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DEVELOPMENT OF PRICE INDEX MODELS FOR ARCHITECTURAL AND ENVIRONMENTAL QUALITY FOR RESIDENTIAL DEVELOPMENTS IN HONG KONG

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Ph.D

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Development of Price Index Models for Architectural and Environmental Quality for Residential Developments in Hong Kong

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A thesis submitted in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

August 2012

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ABSTRACT

Abstract of thesis entitled:	Development of Price Index Models of Architectural and Environmental Quality in Residential Developments for Hong Kong
Submitted by:	Fung Yee Wa
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Residential property prices in Hong Kong are affected by property-specific characteristics. However, despite Hong Kong people spend a large amount of their incomes on housing, they have not been given the information to enable an objective and continuous evaluation of the property-specific quality of a residential unit and the price for that.

Architectural and environmental attributes are the two major categories of property-specific characteristics. Amongst the two categories, architectural attributes including floor area, building form, floor level, window area, orientation, etc. can easily be measured. But this is not the case for environmental attributes which include indoor air quality, acoustic environment, quality of view, daylight performance, and natural ventilation performance. The reason is that there is no

suitable tool for homebuyers to assess their performance. This thesis presents the use of field measurements, site visits, computer simulations and statistical analysis for the development of simple indicators for easy and yet scientific quantification of the environmental performance of residential units. Based upon the simple indicators, and by the use of the hedonic price approach, the influences of architectural and environmental attributes on the residential properties market price are identified.

A series of noise level and PM_{10} concentration measurements were conducted at roadsides of two busy roads in Hong Kong and at ten carefully selected residential units located nearby. Regression analysis on the measurement results indicated that both the traffic-induced noise and the PM_{10} concentrations at the units studied exhibited a linear correlation with the logarithm of their corresponding distance from road (log R). The result concluded that “log R” could be adopted as a performance indicator for evaluating the combined impact of road traffic on the noise and air quality of a residential unit.

In developing a simple indicator for assessing daylight performance and view obstruction, simulations for generations of mean shading mask values ($\overline{SMK}$); site visits for ascertaining actual view obstructions; and calculations of the average angle of unobstructed sky ($\bar{\theta}$) were conducted for a large number of residential units. Through correlation analysis between $\overline{SMK}$ and $\bar{\theta}$ of 708 residential units, the use of $\bar{\theta}$ as a simple indicator for assessing daylight performance and view obstruction of residential units was confirmed.

The influence of different parameters on natural ventilation performance of a hypothetical living room was evaluated. The hypothetical living room was formulated based on an extensive survey of characteristics of living rooms in a representative estate in Hong Kong. The evaluation took into account the living room area, window type, window area, window orientation, and ventilation mode. A total of 224 CFD simulation cases were conducted and the corresponding mean age of air (MAA) values were determined. Through regression analysis, it was found that MAA was most affected by the ventilation mode adopted (VENT) and thus it was selected as the performance indicator for natural ventilation performance.

The last part of study focused on the development of the price index models for identifying the willingness-to-pay (WTP) for better architectural and environmental attributes of residential units. The five attribute characteristics, i.e. LogR, $\bar{\theta}$, VENT, floor area (FLA) and living room window orientation (ORI) were adopted for a price analysis by hedonic price approach. Based upon the 2005 transaction records, the price index models for two residential estates of different homebuyer groups were developed.

Three performance indicators (LogR, $\bar{\theta}$, and VENT) are developed in this study. They enable an objective and continuous evaluation of the environmental quality of a residential unit. Moreover, the WTP information will encourage building developers constructing for better environmental quality; and help homebuyers making home purchase decisions.

PUBLICATIONS

Journal papers based on the research project:

Fung Y.W., Lee W.L., 2011. *Identifying a common parameter for assessing the impact of traffic-induced noise and air pollutions on residential premises in Hong Kong*. Habitat International, **35**, 231-237.

Fung Y.W., Lee W.L., 2012. *Developing a simplified parameter for assessing view obstruction in high-rise high-density urban environment. Habitat International*, **36**, 414-422.

Conference paper

Fung Y.W., Lee W.L., 2008. *Assessing traffic-induced noise in residential environments in Hong Kong*. Indoor Air 2008 Proceedings, 16.

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LIST OF SYMBOLS, NOTATION AND ABBREVIATIONS

%	Percentage
α_1 - α_5	Coefficient
β	Constant
θ	Angle of unobstructed sky, radian
θ_{40}	Angle of unobstructed sky measured -50 ° from the centre of the window, radian
θ_{90}	Angle of unobstructed sky perpendicular to the window, radian
θ_{140}	Angle of unobstructed sky measured +50 ° from the centre of the window, radian
$\bar{\theta}$	Average angle of unobstructed sky, radian
Σ	Summation
^{o}	Degree
^{o}C	Degree Celsius
<	Less than
>	Greater than
3D	Three dimensions
a_0	Constant
a_n	Marginal willingness-to-pay for each X_n

a'_0	Constant
a'_1 -a'_7	Elasticity between the independent variable and market price of a residential unit
A_{ij}	Unshaded area of the jth surface for solar position i, m^2
A_{oj}	Total area of the jth surface, m^2
ACH	Air-change per hour
API	Air pollution index
AREA	Living room area, m^2
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEAM	Building Environmental Assessment Method
BRE	Building Research Establishment
BREEAM	BRE Environmental Assessment Method
c_n	Site-specific constants
C_0	Initial contaminant concentration at the sample point
$C_i(t)$	Contaminant concentration at the sample point as a function of time
CCI	Centa-City Index
CEDD	Civil Engineering and Development Department
CFD	Computational fluid dynamics
CIE	The International Commission on Illumination
CO	Carbon monoxide
CO_2	Carbon dioxide
COS	City One Shatin
CRTN	Calculation of Road Traffic Noise

CV	Contingent valuation
dB	Decibels
dB(A)	A-weighted decibels
e	Desired level of precision.
E	East
EPD	Environmental Protection Department
EU	European Union
f	Function
F	Floor level
FLA	Floor area of the residential unit, ft^2
ft^2	Square feet
GFA	Gross floor area
GIS	Geographic Information Systems
H	Height
HK	Hong Kong
HK$	Hong Kong dollar
HK-BEAM	Hong Kong Building Environmental Assessment Method
hr	Hour
IAQ	Indoor air quality
IEQ	Indoor environmental quality
ISO	International Organization for Standardization
k_n	Site-specific constants
$k-\varepsilon$	Standard k-epsilon model
L	Length

L_{10}(1-hr)	Sound pressure level exceeded for 10% of an hour
L_{10}(30mins)	Sound pressure level exceeded for 10% of 30mins
L_p	Sound pressure level of receiver, dB
L_w	Sound power level of source, dB
Log R	Logarithm of the distance from road
m	Meter
m^2	Squared meter
m^3	Cubic meter
m/s	Meter per second
mg	Mini gram
mm	Mini meter
MAA	Mean age of air, sec
MAA_i	Mean age of air at the sampling point, sec
MAA_{max}	Maximum mean age of air, sec
MAA_{min}	Minimum mean age of air, sec
$\overline{MAA}$	Average mean age of air, sec
MFSC	Mei Foo Sun Chuen
mins	Minutes
n	Corrected sample size
n_0	Sample size
N	North
NE	Northeast
NO_x	Nitrogen oxide
NSDI	Noise sensitivity depreciation index

Num	Population size
NW	Northwest
OLS	Ordinary Least Squares
ORI	Window orientation
ORI_E	Living room window orientation - East
ORI_N	Living room window orientation - North
ORI_S	Living room window orientation - South
$\overline{ORI}$	Mean WTP of window orientation, %
p	Estimated proportion of an attribute that is present in the population
PM_{10}	Particulate matter smaller than 10 micron, mg/m^3
$\overline{PM_{10}}$	Average PM_{10} concentration, mg/m^3
PNAP	Practice note to authorized persons
ppm	Parts per million
PRI	Selling price of a residential unit, HK$/$ft^2$
Q	Directivity of sound source
R	Distance from source, m
R^2	Coefficient of determination
RA	Royal Ascot
RNG	Renormalization group
RSPs	Respirable suspended particulates
S	South
SARS	Severe acute respiratory syndrome
SC	Site coverage

SE	Southeast
sec	Second
SIMPLE	Semi-Implicit Method for Pressure-Linked Equations
$\overline{\mathrm{SMK}}$	Mean shading mask
$\mathrm{SMK}_{\mathrm{AVj}}$	Mean shading mask of the j^{th} surface
$\mathrm{SMK}_{\mathrm{ij}}$	Shading mask of the j^{th} surface for solar position i
SW	Southwest
T	Time period, mins
UK	United Kingdom
US	United States
USEPA	United States Environmental Protection Agency
UVA	Unobstructed vision area
VENT	Ventilation mode
W	West
WINT	Window type
WTP	Willingness to pay, %
WWR	Window to wall ratio
X_n	Attributes of a residential unit
Z	Test statistic

CHAPTER 1 INTRODUCTION

1.1 Background

Hong Kong is a very small city with a total area of 1104 square kilometres. The population density is amongst the highest in the world with an average population density of about 6300 persons per square kilometre, which is much higher than other cosmopolitan cities such as Singapore (about 6100 persons per square kilometre), Tokyo (about 5400 persons per square kilometre) and London (about 4500 persons per square kilometre).

The high and growing population density is a consequence of the influx of immigrants from the Mainland China. Adding to that is a continuous reduction in the average household size from 3.4 members in 1991 to 2.9 members in 2011. As a result, the number of domestic households in the last 15 years increased from 1.58 to over 2.37 million [CSD, 2011]. This led to a sustained high demand of residential housing in Hong Kong. The Hong Kong SAR Government therefore accords a high priority to providing adequate residential housing to Hong Kong citizens.

In Hong Kong, there are two major residential building developers: the Government and private developers. Building developments are correspondingly known as public or private housing. According to statistics released by the Census and Statistics

Department of Hong Kong in 2011 [CSD, 2011], almost 50% of the Hong Kong people reside in public housing estates. They are mostly the lower income group, with rent and sale price heavily subsidized by the Government. The properties are therefore not tradable in the open market. Due to the economies of scale of mass development, the site layout and building design of public housing tend to be uniform in appearance. Private housing, on the contrary have site layouts and building designs which vary largely by developers and locations. They include a wide range of dwellings, but are typically high-rise residential buildings. Prices vary considerably with the quality of the property. As they are privately owned, sale and purchase of properties are very active in the open market.

Motivated by the accelerating net immigration, the increase in smaller size households and the favourable economic influences, the residential property price is very high compared to other developed cities in the world. According to the global house-price indicators published in “The Economist” in 2011, Hong Kong tops the world in residential property prices. In addition, the results of the 2009/10 household expenditure survey showed that the expenditure weight on housing was the highest amongst other expenses, accounting for over 32% of the total household expenditure. This is particularly prominent for people residing in private housing, where the expenditure weight has been over 35% [CSD, 2011].

It can be seen that Hong Kong people have to spend a large amount of their income on housing. A deep and careful consideration must be taken before making a flat buying decision. Unfortunately, very limited and diverse information is available in the public domain, especially for private housing developed by different developers.

People usually make reference to actual transaction records published officially by the Government in making such a decision.

However, it is noted that there are occasions when the economic influence is small, residential properties' price still vary largely from each other. This is believed to be attributed to site-specific and property-specific factors. Site-specific factors include the building locations and the availability of neighboring amenities. Property-specific factors can be classified into two major types: architectural and environmental. Architectural attributes include the floor area, floor layout, floor level, window area, orientation, etc., which can easily be measured as opposed to environmental attributes. Environmental attributes include indoor air quality, quality of view, and other health and safety issues such as natural ventilation, acoustic performance, and daylight performance. They are affected by the interactive influence between indoor and outdoor environments, and thus the quality of environmental attributes vary largely within the same residential estate. It is nonetheless noted that for the same residential estate where site-specific conditions are more or less identical, there are still large variations in property price. This is therefore attributed to the property-specific factors.

In respect of property-specific factors, i.e. both architectural and environmental attributes, little has been stipulated in local codes and regulations (reviewed in section 1.2); site planners and architects are allowed to design internal space the way they deem proper. Thus, property-specific characteristics of residential units differ largely from each other to affect the property price.

Hong Kong people spend more than 85% of time indoors of which 58% of time are at home [Chau et al., 2002]. Considering also the amount of expenses they spent in getting a home, the property-specific characteristics are considered critically important. Accordingly, the influence of architectural and environmental attributes on property price is of particular importance to homebuyers in Hong Kong. While architectural attributes can easily be measured, a question in mind is how to rate the environmental qualities of a residential unit.

1.2 Local Codes and Regulations

A review of the ordinances and guidelines issued by the Government in governing the design of residential buildings in Hong Kong indicates that the requirements can also be classified into two major aspects: architectural and environmental.

1.2.1 Architectural requirements

Architectural requirements are mainly on the basic facilities needed to be provided in residential buildings. In the Building Ordinance (Cap. 123) together with its subsidiary legislations, namely Building (Planning) Regulations, and Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations, the basic facilities, as specified in the related regulations, are summarized as follows:

- Kitchen accommodation should be provided for all residential units, unless exempted by the Building Authority. The internal surface of at least 1.2m from floor level should be faced with tiles, or rendered in cement mortar, not less than 12.5mm in thickness, or other non-absorbent material. Sink and fittings for the supply of water should be provided. Also, fireplace or cooking slab, unless the cooking is to be done by gas, oil or electricity should be constructed properly.

- Every latrine, except a latrine fitted with a chemical closet fitment, should be provided a self-closing door to the full height of the opening. The floor of latrine should be at least 150mm above the level of the ground outside the latrine and non-absorbent material with a smooth surface finishing should be constructed. The internal surface of at least 1.2m from floor level should be faced with tiles, or rendered in cement mortar, not less than 12.5mm in thickness, or other non-absorbent material.

- At least one watercloset fitment, one lavatory basin and one bath or shower should be provided for the domestic building residing less than eight persons. Two or one additional watercloset fitment(s), two or one additional lavatory basin(s) and two or one additional bath(s) or shower(s) should be provided for every 15 such persons, or part thereof, over 20.

- Floor to ceiling height should have at least 2.5m in every habitable room.

In Hong Kong, there is no regulation to govern the occupancy density of individual residential unit. There is only a general rule to suggest 5m^2 usable floor area per person in assessing the likely number of occupants [PBEC, 2007]. The above requirements therefore can only satisfy the basic needs of the occupants, and are not targeted to improve the quality of living of Hong Kong people.

1.2.2 Environmental requirements

As mentioned, little has been stipulated in the Hong Kong Ordinance to enhance the environmental quality of residential buildings. In the Building Ordinance (Cap. 123); only basic provisions required to ensure adequate natural lighting for normal daily activities and fresh air supply for human consumption are specified. They are summarized below:

- One or more windows should be constructed in every habitable room or a kitchen. The aggregate superficial area of glass in the window(s) should not be less than one-tenth of floor area of the room. The area of extendable window(s) should be at least one-sixteenth of floor area of the room. The window head should be at least 2m above the floor.

- Every latrine should be provided with an opening for natural lighting and ventilation. Such opening should (i) be not less than 0.2m^2; (ii) be situated as near the ceiling of the latrine as practicable; (iii) communicate directly with the open air; and (iv) be covered with a metal of other approved mesh fly screen.

Besides the basic provisions required for individual residential unit, the Hong Kong Planning Standards and Guidelines [HKPSG, 2011] also set requirements on the layout of residential estates for minimizing air quality and traffic noise problems.

- The separation distance between high-rise residential estates and low-rise chimneys or industrial buildings should be over 200m, to avoid serious air pollution through direct impingement by the chimney plume onto the taller buildings.

- A buffer distance of at least 100m between residential buildings and the industrial sites should be required.

- In order to avoid siting residential estate close to routes and road with heavy traffic and railways, the maximum permissible noise levels at the external façade should be 70dB(A) for road traffic noise and 65dB(A) for rail traffic noise.

Apart from the statutory requirements for ensuring adequate natural lighting and ventilation, and minimizing air quality and traffic noise problems, there is a Building (Energy Efficiency) Regulation under the Building Ordinance [CAP. 123 sub. leg. M] to govern the maximum thermal transfer permissible into the building through its building envelope to enable efficient use of energy for achieving thermal comfort. However, this regulatory requirement refers only to new commercial and hotel buildings. At present, no ordinance governs the envelope design of residential buildings in Hong Kong.

Other than statutory requirements, there are also voluntary instruments launched by the Government to enhance the environmental quality of residential buildings from unit level to estate level. Examples include the Environmental Report presented by the Government in 1999 to encourage upgrading of the built environment for new and existing buildings; and a Practice Note to Authorized Persons and Registered Structural Engineers [PNAP APP-130] to promote the use of a performance-based standard for evaluating the natural lighting and ventilation performance of residential buildings.

The above statutory and voluntary rinstruments were developed mostly between the 1950s' and 1990s', and thus they are considered archaic and disjointed with today's style of living and building technology. In 2000, the Building Department set up a Building Innovation Unit to encourage the incorporation of green features in new building designs. In collaboration with the Lands Department and the Planning Department, two Joint Practice Notes [JPN1, 2001 & JPN2, 2002] were issued in 2001 and 2002. In there, a list of green features that can be exempted from Gross Floor Area (GFA) and Site Coverage (SC) calculations is given as an incentive to encourage developers' adoption. Some of them, which can improve the environmental quality of residential units, are summarized below:

- A balcony located at living room, dining room and bedroom.

- A utility platform.

- Acoustic fins, sunshades, reflectors and wing walls, which do not project more than 1.5m from the external wall.

- Noise barriers installed for noise sensitive buildings.

It can be seen that the above green features are given without stating their intent. The presence of such features may not necessarily mean that certain environmental performance target will be achieved. As a result, the residential units would still differ largely in their environmental qualities.

1.3 Voluntary Instruments

In the absence of codes and regulations to enhance and rate the environmental qualities of residential units in Hong Kong, reference is made to market-driven voluntary approaches which have been used since the early 1990s to deal with building environmental problems. For building-related instruments, building environmental assessment schemes are most often used. Under such schemes, a building is assessed against a set of quantitative and qualitative performance criteria, and is awarded credits (or points or numeric scores) when the building is deemed to have met the specified criteria. The awarded credits will be transformed into an overall grade to reflect the environmental performance of a building. Most assessment schemes now cover comprehensively different aspects relevant to environmental performance of buildings and embrace a wide range of building premises, such as homes, hotels, offices, industrial premises, retail outlets, schools, etc.

The first building environmental assessment method, BREEAM, launched and operated by the Building Research Establishment (BRE) in UK, came into prominence in 1990. Inspired by BREEAM, the Hong Kong Building Environmental Assessment Method (HK-BEAM) was first launched in December 1996. The original HK-BEAM scheme comprised two versions, one for new (HK-BEAM 1/96) and the other for existing office buildings (HK-BEAM 2/96). It covered a wide range of issues related to impacts of buildings on the environment in terms of global, local and indoor scales. The most current HK-BEAM (renamed as BEAM Plus) documents were released in 2010 (Versions 1.1 for new buildings and existing buildings). On a per capita basis, HK-BEAM has assessed more buildings and more square meters of space than any other scheme in use around the world [Chan, 2005].

One of the key issues considered in HK-BEAM is environmental performance which includes all aspects of building design, installation, finishes and operation affecting the health, comfort and well-being of the occupants. However, similar to other building environmental assessment schemes, HK-BEAM is established for assessing the environmental performance of a building as a whole, and thus cannot be used to rate the environmental quality of individual residential unit.

1.4 Research Objectives

Economic theory suggests that individuals seek to maximize utility. Understanding that price of a residential unit is affected by property-specific factors; homebuyers will prefer to be provided with the information to enable an objective and continuous evaluation of the environmental quality of a residential unit and the price for that.

The review of local codes and standards indicate that little has been stipulated to govern proper design of residential buildings in achieving good environmental quality. Despite the availability of building environmental assessment schemes for assessing the environmental quality of a building as a whole, a tool to enable an objective and continuous evaluation of the environmental quality of a residential unit is lacking. The objectives of this study are therefore:

1. To review the environmental attributes that affect the price of a residential unit;

2. To establish methods for rating the environmental quality of individual residential unit; and

3. To establish the price for different environmental attributes for the information of homebuyers.

1.5 Structure of the Thesis

This thesis comprises eight chapters. Chapter 1 gives an introduction on the background of Hong Kong residential sector, regulatory and voluntary instruments governing the design of residential buildings, and scope and objectives of this research study.

Chapter 2 reviews relevant literature and research work on residential properties price and methods for evaluating the environmental quality. The research gap is identified.

Chapter 3 illustrates the methodology adopted for this study. The reasons of adopting different methods were discussed. The criteria for choosing the case study residential estates and the transaction records adopted were explained.

Chapter 4 presents the development of a performance indicator for assessing the traffic-induced noise and air pollution on residential premises in Hong Kong.

Chapter 5 presents the formulation of a performance indicator for assessing view obstruction and daylight availability in residential units in Hong Kong.

Chapter 6 summarizes the use of computational fluid dynamics simulations and regression analysis for identifying the most influential parameter affecting natural ventilation performance in residential premises in Hong Kong.

In Chapter 7, the influence of various property-specific factors on residential units' market price was evaluated by the hedonic price approach. The results are given and discussed.

Chapter 8 provides the conclusions of this study and recommendations for future study.

CHPATER 2 LITERATURE REVIEW

2.1 Factors affecting the residential properties price

The financial tsunami which happened in 2008 was triggered by the downturn of the residential property market in the United States. This indicates that the residential property market and the economic conditions are closely linked. Many research studies therefore focused on evaluating the economic influence on the residential property market.

Harris [1989]; Krashinsky and Milne [1987] and Tse [1996] found that inflationary expectations played a significant role in property price increases. Leung [2003] found that even when population growth was zero, there was still a positive growth in property prices.

Other than economic influence, there are also studies examining the impacts of government policies on the residential property market. Sagalyn and Sternlieb [1973] conducted a regression study to conclude that city zoning increased property prices. Seidel [1978] pointed out that the widespread adoption of local ordinances restricting the rate and form of development caused an increase in property prices. Bramley [1993] focused on evaluating the impact of tax subsidies and land use planning on the supply and price of residential units in Britain. He developed a model to reflect the effects of planning policies on the supply elasticity. Hannah et al. [1993] adopted a fire development project in Korea as a case study to conclude that the government's tendency to reduce land supply for residential use resulted in a substantial rise in property prices.

It can be seen that economic and government policies affect the residential property market as a whole, but not individual residential property's market price. There are studies indicating that a residential property's market price can be affected by combinations of site-specific and property-specific factors. Site-specific factors, generally speaking, comprise the site locations and availability of neighboring amenities, while property-specific factors consist of architectural and environmental attributes. Architectural attributes consist of floor area, building form, floor level, window area, orientation, etc., and environmental attributes consist of the indoor air quality, acoustic environment, quality of view, daylight performance, natural ventilation performance, etc. Below is a comprehensive review of the relevant research works.

2.1.1 Site-specific factors

Amongst site-specific factors, site location is composed of the physical characteristics of the landscape specific to the area which differs largely between residential estates and thus cannot be directly compared. The focus is therefore be given to the availability of neighboring amenities despite the fact that both factors are beyond the control of building designers and architects.

