URBAN CLIMATIC MAPPING FOR PLANNING – AN EXPERIENCE FROM HONG KONG

Abstract

More than half of the world's population now lives in cities. There are more than a handful of cities that are now mega-cities – that is with a population in excess of 10 million inhabitants. More than 100 cities now have more than 1 million inhabitants. Many of these cities are now in the Topical and sub-tropical regions. Designing them for better human habitation is of paramount importance. The World Meteorological Organisation (WMO) has since their World Climate Conference 3 in 2010 put emphasis on the urban climatic design of cities particularly in view of the coming of climate change. It is known that heat wave will be more frequent, more intense and last longer. The impact to health and safety if climatic issues are not taken into account will be severe.

How to design a city for our next generation that they can continue to sustain life? The paper shares research works on how to design for better urban climate in high density cities in the sub-tropics. It discusses design issues related to greening, urban ventilation and building design. Firstly, it is important to understand the key characteristics of a city's urban heat island intensity due to buildings. Secondly, to allow a better comprehension of the urban climatic characteristics of a city, the methodology of Urban Climatic Map is introduced. The Map synergies the city's morphological characteristics with meteorological data to result in a bio-climatic map that can allow planners and designers a way to visualise the diverse environmental conditions for better decision making. For modifying the urban climate of a city, the four key strategies are introduced. Greening as an effective strategy is explained. Another important design strategy for the sub-tropical climate of Hong Kong is to improve urban air ventilation.

Introduction

Since 2006, more than half of the world population lives in cities. The number of cities and megacities is on the rise; the urban population, especially in Asia, is on the rise as well. There are now more than 20 megacities (i.e., cities with population of more than 10 million) on Earth. More cities are being added to the list. In addition, more than 400 cities now have populations in excess of 1 million. The conversion rate of agricultural land and rural areas into concrete-paved and tarmac-sealed land, especially in rapidly developing regions such as China, is increasing. The United Nations estimated that the urban population in less-developed countries would rise from 0.5 to 3 billion by 2030. Urbanization and higher density living is now an irreversible trend of human urban development (UNFPA, 2009). There are commercial and political reasons for high-density living in mega and compact cities. Higher density and more compact city designs conserve valuable land resources, reduce transport distance (and consequently the energy needed), and make public transport more viable. Advocates argue that high-density cities are more economically efficient. The need for appropriate designs for high-density cities is clear. Designs that take urban climate into consideration are puzzling agenda for planners and urban climatologists.

Mega and high-density compact cities suffer from large conglomerates of urban land mass with high thermal capacity and urban heat island intensity. In addition, they have higher ground roughness and poorer urban ventilation (Landsberg, 1981). High anthropogenic heat and pollution emissions are also problems under weak synoptic wind conditions. High-density compact cities, by their own urban morphological nature, have tall and bulky buildings, which lead to high frontal area density, high building-height-to-street-width ratio, restricted sky view factors, and low solar access . They are also lacking in open and green spaces (Jim, 2004).

Urban landscape creates an urban climate that affects human comfort and environmental health. Generally, the use of climatic knowledge in land use and urban planning is lacking. Planners and policymakers either do not pay sufficient attention to this increasingly important issue, or cannot fully engage the missing link. Understanding this lack of integration between urban climatic and urban planning knowledge is important, especially for planners of mega, high-density, and compact cities (Eliasson, 2000).

Many mega, high-density, and compact cities are located in the tropical and subtropical Southeast Asia, which have hot and humid climatic conditions. Many of these cities are on the coastline. Past ill planning in Hong Kong has resulted in tall buildings that limit incoming sea breeze to inland areas (Ng *et al.*, 2009). For cities next to hills, vegetation is not protected, resulting in lesser katabatic wind and air mass exchange benefits. Cities situated in the basin suffer from low wind penetration and higher air pollution, especially when important air paths through the city are blocked.

In mega, high-density, and compact cities located in the tropical and subtropical region of Southeast Asia, heat-stress-related mortality and morbidity is on the rise (Leung *et al.*, 2008). This has raised the alarm for local politicians and city planners. Given the inevitable event of global warming and extreme weather, health implications of increasing urban heat stress in cities are of topical concern. Heat waves are becoming more frequent, longer in duration, and higher in intensity. One study in Hong Kong has indicated that the occurrence of “heat spells” can increase dramatically. In a nutshell, with 3 ºC of UHI, inhabitants of the city would live almost every day (96 days) and night (127 nights) under high thermal heat stress during the summer (Ng, 2009) (Figure 1). Apart from the impact to health, higher urban temperature also means higher energy consummation for air conditioning (Fung *et al.*, 2006), thereby increasing energy use and CO_2 emission.

