exposure to air pollution.

It was found that the surveyed subjects mainly engaged in nine primary activities: sleeping, working, eating, travelling, shopping, cooking, personal hygiene, outdoor activities and entertainment. The survey results showed that the total time spent in the above nine major activities was about 23.3 hr/day (97%). Hong Kong people spent their daily time in four major locations: indoor at home, indoor in public places, enclosed transits and outdoor. The total time that Hong Kong people spent in indoor environment added up to more than 23 hr/day (96%).

It was found that Hong Kong people spent more time at home, in enclosed transits and outdoors during weekends. On weekdays, more than 2.7 hr/day were spent in various public places, such as in office buildings and schools. Hong Kong people spent much time in restaurants everyday, especially during weekends (2.16 hr/day of the population). Hong Kong people lived a busy life and many people chose to have meals in restaurants, for there were many of them in Hong Kong. Traditional Chinese food usually took more time to cook and eat. Shopping, hanging out in pub, watching movie in cinema were favourite entertainments of Hong Kong people.

Hong Kong people also spent much of their daily time in enclosed transits, especially in various public transit facilities. Bus and subway (MTR) were found to be the most favorite public transits of Hong Kong people. They spent over 0.7 hr/day in buses and 0.45 hr/day in MTR. Although the time spent outdoors was limited, Hong Kong people still hoped to spend more time outdoors during weekends.

According to the results of survey, people in different age groups might have different life styles and time budgets. The time budget and daily activity patterns of Hong Kong people were divided into three subgroups of population: the youngster (6-18 years old), adult (18-60 years old), and elder (>60 years old), respectively.

Individuals from all three age groups, on average, spent more than 86% of their time indoors, 3-7% in enclosed transit, and 3-7% outdoor. Normal office workers (usually adults) in Hong Kong were used to work in office buildings, on average, 7.5 hours and 3.6 hours during weekdays and weekends respectively. It was much higher than people in the other two age groups. On the other hand, the youngsters spent more time (about 4.3 hr/day on weekdays) in school, and the elders spent more time at home (over 16.5 hr/day).

It was also found a heavy reliance of Hong Kong people took the public transport network to meet their daily commuting needs, with approximately 60% youngsters, 50% adults, and 33% elders spending time in buses; and 30%

youngsters, 50% adults and 20% elders in subway (MTR) on a given day. In contrast, less than 20% adults and 17% youngsters commuted by private cars or taxi on weekdays or weekends. Heavy reliance on the public transport network was probably due to two main reasons: (i) the existence of an extensive and convenient transportation network in Hong Kong; and (ii) high operating and maintenance cost of possessing a car in Hong Kong. The elder group was observed to spend less time in enclosed transits, while more time outdoor, than the other two age groups.

Data of the length of time people exposed, and also the percentages of the population who might be exposed in terms of percentage doer, indicated the characteristics of time budget for various subgroups of people. For instance, results indicated that more youngsters (70% of youngest group) would visit restaurants than schools (60%) during weekdays. More adults (61.1% of adult group) would visit restaurants than offices (55.1%) during weekdays. More elders (70.8%) would visit shopping areas than restaurants (33.3%) during weekdays.

8.2 Results of microenvironment study

In this study, the major indoor microenvironments that Hong Kong people spent their daily life were categorized into three groups: indoor at home, indoor away from home, and enclosed transits. The results of microenvironment studies were summarized in this section.

8.2.1 Indoor at home

Comparing with the indoor air quality guideline of Hong Kong, the indoor PM_{10} level could satisfy the requirement of the Level 2, but was over 3 times higher than the requirement of the Level 1. The outdoor PM_{10} level could satisfy the ambient air quality objectives.

The average indoor CO and NO_2 levels could meet the requirement of the indoor air quality guideline, except in several flats. The reason of high CO and NO_2 concentration might due to the smoking and cooking activities. The lower indoor CO_2 concentrations were because of the lower people density.

8.2.2 Indoor away from home

Despite a strong influence by ambient air, the pollutant concentrations in different indoor public places might vary according to the existence and the strength of pollutant sources; as well as the effectiveness of mechanical ventilation and air-conditioning systems.

For places like car park, an extremely high CO concentration level was observed. However, this might not call for an immediate concern for action, as only 3% of the total sampled subjects visited car parks on a given day.

The pollutant concentrations in restaurants, pubs and bars were shown to be among the highest in various microenvironments. The extremely high CO concentrations in pubs, bars, nightclubs and restaurants indicated the presence of vast number of smokers. Accordingly, the air quality in restaurants should receive more government attention as more than 64% of surveyed subjects visited restaurants on a given day, with an average time span of 1.3 hour per day.