The availability of neighboring amenities brings positive effects to the residential properties prices. Mok et al. [1995] stated that the valuation of the properties was favored by big residential estates and the existence of sport and entertainment facilities. Tse and Love [2000] concluded that the property price could be raised by the availability of car park, shopping centre and club house. Hui et al. [2007] found that the availability of a private clubhouse within an estate increased the sale value of an apartment by about 3.5%. These explain why these few years, nearly all new residential estates are provided with a comprehensive club house and developers often use those as one of the key selling points.

Moreover, Jud and Watt [1981] identified that districts with reputable schools were having higher property value comparing with other districts. Hui et al. [2007] further identified that each additional reputable secondary school located in the proximity of the property would lead to an average of 0.1% increase in house price. Mok et al. [1995] pointed out that houses with good security provisions were more valuable.

2.1.2 Property-specific factors

2.1.2.1 Architectural attributes

Architectural attributes include floor area, floor layout, floor level, window area, orientation, etc. With regard to the influence of floor area on property price for a high-density city like Hong Kong, Tse and Love's study [2000] revealed that floor area would have a positive influence on property price. However, the valuation of larger units did not increase proportionally with its area in medium quality residential housing because the demand for small units was relatively higher than large units as homebuyers could not afford the higher property price. Jim and Chen [2006] identified that a residential unit with more bathrooms contributed positively to the price of the property.

The study by Mok, et al. [1995] illustrated that the valuation of a property was most sensitive to changes in the age of the building and the floor level. They found that the valuation of a property was inversely related to the age of the building and higher floor level introduced a positive effect on the property price. Hui et al. [2007] conducted a similar research with focus on the age of building and floor level. For the age of building, it was found that a younger flat would have higher sale price than an older one with other attributes identical. On average, it was observed that there was 1.6% price increase if the flat was a year younger. While for the floor level, it was found that there was a 0.3% decrease in price for each level down. This is somewhat consistent with the pricing strategy of the building developer as revealed from the sale price of the first hand residential properties markets.

Traditionally, Hong Kong people favor a flat with south facing windows for receiving south prevailing wind and smaller solar heat gain in summer. But with the growing preference to residential flats with better view; large and convex-shaped windows have become very popular, and good orientation is often sacrificed. This façade design gives an adverse impact on the thermal performance. Wan [2003] conducted energy simulations to estimate the annual cooling load reduction due to changes in the building design features. The result showed that the most effective means to reduce the annual cooling load in the building would be the use of window glazing of a lower shading coefficient, and the addition of thermal insulation to the external walls. The reduction of the window to wall ratio was also recommended as an effective measure.

In respect of the influence of thermal performance on the energy use, there are research studies on the willingness to pay (WTP) for energy-saving attributes in dwellings. Jim and Chen [2006] used window orientation as an attribute to represent human comfort and air-conditioning energy consumption, with repercussions on housing price. The findings indicated that desirable window orientation contributed 1% to the house price in Guangzhou. Banfi et al. [2005] evaluated the consumers' WTP for energy-saving measures in Switzerland's residential buildings. The WTP for an enhanced insulated façade and insulated windows in old buildings were 3% and 13% respectively. They concluded that the WTP for an attribute was generally higher than the implementation cost for the attribute and it would be economically viable for owner and housing promoters to invest in energy-saving measures.

In the same residential estate, thermal insulation to external walls of building and age of building are identical. The remaining architectural attributes, including floor area, floor level, orientation and window-to-wall ratio are therefore the major parameters influencing the residential properties' market price.

2.1.2.2 Environmental attributes

1. Indoor air quality

Much literature has reviewed the effects of air quality on property prices. There are many sources of indoor air pollution in residential buildings. Some volatile and particulate pollutants are emitted from the occupants themselves, others are originated from sources such as smoking, cooking, gaseous and particulate compounds from building materials and decorations, etc. In respect of the external influence, polluted outdoor air can come from transport systems, industrial activity, power generation, waste disposal dumps, etc. While major source is always with transport systems, traffic-induced pollution is always of key concern.

The United States Environmental Protection Agency (USEPA) ranked indoor air quality (IAQ) one of the top five environmental risks to public health [USEPA, 1994]. Many experts consider that IAQ is the most important IEQ parameter, but is often overlooked in our daily life [Gao, 2002]. Poor IAQ causes a variety of unspecific symptoms, such as irritation or dryness of mucous membranes, burning eyes, headache, or fatigue. Moreover, there is conclusive evidence that some air pollutants, such as formaldehyde vapour and radon, are animal carcinogens [Jones, 1999]. Therefore, many research works were targeted towards finding its influence on property price.

The earliest work was carried out by Ridker and Henning [1967] to study the relationship between air quality and the house price in the St. Louis metropolitan area. They concluded that air pollution variable was a relatively significant variable in explaining residential property values. Harrison and Rubinfeld [1978] later estimated the marginal value of clean air from house prices in the Boston metropolitan area. It was found that the value of clean air was positive, and the effect was positively related to household income. With regard to the effect of indoor particulate levels on property prices, Diamond [1980] and Li and Brown [1980] also found a significantly negative effect.

Chattopadhyay [1999] pointed out that residents in Chicago were willing to pay more for reducing the exposure to the pollution of air particulate (PM_{10}) and sulphur dioxide. A regression diagnostics done by Kim et al. [2003] also showed that the spatial-lag model specification was valid for the housing market in Seoul. The marginal willingness-to-pay (WTP) for a 4% air quality improvement was about 1.43% of the mean house value. To conclude, people prefer a place with better IAQ despite the higher cost.

2. Acoustic environment

The acoustic environment of an indoor space is often associated with traffic noise. Traffic-induced noise is one of the major environmental concerns in most cities. Traffic noise measurements and the associated problems are therefore extensively done [Cannelli, 1974; Elshorbagy, 1984; Garcia and Garrigues, 1998; Ali and Tamura, 2003; Kryter, 1985]. It was generally pointed out that excessive exposure to intense noise environment would damage human hearing and continued exposure to moderate noise daily life became a source of physiological stress which would cause health disorders.

As a result, traffic noise has commonly been regarded as a negative externality to reflect the inevitable sufferance. The higher the traffic noise level; the lower will be the property value. Nelson [1982] carried out a hedonic price study on the impact of traffic noise. The result was represented by a noise sensitivity depreciation index (NSDI). The index relates the percentage depreciation in property price with each decibel (dB(A)) of noise above a threshold level. It was found that a house with a background noise level of 75dB(A) was valued 8% less than a house with a noise level of 55dB(A), and thus the corresponding NSDI was 0.4%. Wilhelmsson [2000] conducted a detailed study on the relationship between traffic noise and the value of single-family houses in Sweden. His empirical analysis found an average drop of 0.6% in property price for each increase in dB(A) or a total discount of 30% in price for a house in a noisy location compared to with a house in a quiet zone.

3. Daylight performance

Daylight is one important environmental attributes that is critical to occupant comfort and health. The use of daylight can reduce the energy use for lighting. Daylight is considered the best light source for living environment because it matches closely with human visual response and is the one with the best colour rendering performance. Li et al. [2006] reviewed that the amount of daylight penetrating a building was mainly through window openings which provided a dual function not only for admitting light for indoor environment with a more attractive and pleasing atmosphere, but also allowing people to maintain visual contact with the outside world. It was concluded that people desired good natural lighting in their living environments.

Levermore and Meyers [1996] conducted a survey aimed at quantifying occupants' perceptions of their interior environments. The questionnaire revealed that daylight was one of the important issues. Ossama [1997] carried out another survey to find out the relation between the indoor environment and worker productivity. He concluded that daylight was an important factor contributing to the enhancement of workers' productivity. Workers appreciated to work under the presence of daylight which made them feel more comfortable. It is therefore evident that daylight performance affect residential properties' price.

4. The quality of view

Nobody will argue that the view that can be seen from a residential unit is one very important factor that affects the price of the residential unit. Previous studies concluded that a good view was one of the main externalities. Homebuyers were willing to pay an extra 8% to 60% in property price for a good view [Brown and Pollakowski, 1977; Rodriguez and Sirmans, 1994; Benson et al. 1998; Tse and Love, 2000]. Benson et al. [1998] found that the extent of influence depended on types and quality of views. It was found that the value of a view varied inversely with distance from the waterfront. Tse and Love [2000] found that a cemetery view lowered the property price.

View quality is normally described by the specific view supplemented by the extent of obstruction. Daylight and view obstruction are closely linked with one another. It is noted that most building environmental assessment schemes in use nowadays combine views and overshadowing performance as one assessment criterion to assess impact of neigbouring buildings in respect of access to daylight and view obstruction. According to BEAM Plus New Buildings Version 1.1 [BEAM Society, 2010], the availability of daylight for a specific room is determined mostly by the external factors like sky obstruction due to the form of the building and its overshadowing from neighbouring buildings. A lot of lawsuits also combine obstruction of view and daylight by neigbouring obstacles as one compliant [REC, 1995; CPC, 2010]. Hence, view obstruction which is generally considered as a neighbouring attribute is also an environmental attribute, and depending on the extent of view obstruction, has substantial impact on the property value [Benson et al. 1998].

5. Natural ventilation performance

According to the survey conducted by Friends of the Earth (HK), about 85% of respondents open windows at home while the air conditioning is not in use. Natural ventilation performance is therefore important to most residents. With the problems of energy shortages and sick building syndrome associated with the excessive usage of air-conditioning, increasing availability of natural ventilation in dwellings helps to reduce residents' reliance on air-conditioners and creates a thermally comfortable environment under moderate outdoor conditions. As a result, natural ventilation contribute to reduction of energy use for air conditioning [Song et al., 2002]. Hirano et al. [2006] had studied the effects of natural ventilation performance on the cooling load reduction in hot and humid regions. Though CFD analysis and airflow network analysis, it was found that better natural ventilation performance could significantly reduce the latent and the total cooling load of two building models. Wang and Wong [2007] studied the indoor thermal environment of four ventilation strategies: nighttime-only ventilation, daytime-only ventilation, full-day ventilation and no ventilation. Their result indicated that full-day ventilation was the most preferred strategy because of the shortest thermal discomfort period for a studied year.

Besides energy use and thermal comfort, natural ventilation also affects IAQ. Chao et.al. [1997] studied the influence of different ventilation rates on indoor radon levels at 12 residential sites in Hong Kong. It was reported that the ratio of indoor to outdoor radon level was 46.5 when the ventilation rate was around 0.2 air-change per hour (ACH). However, when the ventilation rate was increased to higher than 3 ACH, the indoor radon level was close to the outdoor radon level. Murakami et al. [2004] studied two residential building models with and without voids in buildings. The result indicated that the model with voids improved natural cross ventilation effectively and thus saved 2.8% energy use for air-conditioning comparing with the model without natural ventilation. Given the positive contribution of natural ventilation to thermal comfort, energy use and IAQ, it is no doubt that better natural ventilation performance has an impact on the property value.

2.2 Methods to valuating the environmental quality

It is evident from the above that property prices are directly or indirectly related to site-specific and property-specific factors. However, unlike the market for tangible goods, valuing environmental quality is often difficult because they are non-market goods. Moreover, residential housing is a differentiated product whereby there are obvious differences between units of the product, yet the various units are traded in a single market. Since each unit differs, there will not be a single, uniform price in the market even if the market is competitive. The price for which a house sells will depend on consumers' preferences for the characteristics that house embodies.

Reference is made to previous research works which mostly adopt the contingent valuation survey method, travel costs method, and hedonic price approach for valuating environmental quality.

2.2.1 Contingent valuation method

Contingent valuation (CV) method is commonly used to estimate values of certain aspects of environmental quality. This method has great flexibility, allowing to estimate both use and non-use values. The basic principle of CV is directly asking individual consumers, in a survey, to indicate their WTP for a change of specific environmental services as if a market for that environmental quality existed. In some cases, people are asked how much they will be willing to accept for compensation to give up specific environmental services. A hypothetical market scenario is described to each respondent and his or her professed behaviour under that scenario is recorded.

The greatest strength and greatest weakness of contingent valuation is that it is based on what people say they will do rather than what people are observed to do. The conceptual, empirical, and practical problems associated with developing dollar estimates of economic value on the basis of how people respond to hypothetical questions about hypothetical market situations are debated constantly. Meanwhile, many economists, psychologists and sociologists, for many different reasons, do not believe the dollar estimates of the results from CV are valid. More importantly, many policy-makers do not accept the results of CV. It is because the surveys present biases as respondents may have an incentive to either over-or under-report their true WTP, depending on how the questions are worded. Furthermore, the respondents must be extremely cautious about spending money on studies and about using the results of studies [Wood et al. 1995].

2.2.2 Travel cost models

Recreational benefits are often considered as one environmental good. Their valuation is normally achieved by the use of the travel cost method. This method is based on the simple and well-founded assumption that travel costs reflect recreational value. Surveys will be carried out to collect data on the costs to different visitors for visiting a particular site, including the time and travel cost expenses that visitors incur to visit a site. Based on the number of trips that people make at different travel costs, the minimum use value of the site to people can be reflected.

This method is relatively inexpensive to apply and onsite surveys can provide opportunities for large sample sizes as visitors tend to be interested in participating. Also, based on actual behavior, what people actually do, which is better than what people say they will do in a hypothetical situation. However, there are many well-known limitations in travel cost studies:

- how to apportion costs within multi-purpose trips which may overestimate the value of the site;
- interviewing visitors on site can introduce sampling biases to the analysis;
- measuring recreational quality, and relating recreational quality to environmental quality can be difficult;
- it cannot be used to measure nonuse values;
- those who value certain sites may choose to live nearby which may underestimate the values of the site;
- defining and measuring the opportunity cost of time and the value of time spent traveling can be problematic;
- those who enjoy the travel itself, then travel time becomes a benefit, not a cost, which also overestimate the site value;

- …etc.

2.2.3 Hedonic price method

Early work by Jack F. Eisenlauer [1968] set the conceptual basis for using multiple regression analysis as an appraisal methodology for analyzing house price and he believed that the use of multiple regression analysis was 'by far the most revolutionary and promising development in appraisal methodology'. After his article, many other researchers have explored the use of multiple regression analysis. Rosen [1974] developed the hedonic pricing model as a valuation technique to estimate the amenity values of housing attributes by real house transaction prices. Accordingly, the residential properties price (PRI) can be represented as a function of the n characteristics it contains, i.e. $PRI = f(X_1, \ldots\ldots, X_n)$.

However, in the use of the of hedonic price approach, the following assumptions must be noted:

- The supply of houses is fixed in the short run and the prices of existing houses are demand determined.

- The price of a house can be decomposed into attributes and, therefore, that implicit prices can be assigned to each house attribute.

- Each household is in equilibrium, not only with respect to housing prices but also in the respect that prices are known in the market for a given stock of houses and attributes.

- The homebuyers know and choose household attributes so that the implicit price of the attribute equals the marginal rate of substitution between the attribute and the composite good.

The equilibrium price data are normally analyzed using regression analysis, which relates the price of the property to its characteristics and the environmental characteristic(s) of interest. Thus, the effects of different characteristics on price can be estimated. The regression results indicate how much property values will change for a small change in each characteristic, holding all other characteristics constant.

Adopting hedonic pricing approach is time consuming as large amounts of data must be gathered and manipulated. The time and expense to carry out depends on the availability and accessibility of data. In addition, this method is relatively complex to implement and interpret, requiring a high degree of statistical expertise as the analysis may be complicated by a number of factors. For instance, the relationship between price and characteristics of the property may not be linear which means prices may increase at an increasing or decreasing rate when characteristics change. And, many of the variables are likely to be correlated, so that their values change in similar ways. This can lead to understating the significance of some variables in the analysis. Thus, different functional forms and model specifications for the analysis must be considered. Kang & Reichert [1987] examined the accuracy and sensitivity of the regression coefficients based on the choice of functional form. Using the data set of 860 observations, they compared liner, log-linear and semi-log models using both Ordinary Least Squares (OLS) and ridge regression techniques. It was concluded that the significance of the regression coefficients and the estimation accuracy were subject to the choice of estimate technique and functional form and that there was no single estimation technique and functional from that reigned superior in every aspect. It was further suggested that in some "respects non-linear models proved to be more effective than linear models and Ridge Regression techniques were generally superior to OLS estimation." Therefore, the choice of form would depend on a user's desire to minimize estimation error or maximize prediction stability.

Nevertheless, the hedonic pricing is the most commonly used method to reveal people's valuations of environmental qualities as there are many advantages over other methods:

- The method's main strength is that it can be used to estimate values based on actual choices.

- Property markets are relatively efficient in responding to information, so can be good indications of value.

- Property records are typically very reliable.

- Data on property sales and characteristics are readily available through many sources, and can be related to other secondary data sources to obtain descriptive variables for the analysis.

- The method is versatile, and can be adapted to consider several possible interactions between market goods and environmental quality.

It is evident from the above that the contingent valuation method is not reliable; and the travel cost model method is only good for valuating site-specific factors. The hedonic price method, done based on reliable source of data, is considered most suitable for evaluating the price for various environmental attributes contributing to the equilibrium price of residential properties in Hong Kong.

2.3 Research gap

It can be seen from the above that properties market price are affected by property-specific factors which include combinations of architectural and environmental attributes. Architectural attributes contributing to residential properties' market price comprise floor area, floor level, orientation and window-to-wall ratio.

As for environmental attributes, literature review [BEAM Interiors, 2008] shows that there are occupant-specific and property-specific issues. The occupant-specific issues include thermal comfort, electromagnetic environment and IEQ management which are excluded in the study. The parameters consider in this study are the property-specific issues which include acoustic environment, indoor air quality, quality of view, daylight performance, and natural ventilation performance.

For the acoustic environment and indoor air quality, traffic-induced noise and air pollution are of key concern. As for the quality of view, other than the specific view, view obstruction, which is closely linked with daylight performance, should be considered simultaneously.

In respect of the method to be adopted for valuating the environmental attributes, it is concluded that the hedonic price approach is the most suitable method. However, the use of hedonic price approach requires the development of performance indicators to enable an objective and continuous evaluation of the attributes. While architectural attributes can easily be quantified, but such indicators for environmental attributes are found lacking in extant literature.

To fill the research gap, performance indicators for representing each of the environmental attributes will be formulated. Through the use of the hedonic price approach, the price for each architectural and environmental attributes can be determined for the information of homebuyers.

CHAPTER 3 METHODOLOGY

This chapter presents the methodology adopted for developing the performance indicators for objective and continuous evaluation of the environmental quality of a residential unit and the price for that. The development of the indicators, as explained below, was based on field measurements and computer simulations of which were conducted for various carefully selected residential units and estates. While for the price analysis, data were obtained from representative transaction records.

3.1 Methods for development of the performance indicators

According to literature review in Chapter 2, key property-specific factors affecting properties price include architectural and environmental attributes. For the use of the hedonic price approach, the environmental attributes need be quantified to measurable levels. However, the quantifying methods for different environmental attributes can be very complicated, normally including actual site measurements, scale-down model experiments and computer simulations. Moreover, there is a requirement for successful use of the hedonic price approach, that is ‘homebuyers know very well about household attributes and choose the household attribute so that the implicit price of the attribute equals the marginal rate of substitution between the attribute and the composite good'. Unfortunately, most homebuyers do not have the background to understand the physical meaning of the attributes. Hence, a simple indicator for representing the performance of various environmental attributes, which homebuyers know and choose the attribute (a pre-requisite for use of the hedonic price method), needs to be developed. To achieve simplicity objective, the most influential parameter of each environmental attributes will be identified for inclusion in the hedonic price model.

Field measurements and computer simulations were adopted for the identification of the most influential parameter and thus the development of the performance indicators.

3.1.1 Field measurements

Environmental quality of residential dwellings is determined by the interactive effects between indoor and outdoor environments. Field measurements are therefore needed to identify the most influential parameter affecting the performance of a particular environmental attribute. The influential parameter, upon identification and evaluations, can be developed to become performance indicator of the studied environmental attribute.

Parameters to be measured during field measurements are those contributing to the performance of environmental attributes, but there are constraints with field measurements:

- Residential flats are privately owned and thus measurements can only be conducted at limited numbers of residential flats and at road-side of residential estates;

- Measurement days and time are decided by the occupants and thus the weather and sky conditions are beyond control;

- Operational and internal characteristics of residential flats that may affect the indoor environmental quality is beyond control; and

- Measurement methods that may cause nuisance to the occupants cannot be used, e.g. tracer gas technique.

Accordingly, field measurements should be carefully designed, and are limited to measurement of environmental attributes that are not affected substantially by the above constraints.

According to Building Research Establishment Digest [BRE, 1986], daylight performance measurements is weather and sky conditions dependent because it must be conducted under CIE standard overcast sky without direct sunlight. Furthermore, daylight reaching a room consists of three components:

1. The sky component: the light received directly from the sky.

2. The externally reflected component: light received after reflection from the ground, buildings or other external surfaces.

3. The internally reflected component: the light received after being reflected from surfaces inside the room.

The internally reflected component is dominated by internal characteristics of the residential flat, and thus is an occupant-specific characteristic. Site measurement, which cannot exclude this characteristic, is therefore not suitable for assessing daylight performance.

Daylight performance and view obstruction are closely linked as discussed in Chapter 2, and thus view obstruction, in association, will not be assessed by site measurement.

Tracer-gas technique is most widely used for laboratories and field measurements of natural ventilation rate through openings. During site measurements, a readily detectable tracer gas is injected into a space and the concentration history in the building is recorded. The inflow rate of fresh air can then be determined by the variation in tracer gas concentration. However, the injection of tracer gas (normally CO_2) will cause nuisance to the occupants, and thus field measurement of natural ventilation performance is not desirable.

As a result, traffic-induced noise and air quality measurements are the two attributes that can be evaluated by field measurements. The field measurements were conducted in typical residential flats, and at road sides. The measurements details and results are reported in Chapter 4. After analysing the measurement results, performance indicator for traffic-induced noise and air quality were identified.

3.1.2 Computer simulations

It is evident from the above discussions that the determination of performance indicators for representing daylight performance, view obstruction, and natural ventilation performance has to be achieved by the use of other methods. Computer simulation is the most popular alternative. It can predict conditions that cannot be measured in experiments and on-site, and are free from field constraints.

According to discussions in Chapter 2, daylight performance and view obstruction are closely linked with one another. Recent advances in laser ranging combined with Geographic Information Systems (GIS) facilitate the use of viewshed analysis for a precise and objective measure of view quality for residential property to circumvent type of view [Hamilton & Morgan, 2010]. Given the complications in collecting data for viewshed analysis (discussed in Chapter 5) and the strong link between daylight performance and view obstruction, shading mask (a mechanism that records which parts of the sky are obstructed from a particular point in a building) was selected to represent daylight performance and view obstruction. In this study, ECOTECT computer software was used to generate the shading mask table. The study and the results are given in detail in Chapter 5.

In respect of natural ventilation performance simulations, CFD simulations by the use of AIRPAK were adopted. By solving a set of partial differential equations, detailed field distributions of air pressure, air velocity, air temperature, relative humidity, contaminants concentrations and mean air change can be provided. The theoretical principle of CFD technique and the indicator identified for representing natural ventilation performance are discussed in Chapter 6.

3.2 Typical residential estates

Given the large population of domestic households which is over 2.36 million [CSD, 2011] in Hong Kong, it is expected that the sample size covered in site measurements and computer simulations account for just a very small percentage of the household population. Thus, the samples must be representative and are chosen carefully.

As discussed in Chapter 1, there are public and private housing in Hong Kong. Public housing is not tradable in the open market, while sale and purchase of private housings are very active in the open market. Furthermore, prices of private housing vary considerably with the quality of the property, and thus the focus of this study is on private housings.