Increase of Very Hot Days and Very Hot Nights *(due to intra-urban heat island [T_{iu}] of up to 3 degree C).*

HKO data	**Very hot days** (Tmax>=33)	(Tmax>=32)	Hot days (Tmax>=30)	Hot nights (Tmin>=25)	(Tmin>=27)	**Very hot nights** (Tmin>=28)
T_{iu} increase	T_{iu}= 0	T_{iu}= +1	T_{iu}= +3	T_{iu}= +3	T_{iu}= +1	T_{iu}= 0
	No., of very hot days			No., of very hot nights		
2008	**15**	42	74	115	48	**15**
2007	**25**	61	117	121	52	**23**
2006	**3**	25	82	117	53	**15**
2005	**12**	33	93	135	51	**26**
2004	**6**	26	94	123	47	**19**
2003	**14**	40	91	139	62	**20**
2002	**10**	32	93	133	45	**17**
2001	**9**	38	90	121	41	**16**
2000	**10**	40	99	124	51	**22**
1999	**6**	49	113	133	56	**17**
average	**10.6**	38.2	96.9	127.3	50.8	**19.5**

(no. of very hot days) = 28.85*(Tiu)+ 10.1 R2 = 0.99
(no. of very hot nights) = 36.26*(Tiu) +17.5 R2 = 0.99

Figure 1: Impact of increasing urban heat island to the occurrence of very hot days and very hot nights.

Noting the inevitable implications of urban climatic issues on health and comfort, the green and sustainable movement for city planning has gathered momentum in recent years. Since 2002, the Cabinet in Tokyo has had a general task force comprising the ministries concerned to address such issues. In 2005, the Hong Kong government established the First Sustainable Development Strategy for Hong Kong; in 2006, it launched the Feasibility Studies for the Establishment of Air Ventilation Assessment System. Since 2004, the Singaporean government has been finding ways to understand these problems and has attempted to address them by commissioning various studies. Since 2009, the city government of Taipei has begun to pay attention to these same problems. At least for some quickly urbanizing areas, political will is present; only the methods remain to be a concern for the planners and the politicians.

Urban Climate Map and Urban Diversity

The preparation of the draft Urban Climatic Analysis Map for Hong Kong takes into account the German and Japan experiences [including references to the Federal German Standard VDI-3787-Part1 Environmental Meteorology] and the unique climatic characteristics and urban morphologies of Hong Kong. The Urban Climatic Analysis Map (UC-AnMap) translates the urban climatic factors into a classification system with different climatopes and values assigned according to their positive or negative effects on Thermal Load and Dynamic Potential.

Climatically relevant geometrical data (topographical, land use and buildings information) from the Planning Department, as well as evaluated data from urban climatologists and wind experts of the consultant team are input to a Geographic Information System (GIS) to become the UC-AnMap. The collated information of the UC-AnMap is stored in 100m x 100m grid layers in the GIS system. They are classified and calculated based on the Dynamic Potential and Thermal Load contributions to the urban climate. The two considerations are then combined based on their net effects on human thermal Physiological Equivalent Temperature (PET) values to result in a 1:5000 scale map. Some field case studies have been conducted to refine and verify the UC-AnMap. On this basis, further Wind Information based on HKO measured data and simulated wind data (MM5) from Hong Kong University of Science and Technology are added, and air paths are evaluated to produce the final UC-AnMap.

