Justin CK Ho

A review of studies on the relationship between urban morphology and urban climate towards better urban planning design in (sub)tropical regions

Justin CK Ho[1], Chao Ren[2], Edward Ng[3]

[1] *Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong SAR, China, justinhe@cuhk.edu.hk*

2 School of Architecture & Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong SAR, China, renchao@cuhk.edu.hk

3 School of Architecture & Institute of Environment, Energy and Sustainability, The Chinese University of Hong Kong, Hong Kong SAR, China,edwardng@cuhk.edu.hk

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1. Introduction

Rapid urbanization and urban growth have some negative effects on urban climate such as urban heat island, bad air quality and lower air flow, which consequently affect the health of habitants living in the cities. Thus better urban planning and design are of great importance to reduce the impact of built-up areas on the surrounding environments. Especially in (sub)tropical regions with rapid urban population growth, built-up areas in these regions expand fast with significant consequences for urban climate.

Researchers have conducted some studies in (sub)tropical regions on the relationship between urban morphology and urban climate. Some urban morphological parameters such as aspect ratio, sky view factor, and frontal area density, etc. have been understood that they have significant impact on urban climate. However, the link between urban morphological parameters and urban planning and design strategies is still weak. Scientific understanding of some morphological parameters affecting urban climate may not easily be transferred to planning and design guidelines to mitigate the negative effects of urban developments. The implication of urban morphology parameters to better urban planning and design in (sub)tropical regions needs to be assessed.

The study reviews the studies on the dependency of urban climate on urban morphological parameters in (sub)tropical regions in several aspects including 1) the spatio-temporal aspect; 2) the dimensions of urban morphological parameters; and 3) the implication to urban planning and design. This review assesses the urban morphological parameters in terms of similarities and contrasts to recommend some suitable parameters for urban climate studies under (sub)tropical climate conditions, which can be transferred to architectural practices without difficulty towards better urban planning and design to improve the urban living quality. Also further work is recommended for collaborative efforts between climatologists and urban planners and designers based on understanding the scientific needs of urban climate studies and the practical needs of urban planning and design applications in (sub)tropical regions.

2. Urban climate and urban living

Two papers presented in World Climate Conference-3 which held in Geneva in 2009 outlined the state-of-art understanding of urban climate for urban planning and design from capabilities perspectives as well as needs perspectives (Grimmond *et al.*, 2010; Mills *et al.*, 2010). Fig. 1 illustrates the schematic framework of the understanding of the linkages between urban climate and urban living based on these two papers. Due to rapid urbanization and urban growth, urban climate has some negative impacts on urban living such as UHI, weak urban ventilation and poor air quality. As fundamental human requirements for thermal comfort and health, there is a need for urban habitants to respond appropriately to mitigate the negative impacts of urban climate for better urban living environments.

The science of understanding urban climate has been developed during the past decades all over the world(Ahmed, 2003; Grimmond *et al.*, 2010) as well as in specific tropical and sub-tropical regions (Roth, 2007). However, information was mainly available in observing and modeling the urban environments and their effects on urban living. Systematic understanding of the responses to the negative impacts of urban climate from human comfort perspective (the linkage of the lower part of the circle in Figure 1) is limited (Mills *et al.*, 2010) especially in tropical and sub-tropical regions. To address this gap, this paper is organized as follows under tropical and sub-tropical climate context: starting from the human comfort needs, towards a systematically understanding of the climate-based responses, to urban planning and design strategies.