Amongst private housings, sale and purchase can be completed through first-hand and second-hand markets. First-hand market refers to purchase directly through developers; and second hand market is through existing owners. In the first hand market, transactions are normally completed at the construction stage, and thus properties price is determined by developers, which may not on the environmental quality of the property. The situation is different for the second-hand market. Homebuyers can access different units for a visual comparison of their environmental qualities. The actual transaction price of the residential property is an objective, significant and direct value representing the favour of the flat by the homebuyer, and thus reflects the willingness to pay for the property-specific characteristics.

Accordingly, the criteria for selecting typical residential units and residential estate for field measurements are:

1. They are existing private housing estates.

2. Transaction records are readily available.

3. Access to the residential units is possible.

Criteria for selection and sampling of the typical residential units and estates for each of the studied environmental attribute are reported in Chapters 4, 5 and 6.

3.3 Adoption of 2005 transactions records

Hong Kong residential property price fluctuates month by month and year by year due to different economic factors. In early 1990s, the Hong Kong property market rose strongly reflecting a positive impact of factors including booming economic activity; low interest rates; strong increases in the number of households due to immigration from China and moderate growth in public housing supply. However, there was a sharp decline in property prices in 1997 due to Asian financial crisis. In the following years, the property price continued to drop due to combinations of reasons: the contraction of economic activities; the '85000' Housing plan (supplying 85,000 new units per annum) announced by the Hong Kong Government; and SARS occurred in 2003. However, as discussed in Chapter 2, economic and governmental policies affect the property market as a whole, not specific flats or estates.

For evaluating the influence of the identified attributes on Hong Kong residential buildings, a specific year's transaction record with the smallest fluctuation in price to indicate little impact of the economic and governmental policy factors should be selected for this study.

Reference was made to government statistics for identifying a period of time when property prices were relatively stable, and were not affected by intervention events such as policy changes, strikes, environmental regulations, and economic conditions. In Hong Kong, movements of property prices are often measured by the annual Private Domestic-Price Indices compiled by the Rating and Valuation Department

[RVD, 2010]. Table 3.1 provides monthly price indices for the period 2000 to 2005. It can be seen that the variation in price indices is the smallest in 2003 (=5.654); following that is 2005 (=9.146). The small variation in price indices in 2003 was the effect of SARS[1]. During SARS, the property market was seriously affected in terms of prices and transaction volume. The impact can be reflected by the substantial drop in price indices (Table 3.1) and the number of sale and purchase agreements in 2003. Statistics of the Land Registry show that the numbers of property transactions in 2003 and 2005 were 71,576 and 103,362, respectively [Lands, 2010]. Accordingly, transaction records of 2005 were used for price analysis in this study.

Table 3.1 2000-2005 price indices of private domestic from Rating and Valuation Department

Year		2000	2001	2002	2003	2004	2005
Month	1	75.5	80.7	74.1	63.6	69.5	85.7
	2	75.5	80.2	73.9	63.4	73.2	89.4
	3	75.3	82.1	73.3	61.2	78.1	94.6
	4	73.9	82.2	72.3	60.5	79.4	95.4
	5	90.3	80.5	72.4	59.7	77.5	95.3
	6	86	80.9	71.9	59.3	74.7	92.9
	7	86.6	80.2	70.9	58.4	74.9	92.8
	8	87.2	78.5	68.3	58.6	77.6	93.9
	9	88.2	77.2	66.7	60.9	80.9	94
	10	87	74.1	65.4	63.4	94.1	91.8
	11	83.7	73.6	65.1	64.3	82.7	88.5
	12	81.8	73.8	64.8	65.4	83.3	90.1
Maximum		90.3	82.2	74.1	65.4	94.1	95.4
Minimum		73.9	73.6	64.8	58.4	69.5	85.7
Standard Derivation		5.957	3.217	3.622	**2.378**	6.236	**3.024**
Variance		35.49	10.35	13.12	**5.654**	38.89	**9.146**

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[1] SARS stands for Severe Acute Respiratory Syndrome. SARS in Hong Kong killed almost 300 people over a four month period.

3.4 Conclusion

Field measurements and simulations will be adopted for the development of performance indicators for different environmental attributes in private housing. For traffic-induced noise and air quality, field measurements at typical residential units will be conducted for the development of a common indicator. While for daylight performance and view obstruction, a common indicator will be formulated by simulations using ECOTECT. In respect of natural ventilation, CFD simulations will be adopted to identify the most influential parameter affecting natural ventilation performance of a residential unit, of which will become the performance indicator. For price analysis, transactions records in 2005 will be used for the stable price indices and large transaction volume.

CHAPTER 4 DEVELOPING THE INDICATOR FOR TRAFFIC-INDUCED NOISE AND AIR QUALITY

As discussed in Chapter 3, field measurements are adopted for identifying the performance indicators for traffic-induced noise and air quality.

For traffic-induced noise, the inverse-square law, where the sound pressure radiating from traffic machines decreases with the road distance (R) is well-established and recognized [ASHRAE, 2005; Davis and Masten, 2003], and thus it is straight forward to conclude that R is the most influential parameter affecting traffic-induced noise performance. However, traffic is a shared source for noise and air pollution. They are similarly air-borne. Although they are often studied separately [Yusoff and Ishak, 2005], there is a recent notable exception of a study by King et al [King et al, 2009] which developed an air-noise reduction index to represent the effectiveness of the use of a boardwalk in reducing pedestrian exposure to noise and air pollutions. The results pointed to the need of a combined analysis on the impact of traffic-induced noise and air pollution on residents for the formulation of a performance indicator to represent their overall performance.

4.1 Methodology

The traffic-induced noise and air pollution measurements were conducted both at the roadsides and at the case study residential units. The noise level measurements aim at identifying the case study units that are directly exposed to road traffic and are free from external screenings for the study of traffic-induced air-pollution, whereby such information, in particular screening by noise barriers and trees, cannot be ascertained from site layout plans.

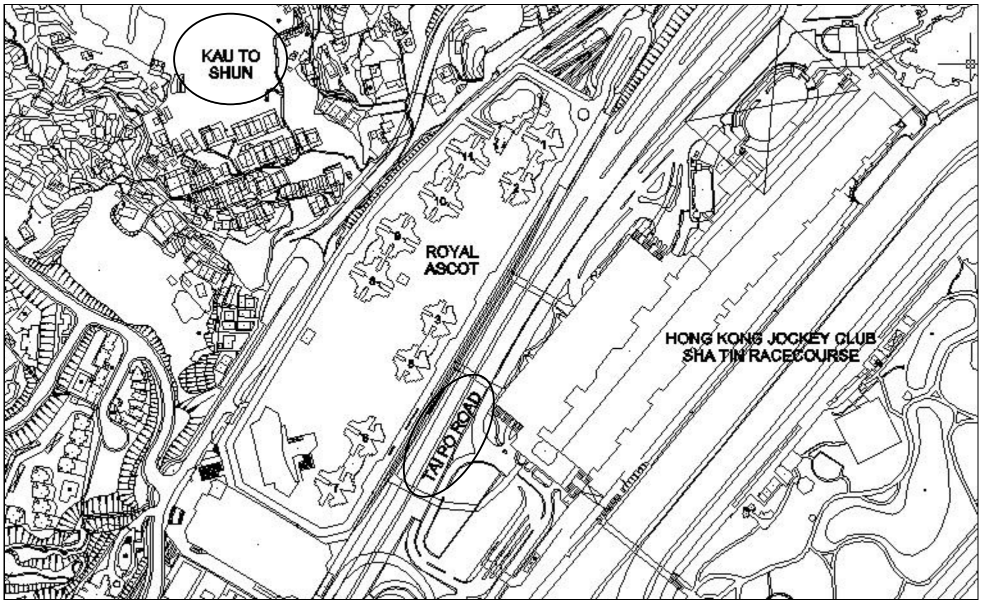
4.1.1 Case study residential estates and units

Site measurements on traffic-induced noise and air pollutions were conducted at the roadsides and the case study residential units of two major residential estates in Hong Kong, namely: Royal Ascot (Site 1) and City One Shatin (Site 2). The two estates have been chosen because they are built near busy roads, and are popular amongst buyers and speculators. Their housing price is one of the constituent estates of Centa-City Index (CCI), which is a monthly index to reflect the trends in Hong Kong's property market.

4.1.1.1 Royal Ascot

Royal Ascot consists of 10 blocks with 2500 units. Each block has around 33 to 40 stories and eight units in each floor. There are three types of building layouts. It can be seen in Figure 4.1 that the estate is located along Tai Po Road. It is one major highway serving the Northeast New Territories in Hong Kong. The noise generated is greater than 75dB(A). The road itself has been provided with an extensive noise barrier by the Civil Engineering and Development Department (CEDD) of Hong Kong with the objective to reduce the traffic noise impact to the neighboring residential estates. In addition to that, the developer has installed a noise barrier at the podium of the estate to further reduce the traffic noise impact on this particular estate.

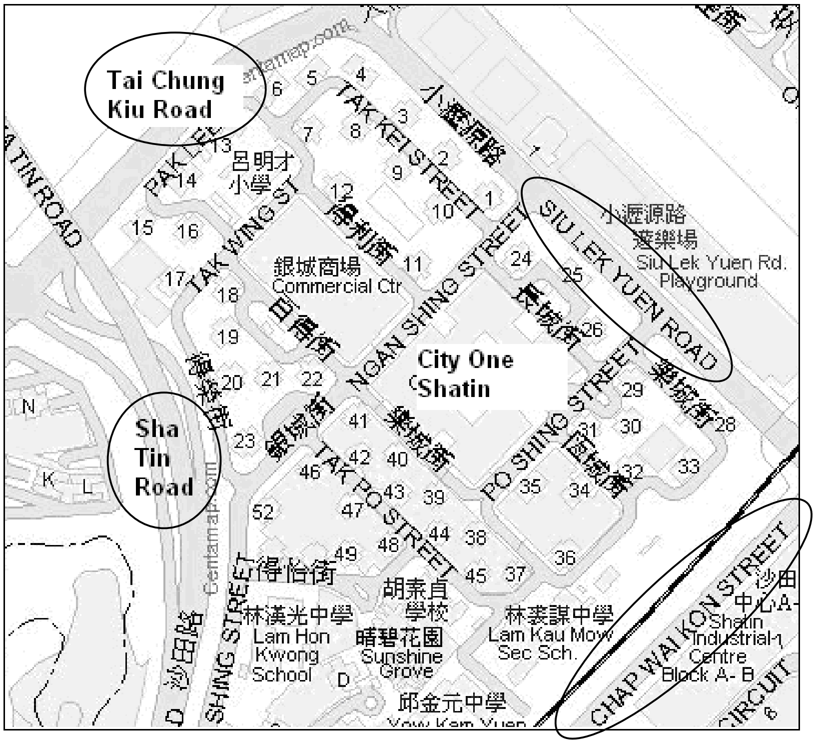
Figure 4.1 Royal Ascot location and environment



4.1.1.2 City One Shatin

City One Shatin consists of 52 blocks with nearly 10000 units. There are nine types of building layouts. Each block has around 27 to 33 stories and four to eight units in each floor. The site plan is shown in Figure 4.2. It can be seen that the estate is bounded by four roads, namely: Tai Chung Kiu Road, Shatin Road, Siu Lik Yuen Road and Chap Wai Kon Street. Amongst these four roads, Tai Chung Kiu Road is the busiest road with a dual 3-lane carriageway and is a major corridor to link to other major distributions. A camera was set up from top view to record the actual road traffic conditions during the measurement period. It was found that Tai Chung Kiu Road had a heavy and generally continuous flow of vehicles, amounting to 2600 vehicles per hour in the daytime. The traffic condition was similar for all measurement days. Although Tai Chung Kiu Road has already exceeded the flow of a “major road” by the definition of the EPD [EPD, 2009], other than the planting of trees, there is no other noise abatement provision along the Road. The residential units located nearby are considered most affected by the traffic noise.

Figure 4.2 City One Shatin location and environment



4.1.1.3 Residential units

To gain access to suitable residential units for on-site measurements is the most challenging aspect in this study because all residential units in the two estates are privately owned. Owing to security and privacy reasons, most residents declined our invitation to participate in this study. Nevertheless, with enormous effort made through direct and indirect contacts, four case study units in Site 1 and five case study unites in Site 2 were arranged for site measurements. Although nine case study units are far lower than the minimum sample size (~708 units) required for achieving a confidence level of 95% based on the probability that 50% of units were randomly picked and sampling error is ±5% [Cochran, 1963; Franklin, 1999], the number of studied locations are already much more than previous studies typically in the range of two to six [Roodaknape et al, 1998; Morswska et al, 1999; Hitchins et al, 2000; Wu et al, 2002]. Furthermore, the case study units have been carefully chosen on the basis that they are either located by the busy roads at different distances (i.e. the perimeter zone), or at the interior zone, enabling study and evaluation of traffic-induced noise and air pollutions, as well as distance effect.

Amongst the four case study units in Site 1, whilst RA3 is in the interior zone blocked by an adjacent tower, the other three perimeter zone units (RA1 and 2 and 4) are directly exposed to Tai Po Road with RA 4 slightly setback from the road. In Site 2, three case study units (COS1, 2 and 5) are located along Tai Chung Kiu Road; and two other units (COS3 and 4) are in the interior zone bounded by other towers of the same estate.

Details of the case study units are summarized in Tables 4.1 and 4.2. The exact addresses are not given to avoid disclosing the price sensitive traffic-induced noise and air pollution information to potential homebuyers.

Table 4.1 Details of the case study residential units in Royal Ascot

Residential Unit	RA1	RA2	RA3	RA4
Block Number	3	7	10	11
Floor Number (/F)	33	13	22	35
Zone	perimeter	perimeter	interior	perimeter
Distance from Tai Po Road (m)	132.5	84.6	147	158

Table 4.2 Details of the case study residential units in City One Shatin

Residential Unit	COS1	COS2	COS3	COS4	COS5	COS 6*
Block Number	6	4	11	8	13	6
Floor Number (/F)	2	18	33	8	25	5
Zone	perimeter	perimeter	interior	Interior	perimeter	perimeter
Distance from Tai Chung Kiu Road (m)	16.4	54.3	131.3	51.1	75.1	21.0
Remark: * Inclusion of COS6 is explained in Section 4.2.2						

4.1.2 Traffic-induced noise measurements

The A-weighted sound level (dB(A)) is shown to correlate well with the subjective response on loudness of broad-band sounds, so it has been chosen to use in this study to reflect the loudness of the traffic-induced noise on human hearing. For measurement of the A-weighted noise level, reference is made to the guideline published by the Environmental Protection Department (EPD) [EPD, 2009] of Hong Kong. The guideline is largely based on ISO1996-2 [ISO, 2007], and the UK method for the Calculation of Road Traffic Noise (CRTN) [HMSO, 1988], with the exception that $L_{10}(1\text{ hr})$ [2] is specified for road traffic measurement. However, instead of using $L_{10}(1\text{-hr})$, $L_{10}(30\text{mins})$ was adopted in this study. This is in accordance with the recommendation made by Ng and Tang [Ng and Tang, 2004] to shorten the measurement duration for increasing the number of samples without sacrificing the accuracy of the measurements. The monitoring locations, according to the guideline, were set at position 1m measured out from the external façade and 1.5m above the ground of the living room and the master bedroom of each case study unit. The equipment used was Bruel & Kjaer type 2238F sound level meter, which were calibrated according to ISO1996-2 before and after each series of measurements [ISO, 2007].

The classic relationship between source sound power level and sound pressure level at the same frequency follows the inverse square law as depicted below [ASHRAE, 2005; Davis and Masten, 2003]:

$$L_p = L_w + 10\log_{10}\left(\frac{Q}{4\pi R^2}\right)\text{dB} \tag{4.1}$$

where

---

[2] $L_{10}(1\text{-hr})$ is defined as over an hour period, the noise level of each monitoring location may exceed a given level for 10 percent of the time.

L_p = sound pressure level of receiver, dB

L_w = sound power level of source, dB

R = distance from source, m

Q = directivity of sound source

From Equation (4.1), it is noted that for traffic-induced noise, the sound pressure at a reception point (the case study unit) from a source (road traffic) of known sound power level depends on magnitude (L_w) and directivity (Q) of sound sources, where L_w is affected by traffic conditions and road surface materials, and Q is influenced by screening of external obstructions [HMSO, 1988].

In applying Equation (4.1) to the same estate, it is noted that if the traffic conditions during measurements are steady, and the case study units are free from external obstructions, L_w and Q will be the same [HMSO, 1988]. For the two residential estates in this study, L_w and Q refer to Tai Po Road and Tai Chung Kiu Road correspondingly. Hence, L_w and Q, each for Sites 1 and 2, can be assumed constant, and the intensity of the traffic-induced noise at the point of measurement and the road distance can be related as:

$$L_p = 10\log_{10}\left(\frac{c_1}{R^2}\right) + c_2 \qquad (4.2)$$

Equation (4.2) can be re-wriiten as:

$$L_p = c_3 \log(R) + c_2 \qquad (4.3)$$

where c_n are site-specific constants

On the basis of Equation (4.3), it can be hypothesised that should the noise level measurement results at the case study units exhibit a linear relationship with the logarithm of the corresponding distance from road (i.e. Log R), it can be concluded that the case study units are directly exposed to road traffic without external screening.

Due to instrumentation constraints, instead of monitoring the noise levels of all case study units and the roadsides simultaneously, the noise levels of one case study unit and the corresponding roadside (Tai Po Road or Tai Chung Kiu Road) were simultaneously monitored for each set of measurement. In this study, the noise levels were monitored in weekday afternoons from 2 pm to 5 pm for 10 days in early summer time where the road traffic conditions were steady and continuous to minimize variations in traffic volume in terms of the number of vehicles per hour, the traffic speeds and the traffic compositions of the roads.

In determining R of each of the case study unit, the horizontal distance from the road was checked by the use of 1:1000 digital maps of Hong Kong, whilst the vertical level was found by site measurements. The source of traffic noise was taken to be a line 0.5m above the carriageway level and 3.5m from the nearside carriageway edge as recommended in the EPD guideline [EPD, 2006].

4.1.3 Traffic-induced air pollution measurements

With regard to the most influential parameter affecting traffic-induced air pollution, study by Zechmeister et al [Zechmeister et al, 2005] reported that the concentration of metal particles generated by traffic machines exhibited a logarithmic relationship with road distance (R). However, the correlation with respirable suspended particulates (RSPs) near major roads most concerned to residents was not reported.

Traffic-induced RSPs are frequently estimated by measuring concentrations of particulate matters of 10 micrometers or less (PM_{10}) [He et al, 2009; Kuhnsa et al, 2003]. They are the reported primary source for PM_{10}. The air pollution index (API) launched by the Environmental Protection Department of Hong Kong (EPD) frequently adopts PM_{10} to quantify the air quality by the roadside of different districts. PM_{10} is also introduced as an air quality standard in the US, EU, and China (USEPA, 2010; SEPA, 2008; EUROPA, 1999).

In respect of the dispersion of PM_{10} near busy roads, there have been several studies conducted on the horizontal and vertical profiles of their mass concentrations. Roodaknape et al [Roodaknape et al, 1998] reported that there was no significant correlation between horizontal road distance and indoor PM_{10} concentration. A similar study was done by Morswska et al [Morswska et al, 1999], but the focus was on outdoor PM_{10} concentration. The study was conducted at two sites within the city area of Brisbane. It was again found no significant correlation for vertical profile and height at the first site, but there was a decrease in concentration at the second site. The difference was thought to be due to the topography and traffic volume. Additional investigations were carried out by Hitchins [Hitchins et al, 2000] at two other sites in Brisbane. The sites were near major roads with open topography. It was found that PM_{10} concentration decreased as distance from road increased. Positive correlation for vertical profile was also reported in a study by Wu et al [Wu et al, 2002] at 4 different locations in Macau where roadside PM_{10} level was comparable to Hong Kong (0.1 to 0.6 mg/m^3), but much higher than the levels of western countries [Tung et al, 1998]. Although diverse results were found from studies at different regimes and at different measurement periods, it is noted from previous studies that correlations tend to be stronger for higher roadside PM_{10} levels, longer distance from roadside and at sites with open topography. This is reasonable because several studies have already reported that traffic-related PM_{10} generation and dispersion are affected by many compounding factors including the climate conditions, the road surface materials, the traffic volume, the screening by external obstructions and the driving patterns [HMSO, 1988].

In this study, PM_{10} measurements were conducted for two purposes: i) to identify case study residential units that were directly exposed to road traffic; and ii) to identify the most influential parameter to represent traffic-induced air pollution.

For identifying the case study units that were directly exposed to road traffic, monitoring of PM_{10} concentrations at the roadside and at each of the identified case study unit were conducted simultaneously at similar measurement period as the noise level measurements for consistency. DustTrak air monitor with one minute data-logging intervals was used in the measurements. The monitoring locations at the roadside (Log R = 0) of Tai Po Road and Tai Chung Kiu Road were set at the respiratory level of 1.5m above ground and are free from obstacles.

The monitoring points for the identified case study units were again the same as the noise level measurements, which were at 1m from the external façade and at 1.5m level of the centre of the window of living room. The indoor PM_{10} levels have not been monitored because the levels are significantly affected by the occupancy activities [Spengler et al, 1981].

To minimize the profound effect of extreme weather conditions on the measurements as recommended by Tanner and Law [Tanner and Law, 2001], measurements were carried out in three consecutive days where the average wind speed was 2.38m/s (±0.16m/s); outdoor air temperature was 23.8^{o}C (±0.4^{o}C); and relative humidity was 60% (±1%). However, the prevailing wind directions were rather fluctuating to vary from easterly to westerly, and there were unexpected heavy rain over the measurement periods.

4.2 Results and analysis

4.2.1 Traffic-induced noise levels

The monitoring results of the nine case study units have been evaluated and are summarized in Figures 4.3, 4.4 and 4.5. It can be seen from Figures 4.3 and 4.4 that the measured noise levels range between 55 and 75 dB(A). The three units (RA3, COS3 and COS4) blocked from the busy roads by the adjacent towers were of relatively lower noise levels with average ranged between 58dB(A) and 65dB(A), whilst noise levels of the other units (RA1, RA2, RA4, COS1, COS2, and COS5A) were higher with average ranged between 63dB(A) and 72dB(A). The results indicated that the attenuation by the adjacent towers were between 5dB(A) to 7dB(A). There were little variations in roadside noise levels over the monitoring period (±1dB(A)), which indicated that measurements were conducted at steady and continuous road traffic conditions.

In accordance to Equation (4.3), the measured noise levels of the six case study units with the logarithm of the corresponding distance from road (Log R) for the monitoring period were related and results are shown in Figure 4.5. It can be seen that the six units (RA1, RA2, RA4, COS1, COS2 and COS5) located at the perimeter zone exhibit a rather linear relationship with coefficient of determinations (R^2) ranged between 0.76 and 0.91.

The results support the hypothesis and it can be concluded that these six case study units are directly exposed to road traffic without external screening. They are considered correctly chosen for the study of the traffic-induced air pollution measurements.