Meanwhile, the effectiveness of mechanical ventilation system also had a significant impact on the indoor pollutant concentration levels. Given a constant source strength, greater pollutant removal rates and smaller indoor pollutant concentrations would be obtained if indoor places were equipped with more effective ventilation or air-conditioning systems.

Nowadays, nearly all indoor public places including schools in Hong Kong were air-conditioned. Apart from providing improved thermal comfort, air-conditioning systems also helped improve the indoor air quality by removing the indoor pollutants. The amount of pollutant removed depended directly on the effectiveness of air-conditioning systems, which could be revealed by observing the CO_2 concentrations inside different microenvironments. A CO_2 concentration level of higher than 1000 ppm implied an inadequacy of ventilation effectiveness. It could be seen that many public indoor places in Hong Kong, like restaurants, pubs, bars and nightclubs, were under ventilated with respect to number of occupants, smoking and cooking activities. Besides, heavy CO dominated car parks were also observed to be under ventilated, or had lower ventilation effectiveness.

8.2.3 Enclosed transits

In general, a descending order of pollutant levels was observed for the enclosed transits in Hong Kong: private car, buses, minibuses, trams, subway and trains, and ferries. The results revealed were similar to those shown in a recent report submitted to the Environmental Protection Department in Hong Kong (HKPU, 2001). The pollutant concentration levels inside double-decker buses and mini-buses were observed to be lower than private cars as their venting positions were located at a higher level for taking in cleaner air at higher road levels. Subways and railways, which were usually positioned at a distance from the roadside, were less influenced by vehicular borne pollutants. Unlike other enclosed transits, ferries had a substantially low pollutant concentration as they were always exposed to ambient air away from polluted vehicle sources.

8.3 Results and future studies

The indirect method of exposure assessment was used in this study. Based on the result of telephone survey and microenvironment study, the pollutant exposures were obtained through three approaches. The results were summarized in this section.

8.3.1 Pollutant exposure in different microenvironments

The daily PM_{10} and CO exposures in eight major microenvironments, obtained through three approaches, were compared. The values of daily PM_{10} exposure in home, shops and restaurants obtained by three approaches were similar. It might due to the reason that most of the Hong Kong people usually spent their time in these microenvironments everyday. For the microenvironments, such as pub & bar; MTR; and school, only some people spent their daily time. There were differences between the pollutant exposures obtained through parametric approach and theoretical approach.

8.3.2 Pollutant exposure in various subgroups of population

The total amount of exposure could be varied among different subgroups of Hong Kong people. The males and females, the youngsters and oldsters, the office workers and non-office workers had different living styles. Thus, their daily activity patterns and time budgets were also different. The daily PM_{10} and CO exposures, obtained through three approaches were compared. It was found that the results were similar for three methods. The exposure obtained by parametric approach of each subgroup of Hong Kong population varied within 3% comparing with the theoretical approach. Only few data of non-parametric approach varied about 10% comparing with the theoretical approach.

8.3.3 Recommendations for future studies

In this study, some preliminary findings on exposure assessment of Hong Kong population were obtained. However, there are still some gaps due to the resources limitation. Here are some recommendations for the future studies.

According to the results of the exposure assessment, subgroups of population, which are endangered by certain kind of pollutant, are identified. Since then, direct approach can be applied to estimate the individual exposure of these people. It will be helpful to obtain more precise data, so that measures can be taken to provide them from health risks caused by air pollutant.

The major microenvironments that affect the total exposure of Hong Kong people are also identified. Therefore, more studies should be conducted to these certain microenvironments. To study the reasons that caused indoor pollution, the building services engineers may take effective measures to control the indoor air quality.

Since the exposure assessment is part of the risk management. The results of this study also provide a basement for the risk assessment and control. Although the endangered population is found, the health risk of these people can only be quantified through dose-response assessment, which can only fulfilled in the cooperation of the researchers in other fields.

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Appendices Questionnaires

香港理工大學 The Hong Kong Polytechnic University

屋宇設備工程學系 Department of Building Services Engineering

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All information will be used for research purpose only and will be treated confidentially.(所有資料隻作研究之用并將予以保密)

A Time Budget Survey of the Hong Kong Population

香港居民日常生活時間安排調查

Personal Information(個人資料)

Name (姓名): ________________________(Optional 任選)

Contact No.(聯系電話):________________(Optional 任選)

Age(年齡): □ under 10 □ 10-18 □ 18-30

□ 30-40 □ 40-60 □ > 60

Gender(性別): □ Male(男) □ Female(女)

Occupation(職業): □ White collar(白領)

□ Blue collar(藍領)

□ Unemployed(無業)

Smoking habit(吸煙習慣): □ Nonsmoker(不吸煙)