Information regarding meteorological, topographical, land use, building volume, building coverage, open spaces, urban and natural landscaping are evaluated and generalised to form the UC-AnMap at 1:5000 scale useful for the planning purpose. The reference time frame of the UC-AnMap is the summer months of 2007. The UC-AnMap is useful for planning purpose at OZP level. Based on the UC-AnMap, eight climatic classes have been categorized. They are:

Moderately Negative Thermal Load and Good Dynamic Potentials (Class 1) These areas are situated on the higher altitudes of mountains and steep vegetated slopes. Adiabatic cooling and trans-evaporative cooling are prevalent to bring about good dynamic potentials and moderately negative thermal load. As a result, the temperature is usually very cool. These areas are sources of cool and downhill wind;

Slightly Negative Thermal Load and Good Dynamic Potentials (Class 2) These areas are extensively covered by natural vegetation, greenery, and natural coastal areas including the hilly slopes. Trans-evaporative cooling is prevalent to bring about good dynamic potentials and slightly negative thermal load. As a result, the temperature is generally cooler. These areas are sources of cool and fresh air;

Low Thermal Load and Good Dynamic Potentials (Class 3) These areas usually consist of more spaced out developments with smaller ground coverage and more open space very near the sea. As a result, the temperature is mild;

Some Thermal Load and Some Dynamic Potentials (Class 4) These areas usually consist of low to medium building volumes in a developed yet more open setting;

Moderate Thermal Load and Some Dynamic Potentials (Class 5) These areas usually consist of medium building volumes situated in low-lying areas further inland from the sea or in areas fairly sheltered by natural topography. As a result, the temperature is warm;

Moderately High Thermal Load and Low Dynamic Potentials (Class 6) These areas usually consist of medium to high building volumes located in low-lying development areas with relatively less urban greenery. As a result, the temperature is very warm;

High Thermal Load and Low Dynamic Potentials (Class 7) These areas usually consist of high building volumes located in low-lying well-developed areas with little open space. As a result, the temperature is generally hot in these areas;

Very High Thermal Load and Low Dynamic Potentials (Class 8) These areas usually consist of very high and compact building volumes with very limited open space and permeability due to shielding by buildings on many sides. Full and large ground coverage is prevalent and air paths are restricted from the nearby sea or hills. As a result, the temperature is very hot in these areas.

The categorization and grouping of the UC-AnMap are by magnitudes of their positive dynamic potentials and negative thermal load effects (Figure 2). Urban climatically valuable areas should be preserved. Planning actions and mitigations should be directed to climatic zones that are critical and important, most particularly, the highly climatically sensitive areas.

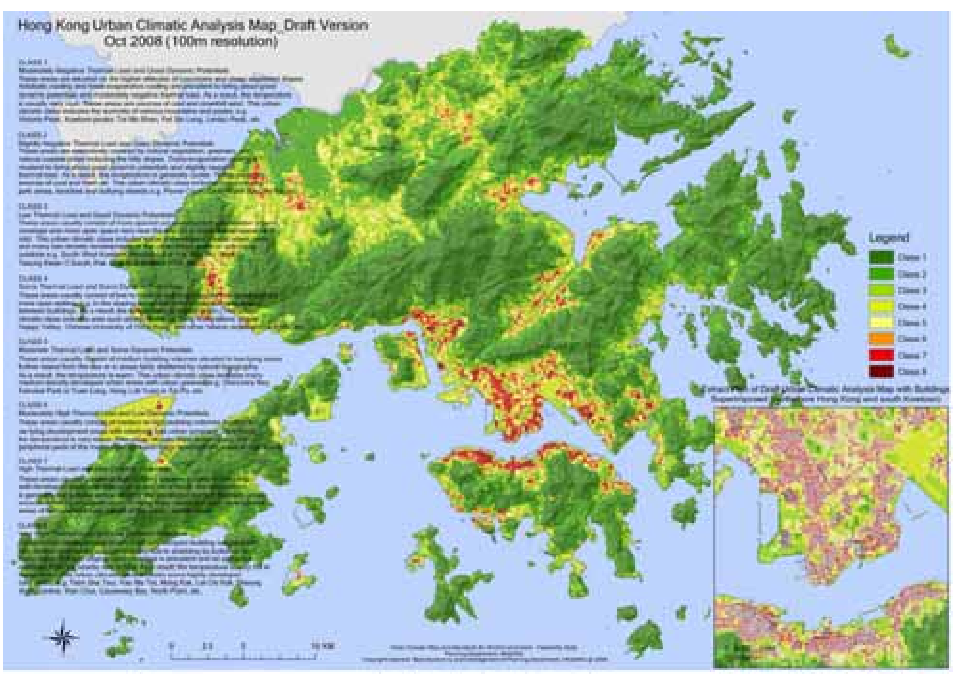

Figure 2: The Urban Climatic Analysis Map of Hong Kong.