Figure 4.3 Measured noise levels of the 4 residential units in Royal Ascot

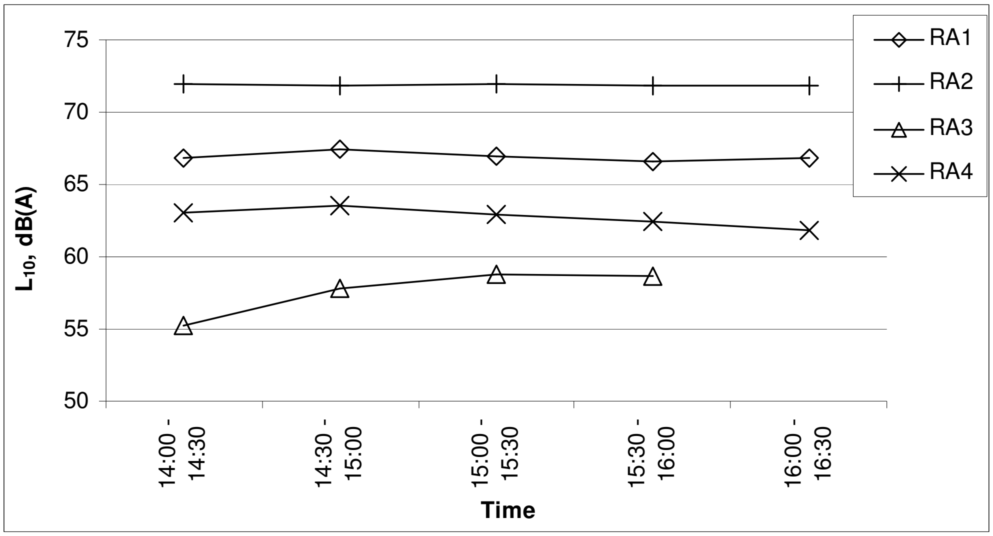


Figure 4.4 Measured noise levels of the 5 residential units in City One Shatin

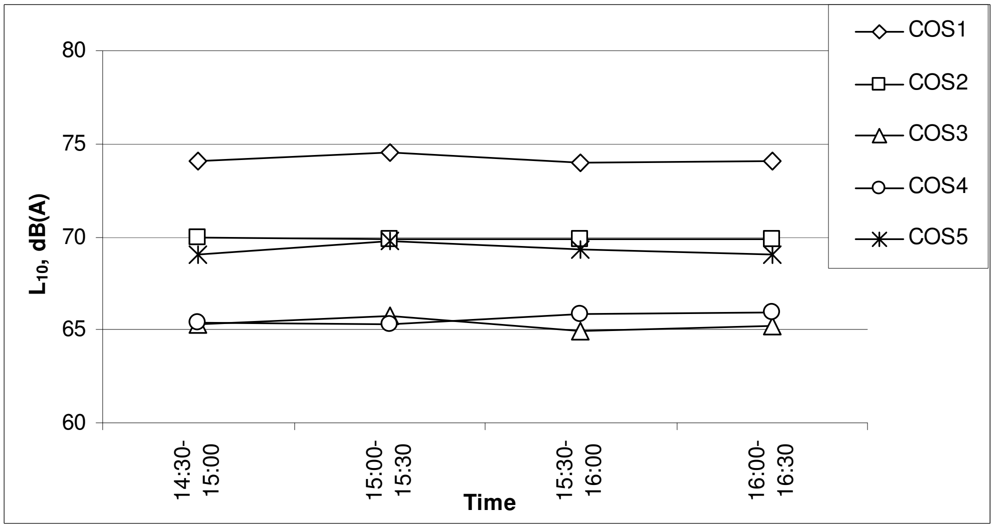
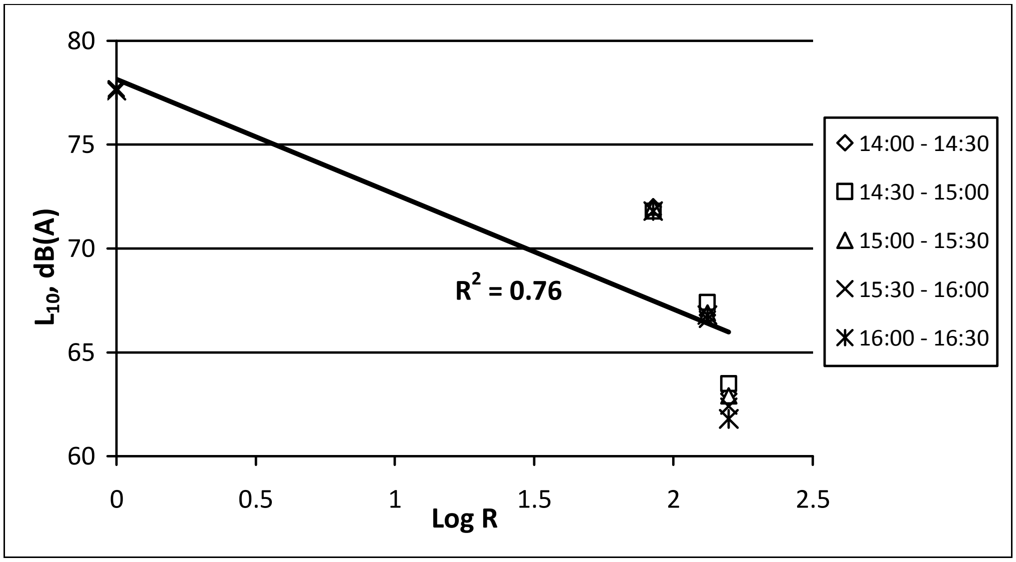
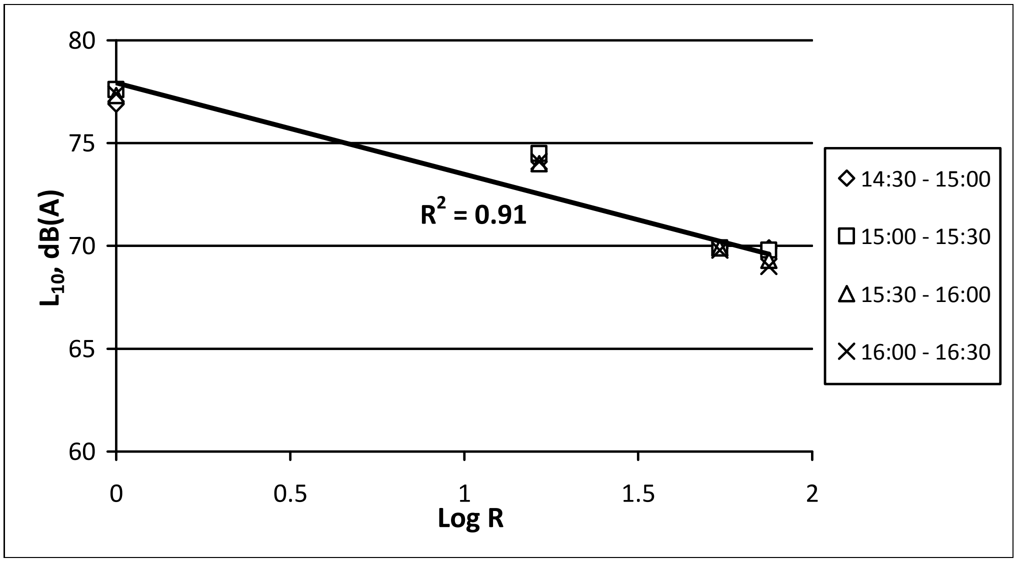


Figure 4.5 Relating measured noise levels with log R for the 6 residential units located in the perimeter zone

(a) Royal Ascot (Site 1)



(b) City One Shatin (Site 2)

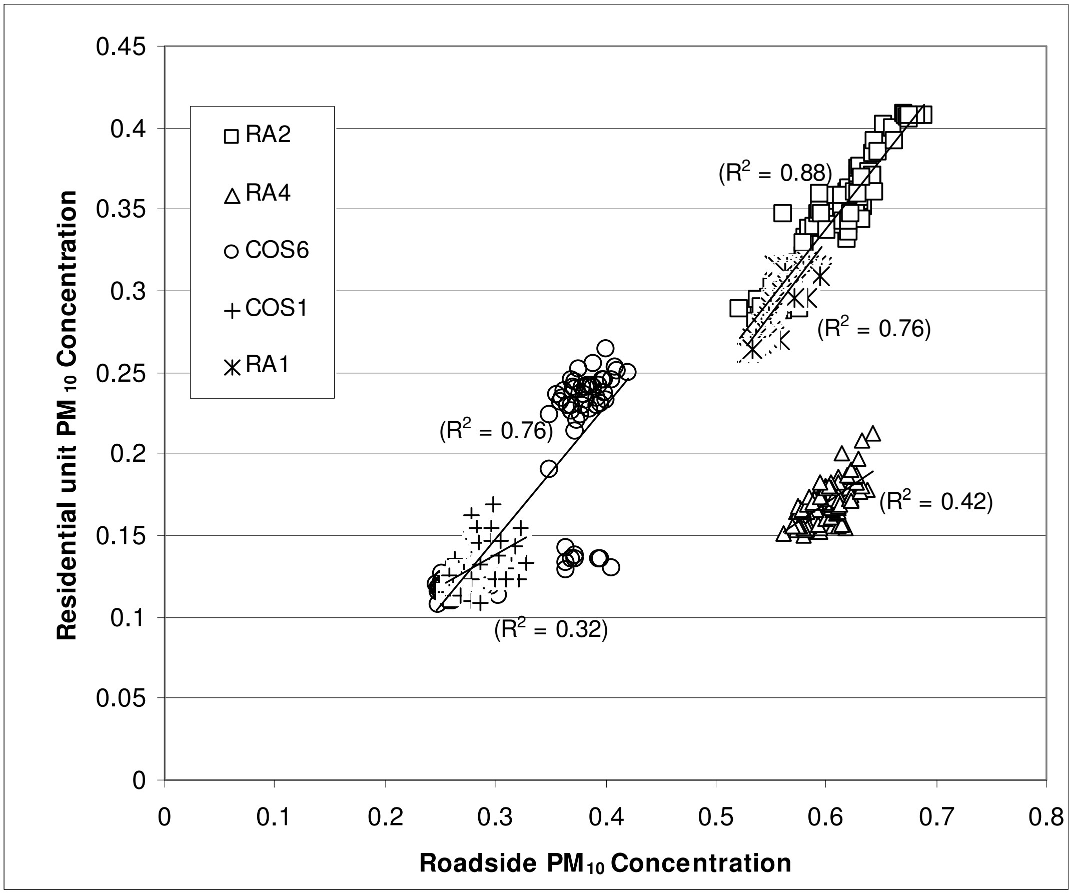


4.2.2 Traffic-induced PM_{10}

Despite efforts made to select the measurement dates, adverse weather cannot be avoided. The measurements at unit COS2 and COS5 were in vain because there were an unexpected heavy rain during the measurement periods to result in unreasonably low PM_{10} concentrations ($<0.01mg/m^3$). The compounding problem was that the units could not be made available for a re-measurement. To enable evaluation of the distance effect on the dispersion of air pollutants, one additional residential unit (COS6) 3 levels directly above unit COS1 was included in this study. The two units differ from each other only in the vertical distance from road. Details are shown in Table 4.2.

The roadside PM_{10} concentrations monitored simultaneously with each of the five case study units (RA1, RA2, RA4, COS1 and COS6) were pairwise compared. The results are shown in Figure 4.6. It can be seen that the coefficient of determination (R^2) ranged between 0.32 and 0.88, where COS1 and RA4, being the nearest and the furthest from the roadside, have relatively lower R^2 (0.32 and 0.42). Based on results of SPSS, for over 100 samples of each case study unit, R^2 ranged between 0.32 and 0.88 indicating correlations were significant at the 0.01 level (2-tailed) to confirm a significant correlation [Milton & Arnold, 1987]. The results indicate that PM_{10} concentrations at the case study units are traffic-induced. A detailed investigation of the monitored data indicates that the levels for different measurement periods are comparable (0.52 mg/m^3 to 0.68 mg/m^3, ±0.08 mg/m^3 in Royal Ascot; 0.24 mg/m^3 to 0.41 mg/m^3, ±0.08 mg/m^3 in City One Shatin), but the profiles vary by the measurement periods. This is reasonable because wind directions changed with the measurement periods. Nevertheless, the result demonstrates that there is no statistically significant difference in roadside PM_{10} concentrations.

Figure 4.6 Pairwise comparison of the simultaneously monitored PM_{10} concentrations (mg/m^3) at the roadside and at the 5 residential units



It is clear that the same roadside PM_{10} concentration is required for the study of distance effect on the decay in PM_{10} concentrations. Accordingly, the 10-min averaged PM_{10} concentrations at the roadside and at the case study units were calculated as depicted in Equation (4.4).

$$\overline{PM_{10}} = \frac{\sum_{t=0}^{t=T} PM_{10}}{T} \tag{4.4}$$

Where $\overline{PM_{10}}$ is the averaged PM_{10} concentration for each measurement position over a time period T (10 mins). The concentrations monitored at the case study units under the same average roadside concentrations were directly compared.

In relating $\overline{PM_{10}}$ with R, reference was made to previous studies by Ning et al [Ning et al, 2005] and by Zechmeister et al [Zechmeister et al, 2005]. Ning et al concluded that NO_x and CO generated from idle vehicles decayed in an exponential fashion with road distance, whilst Zechmeister et al found that the concentration of metal particles generated by traffic machines exhibited a logarithmic relationship with road distance. Although the results of these two studies cannot be directly applied for the difference in the pollutants investigated, the distances from the road and the conditions of the vehicles, attempts have been made to relate $\overline{PM_{10}}$ with R and Log R. It is noted that due to the relatively long road distances between the source and the receivers, the regression results indicate that $\overline{PM_{10}}$ exhibits an exponential relationship with R (R^2= 0.94 and 0.99), as well as a linear relationship with Log R (R^2 = 0.91 and 0.98). Considering that traffic is a shared source for noise and air pollution and it is intended to identify a common parameter to indicate their combined environmental impact, it is reasonable to assume that the source PM_{10}

concentrations also decay in a linear relationship with the logarithm of the distance from road (Log R). Regression models were therefore constructed between $\overline{PM_{10}}$ and Log R, as shown in Equation (4.5). The correlations for Sites 1 and 2 are shown in Figures 4.7 and 4.8.

$$\overline{PM_{10}} = k_1 \mathrm{Log}R + k_2 \tag{4.5}$$

where

R = the distance from road, m

k_n = site-specific constant

Although the regression analysis has been based on a limited numbers of residential units, high levels of correlation between $\overline{PM_{10}}$ concentrations and Log R ($R^2 = 0.91$ for Royal Ascot and $R^2 = 0.98$ for City One Shatin) confirm that Log R can be used as a common indicator for the evaluation of traffic-induced noise and air pollutions on a residential unit directly exposed to road traffic.

Figure 4.7 The correlation between PM_{10} concentrations and Log R in Royal Ascot

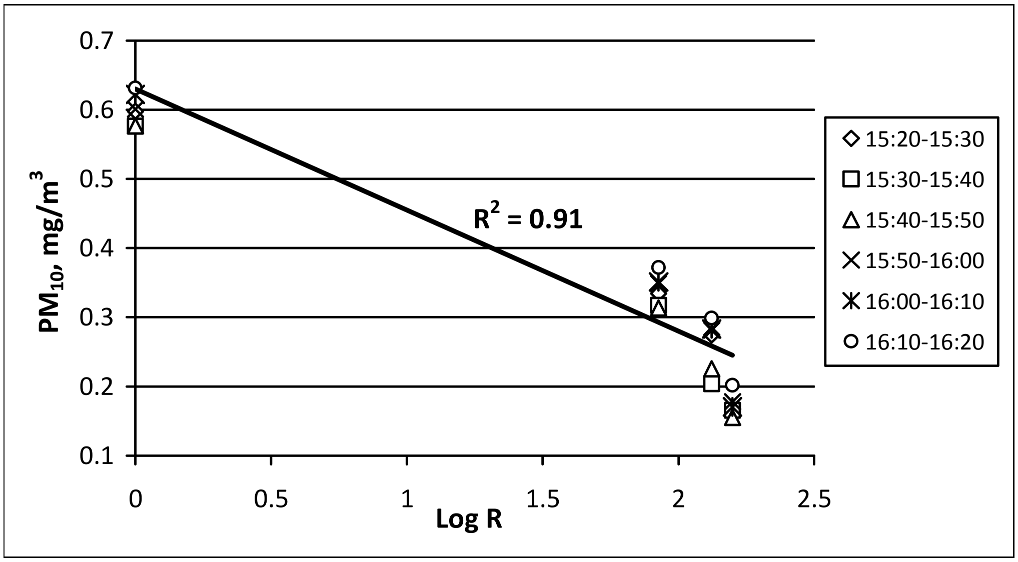
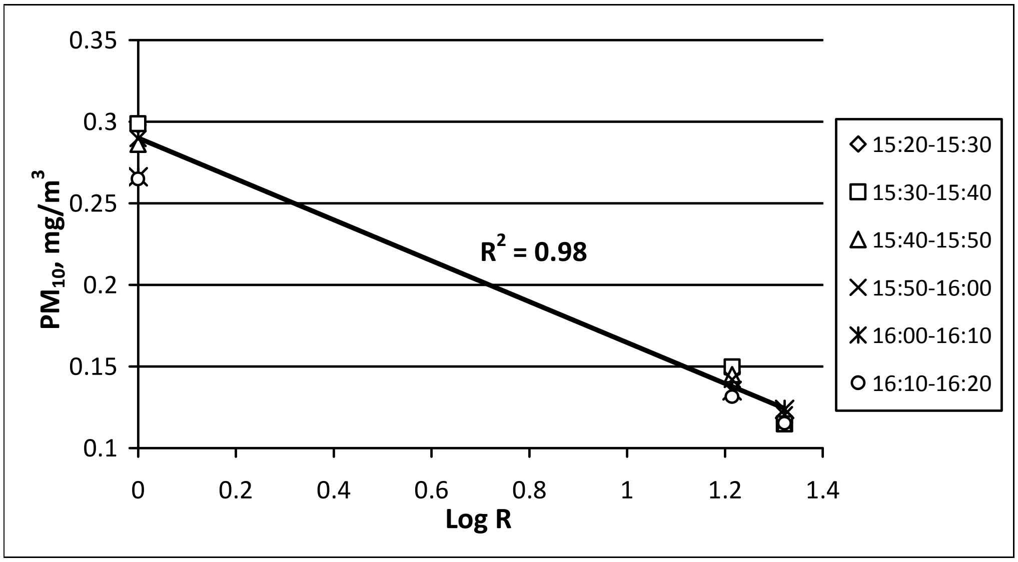


Figure 4.8 The correlation between PM_{10} concentrations and Log R in City One Shatin



4.3 Conclusion

The traffic-induced noise levels and PM_{10} concentrations were measured by the roadside of two busy roads in Hong Kong (Tai Po Road and Tai Chung Kiu Road) and at selected case study residential units at Royal Ascot and City One Shatin. The case study units are located 16m to 158m from the two busy roads. The measurements were conducted from 2:00 pm to 5:00 pm in weekdays during early summer time where the road traffic conditions were steady and continuous. The temperature, relative humidity and wind conditions were moderate. The noise level measurements enable the establishment of the measurement protocol to identify residential units that are free from external screening. In this study, linear correlation was observed ($R^2 = 0.76$ and 0.92) between the measured levels at six case study units and the logarithm of the distance to confirm that the six case study units were directly affected by road traffic-induced noise, and were selected for subsequent PM_{10} concentrations monitoring. The PM_{10} concentrations monitored at roadsides and at the selected case study units were found to be correlated. The regression analysis suggests that the 10-min averaged PM_{10} concentrations correlates with the logarithm of the distance from road (Log R) with a linear relationship with Log R ($R^2 = 0.91$ and 0.98).

From the findings of this study it is clear that under high roadside PM_{10} level, at moderate weather conditions, within the investigated road distance, and in the absence of external screening, "Log R" can be used as a common parameter to evaluate the impact of traffic-induced noise and air pollutions on a residential unit.

Hence, distance from road (Log R) can be used as a performance indicator for road-induced traffic noise and air quality for residential units directly exposed to road traffic.

CHAPTER 5 DEVELOPING THE INDICATOR FOR DAYLIGHT PERFORMANCE AND VIEW OBSTRUCTION

As discussed in Chapter 3, simulations are adopted for identifying a combined performance indicator for daylight performance and view obstruction.

Daylight and view obstruction are closely linked with one another. It is noted that most building environmental assessment schemes in use nowadays combine views and overshadowing performance as one assessment criterion to assess impact of neigbouring buildings in respect of access to daylight and views [BEAM Plus, 2010; LEED, 2008]. A lot of lawsuits also combine obstruction of view and light by neigbouring obstacles as one compliant [REC, 1995; CPC, 2010]. In Hong Kong, site planners and architects adopt a simplified method called the unobstructed vision area (UVA) method originally developed for quantifying the visible sky area due to external obstacles [Ng and Cheng, 2004] to demonstrate compliance to the performance-based requirements for daylighting in buildings [BD, 2010], though the proper application of the UVA method is subject to many constraints [Chung and Cheung, 2006; Cheung and Chung, 2007]. Nevertheless, it can be seen that assessing visible sky area, which in other words is view obstruction, is widely accepted as an alternative means to assess the availability of daylight.

In developing the performance indicator, reference is made to the influence of external obstacles on daylight performance owning to the interactive characteristics between view obstruction and daylight availability.

5.1 What is view obstruction?

A ‘view’ is a single view even if broken into segments by structures or other objects. The significance of those structures and objects, being an inherent part of the view, increases with the distance from the view. It is therefore difficult to simply reply on pictorial description to define a ‘view’. Reference can be made to a legal case in Texas to settle disputes on views by the use of the extent of obstructions [ARC, 2007]. A study has also been done by Yu and Chai [2004] to investigate the impact of view obstruction on residential apartment prices. It can be seen that view obstruction is considered key information to better define a ‘view’.

View obstruction, according to dictionary, is the act of blocking so that the view is hidden from sight. From a homebuyer’s or a designer’s perspective, view obstruction data for each residential unit, particularly high rise building in dense environment represent a wealth of potential decision making and design information. View obstruction in fact can be solved by computer calculations taking into account the explicitly defined distance and characteristics of the obstructions [DeFloriani and Magillo, 2003]. For instance, with the advent of Geographic Information Systems

(GIS) and ArcView 3D Analyst, the Viewshed Index Construction is applied to the simulation of the maximization of views for a new development.

5.2 Existing method used to quantify view obstruction

Viewshed analysis is commonly used nowadays for quantifying view obstruction. A viewshed is a two-dimensional spatial layer that records the intervisibility between points in a landscape and accounts for the location, height and angle of view of an observer located in three dimensions. Within a specified distance of an observation point in an elevation model, the viewshed can check whether the target location can be connected by a line of sight to a viewpoint location.

Recent advances in laser ranging combined with Geographic Information Systems (GIS) facilitate the use of viewshed analysis for a more precise and objective measure of view obstruction for each property to circumvent previous view classifications [Hamilton and Morgan, 2010]. In constructing viewshed variables, information of the built landscape features of the subject property is required. This is less of a problem for a new development, or for urban and natural resource planning. It is difficult to capture a residential unit's view obstruction due to poor availability of high resolution spatial data for buildings, especially their locations and heights, which are rarely reflected in commonly available maps; collecting these data can be complicated because of the time, effort and expense involved [Sander and Manson, 2007]. Furthermore, a viewshed analysis basically assesses the visibility of a viewpoint for an area of interest (view). A value of unity indicates that the viewpoint is visible, while a value of zero indicates that the viewpoint is not visible [Kim et al., 2004]. In high density urban developments like Hong Kong, uniform high-rise buildings are closely packed to create a solid wall-effect that blocks the view [Giridhara et al., 2004]. As such, even when spending is allowed, the variation in viewshed value will be too small to provide a precise measure of view obstruction. This explains why viewshed analysis, if conducted to measure a property's views, is confined to property developments where there is an unobstructed distinguished view nearby [Germino, Reiners, Blasko, McLeod & Bastian, 2001].