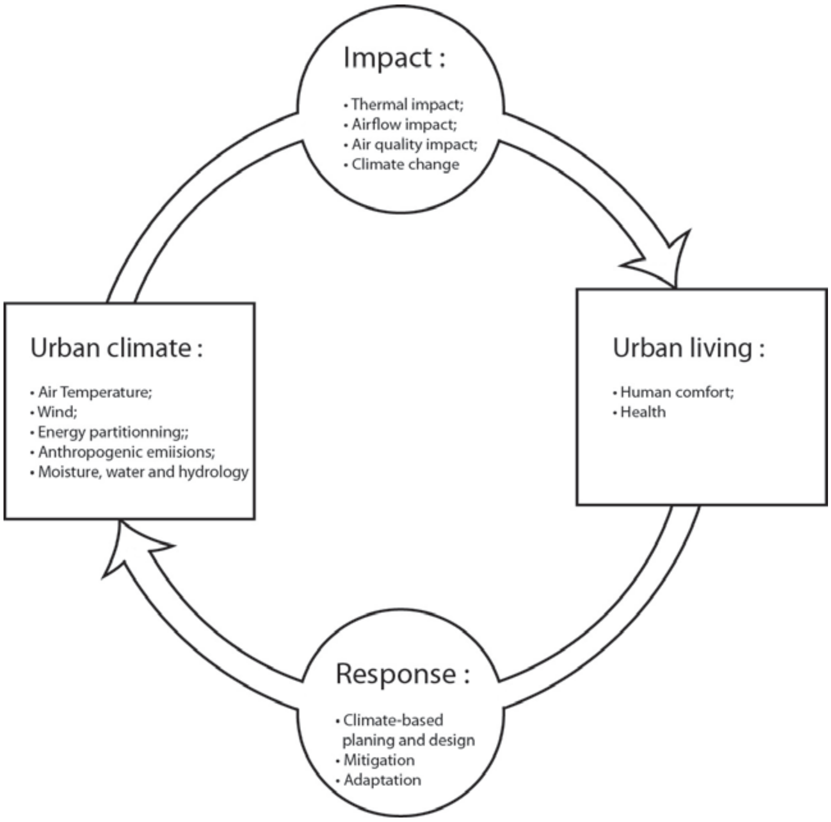

*Fig. 1 Framework of the understanding of the relationship between urban climate and urban living based on Grimmond et al.***(2010)** *and Mills et al.***(2010)***.*

Table 1 A summary of climate information for planning and design at different spatial scales outlined by Ng (2012)

Planning level	**Spatial scale**	**Climate information input**	**Analysis method and tools**	**Climatic understanding for planners /architects**
Regional Planning	Tens or hundreds of kilometers	Long-term meteorological data;	GIS-based mapping; Simulations (meso-scale) and experimental studies	General climatic patterns; Important issues; Criticality of climatic information
District Planning	A few or tens of kilometers	meteorological data, boundary conditions based on the results of meso-scale modelling	GIS-based mapping; Computational fluid dynamics; Field measurements	Descriptive climatic information of a district (map); Parametric understanding of urban morphology and urban climate; Before and after urban climatic scenarios of an intervention
Master Layout Planning /Building design	Half a kilometer or less	Nearby meteorological data	Simulations and experimental studies	Cost-performance studies

3. Climate understanding at different scales

To respond the urban climate impacts from human needs perspective, different climate information are needed for different purposes at different spatial scales, and the focuses and approaches at different spatial scales to understand the climate information vary accordingly. Ng (Ng, 2012) outlined the understanding of climate information in planning practices based on a case study in sub-tropical Hong Kong at different spatial scales (Table 1): regional planning, districting planning, and master layout planning/building design corresponding to different atmospheric scales (Oke, 1987): macro or meso, local and micro scales respectively. No matter at different planning level, for better communication between climatologists and planners/architects, the climate information should be understandable in a simple and graphical way (Ng, 2012). Climatic maps based on scientifically understanding of thermal needs, urban morphology and natural settings such as topography and water bodies can be useful tools for urban planning and design (Chen and Ng, 2011; Katzschner and Mülder, 2008; Ren *et al.*, 2011).

4. Relationship between urban climate and urban morphology

Urban morphology affects the urban microclimate. By knowing the relationship between climate comfort and some urban morphological parameters, guidelines for urban planning and design can be proposed to modify the urban geometry to achieve better urban climate conditions.

Urban form studies are mainly considered in street geometry (height-to-width (H/W) of street canyon), street orientation, Sky View Factor (SVF), density, and other morphological parameters at different spatial scales and under different climate conditions. Table 2 show a summary of studies of urban from affecting urban climate in tropical and sub-tropical regions.