Key Planning and Design Strategies

Based on the UC-AnMp understanding, there are fundamentally 4 key strategies to mitigate the ill-effects of urban climatic issues. They are: Albedo, Vegetation, Shading and Ventilation (Figure 3). Based on the scientific understanding, a number of planning actions can be formulated. Their effectiveness has different time and spatial scale. For example, dealing with urban ventilation needs a long time scale as it can be difficult to quickly change the existing urban fabric. It also has a small spatial scale in that an air path will only benefit its immediate surroundings, thus one may need a whole array of air paths for the city as a whole.

Figure 3: Strategies and Planning Actions towards better urban climate.

Greening and Tree Planting

Greening reduces surface temperature and thus minimizes the radiant energy of the urban environment. Moist soil and leave surfaces increase the city's Bowen Ratio and increase Trans-evaporation, thus help to lower urban air temperature. However, grass surfaces are less effective than tree planting in that the leaf area ratio of grass surfaces is a lot less that trees, and more importantly, it does not provide a shaded air space that human activity can take place underneath. Experimental results have indicated that 30% greening can be effective lowering urban air temperature by 1 degree. Groups or lines of trees are more useful than simple trees; trees with leaved canopy are better than palm trees; and trees at grade where pedestrian frequent is more effective than trees on roof tops.

Cool Materials

Under sun, tarmac road surfaces can have surface temperatures reaching up to 65 degree C, lighter colour concrete surfaces are around 40 degree C and leaf surfaces are cooler at only one or two degrees above air temperature. Cool materials are normally light colour materials that reflect back short wave radiation. The surface temperatures of cool materials are lower than normal materials. This helps to lower the urban environment's mean radiant temperature and improve human comfort. Recently, advancement in material science means that some darker colour materials can behave like light colour materials. However, they are still expansive. Some cool materials are perforated meaning that water can be stored and evaporate back cooling the air. They are useful to be considered for paving.

Air Space and Building Ground Coverage

For hot and humid climatic conditions, in order to promote evaporation of sweat from our skin surfaces, air ventilation is very important. Urban air ventilation depends on the roughness of the ground surface, the street canyon ratio and most importantly, the air volume near ground. Reducing urban ground coverage is an effective design strategy. Experimental results evaluating air ventilation potentials and the urban frontal air density indicate that the overall urban ground coverage should not exceed 50%. That is to say, the site coverage should be less than 70%. Site level non building areas, street level building setbacks, stepped podia, building gaps near ground – design strategies inline with Hong Kong Planning Standards and Guidelines – are useful design strategies.

Urban Building Porosity and Permeability

In line with the understanding above, building porosity and permeability reduces urban frontal area density and improves air ventilation. Buildings Department has recently published APP152 that contains good guidelines for designers.

Shading

Colonnades and canopies shade pedestrian from the direct sun in the summer. This greatly reduces human body's mean radiant temperature. Tree shading can be more effective as the surface temperatures of leaf surfaces are lower than concrete or metal surfaces. It is important that no glazed materials should be used as shading devices. In addition, metal surfaces can hot quickly and are also not suitable to be used especially when the surfaces are close to human head levels.

Building Volumes and Building heights

Concrete and artificial surfaces store heat and re-radiate it back to the urban environment, thus causing urban heat island. Tall buildings and narrow street canyons reduces the sky view of the surfaces and limits its re-radiation potentials; heat is than trapped inside the urban canyon causing heat stress in the summer months. Limiting building volume may mitigate the problem. However, for high density Hong Kong, this design strategy may be difficult to implement. As such, a balanced approach to increase air volume near the ground level whilst allowing taller buildings to be built is a reasonable compromise. Experimental results also show that a city with a good variation of building heights in close proximity can improve air mixing, allow wind downwash and increase air diffusion.

Reduce Anthropogenic Heat of the City

Traffic and building waste heat are anthropogenic heat sources that increase urban air temperature. Building energy efficiency measures are useful reducing this. District cooling measures that take away the waste heat source is a useful strategy. Reducing vehicle volume, encouraging public transport and promoting cycling and walking are helpful too; but of course this has to be coupled with a general improvement of the urban outdoor environment before walking and cycling can be more comfortably conducted.