5.3 Influence of view obstruction - Hong Kong situation

The review in Chapter 2 indicates that view obstruction affects property price. However, Hong Kong is characterized by the high-rise high-density environment and the sky view factor is low in most residential estates. Owning a residential unit without external obstacles is a luxury to most Hong Kong people. As such, it is worthwhile to review if there is a premium available for a slightly better view in Hong Kong.

In respect of price analysis, the discussions in Chapter 3 suggested the use of transaction record in 1995. However, there were altogether 87,368 transactions for previously owned residential units in 2005 [Lands, 2010]. Given the large transaction volume, it is almost impossible to accurately define the view obstruction of each particular residential unit. For more effective capturing of information, four popular residential estates offering different kinds of views were randomly selected across the three primary regions of Hong Kong, i.e. the New Territories, Kowloon Peninsula and Hong Kong Island, for detailed analysis. Selection was on the basis that they offered different kinds of views; of similar scale of development (each consists of five to seven blocks) and the numbers of transactions were comparable.

Each of the four studied residential estates witnessed approximately 100 transactions in the year 2005, in respect of which transaction details, including address of the unit, gross floor area, price, pictorial view, etc. could be obtained from property portal sites operated by the two leading property agencies in Hong Kong [Midland Realty, 2010; Centreline, 2010]. For ascertaining the view obstruction of each residential unit included in transaction records, reference was made to descriptions given in transaction details and were checked by the use of 1:1000 digital maps of Hong Kong prepared by the Lands Department. To further enhance the accuracy of the collected information, site visits were conducted in winter of 2006 to better appreciate the three dimensional view of some of the residential units.

Upon confirming the view obstruction of each residential unit, the method used by Benson et al. [1998] was adopted to classify individual views (point of interest) into three performance levels, namely, unobstructed, good partially obstructed, and poor obstructed views. In defining the different levels of view, it has been assumed that for 500m from the living room window, an unobstructed view means facing to an unobstructed space formed by two angles of 50 degrees measured horizontally from the centre of the window (the use of 50 degrees and 500 m are explained in a later section). While good partially obstructed view means facing to an unobstructed space formed by an angle of 50 degrees measured horizontally from any one side of the centre of the window; and poor obstructed view means facing no unobstructed space formed by two angles of 50 degrees measured horizontally from the centre of the window. Three performance levels were used, as opposed to four recommended by Benson et al. [1998], was due to the fact view obstruction could not be precisely determined for some 411 residential units at four different locations.

In the four studied developments, specific views available are sea view, racecourse view and hill view. Average and range of transaction prices (HK\$/ft^2) for each level of view for the four developments are summarized in Table 5.1. It can be seen that units with good partially obstructed and unobstructed views are 9.1% to 14.8% higher than poor obstructed views. To further confirm if there were correlation between the levels of view obstruction to transaction prices, Pearson correlation analysis was conducted. It was found that correlation coefficients for the four studied developments were between 0.499 and 0.612; indicating correlations were significant at the 0.01 level (2-tailed). The preliminary analysis indicates that in addition to the view of a residential unit, the level of obstruction also has impact on property prices.

Table 5.1 Property Price of 4 Residential Estates with Different View obstruction

Region	Residential Estate	Unobstructed View			Good Partial Obstructed View			Poor Obstructed View		
		Unit	Unit Price (HK$/ft2)		Unit	Unit Price (HK$/ft2)		Unit	Unit Price (HK$/ft2)	
			Average	Range		Average	Range		Average	Range
HK Island	Tai Koo Shing (Harbour View Gardens)	A, H	6,427 (+14.8%)	5032 ︱ 8624	B, G	6,355 (+13.5%)	4672 ︱ 7492	C, D, E, F	5,601	4004 ︱ 6825
Kowloon	Galaxia	1, 2, 3, 5	4,609 (+9.1%)	3790 ︱ 5326	---	---	---	6, 7, 8, 9	4,225	3657 ︱ 4604
New Territories	Royal Ascot (Phase 1)	E, F	5,730 (+14.3%)	4757 ︱ 7505	---	---	---	A, B, C, D	5,011	4207 ︱ 6031
New Territories	Oscar by The Sea (Phase 2)	C, H	3,568 (+11.2%)	3281 ︱ 4288	A, B	3,546 (+10.5%)	3067 ︱ 4120	D, E, F, G	3,208	2691 ︱ 3424

5.4 Quantifying view obstruction by shading mask

A view is what can be seen in a range of vision. Vision is the interpretation of visible light information reaching the eyes. Light drives the presence of a view. Admission of daylight allows people to enjoy view. External structures and objects blocking the incident daylight resemble view obstruction. Hence, it is very suitable to use the availability of daylight at the glazed surface as an indicator of view obstruction.

The shading mask (a mechanism that records which parts of the sky are obstructed from a particular point in a building) is selected to represent view obstruction level for conducting a detailed study. The obstructing objects include all external obstacles in front of the window. It is often used to determine the actual contribution of sky to daylight, and is typically adopted to quantify the availability of daylight outside a residential unit because it enables accurate estimation of the vertical angle of the sky as seen from the centre of a window [Tregenza, 1995].

For a given set of obstacles, the shading mask is the fraction of unshaded area of a surface at a specific solar position which can be represented in Equation (5.1):

$$SMK_{ij} = \frac{A_{ij}}{A_{oj}} \tag{5.1}$$

Where

SMK_{ij} = shading mask of the j^{th} surface for solar position i

A_{ij} = unshaded area of the j^{th} surface for solar position i

A_{oj} = total area of the j^{th} surface

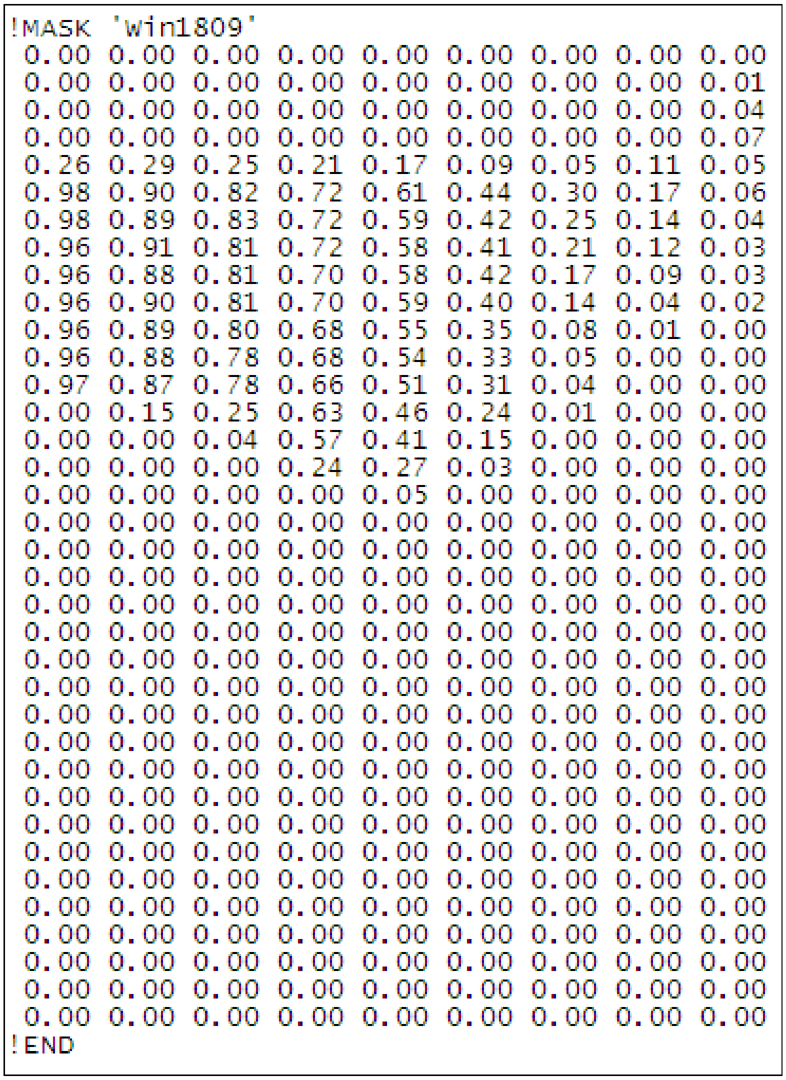
In specifying the solar positions, it is common to subdivide the sky dome into discrete segments. Some seek to achieve a roughly equal area (solid angle) for each segment while others apply a simpler latitude/longitude or equal angle approach. The equal angle approach uses altitude and azimuth values to index the shading mask, which is often considered a simpler method [Marsh, 2005]. Obviously, the smaller the size of each segment, the greater will be the accuracy of calculations. CIE [1994] suggested that for daylight calculations, segments with a solid angle of approximately 0.2 radians, i.e. 11.5 degree, are small enough to be considered as point sources without significant error. Reference is also made to a computer simulation package HTB2 adopting the shading mask concept to estimate the inter-shadowing effect on solar heat gain through windows and on conduction heat transfer through envelope [Alexander, 1994]. In HTB2, 10 degree segments are used. This corresponds to the 324 equal area segments (i.e. 0^o to 360^o from azimuth, and 0^o to 90^o horizon to zenith). For a given surface and any given set of obstructions, the shading mask can be recorded in a shading mask table (Figure 5.1) comprising 36 rows and 9 columns.

In summing up the 324 shading mask figures, it can be assumed that the figures are independent, and are of equal importance because they are from equal sky segments. It is therefore acceptable to use simple arithmetic mean of the figures to devise a single mask for a specific surface [Watson et al., 1996; Scheaffer, et al., 1996] which can be represented as follows:

$$\mathrm{SMK}_{\mathrm{AVj}} = \frac{\sum_{i=1}^{i=324} \mathrm{SMK}_{\mathrm{i\,j}}}{324} \tag{5.2}$$

Where $\mathrm{SMK}_{\mathrm{AVj}}$ is the mean shading mask of the j^{th} surface. Higher values represent smaller view obstructions.

Figure 5.1 Shading Mask Table



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!MASK 'win1809'
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 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.07
 0.26 0.29 0.25 0.21 0.17 0.09 0.05 0.11 0.05
 0.98 0.90 0.82 0.72 0.61 0.44 0.30 0.17 0.06
 0.98 0.89 0.83 0.72 0.59 0.42 0.25 0.14 0.04
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!END
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In this study, ECOTECT computer software was used to generate the shading mask table. The overshadowing accuracy and the azimuth and altitude increment were set at medium and 2.0, respectively. These were determined after trial simulations with changed settings, in order to observe the influence on shading mask values. Detailed description of ECOTECT simulation can be found in the product website [Marsh, 2010]. In preparation for the simulation, a scaled three-dimensional (3D) model of the target building, together with the neighboring buildings and other external objects and structures within a circumference of 500m were drawn by using AutoCAD. AutoCAD has been used because it is popular in the construction industry, and is compatible with ECOTECT. The site boundary was determined based on findings of Chau, Wong & Yiu (2005), indicating that a view with a premium referred to the panoramic view within 500m of the living room. This is consistent with distance zone suggested by other studies (Bishop & Hulseb, 1994; Leeds et al., 2008). As for the target unit, the apertures and the fenestration details including fins and canopy were precisely drawn, while other surfaces were modeled as flat planes. On exporting the AutoCAD files to ECOTECT, a shading mask table for each window surface is generated. In this study, the window pane position is assumed to be the standing position for a view.

For ascertaining feasibility of using the mean shading mask ($\overline{\mathrm{SMK}}$) to assess view obstructions, Royal Ascot, the residential estate chosen for traffic-induced noise and air pollution measurements (Site 1), was again chosen as the case study development.

5.5 Case study residential estate and units

Royal Ascot consists of 10 blocks with 2500 units. It was chosen again because access could be gained to some of the privately owned residential units to ascertain the actual view of which was dominated by the view obstruction level. As can be seen from the site layout in Figure 5.2, there is a racecourse 70m from the southeastern side of the development. To the northwestern side, there is a small hill 50m apart, of 150m height. Other orientations are bounded by the neighboring buildings 10m to 40m apart. Given the precise view obstruction for this estate can be ascertained, Benson et al. [1998] method was adopted to classify the residential units into four subjective levels of view as described below:

1. Unobstructed view (Level 1): facing to racecourse view within 500m from the living room window formed by two angles of 50 degrees measured horizontally from the centre of the window. Note that there is no unobstructed hillview.

2. Good partially obstructed view (Level 2): facing to an unobstructed hill/racecourse view within 50m from the living room window formed by two angles of 50 degrees measured horizontally from the centre of the window. 50m was assumed because the small hill is 50m apart.

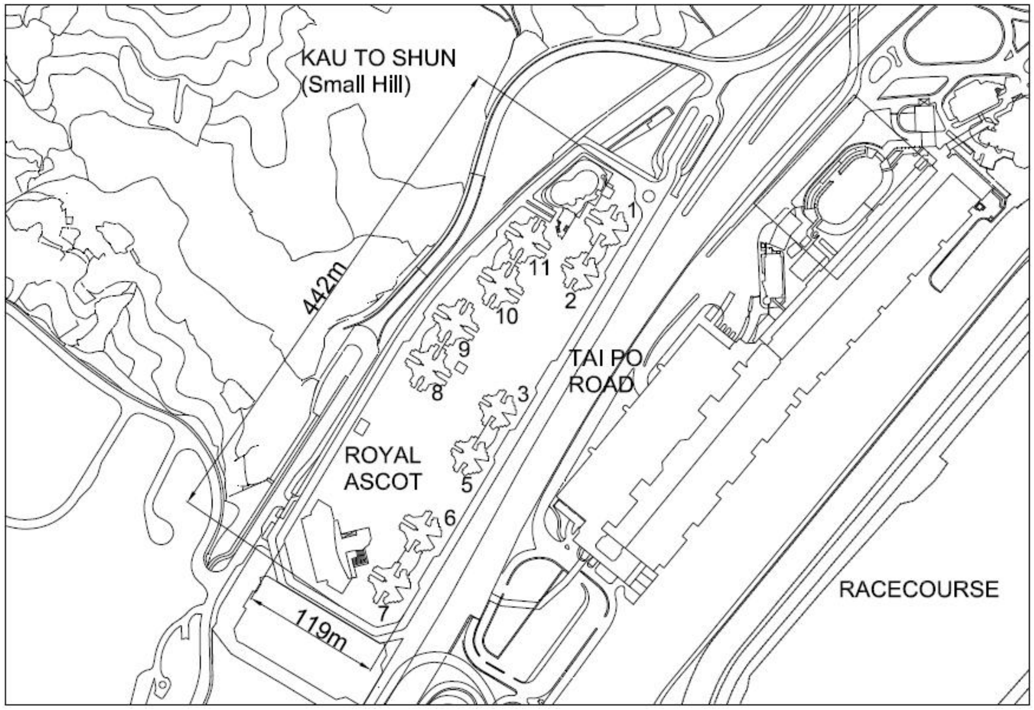
3. Partially obstructed view (Level 3): facing to an unobstructed hill/racecourse view within 50m from the living room window formed by an angle of 50 degrees measured horizontally from one side of the centre of the window.

4. Poor obstructed view (Level 4): facing a building within 50m from the living room window formed by an angle of 50 degrees measured horizontally from both sides of the centre of the window.

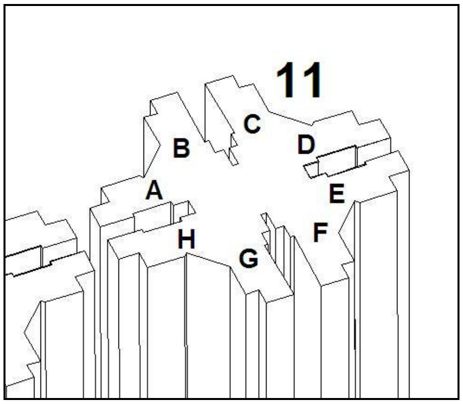
Amongst the 10 housing blocks, Block 11 was chosen for detailed evaluation because it typically consists of all four levels of view. The target block is 40-story, and eight units per story. It is 10-story taller than Blocks 1 and 2, which are in the front. The block's plans, together with neighboring features, are shown in Figure 5.2. Case study units were selected on the 1st, 11th, 21st, 31st, 35th and the topmost (40th) floors of the target block. The selections were on every 10th floor basis because view obstruction of lower floors does not vary significantly, and the influence of neighboring obstacles is mainly on views of upper floors. Hence, the 35th and the topmost floors were included.

Figure 5.2 Site Layout of Royal Ascot

(a) Site plan



(b) Floor layout of block 11



5.6 Subjective views

Upon selection of the case study units, subjective views were given on the basis of the classifications in section 5.5. It can be seen in Figure 5.2 that the topmost floors of Units A through H are higher than the small hill and the other blocks, resulting in an unobstructed hill/racecourse view within 500m to conclude Level 1 view; Units C and D are facing to the small hill 50m apart, and thus have Level 2 view; Units A and B have Level 3 view because part of the hill view is blocked by the adjacent blocks 30m apart; and lower floors of Units E and F are completely blocked by adjacent buildings to conclude Level 4 view. Results are given in Table 5.2.

Views of lower floors of Units G and H (Levels 3 or 4) cannot be ascertained from the block plan because there is an observation tower at the racecourse that possibly blocks the racecourse view. Similarly, the racecourse view of upper floors of E, F, G and H (Levels 2 or 3) cannot be ascertained because Blocks 1 and 2 are in the front. Site visits were therefore made to units in the 17th, 27th and 35th floors in January 2008 through personal contacts and the local property agent, Midland Realty. Subjective levels of views of the units concerned were then confirmed by visual inspection.

Table 5.2 Simulated obstruction levels ($\overline{\text{SMK}}$) of different flats in the sample site

Flat	A	B	C	D	E	F	G	H
Floor	Partially obstructed hill view (Level 3)		Good Partial obstructed hill/racecourse view (Level 2)		Poor obstructed building view (Level 4)			
1st	0.201	0.225	0.249	0.241	0.127	0.125	0.140	0.136
11th	0.207	0.230	0.264	0.256	0.130	0.131	0.144	0.139
21st	0.213	0.233	0.275	0.269	0.148	0.159	0.156	0.146
					Partially obstructed racecourse view (Level 3)			
31st	0.227	0.242	0.284	0.276	0.236	0.255	0.203	0.191
35th	0.244	0.257	0.287	0.279	0.278	0.294	0.234	0.229
	Unobstructed hill/racecourse view (Level 1)							
40th	0.348	0.376	0.366	0.360	0.355	0.370	0.358	0.355

5.7 Mean shading mask performance, $\overline{\text{SMK}}$

$\overline{\text{SMK}}$ of the window surface of the living room of the 48 case study units were calculated by Ecotect to determine the corresponding view obstructions. The calculation results are compared with subjective view levels determined above (Table 5.2), which indicates that:

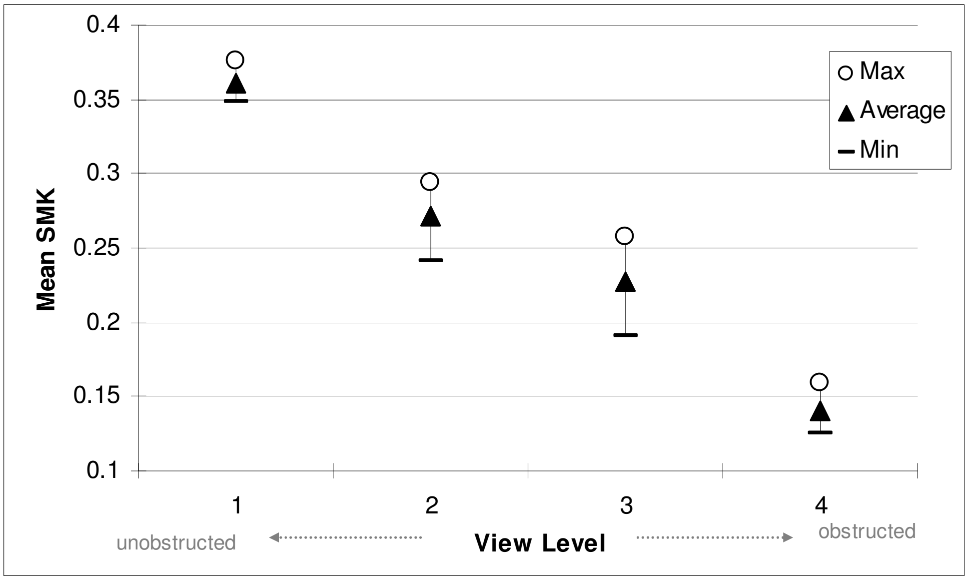
1. For Units A through D and lower floors of Units E through H, the increase in $\overline{\text{SMK}}$ is driven basically by an increase in floor levels, indicating a decrease in view obstruction.

2. For upper floors of Units E through H, there is a substantial increase in $\overline{\text{SMK}}$ to reflect a less obstructed view in comparison to the lower floors.

3. For the topmost floor, $\overline{\text{SMK}}$ are comparable for the eight units because there are no external structures and objects to block the view.

$\overline{\text{SMK}}$ values for the four view levels are compared in Figure 5.3. It can be seen that the $\overline{\text{SMK}}$ ranged between 0.127 and 0.37, which correlates well with the subjective view levels; obviously $\overline{\text{SMK}}$ values provide a continuous measure of view obstruction to confirm that $\overline{\text{SMK}}$ can be used as an objective indicator of view obstruction, where 0 represents fully obstructed view and 1 represents 100% unobstructed view.

Figure 5.3 Relating $\overline{\text{SMK}}$ and Subjective View Levels



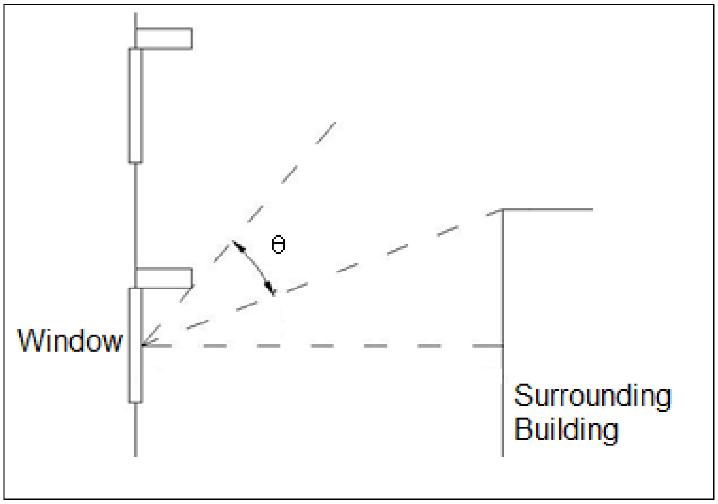
5.8 Angle of unobstructed sky, θ

Modeling the obstruction situations that arise in a simple building requires preparation of detailed 3D models and interactions with a large number of external structures and objects for ECOTECT simulations so as to determine the $\overline{\mathrm{SMK}}$. This is less of a problem for designers if evaluation of view obstruction is a major design objective. However, if the view obstruction level is only a decision-making information for an existing building, site inspections to confirm building apertures and obstruction details will be difficult and effort intensive. Furthermore, it is not common for stakeholders in the property market to familiarise themselves with 3D drafting skills and ECOTECT simulations. Consequently, it is imperative to establish a simple method to assess view obstruction based upon the conceptual background of shading mask.