□ Light smoker(偶爾吸煙)

□ Heavy smoker(經常吸煙)

香 港 理 工 大 學 The Hong Kong Polytechnic University

屋 宇 設 備 工 程 學 系 Department of Building Services Engineering

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All information will be used for research purpose only and will be treated confidentially.(所 有 資 料 隻 作 研 究 之 用 并 將 予 以 **保 密**)

Personal Information（ **個 人 資 料** ）

Place of work (工 作 地 點) : ___________________(District / 地 區)

Average number of working hours per week :

(平 均 每 周 工 作 時 間) ______________(Hour / 小 時)

Working area with air-conditioning (工 作 地 點 是 否 安 裝 空 調):

□ Yes (是) □ No (否)

Place of residence (住 宅 地 點) : _____________ (District 地 區)

Number of people living together (共 同 居 住 人 數): _________(人)

Area of the flat (居 住 單 位 面 積) : _________(square ft/平 方 呎)

Type of cooking fuel:

(煮 食 用 燃 料)

□ LPG (石 油 氣)

□ Towngas (煤 氣)

□ Kerosene (火 水)

□ Others (其 他)

Duration of using air-conditioning at home :

(住 宅 空 調 每 日 開 啟 時 間)

(in summer / 夏 天) : ____________________(hour / day 小 時 /天)

(in winter / 冬 天) : ____________________(hour / day 小 時 /天)

Time budgets of weekdays

工 作 日 時 間 安 排

Time 時 間	Microenvironment code 微 環 境 編 碼	Time 時 間	Microenvironment code 微 環 境 編 碼

Example (舉 例)

Time 時 間	Microenvironment code 微 環 境 編 碼	Time 時 間	Microenvironment code 微 環 境 編 碼
23:00-09:00	02*	09:30-12:00	30*

*Please check and fill in the code of microenvironment in Table-1

(請 參 閱 表-1 中 微 環 境 編 碼 填 寫)

Time budgets of weekends 周 末 時 間 安 排			
Time 時 間	Microenvironment code 微 環 境 編 碼	Time 時 間	Microenvironment code 微 環 境 編 碼

Example / 舉 例

Time 時 間	Microenvironment code 微 環 境 編 碼	Time 時 間	Microenvironment code 微 環 境 編 碼
23:00-09:00	02*	09:30-12:00	30*
09:00-09:30	13*	12:00-13:00	40*

*Please check and fill in the code of microenvironment in Table-1

(請 參 閱 表-1 中 微 環 境 編 碼 填 寫)

Table-1 Codes for Microenvironments of the Questionnaire 表-1 微 環 境 編 碼	
Home (家 宅)	
00	Respondents yard/Driveway/General/Outdoor / 宅 院
01	Bathroom / Toilet (washing, shower, etc.) / 衛 生 間 或 浴 室
02	Bedroom (sleep, getting ready, etc.) / 臥 室
03	Dining room (eating) / 餐 廳
04	Study room / 書 房
05	Family room/Front room/Living room / 客 廳 或 起 居 室
06	Garage / 車 庫
07	Kitchen (eating, cooking, etc.) / 廚 房
08	Others / 其 他
Transit (交 通)	
10	Mass Transit Railway ((MTR) / LRT / 地 鐵 或 輕 鐵
11	Private car/Taxi / 的 士 或 私 家 車
12	Truck/Van / 貨 車
13	Bus / 公 共 汽 車
14	Minibus / 小 型 公 共 汽 車
15	KCRC Train / 九 廣 鐵 路 列 車
16	Tram / 電 車
17	Ferry / 小 輪

18	Walking, Hiking, Jogging, etc./ 步 行 或 慢 跑
19	Biking / Motorcycle / 單 車 或 電 單 車
20	Others / 其 他
Public Places (公 眾 地 方)	
30	Office building / 辦 公 大 樓
31	Industrial Plant/Factory / 工 廠
32	Hospital / 醫 院
33	School / 學 校
34	Construction site / 地 盤
35	Hotel / 旅 館 或 酒 店
36	Shopping Center/Store/Beauty Parlors, etc. / 購 物 中 心 或 商 場
37	Cinema/Theater / 電 影 院 或 戲 院
38	Church / 教 堂
39	Park/Garage/Gas Station / 停 車 場 、 車 庫 、 加 油 站
40	Restaurant/ Canteen/Fast food place / 餐 廳 或 快 餐 店
41	Bar/Pub/Night club/Karaokey etc./ 酒 吧 、 夜 總 會 、 卡 拉 OK
42	Banks/Library, etc / 銀 行 、 圖 書 館
43	Others / 其 他

Publications originated from this study

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