Central in Hong Kong as an Example

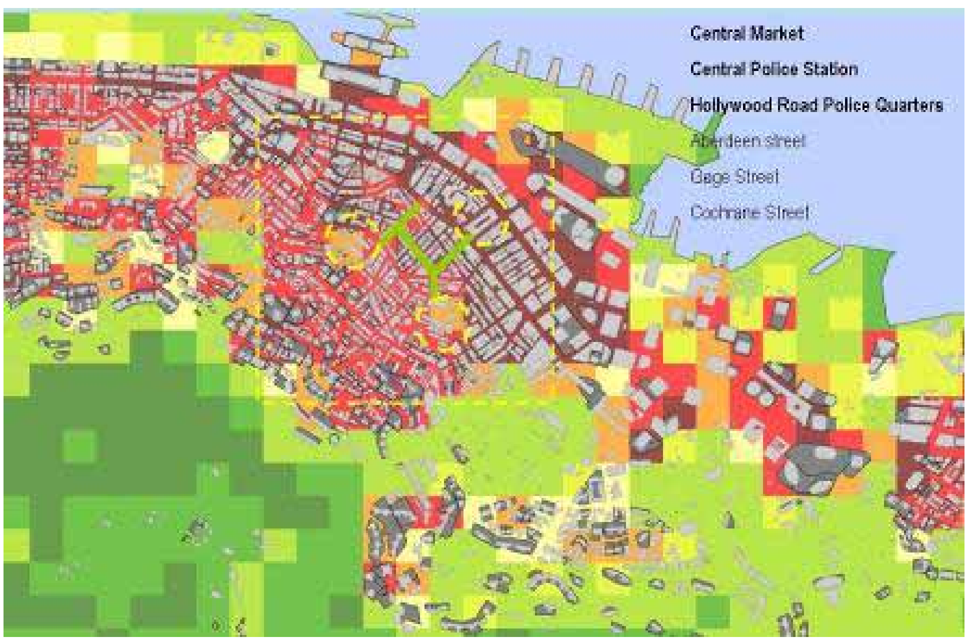

Figure 4: Central / Sheung Wan areas of Hong Kong with a large concentration of UC-AnMap Class 8 areas. Open spaces and green oasis networked with green corridors will improve the area.

Referring to Figure 4, the UC-AnMap of Hong Kong indicates that Central / Sheung Wan Districts currently suffer from having a large cluster of Very High Thermal Load and Low Dynamic Potentials (Class 8) areas (Figure 4). In the summer months of Hong Kong, the probability of human suffering from heat stress is high. To immediately mitigate the adverse urban climatic condition of the area, it is suggested that green corridors and green oasis be planted into the area allowing breathing and resting spaces for pedestrian (Figure 5). Experimental results have indicated that a networked green oasis with enhanced tree planting to three of the existing open spaces and three of the connecting streets can help to reduce the UC-AnMap class by 1 thus providing relieves to the stressful urban environment. As such the Government's initiative to preserve Central Market and turn it into a green oasis is supported (Figure 6)