There are three possible paths along which daylight can reach a point inside a room through glazed windows - the sky component, the external reflected component, and the internally reflected component. However, when view is concerned, the most significant factor is the availability of daylight at the window, which is the sky component. Thus assessing sky component for a window does provide a quick and simple guide to the potential for daylight to satisfy the intended objectives of this study. Different methods are available for calculating the sky component [Capeluto, 2003; Littlefair, 1995; Littlefair, 2001; Tregenza, 1989] for a point of interest. Angle of unobstructed sky (θ) is often considered the simple design method for architects during initial design stages to assess the daylight potential of a building site [Littlefair, 2001].

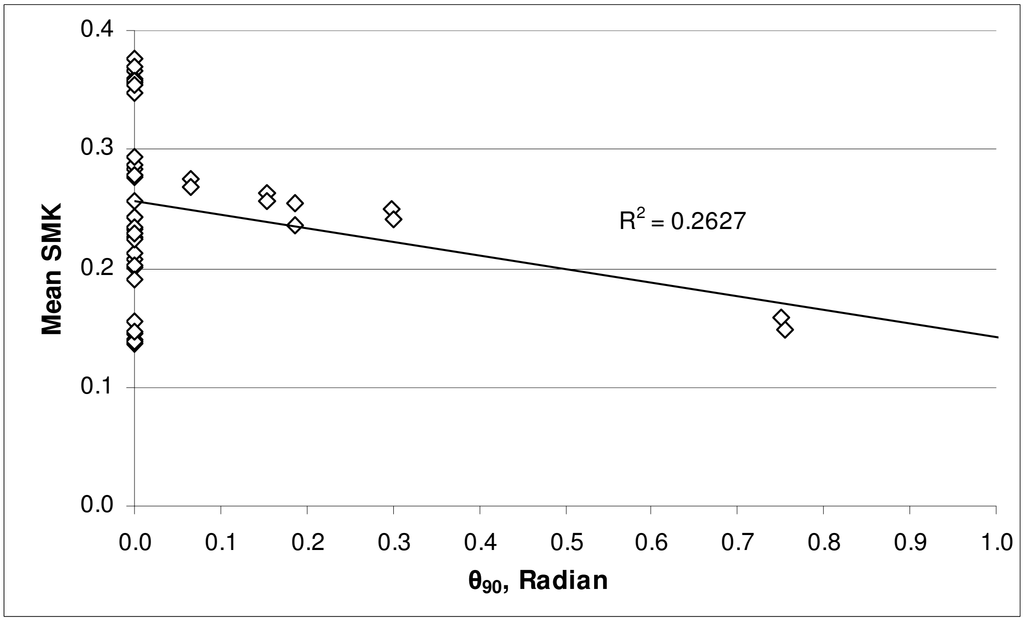
In determining the angle of unobstructed sky (θ) as shown in Figure 5.4, some research studies (and also regulatory requirements on daylight availability) simply based on the angle of unobstructed sky perpendicular to the window (θ_{90}) for simplicity [Li, et al., 2006; Yu & Chai, 2004]. This however depends only on the height of neighboring obstacles and separations perpendicular (90 degree) to the window; it does not take into account obstacles not blocking the perpendicular line but that still block the view and daylight significantly. Windows facing a narrow street is one typical example.

Figure 5.4 Angle of unobstructed sky, θ



It is rather obvious from the above discussion that θ_{90} is not a sufficient basis to quantify availability of daylight. However, given its wide adoption in similar studies (Li, et al., 2006; Yu & Chai, 2004), to better illustrate if θ_{90} can be used to gauge daylight availability, an attempt has been made to relate simulated $\overline{\text{SMK}}$ of the 48 case study units (i.e. 8 units in 1st, 11th, 21st, 31st, 35th and 40th floor of Block 11, Royal Ascot) with the corresponding angles of unobstructed sky (θ_{90}) to reveal how well they correlate with each other. The θ_{90} of the 48 case study units were calculated based on measurements in a 3D model, drawn on the basis of 1:1000 digital maps. The results are shown in Figure 5.5. It can be seen that $\overline{\text{SMK}}$ does not correlate significantly with θ_{90}, particularly in units A, B, G and H where the obstacles are not directly blocking the perpendicular view to yield zero in θ_{90}. The results confirm that θ_{90} is not a sufficient base to quantify availability of daylight.

Figure 5.5 Correlation of $\overline{\text{SMK}}$ and θ_{90} in Royal Ascot



As the use of θ_{90} has been shown to be ineffective, an appropriate method for calculating an average angle of unobstructed sky ($\bar{\theta}$) is required to be formulated. According to Littlefair [1988], $\bar{\theta}$ should be calculated based on the average height of external obstacles, but there is no suggestion on the required horizontal angle measured from the centre of the window surface. With regard to the angle required, reference is made to Becker & Jürgens's [1990] study on human vision, as well as the horizontal angle used in calculation of unobstructed vision area (UVA) [BD, 2010]. In Becker & Jürgens's study, it was suggested that the 90 to 95 degree section of the horizontal monocular field of vision offered the highest resolution to the eye, at any time, to see the view, while the UVA method suggested 100 degree.

Within 90 to 100 degrees, obviously, the smaller the angle divisions, the greater is the accuracy of calculations. Considering the size of external obstacles is normally huge, using small divisions to increase the computation time is considered ineffective. Reference is therefore made to the UVA method to base only on two additional angles of unobstructed sky, each measured 50 degree horizontally from centre of the window. Accordingly, besides 90 degree (θ_{90}), two other angles of unobstructed sky, i.e. 40 (= 90-50) (θ_{40}) and 140 (=90+50) (θ_{140}) degrees, are proposed to be included for calculation of $\bar{\theta}$.

In summing up the three angles of unobstructed sky, as human eye is free to move around a scene to see all the detail, they are considered of equal resolution portion, the use of simple arithmetic mean is considered acceptable. Hence $\bar{\theta}$ is formulated as:

$$\bar{\theta} = \frac{\sum \theta_i}{3} \qquad (5.3)$$

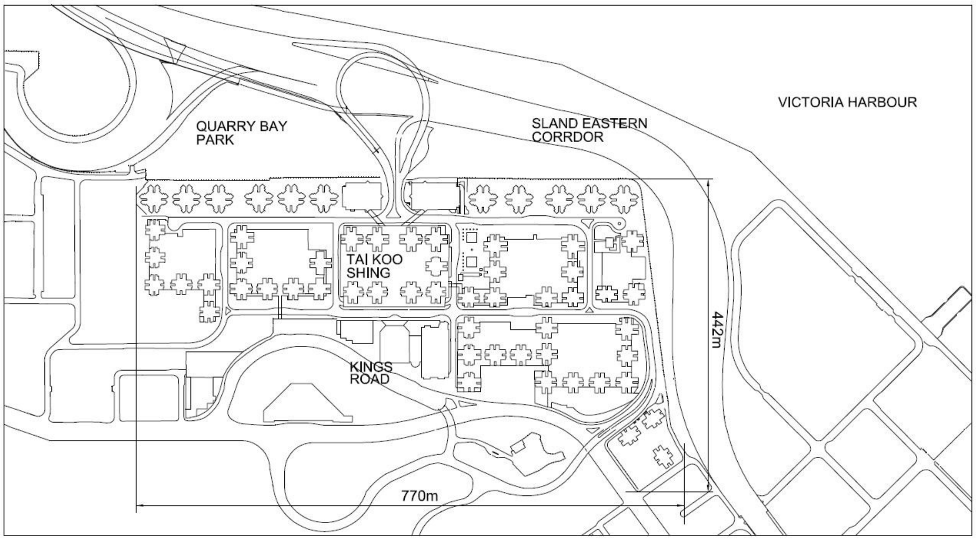
Where i = 40, 90 and 140 degrees

5.9 The performance indicator, $\bar{\theta}$

Based upon the above discussions, it can be hypothesized that if $\bar{\theta}$ can be developed as a performance indicator for view obstruction, $\overline{\mathrm{SMK}}$ and $\bar{\theta}$ will exhibit a correlation with an interception at zero.

A correlation analysis was conducted based on the calculated $\bar{\theta}$ and the simulated $\overline{\mathrm{SMK}}$ of representative samples of residential units randomly selected from Royal Ascot and one additional residential estate - Taikoo Shing.

Figure 5.6 Site Layout of Taikoo Shing



Taikoo Shing is a high-rise residential estate comprising 61 blocks developed in 11 phases with a total of around 12,700 residential units. Each phase consists of two to nine blocks of 20 to 28 story height. There are eight units on each floor. As can be seen from the site layout in Figure 5.6, Taikoo Shing have been built along the seafront, where northern and northeastern sides of the development are facing an ocean and a park. The other orientations are bounded by the neighboring buildings. Taikoo Shing has been chosen because the flat sizes (ranging from 55 m^2 to 110 m^2) are comparable to those of Royal Ascot (ranging from 69 m^2 to 150 m^2). As such, the overall block dimensions are similar. Furthermore, Taikoo Shing is equally popular among buyers and speculators. For a significant time in the 1980's and 1990's, Taikoo Shing's house prices were a general indicator of Hong Kong's housing market health in general. Its house prices are one of the key constituents of Centa-City Index (CCI), which is a monthly index that reflects the trends in Hong Kong's property market.

The sample size (n_0) was determined based on Equation (5.4) for achieving a confidence level of 95% based on the probability that 50% of the residential units were picked (p = 0.5), and the sampling error (e) is ±5% [Franklin, 1999]:

$$n_0 = \frac{Z^2 p(1-p)}{e^2} \tag{5.4}$$

Where

n_0 = the sample size;

Z = the test statistic which is 1.96 for 95% confidence level;

p = the estimated proportion of an attribute that is present in the population; and

e = the desired level of precision.

As populations of the two developments are small, Equation (5.5) developed by Cochran [Cochran, 1963] has been adopted to adjust the sample size:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{\text{Num}}} \tag{5.5}$$

Where

n = the corrected sample size; and

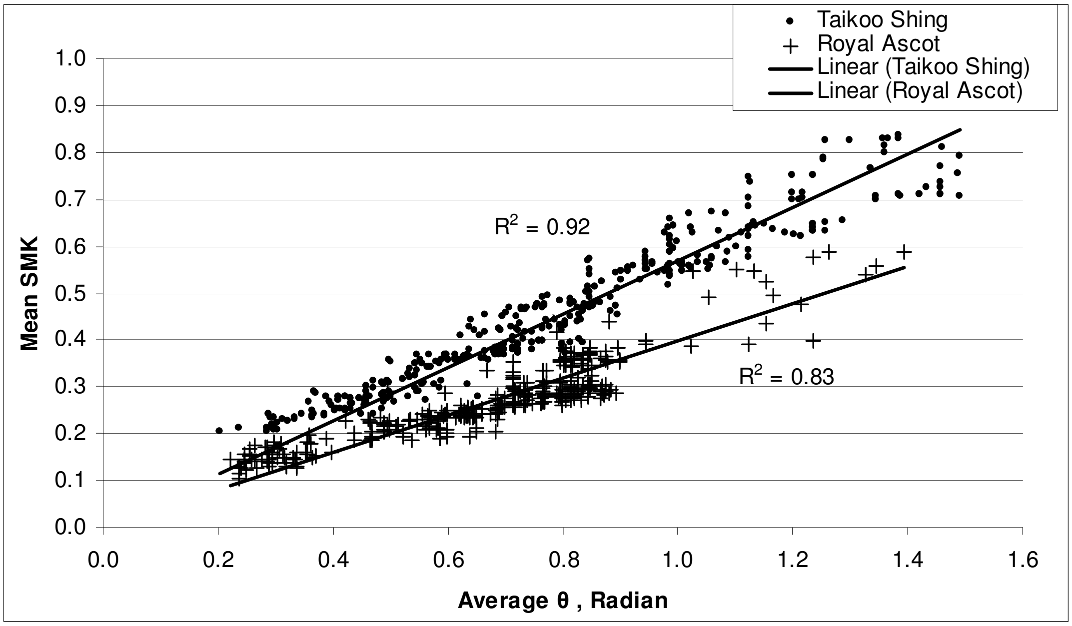
Num = the population size.

Incorporating n_0 and N of the two developments in Equation (5.5), the corrected sample size (n) required for Royal Ascot and Taikoo Shing was found to be 334 and 374, respectively.

The selection of sample units was again on every 10th floor plus the topmost floor basis. However, the number of specific units selected for the sample differs slightly between Royal Ascot and Taikoo Shing owing to the difference in the scale of the two developments. For Royal Ascot, depending on the number of units on each floor, five to six residential units were randomly selected from the six target floors of all 10 housing blocks for a sample of 334 units. In case of Taikoo Shing, depending on the total number of blocks for each phase of development, one to two constituent blocks were randomly selected. For each target floor of the selected block, all eight residential units were selected as sample units to meet the sample size of 374 units.

Based on the precisely built 3D models for Royal Ascot and Taikoo Shing, $\overline{\text{SMK}}$ and $\bar{\theta}$ of the sample units were accurately determined for the correlation analysis.

Figure 5.7 Correlation Analysis of $\overline{\text{SMK}}$ and $\bar{\theta}$ of Two Residential Estates



The simulated $\overline{\text{SMK}}$ and the calculated $\bar{\theta}$ of the sample units of the two case study developments were correlated, as shown in Figure 5.7. They were separately correlated to acknowledge the site specific characteristics of the two developments. It can be seen that they both exhibit a strong linear correlation and the trend lines are intercepted at zero. The R^2 for Royal Ascot is 0.83, while that of Taikoo Shing is

0.92. Correlations tend to be stronger for a wider range of values [Hill and Lewicki, 2006]. While the site scale of Taikoo Shing is much bigger than that of Royal Ascot, there is a wider range of $\overline{\text{SMK}}$ and $\bar{\theta}$ (ranging from 0.2 to 0.84 for $\overline{\text{SMK}}$ and 0.2 to 1.49 for $\bar{\theta}$), as opposed to a range of 0.1 to 0.59 for $\overline{\text{SMK}}$ and 0.22 to 1.39 for $\bar{\theta}$. Thus, the correlation is weaker in the Royal Ascot case.

The strong correlations between $\overline{\text{SMK}}$ and $\bar{\theta}$ support the hypothesis that $\bar{\theta}$ can be used as a performance indicator for view obstruction of a residential unit to supplement view description.

5.10 Conclusion

A review of methods commonly adopted to assess view obstruction was conducted. The properties transaction record of four representative residential estates in Hong Kong in 2005 and the pictorial view of each residential unit in the record were reviewed. It was confirmed that there is a correlation between property price and view obstruction in Hong Kong. On the basis of the findings, it is recommended that for high-rise high-density urban environments like Hong Kong, where the view obstruction level differs only slightly among residential units, view should be represented by daylight obstruction to enable scientific allocation of a premium for view obstruction. Accordingly, shading mask was adopted to assess view obstruction. Case studies were conducted to confirm that the mean shading mask value ($\overline{\text{SMK}}$) can be effectively used to represent the subjective view obstruction level of a residential unit as checked from 1:1000 digital maps and by site visits. Along the conceptual background of shading mask, a performance indicator, i.e. the average angle of obstruction ($\bar{\theta}$), which can be determined based on the geometrical primitives of a residential unit was established as an alternative to shading mask simulations. The $\overline{SMK}$ and $\bar{\theta}$ of 708 residential units randomly selected from two representative residential estates in Hong Kong were determined for a correlation analysis. Comparison of $\overline{SMK}$ determined by the detailed computer simulation method and the calculated $\bar{\theta}$ showed a strong correlation ($R^2 = 0.83$ and 0.93). The strong correlation confirmed that $\bar{\theta}$ could be used as a performance indicator for daylight obstruction of a residential unit. Upon the establishment of $\bar{\theta}$, a monetary value for different view qualities can be more accurately determined. Accordingly, stakeholders will be provided with useful information to enable an objective and continuous evaluation of view obstruction of a residential unit for an optimum decision.

CHAPTER 6 DEVELOPING THE INDICATOR FOR NATURAL VENTILATION PERFORMANCE

As discussed in Chapter 3, CFD simulations are adopted for evaluating the influence of different parameters affecting natural ventilation performance.

Previous study [Gao and Lee, 2011a] identified that openings configurations, orientation of the unit, and the prevailing wind directions exert substantial influence on natural ventilation performance of a residential unit. Openings configuration is defined by many spatial parameters, including orientation of the unit, relative positions and sizes of window openings, type of window and the prevailing wind directions.

In respect of relative positions of window openings, previous research works are focused on evaluating the performance of cross and single-sided ventilations. Hassan et al. [Hassan, 2007] conducted CFD simulations and wind-tunnel experiments to investigate the effects of window positions on ventilation characteristics of a simple single room. It was concluded that single-sided ventilation with two distant openings (one far left and one far right) performed better than two adjacent openings (center-located). Favarolo et al. [Favarolo, 2005] also adopted CFD simulations and laboratory experiments to analyze the influence of openings configurations on natural ventilation performance. It was concluded that when dealing with single-sided ventilation, ventilation performance was most affected by the vertical level and width of the openings. For cross ventilation, Tantasavasdi et al. [Tantasavasdi, 2001] found that ventilation performance was better with a larger inlet than with a larger outlet; and Yin et al. [Yin, 2010] reported that ventilation performance was most influenced by the relative level of the two window openings.

It is evident from the above as far as relative positions of window openings is concerned; the mode of ventilation (cross- and single-sided ventilation) is of major consideration. Thus, natural ventilation performance of a residential unit is mainly affected by the mode of ventilation (cross or single-sided), orientation of the unit, size of window openings, and type of window.

To provide a basis for the study of the most influential parameter affecting natural ventilation performance under varying wind directions, a hypothetical residential unit(s) representing typical residential units was formulated. Formulation of the hypothetical unit was based on an extensive survey of floor areas, window types, window areas and window orientations of a representative residential estate in Hong Kong.

6.1 Representative residential estate

Given the vast number of domestic households in Hong Kong (2.05 millions), a representative residential estate needs to be identified to facilitate the investigation of the influence of various parameters on the ventilation performance of residential premises.

One of the constituent estates of Centa-City Index, Mei Foo Sun Chuen (MFSC) located at Kowloon Hong Kong, has been identified as the representative residential estate for further investigations owing to four key features: i) it consists of 99 blocks, which is the largest residential estates in Hong Kong; ii) the household distribution by floor area matches perfectly with that of Hong Kong (i.e. 40-69.9m^2, 70-99.9m^2, 100-159.9m^2 and over 160m^2, to be explained in 6.1.1); iii) the ventilation mode adopted includes both cross ventilation and single-sided ventilation types; and iv) a wide variety of window areas and window types are adopted.

MFSC aged over 40 years consists of 13,500 residential units accommodating approximately 60,000 people. The 99 blocks in MFSC were developed in eight phases with large variations in floor layouts. A review indicates that there are altogether 48 different types of floor layouts. It is therefore almost impossible to conduct simulations based on all the layouts. Accordingly, hypothetical layouts need to be formulated to represent typical characteristics of all 48 floor layouts.

Living room is considered the most used area in a household**.** To be consistent with the study on view obstruction (Chapter 5), focus was given to living room layouts. A survey of their architectural characteristics was therefore conducted to identify typical living room floor areas, window types, orientations and window areas.

6.1.1 Floor area

According to the Rating and Valuation Department of Hong Kong [RVD, 2004], residential units are classified into Classes A to E according to the saleable areas (Class A: <39.9 m^2; Class B: 40–69.9 m^2; Class C: 70–99.9 m^2; Class D: 100–159.9 m^2; and Class E: >160 m^2), while Classes B to E are most found. Based on the same classification, the dimensions of living room of all 48 layouts were measured. The average dimensions of living rooms by area group are summarized in Table 6.1. Accordingly, the hypothetical living room was assumed with the following four dimensions.

Table 6.1 Average dimensions and area range of living rooms

Class Unit	Area range, m^2	Length, m	Width, m	Average floor area, m^2
B	40 - 69.9	2.36	1.57	3.71
C	70 - 99.9	4.47	3.22	14.39
D	100 - 159.9	5.84	4.97	29.02
E	> 160	8.46	6.72	56.85

6.1.2 Window type

A survey of the types of window used in MFSC was conducted. It was noted that two types of windows were commonly used: side hung and end-slider types. Side hung windows are popular because of large operable area, while end-slider type is simple and space saving. For side hung window, depending on the position of the fixed vision pane, can further be classified into high head and medium head types. They are therefore further classified as high head (Type A) and medium head (Type

B) windows. Thus there are altogether three window types as shown in Figure 6.1, where Type C refers to the end-slider type.

Figure 6.1 Three window types

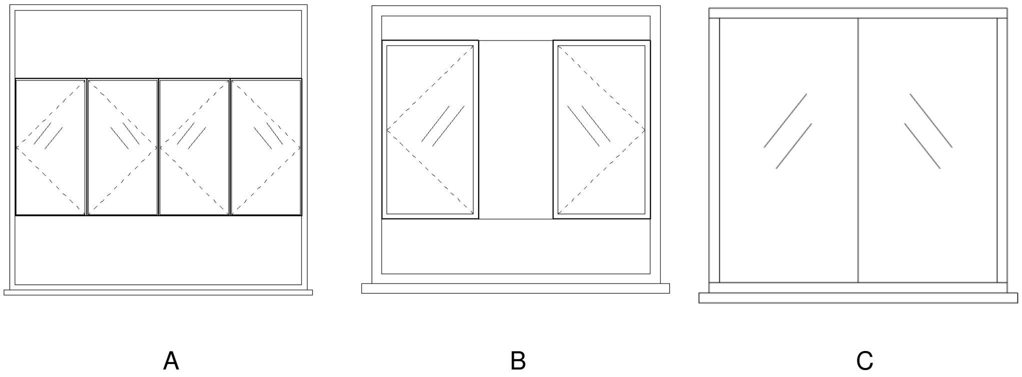
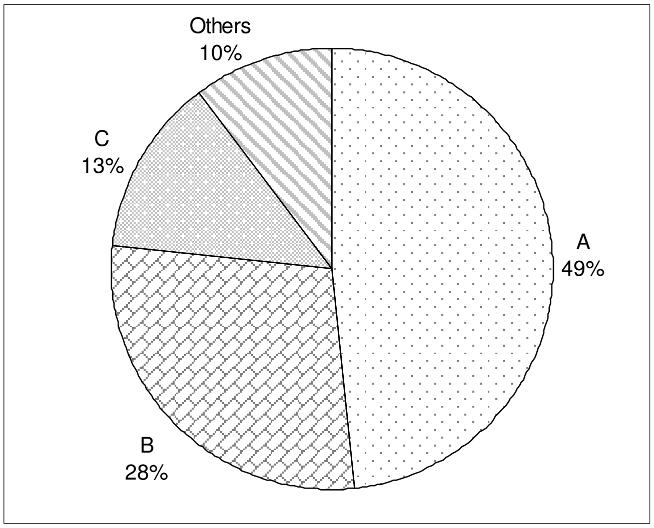


Figure 6.2 Distributions by window type

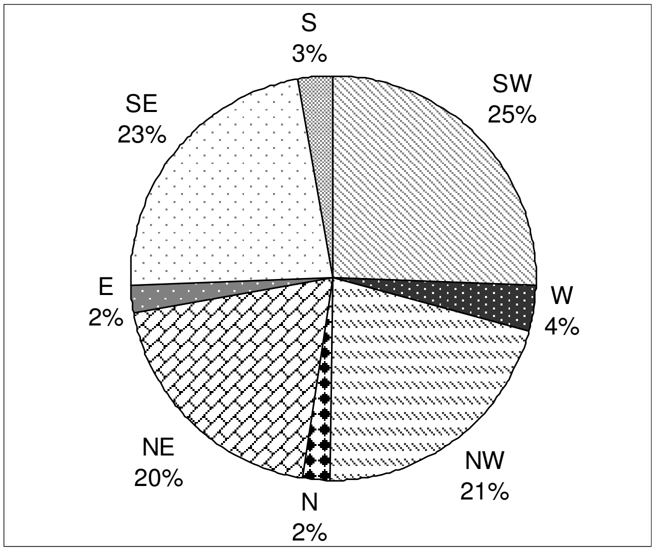


The distribution of window types in MFSC is shown in Figure 6.2, and the hypothetical living room is assumed provided with these three window types.