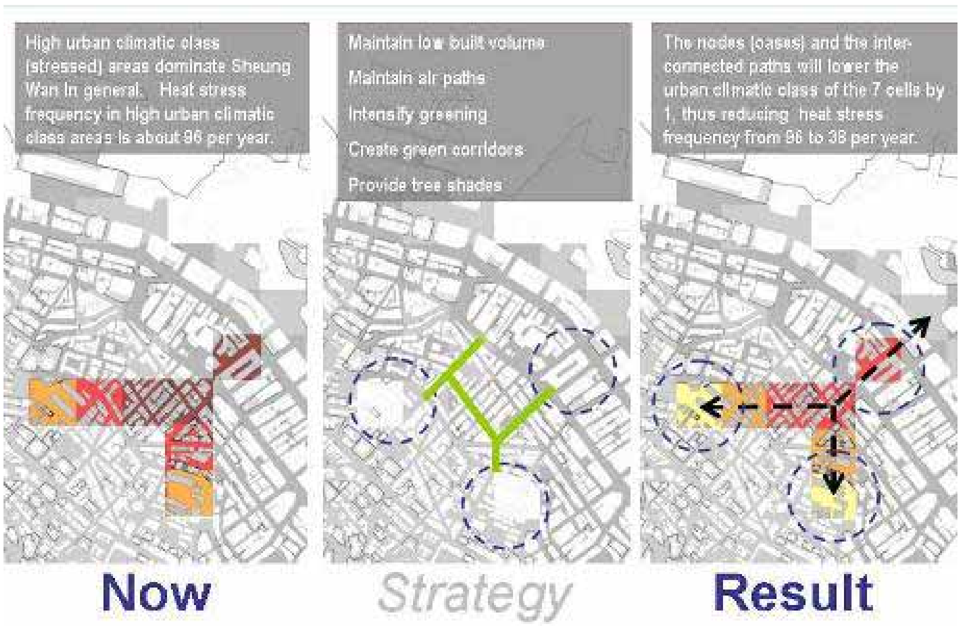

Figure 5: Design strategies recommended.

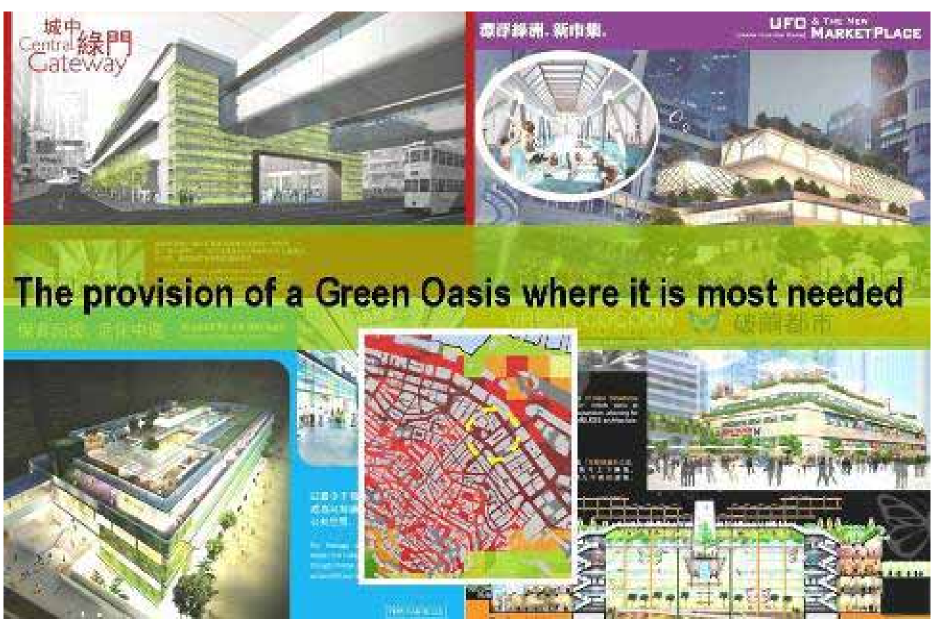

Figure 6: Greening Central Market: Intensify greening (tree planting) on the roof and in the courtyard, as well as providing vertical greening is suggested.

References

Eliasson I. 2000. The use of climate knowledge in urban planning. *Landscape and Urban Planning* **48**: 31-44.

Fung WY, Lam KS, Hung WT, Pang SW, Lee YL. 2006. Impact of Urban Temperature on Energy Consumption of Hong Kong. *Energy* **31**: 2623-2637.

Jim CY. 2004. Green-space preservation and allocation for sustainable greening of compact cities. *Cities* **21**: 311-320.

Landsberg HE. 1981. *The Urban Climate*. Academic Press: New York.

Leung YK, Yip KM, Yeung KH. 2008. Relationship between thermal index and mortality in Hong Kong. *Meteorological Applications* **15**: 399-409.

Ng E, Ren C, Katzschner L, Yau R. 2009. Urban Climatic Studies for Hot and Humid Tropical Coastal City of Hong Kong. *In Proceedings of 7th Int. Conf. on Urban Climate (ICUC2009),* Yokohama, Japan, 29 June-3 July 2009.

Ng E. 2009. Policies and technical guidelines for urban planning of high-density cities - air ventilation assessment (AVA) of Hong Kong. *Building and Environment* **44**: 1478-1488.

UNFPA. 2009. *The State of World Population*. United Nations Population Fund.

Acknowledgement

The research work of Hong Kong's UC-AnMap is funded by Planning Department of HKSAR Government.

Contact

Professor Edward Ng
School of Architecture, Chinese University of Hong Kong
Shatin, NT, Hong Kong. www.edwardng.com