6.1.3 Orientation

Windows can be located at different positions in a living room. A survey of the orientation of living room windows of MFSC was conducted. They were then classified into eight orientation groups, namely: south (S), southwest (SW), west (W), northwest (NW), north (N), northeast (NE), east (E) and south east (SE). It was found that SW (25%), NW (24%), NE (20%) and SE (23%) were the four most occurred orientations, as shown in Figure 6.3. Accordingly, the window of the hypothetical living room was assumed facing these four orientations.

Figure 6.3 Distributions by window orientation

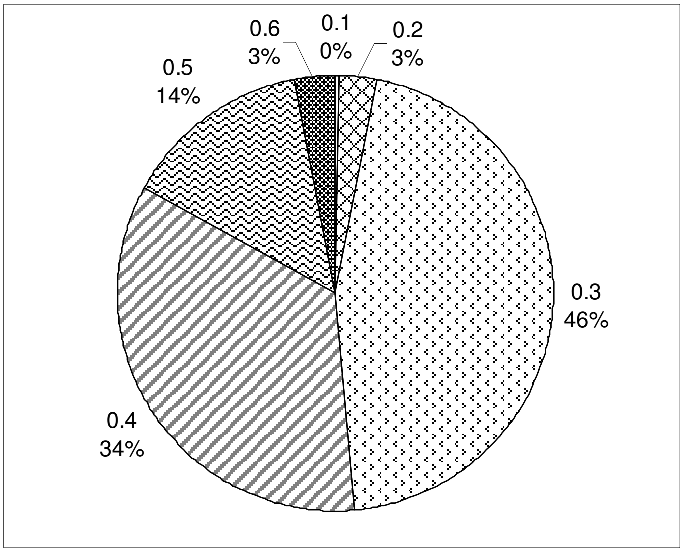


6.1.4 Window to wall ratio, WWR

Since MFSC aged over 40 years, elevation drawings of building blocks are not available in government record and in public domain for ascertaining window areas. Given window area is linked with wall area, a commonly used parameter, window-to-wall area ratio (WWR), is adopted instead.

Ascertaining WWR was accomplished from photographs taken on site. Although a certain level of uncertainty could not be avoided, the living room windows could still be classified into groups of WWR between 0.1 and 0.6, as shown in Figure 6.4. It can be seen that the most frequently occurred WWR are of values 0.3 to 0.5 of which have been assumed for the hypothetical living room.

Figure 6.4 Distributions by WWR



6.2 CFD simulations

Upon determining the floor areas, window types, orientations and WWR values of the hypothetical units, CFD software AIRPAK was used to simulate airflow distributions.

Mean age of air (MAA) was adopted to reflect natural ventilation performance of the simulation models. This concept has been widely applied in similar studies. [Walker & White, 1992; Gan, 2000; Gao & Lee, 2011b]. The area with smaller MAA indicates better ventilation performance. MAA at a sample point is defined as:

$$\mathrm{MAA_i} = \frac{1}{\mathrm{C_0}} \int_0^\infty \mathrm{C_i}(\mathrm{t})\mathrm{dt} \tag{6.1}$$

Where

$\mathrm{MAA_i}$ = the mean age of air at the sample point;

$\mathrm{C_0}$ = the initial contaminant concentration at the sample point;

$\mathrm{C_i}(\mathrm{t})$ = the contaminant concentration at the sample point as a function of time, obtained by regression of measured values over the decay period.

A mathematical module is embedded in AIRPAK for calculation of MAA. It relates the local air age spectrum to properties of the air flow pattern in the domain. Under steady state condition, the local air age at any position depends only on the flow characteristics. Upon checking the IAQ/thermal comfort item in the basic parameter settings dialog box prior to running the solver, MAA at any position in the domain can be determined when the solution is converged.

6.2.1 Simulation cases

Based upon results in section 6.1, simulation cases were established as summarized in Table 6.2. For cases with type C window, WWR of 0.5 was assumed because they served also as the full-height full-width balcony access door. Accordingly, cases generated by changing the parameters include 2 ventilation modes, 2 window types, 3 WWR, 4 orientations and 4 living room dimensions to become 192 cases. Adding the 32 cases generated by type C window, there are altogether 224 cases. Simulations were conducted based on varying only one input parameter for each simulation, with all other parameters retained.

Table 6.2 Simulation cases

Ventilation Mode	Single-sided; Cross	
Window Type	A; B; C	
WWR	0.3; 0.4; 0.5	
Window Orientation	SW; NW; NE; SE	
Living Room	Dimensions (L x W x H; m)	Area (m^2)
	2.36 x 1.57 x 2.7	3.7
	4.47 x 3.22 x 2.7	14.39
	5.84 x 4.97 x 2.7	29.02
	8.46 x 6.72 x 2.7	56.85

6.2.2 CFD simulations settings

6.2.2.1 Prevailing wind conditions

Natural ventilation performance of a residential unit can change from time to time when wind direction and conditions change. The weather condition in summer in Hong Kong was taken as the boundary conditions in the simulations, which was south-westerly wind of 2.65m/s. The wind direction was assumed based on a review of the meteorological conditions of Hong Kong in July and August between 1961 and 1990 of which the prevailing wind directions were at southwest for over 67% of the time [HKO, 2005], while the wind speed was with reference to that of the Typical Meteorological Year (TMY) of Hong Kong (i.e. 1989). The influence of ambient temperature was ignored because temperature difference between indoor and outdoor environments is small during ventilation seasons in Hong Kong. Ventilation was therefore taken as isothermal.

6.2.2.2 CFD model and settings

Three dimensional models were constructed by AIRPAK for CFD simulations.

The renormalization group (RNG) $k-\varepsilon$ turbulence model was used to simulate the steady state natural ventilation. The SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) pressure-velocity coupling algorithm was used to discretize the controlling equations in AIRPAK. The solution was considered converged when residual flow were less than or equal to their specified convergence criteria 10^{-3}.

The calculation domain was set as 5L x 5W x 3H, where L, W & H are the length, width and height of the hypothetical units.

The selected turbulence model, associated parameter settings and calculation domain were determined by reference to a similar study with same terrain category [Gao and Lee, 2011b].

6.3 Results

Indoor air flow distributions of the 224 cases were simulated by the use of AIRPAK. The simulated MAA values as well as the maximum (MAA_{max}), minimum (MAA_{min}) and average MAA ($\overline{MAA}$) values were compared for evaluating the influence of each parameter on natural ventilation performance of the hypothetical units.

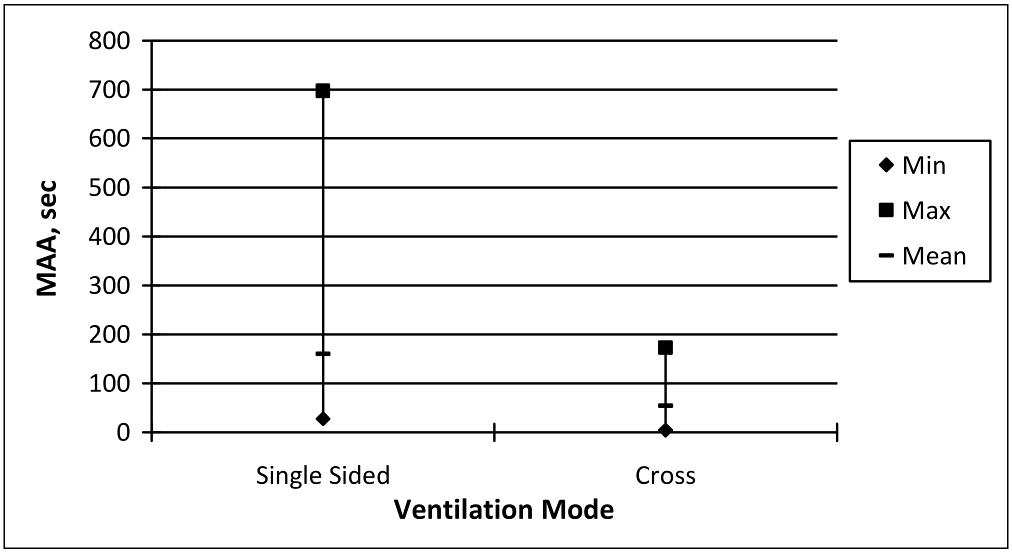
6.3.1 Influence of ventilation mode

The 224 simulation cases were grouped by ventilation mode: cross and single-sided ventilation. The simulated MAA values are compared in Table 6.3 and Figure 6.5. It can be seen in Table 6.3 that $\overline{MAA}$, MAA_{min} and MAA_{max} of single-sided ventilation mode are bigger than that of cross ventilation mode by 1.9 to 5.3 times. While in Figure 6.5, it can be seen that MAA of the single-sided ventilation cases are constantly higher than that of the cross ventilation cases. The results indicate that MAA is significantly affected by the mode of ventilation.

Table 6.3 MAA values by ventilation mode

Ventilation Mode	MAA_{min} (sec)	MAA_{max} (sec)	$\overline{MAA}$ (sec)
Single-sided	27.92 (+527%)	697.42 (+304%)	159.7 (+193%)
Cross	4.45 (0%)	172.58 (0%)	54.33 (0%)

Figure 6.5 Simulated MAA by ventilation mode



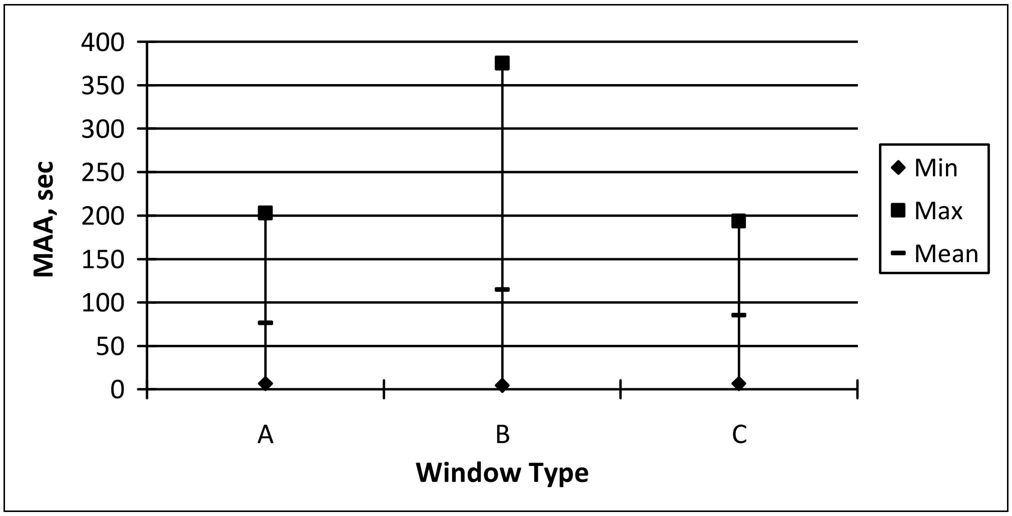
6.3.2 Influence of window type

The 224 simulation cases were grouped by window type. There were 96 cases each for types A and B window, and 32 cases for type C window. Since WWR of 0.5 was only considered for type C window, MAA values of window types A and B with same WWR were therefore extracted for a fair and focused comparison. Comparisons are shown in Figure 6.6 and Table 6.4. It can be seen in Figure 6.6 that there are cases that MAA of window type B is greater than 350sec, while other window types are only around 200sec. The comparison in Table 6.4 indicated that MAA_{min}, MAA_{max}, and $\overline{MAA}$ values of window types A and C were comparable, but that of window type B were 85% and 51% higher than window type A. The results indicate that window types A and C are better performing than window type B.

Table 6.4 MAA values by window type (WWR = 0.5)

Window Type	MAA_{min} (sec)	MAA_{max} (sec)	$\overline{MAA}$ (sec)
A	6.52 (0%)	202.83 (0%)	76.30 (0%)
B	4.45 (-32%)	375.51 (+85%)	114.89 (+51%)
C	6.69 (-2.6%)	193.42 (-4.6%)	85.42 (+12%)

Figure 6.6 Simulated MAA by window type (WWR=0.5)



6.3.3 Influence of WWR

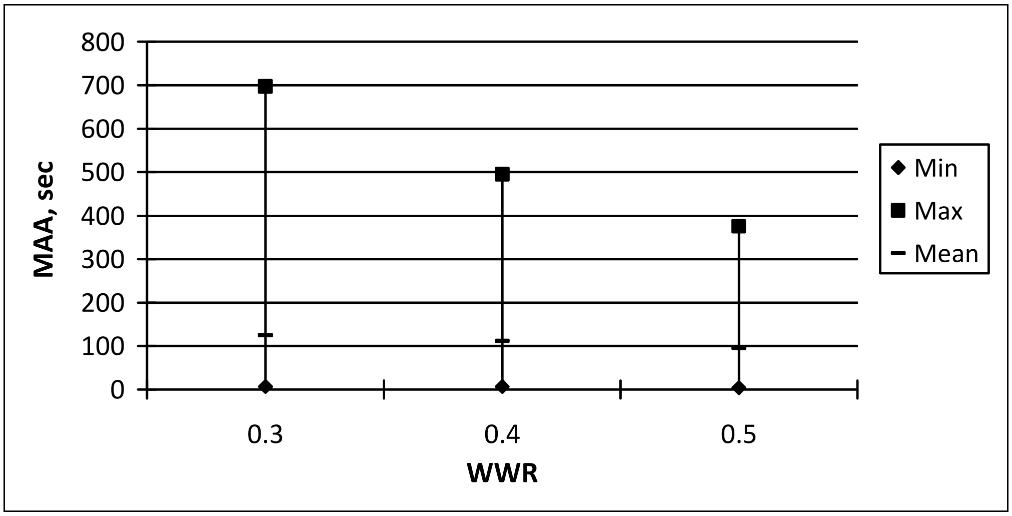
The 224 simulation cases were grouped by WWR (=0.3, 0.4 and 0.5). There were 64 cases each for WWR of 0.3 and 0.4 and 96 cases for WWR of 0.5 As discussed in section 6.3.2, cases with window type C (WWR = 0.5 only) were excluded for a focused and fair comparison of MAA by WWR. Comparisons are shown in Figure

6.7 and Table 6.5. It can be seen in Figure 6.7 that MAA decreased with an increase in WWR. The comparison in Table 6.9 indicated that MAA_{min}, MAA_{max}, and $\overline{\text{MAA}}$ values of cases with WWR of 0.5 were on average 50.5%, 59% and 23.5% smaller than those of WWR 0.3 and 0.4.

Table 6.5 MAA by WWR (window type C excluded)

WWR	MAA_{min} (sec)	MAA_{max} (sec)	$\overline{\text{MAA}}$ (sec)
0.3	6.84 (+53%)	697.42 (+86%)	124.64 (+30%)
0.4	6.62 (+48%)	495.72 (+32%)	111.61 (+17%)
0.5	4.45 (0%)	375.51 (0%)	95.60 (0%)

Figure 6.7 Simulated MAA by WWR (window type C excluded)



6.3.4 Influence of window orientation

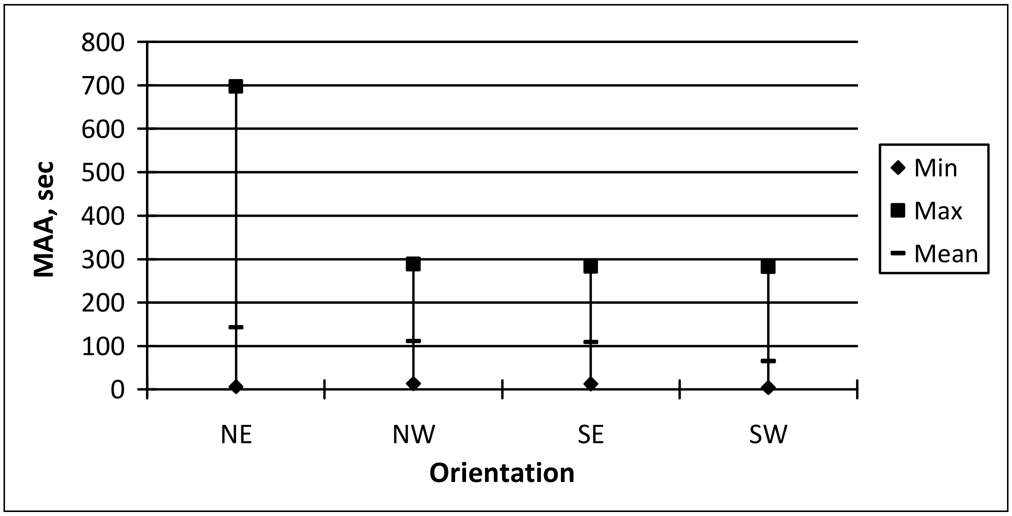
The 224 simulation cases were grouped by window orientation (NE, NW, SE, and SW). Results are shown in Figure 6.8 and Table 6.6. It can be seen in Figure 6.8 that the average MAA of SW facing windows are constantly smaller than those of other orientations. The comparison of MAA_{min}, MAA_{max}, and $\overline{\text{MAA}}$ values in Table 6.6

indicated SW facing window was the best, followed (in descending order) by SE, NW and NE facing windows.

Table 6.6 MAA values by window orientation

Window Orientation	MAA_{min} (sec)	MAA_{max} (sec)	$\overline{MAA}$ (sec)
NE	6.52 (+47%)	697.42 (+147%)	142.64 (+118%)
NW	13.32 (+199%)	288.83 (+2%)	111.29 (+70%)
SE	12.61 (+183%)	283.42 (0%)	108.64 (+66%)
SW	4.45 (0%)	282.56 (0%)	65.49 (0%)

Figure 6.8 Simulated MAA by window orientation



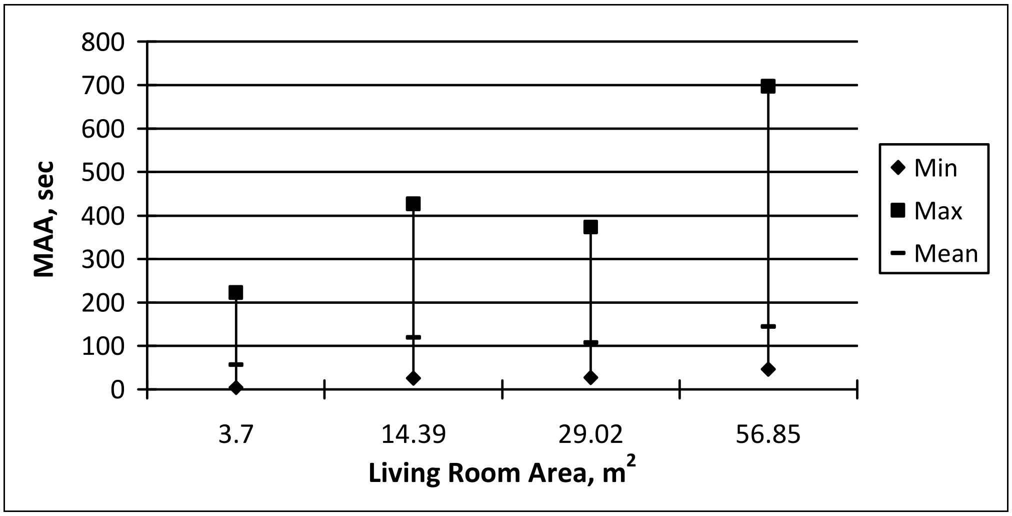
6.3.5 Influence of living room floor area

The 224 simulation cases were grouped by living room floor area. Results are shown in Figure 6.9 and Table 6.7. It can be seen in Figure 6.9 that MAA increases with an increase in floor area. The comparison of MAA_{min}, MAA_{max}, and $\overline{MAA}$ values in Table 6.7 indicated that living room with smallest area performed much better than other area range. Their difference in $\overline{MAA}$ (s) ranged between 90% and 155%.

Table 6.7 MAA by living room area

Living Room Area (m^2)	MAA_{min} (sec)	MAA_{max} (sec)	$\overline{MAA}$ (sec)
3.7	4.45 (0%)	222.53 (0%)	56.66 (0%)
14.39	25.84 (+481%)	426.57 (+92%)	119.47 (+111%)
29.02	27.38 (+515%)	373.03 (+68%)	107.68 (+90%)
56.85	46.68 (+949%)	697.42 (+213%)	144.25 (+155%)

Figure 6.9 Simulated MAA by living room area



6.4 Performance indicator identification

It is evident from the above that each of the studied parameter will exert a certain level of influence on natural ventilation performance of the hypothetical units. For identifying the most influential parameter for representing natural ventilation performance of a residential unit, regression study was conducted for sensitivity analysis.

The studied parameters affecting natural ventilation performance of a residential unit were assumed independent variables for inclusion into a regression model as shown in Equation (6.2). Linear regression analysis was conducted using the statistical package, SPSS [2011].

$$\begin{aligned} MAA = {} & \alpha_1 VENT + \alpha_2 WIN_A + \alpha_3 WIN_B + \alpha_4 ORI_{NE} + \alpha_5 ORI_{NW} \\ & + \alpha_6 ORI_{SE} + \alpha_7 WWR + \alpha_8 AREA + \beta \end{aligned} \tag{6.2}$$

Where

MAA = the mean age of air (sec)

VENT = ventilation mode (0 for single-sided ventilation, and 1 for cross ventilation)

WIN_A = window type A (0 for no, 1 for yes)

WIN_B = window type B (0 for no, 1 for yes)

ORI_{NE} = living room window orientation - NE (0 for no, 1 for yes)

ORI_{NW} = living room window orientation - NW (0 for no, 1 for yes)

ORI_{SE} = living room window orientation - SE (0 for no, 1 for yes)

WWR = window to wall ratio (dimensionless)

AREA = living room area (m^2)

α_n = coefficient (n = 1 thru' 8)

β = constant

It is worth to mention that qualitative variables in Equation (6.2) were numbered as described to facilitate the regression analysis. The "enter" regression method was adopted for determining the standardized coefficients for the variables. The standardized coefficients are used to reflect the level of significance. A higher value indicates an increase in significance. A negative coefficient indicates that MAA decreased with an increase in the variable, and vice versa.

The resultant model constructed by regression analysis is:

$$\begin{aligned} MAA = 134.44 - 105.37VENT - 9.23WIN_A + 30.58WIN_B + 77.15ORI_{NE} \\ + 43.15ORI_{NW} + 45.8ORI_{SE} - 1.45WWR + 1.34AREA \end{aligned} \quad (6.3)$$

Table 6.8 Summary of standardized coefficients

	Standardized Coefficients
VENT	-0.565
WIN_A	-0.049
WIN_B	0.162
ORI_{NE}	0.358
ORI_{NW}	0.200
ORI_{SE}	0.213
WWR	-0.130
AREA	0.286

Standardized coefficients determined by regression analysis are compared in Table 6.8. It can be seen that signs of the coefficients are judged to be reasonable. Amongst all studied parameters, ventilation mode (VENT) is the most significant parameter affecting natural ventilation performance of a residential unit, followed (descending order) by window orientation (ORI_{NE}, ORI_{NW} & ORI_{SE}), living room area (AREA), window-to-all ratio (WWR), and window type (WIN_A & WIN_B).

Furthermore, based upon the influence of the studied parameters on the MAA as discussed in 6.3.1 to 6.3.5, negative coefficients for VENT, WIN_A and WWR, and positive coefficients for WIN_B, ORI_{NE}, ORI_{NW}, ORI_{SE} and AREA are judged to be reasonable.

It is therefore evident that the mode of ventilation (VENT) will be selected as the indicator to represent natural ventilation performance of residential units.

6.5 Conclusion

CFD simulations using AIRPAK were used to evaluate the influence of various parameters on natural ventilation performance of residential dwellings. Hypothetical living rooms were formulated to facilitate the analysis. They were formulated on the basis of an extensive survey of living room area, window type, window area, and window orientation of residential units in a representative estate in Hong Kong. Cases generated by varying the parameters include two ventilation modes, three window types, three window areas, four orientations, and four floor areas. The influence of the parameters was evaluated by regression analysis. Based on the determined standardized coefficients, it was found that natural ventilation performance, represented by the mean age of air (MAA), was most affected by the ventilation mode adopted (VENT) and thus it was selected as the performance indicator for natural ventilation performance.

CHAPTER 7 DEVELOPING THE PRICE INDEX FOR ARCHITECTURAL AND ENVIRONMENTAL QUALITY OF RESIDENTIAL UNITS IN HONG KONG

In the literature review in Chapter 2, it was identified that residential properties' market price were affected by combinations of architectural and environmental attributes. The identified architectural attributes include floor area, floor level, orientation and window-to-wall ratio. Whilst for environmental attributes, simple indicators to enable quantifying traffic-inducted noise and air quality, daylight performance, view obstruction, and natural ventilation performance were formulated in Chapters 4, 5, and 6. In respect of the method to be adopted for valuating the architectural and environmental attributes, it was concluded that the hedonic price approach was the most suitable method.

This chapter presents the adoption of the hedonic price approach for developing the price index for architectural and environmental quality of residential properties in Hong Kong. Given residential properties' market price is affected also by site-specific factors (discussed in Chapter 2); the price index model will be different between residential estates. In this study, two residential estates were selected for establishing the price index models for comparison and analysis. Based upon the developed price index models, willingness-to-pay (WTP) for each architectural and environmental attributes will be identified.

7.1 Development of the price index model by hedonic price approach

7.1.1 Forms of price index model

The hedonic price approach provides different forms of equations for determining the price and WTP of a commodity. Whilst there is no theoretical linkage between the functional notation and a specific functional form, linear and semi-log forms are generally used for studies on housing markets [Jim and Chen, 2006]. Accordingly, bundle of architectural and environmental attribute characteristics of a residential unit can be related to its market price by the linear model:

$$PRI = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + \ldots\ldots + a_nX_n \tag{7.1}$$

Where

PRI = the selling price of a residential unit (HK$/ft^2)

X_n = the attributes of a residential unit

a_n = the marginal willingness-to-pay for each X_n

a_0 = the constant

Whilst for the semi-log form, it can be used to relate the unit change in market price of a residential unit for unit change of each constituent variable (X)

Since,

$$\ln PRI = a'_0 + a'_1 \ln X_1 + a'_2 \ln X_2 + a'_3 \ln X_3 + \ldots\ldots + a'_n \ln X_n \qquad (7.2)$$

Considering the change of dependent and independent variables

$$\Delta \ln PRI = a'_0 + a'_1 \Delta \ln X_1 + a'_2 \Delta \ln X_2 + a'_3 \Delta \ln X_3 + \ldots\ldots + a'_n \Delta \ln X_n \qquad (7.3)$$

By conducting partial derivatives of Equation (7.2) with respect to each constituent variable (X_n),

$$\frac{\partial PRI}{PRI} = a'_1 \frac{\partial X_1}{X_1} + a'_2 \frac{\partial X_2}{X_2} + a'_3 \frac{\partial X_3}{X_3} + \ldots\ldots + a'_n \frac{\partial X_n}{X_n} \qquad (7.4)$$

It can be seen in Equation (7.4) that the physical meaning of a'_n is the percentage change in market price of a residential unit for unit change of X, which in other words, is the elasticity between the independent variable and the market price of a residential unit.

As dummy variables cannot be log-transformed (e.g. X_3, X_n, etc.), the semi-log form of the price index model (Equation (7.2)) becomes:

$$\ln PRI = a'_0 + a'_1 \ln X_1 + a'_2 \ln X_2 + a'_3 X_3 + \ldots\ldots + a'_{n-1} \ln X_{n-1} + a'_n X_n \qquad (7.5)$$

7.1.2 Selection of model variables

The dependent variable, i.e. market price of a residential unit (PRI) and five independent variables included in this study are summarized in Table 7.1.

It can be seen in Table 7.1 that amongst the several architectural attributes identified affecting the properties' market price; only two completely different parameters are included as independent variables. They are the floor area of the residential unit (FLA), and living room window orientation (ORI). The reason for excluding the other two identified architectural attributes (floor level, and window-to-wall ratio) is to avoid multicollinearity (near linear dependence) with LogR and VENT respectively. The concern about multicollinearity can be revealed from Table 7.1 that floor level is directly related to LogR (the logarithm of the distance from road), and window-to-wall ratio is affected by FLA.

Besides FLA, ORI, Log R, and VENT, the other independent variable included in the model is the mean angle of unobstructed sky ($\bar{\theta}$), which was identified as a simple indicator for quantifying daylight performance and view obstruction.

For evaluating the unit change in market price of a residential unit per unit change of X, there is a need to identify the baseline case for qualitative attributes, which in this case, are ORI and VENT. For ORI, according to the results in Chapter 6 and literature review in Chapter 2, the west facing windows were less preferred, and thus they were identified as the baseline case. As a result, only ORI of north (N), south (S) and east (E) were coded. Likewise for VENT, single-sided ventilation was less preferred, and thus only cross ventilation was coded.

Table 7.1 Independent variables

Variable		Details	Unit / Code
PRI		Market price of the residential unit	HK$ / ft^2
FLA		Floor area of the residential unit	ft^2
ORI	N	Living room window orientation - North	No = 0; Yes = 1
	E	Living room window orientation - East	No = 0; Yes = 1
	S	Living room window orientation - South	No = 0; Yes = 1
LogR		The logarithm of the distance from road	---
$\bar{\theta}$		Mean angle of unobstructed sky	Radian
VENT		Existence of the cross ventilation window	No = 0; Yes = 1

7.1.3 Construction of price index models

Based upon Equation (7.1), the correlation between the properties' market price and attribute characteristics of the residential units (the identified independent variables) can be expressed by the below linear hedonic price model:

$$PRI = a_0 + a_1(FLA) + a_2(ORI_N) + a_3(ORI_E) + a_4(ORI_S) + a_5(LogR) + a_6(\bar{\theta}) + a_7(VENT) \quad (7.6)$$

Where

a_0 = constant

$a_1 - a_7$ = the marginal willingness-to-pay for each attribute

As discussed in Chapter 3, transactions records in 2005 will be adopted in this study and thus reflects the marginal willingness-to-pay (WTP) of each studied attribute.

The qualitative independent variables, i.e. ORI_N, ORI_E, ORI_S and VENT, have not been log-transformed and based upon Equation (7.5); the semi-log hedonic price model is expressed as:

$$\begin{aligned} \ln PRI = {} & a'_0 + a'_1\ln(FLA) + a'_2(ORI_N) + a'_3(ORI_E) + a'_4(ORI_S) \\ & + a_5'\ln(LogR) + a'_6\ln(\bar{\theta}) + a'_7(VENT) \end{aligned} \tag{7.7}$$

Where

a'_0 = constant

$a'_1 - a'_7$ = elasticity between the independent variable and market price of a residential unit

7.2 Case study estates and data collections

The two residential estates chosen for price analysis were Royal Ascot (RA) and City One Shatin (COS). They were widely referenced and adopted in previous Chapters' evaluations and studies. The site-specific conditions and characteristics of these two estates were described in Chapter 4.

The actual transaction data of the two case study estates in 2005 were collected from the Land Registry of Hong Kong. It was found that the average market price of RA was HK$5251/ft^2 whilst that of COS was HK$3146/ft^2. This indicates that the two estates attract different groups of home buyers and hence as discussed in the earlier sections, the data will be separately analyzed and likewise for the development of price index models.

On collection of the transaction data, it is noted that there are data points “very distant" from the other points for unknown reasons, and thus the box plot analysis was conducted to remove the outliners. Upon removal of the outliners, 134 (out of 143) and 1134 (out of 1139) transaction data were included in price analysis for RA and COS, respectively.

Different methods were adopted in ascertaining the attribute characteristics of the residential units in the transaction record. Floor area of the residential units (FLA) was obtained directly from the transaction record. Orientations of the residential units’ living room windows (ORI) were ascertained from the map of the case study estates, whilst methods for determining the distance from room and thus Log R and the mean angle of unobstructed sky ($\bar{\theta}$) were described in Chapter 4 and Chapter 5, respectively. Finally, the existence of the cross ventilation (VENT) of the residential units were identified from the layout plan of each residential units.

7.3 Price index model

Upon ascertaining the attribute characteristics of 134 and 1134 residential units in RA and COS, linear regression analysis was performed using the statistical package, SPSS. Since this study objects to find out the WTP of the architectural and environmental attributes, all identified variables will therefore be included in the regression analysis. Accordingly, 'Enter' regression method was adopted to determine the coefficients for each independent variable. The results generated from the regression analysis include the price index models and standardized coefficients. The price index models for RA and COS are shown in correspondingly in Equations (7.8) and (7.9), and Equations (7.10) and (7.11), whilst that of the standardized coefficients are summarized correspondingly in Tables 7.2 and 7.3, and Tables 7.4 and 7.5.

Linear model for RA:

$$\begin{aligned} \mathrm{PRI} = {} & 2281.17 + 0.05(\mathrm{FLA}) + 17.25(\mathrm{ORI_N}) + 339.09(\mathrm{ORI_E}) \\ & + 305.75(\mathrm{ORI_S}) + 198.3(\mathrm{LogR}) + 385.85(\bar{\theta}) + 367.96(\mathrm{VENT}) \end{aligned} \tag{7.8}$$

Semi-log model for RA:

$$\begin{aligned} \mathrm{lnPRI} = {} & 8.163 + 0.008\ln(\mathrm{FLA}) + 0.005(\mathrm{ORI_N}) + 0.066(\mathrm{ORI_E}) \\ & + 0.058(\mathrm{ORI_S}) + 0.042\ln(\mathrm{LogR}) + 0.076\ln(\bar{\theta}) + 0.071(\mathrm{VENT}) \end{aligned} \tag{7.9}$$

Table 7.2 Standardized coefficients of linear model for RA

	FLA	ORI_N	ORI_E	ORI_S	LogR	$\bar{\theta}$	VENT
Standardized coefficients	0.026	0.016	0.299	0.261	0.347	0.246	0.384

Table 7.3 Standardized coefficients of semi-log model for RA

	lnFLA	ORI_N	ORI_E	ORI_S	lnLogR	$\ln\bar{\theta}$	VENT
Standardized coefficients	0.200	0.023	0.305	0.263	0.309	0.228	0.390

Linear model for COS:

$$\begin{aligned} PRI = {} & 2587.71 + 0.02(FLA) + 55.70(ORI_N) + 145.19(ORI_E) + 105.25(ORI_S) \\ & + 102.11(LogR) + 225.04(\bar{\theta}) + 412.73(VENT) \end{aligned} \tag{7.10}$$

Semi-log model for COS:

$$\begin{aligned} lnPRI = {} & 7.857 + 0.016\ln(FLA) + 0.019(ORI_N) + 0.048(ORI_E) + 0.035(ORI_S) \\ & + 0.080\ln(LogR) + 0.052\ln(\bar{\theta}) + 0.122(VENT) \end{aligned} \tag{7.11}$$

Table 7.4 Standardized coefficients of linear model for COS

	FLA	ORI_N	ORI_E	ORI_S	LogR	$\bar{\theta}$	VENT
Standardized coefficients	0.007	0.065	0.181	0.131	0.076	0.189	0.481

Table 7.5 Standardized coefficients of semi-log model for COS

	lnFLA	ORI_N	ORI_E	ORI_S	lnLogR	$\ln\bar{\theta}$	VENT
Standardized coefficients	0.032	0.065	0.182	0.134	0.096	0.193	0.430

It can be seen that positive coefficients have been generated for all the variables of which are judged to be reasonable. Positive coefficients indicate a positive effect on the properties market price. The four models have similar coefficient of determination (R^2) which range between 0.464 and 0.541. Considering there are over 100 samples for both case study estates, the resultant R^2 indicates a significant correlation to confirm architectural and environmental attributes have a positive influence on the properties' market price [Milton, 1987].

The R^2 for RA is 0.541 (linear model) and 0.534 (semi-log model), whilst that of COS is 0.5 (linear model) and 0.464 (semi-log model). Correlations tend to be stronger for a smaller number of samples [Hill & Lewicki, 2006]. Whilst the site scale of COS is much bigger than that of RA, the correlation is thus stronger in the RA case.

From the standardized coefficients of the independent variables in the two semi-log modes (Tables 7.4 and 7.5), WTP for the studied attributes of the two case study residential estates are compared in Table 7.6.

Table 7.6 WTP for various attributes

Attributes			Independent Variable	RA	COS
Architectural	Floor area of residential unit		FLA	0.8%	1.6%
	Orientation of living room window	North	ORI_N	0.5%	1.9%
		East	ORI_E	6.6%	4.8%
		South	ORI_S	5.8%	3.5%
Environmental	Traffic-induced noise and air quality		LogR	4.2%	8%
	Daylight performance and view obstruction		$\bar{\theta}$	7.6%	5.2%
	Natural ventilation performance		VENT	7.1%	12.2%

7.4 Influence of various attributes on property price in Hong Kong

It can be seen in Table 7.6, WTP is the lowest for ORI_N of RA. However, considering ORI has been split into three options (N, E and S); WTP of ORI options will be separately discussed.

Amongst other attributes, it is noted that FLA of both RA and COS elicit the smallest WTP, which are 0.8% and 1.6%, respectively. Another attribute which shows similar result in both estates is the angle of unobstructed sky ($\bar{\theta}$). The WTP are 7.6% in RA and 5.2% in COS. The results indicate that floor area of a residential unit exert relatively insignificant impact on properties' market price, whilst the impact of daylight performance and view obstruction are comparable for the two studied estates. Consistent results have been obtained because they both consist of a wide range of unit floor areas (ranging from 715 ft^2 to 1620 ft^2 for RA and 389 ft^2

to 1018 ft^2 for COS), and offer different kinds of views (Racecourse view for RA and river view for COS).

WTP of LogR of COS is nearly double that of RA (8% vs 4.2%). The result is reasonable because as described in Chapter 4, building towers in COS are distinctively located in the interior and perimeter zones. Towers in the interior zone (with higher LogR) are blocked by towers in perimeter zone units and thus they are more preferred for less traffic-induced noise and air quality problem. Whilst building towers in RA is constructed along a busy road. The influence of distance from road is therefore less significant to result in smaller WTP for LogR.

WTP of VENT for COS (12.2%) is the highest amongst attributes and is slightly smaller for RA (7.1%). The results are also judged to be reasonable because COS is a large scale development consisting of 51 blocks, as opposed to 10 blocks of RA. The 51 blocks in COS are blocking each other and thus the availability of cross ventilation to enhance natural ventilation performance is more preferred as compared to RA.

Whilst for WTP of ORI, the results revealed that changing the living room window orientations from west facing to east and south facings exerted the highest impact on the properties' prices, with WTP ranging between 3.5% and 6.6%. This matches with the conventional wisdom of Hong Kong people favoring east and south facing windows. WTP of ORI ($\overline{ORI}$ = 3.1% and 4%) has been found smaller than other environmental attributes is also considered reasonable because over 80% households in Hong Kong rely on air-conditioner to maintain thermal comfort in summer [Lee, et al., 2010] to minimize the influence of ORI.

It is worthy to mention that the constant value for Equations (7.8) and (7.10) are relatively large to indicate that there is a premium for each residential unit and the corresponding site specific characteristics.

7.5 Conclusion

In order to identify the price influence of different architectural and environmental attributes on residential properties' market in Hong Kong, price index models were developed by the hedonic price approach. The models relate the market price of residential units with five independent variables. The independent variables include two parameters for reflecting the architectural characteristics of a residential unit which include floor area (FLA) and orientation of the living room windows (ORI). Whilst the other three independent variables are the simple indicators identified to represent the environmental characteristics of residential units. They are the distance from road (LogR), mean angle of unobstructed sky ($\bar{\theta}$) and existence of cross ventilation (VENT). Following on the generally used hedonic price approach for residential properties' market, linear and semi-log forms were adopted in developing the price index models.

The resultant price index models were generated by regression analysis using the statistical package, SPSS. Based upon the coefficients obtained from the semi-log price index models of two studied estates, the willingness-to-pay (WTP) of various architectural and environmental attributes on properties' market price was found. Environmental attributes including natural ventilation performance, daylight performance and view obstruction, and traffic-induced noise and air quality were given higher WTP, whilst the architectural attributes including floor area and living room window orientation (represented by $\overline{\mathrm{ORI}}$) were given lower WTP.

The results revealed that WTP for good environmental quality contributed to 0.5% to 12.2% of the property price in Hong Kong. This information, of which is in absence in extant literature, will be useful for encouraging building developers to construct for better environmental quality, and for the homebuyers in making home purchase decisions.

CHAPTER 8 DISCUSSIONS AND CONCLUSIONS

Review of relevant literatures showed that residential property prices are affected by property-specific characteristics. Little has been stipulated in local codes and ordinances in governing the design of residential buildings in Hong Kong, and thus residential units differ largely in property-specific characteristics. Understanding that price of a residential unit is affected by property-specific characteristics; homebuyers prefer to be provided with the information to enable an objective and continuous evaluation of the property-specific quality of a residential unit and the price for that.

Property-specific characteristics can be categorized into architectural and environmental attributes. Architectural attributes include floor area, building form, floor level, window area, orientation, etc., and environmental attributes include the indoor air quality, acoustic environment, quality of view, daylight performance, natural ventilation performance, etc. While architectural attributes can easily be measured, suitable tools to enable an objective and continuous evaluation of the environmental quality of a residential unit are lacking in extant literature. The review concluded that the development of such tools and the price for different architectural and environmental attributes were needed.

This study adopted field measurements, site visits, simulations and statistical analysis for the development of the tools, whilst the hedonic price approach was used for the identifying the market price for the architectural and environmental attributes.

Field measurements were conducted for identifying a common performance indicator for traffic-induced noise and air-quality in residential units. These included noise level and PM_{10} concentration measurements. They were done at six carefully selected residential units (located at two residential estates) and their nearby road sides. The noise level measurements enabled the establishment of the measurement protocol to identify residential units that were free from external screening. The PM_{10} concentrations monitored at the case study units that were free from external screening and the corresponding roadsides were found logarithmically correlated. The strong correlation ($r^2 = 0.91$ and 0.98) confirmed the reliable use of logarithm of the distance from road (Log R) as the performance indicator for traffic-induced noise and air-quality.

ECOTECT simulations and site visits were conducted for identifying a common indicator for daylight performance and view obstruction (for representing quality of view) of which were reported closely linked. Shading mask, being commonly used for quantifying daylight performance, was proposed also for quantifying view obstruction. ECOTECT simulations were done for generation of the mean shading mask values ($\overline{\mathrm{SMK}}$). Through verifications by site visits, the use of $\overline{\mathrm{SMK}}$ as a performance indicator for assessing view obstruction was confirmed. For easier use of the indicator by non-technical stakeholders, the average angle of unobstructed sky

($\bar{\theta}$) was further proposed as a simplified indicator for $\overline{SMK}$. The reliable use of $\bar{\theta}$ was confirmed ($R^2 = 0.83$ and 0.93) by correlation analysis based on $\overline{SMK}$ and $\bar{\theta}$ of 708 residential units (randomly selected from two representative residential estates in Hong Kong).

CFD simulations were conducted for evaluating the influence of different parameters on natural ventilation performance of residential dwellings. A hypothetical living room was formulated to represent characteristics of living rooms in Hong Kong. They were formulated on the basis of an extensive survey of living room area, window type, window area, and window orientation of residential units in a representative estate in Hong Kong. Based on the hypothetical living room, simulation studies using CFD software AIRPAK were conducted. In the simulations, mean age of air (MAA) of the hypothetical living room with two ventilation modes, three window types, three window areas, three orientations, and four floor areas (altogether 224 cases) were evaluated by regression analysis. Based on the determined standardized coefficients, it was found that MAA was most affected by the ventilation mode adopted (VENT) and thus it was selected as the performance indicator for natural ventilation performance.

Upon the development of the performance indicators for environmental attributes, including traffic-induced noise and air quality, daylight and view obstruction, and natural ventilation, the independent architectural attributes including the floor area of the residential unit (FLA), and living room window orientation (ORI) were also identified. The five attribute characteristics, i.e. LogR, $\bar{\theta}$, VENT, FLA and ORI were taken as independent variables for a price analysis. Hedonic price approach based on linear and semi-log models were adopted for the price analysis. The property price data were based on transaction records in 2005. Price models for two residential estates of different homebuyer groups, namely Royal Ascot (RA) and City One Shatin (COS), were developed. A side-by-side comparison of the two price models indicated that willingness-to-pay (WTP) of FLA was the smallest; and VENT was the highest for COS and the second highest for RA. Whilst for the WTP of other attribute characteristics, there was a minor difference between the two estates but could be explained by their site-specific characteristics. The results revealed that WTP for good environmental quality contributed significantly in Hong Kong's property price.

The WTP information will be useful for encouraging building developers to construct for better environmental quality, and for the homebuyers in making home purchase decisions. While the three performance indicators (Log R, $\bar{\theta}$, and VENT) that have been developed, will enable an objective and continuous evaluation of the environmental quality of a residential unit, which will be useful tools for future research in this area.

However, considering the property price data selected for the analysis are those with less influence by economic and government policies; plus the WTP concluded are based on the results of only two residential estates, the results drawn may not be applicable to buildings with site-specific characteristics that differ greatly to the case study estates, and when the property market is highly fluctuating.

Further study is needed for formulating more generic WTP information to include the influence of economic and government policies as well as site-specific factors.

Moreover, as the noise and air quality measurements were conducted at residential units directly exposed to a major road, the developed performance indicator for traffic-induced noise and air pollution (i.e. LogR) would be restrictive to residential units suffering from road traffic. It is also worthy to mention that as the field measurements conditions and conditions set for simulations including climate conditions, road conditions, traffic volume, building forms, and window characteristics are restrictive to Hong Kong conditions; the performance indicators developed in this study may be not applicable to other countries or regions that have significantly different climate, road traffic and building characteristics with Hong Kong. Further works in ascertaining their influence on the accuracy of the developed indicators are yet to be investigated.

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