Table 2 A summary of studies on urban forms affecting urban climate

Researchers	**City**	**Climate**	**Spatial scale**	**Urban morphological parameters**	**Approaches**
Emmanuel & Fernando (2007)	Colombo, Sri Lanka; Phoenix, Arizona	equatorial wet; sub-tropical dry	Micro scale	Density	Numerical simulation
Johansson & Emmanuel (2006)	Colombo, Sri Lanka;	equatorial wet;	Micro scale	H/W, SVF, Orientation	Numerical simulation, Field measurements
Ali-Toudert et al. (2005); Ali-Toudert & Mayer (2006)	Beni-Isguen and Ghardaia ,Algeria	sub-tropical dry	Micro scale	H/W	Numerical simulation, Field measurements
Johansson (2006)	Fez, Morocco	sub-tropical dry	Local scale	H/W, Orientation	Field measurements
Fahmy & Sharples (2009)	Cairo, Egypt	sub-tropical dry	Local scale	compactness factor	Numerical simulation
Middel et al. (2014)	Phoenix, the United States	sub-tropical dry	Local scale	LCZ classification	Numerical simulation
Krüger et al (2011)	Curitiba, Brazil	sub-tropical highland		SVF	Numerical simulation, Field measurements
Chen et al.(2012)	Hong Kong	sub-tropical humid	Local scale	SVF	GIS-based simulation
Ng et al.(2011)	Hong Kong	sub-tropical humid	Local	Frontal area density, Ground coverage ratio	Numerical simulation
Yuan & Ng (2012a)	Hong Kong	sub-tropical humid	Local	Different building morphologies	Numerical simulation
Hwang et al (2011); Lin et al. (2012)	Huwei Township, central Taiwan	sub-tropical humid	Local	SVF	Numerical simulation, Field measurements

Some studies mainly focused on street scale by investigating the aspect ratio (H/W) and street orientation effects in the following cities: Colombo in Sri Lanka with hot and humid summer (Emmanuel *et al.*, 2007; Emmanuel and Fernando, 2007; Johansson and Emmanuel, 2006); Beni-Isguen and Ghardaia in Algeria with hot and dry summers (Ali-Toudert *et al.*, 2005; Ali-Toudert and Mayer, 2006) ; Fez in Morocco with hot dry summer (Johansson, 2006). These studies found that deeper street canyon (high H/W ratio) is beneficial to thermal comfort in summer.

For larger urban scales, some factors and methods which can parameterize the urban fabric characteristics were adopted. Fahmy & Sharples (2009)investigated the impacts of different urban forms at a neighborhood scale in Cario, Egypt by adopting an urban morphological factor called compactness factor, which together with other parameters are related to urban thermal comfort represented by PMV values. Middel et al. (2014) studied the microclimate effects in Phoenix, the United States under five different scenarios, which can be fitted into the classification of Local Climate Zone (LCZ)(Stewart and Oke, 2012). Among the five different urban forms, they found that “local cool islands” can be formed in more compact urban geometry (0.2-0.4 SVF) in mid-afternoon. Another studies of SVF conducted in Taiwan and Brazil indicated that the higher SVF may cause thermal discomfort during daytime(Hwang et al., 2011; Krüger et al., 2011; Lin et al., 2010). However, for high-rise, high-density Hong Kong with hot and humid summers, Chen et al.(2012) mapped the SVF for the entire city using a GIS-based method. The results of their studies show that “a decrease of 0.15 in a 100-m radius neighborhood average of SVF may result in 1oC temperature elevation”. As natural ventilation is an important factor contributing to thermal comfort under hot and humid climates (Ahmed, 2003; Chen and Ng, 2012; Ng and Yuan, 2012), some urban morphological parameters such as Frontal Area Density (FAD), Ground Coverage Ratio (GCR)were mapped in Hong Kong to understand the relationship between urban wind environment and urban form for better ventilation(Ng et al., 2011). Another study in Hong Kong investigated the natural ventilation effects at pedestrian level by modifying building morphologies(Yuan and Ng, 2012b).

Table 4 Qualitative Guidelines on Air Ventilation in Chapter 11 of HKPSG(Hong Kong Planning Department, 2011)

Level	**Qualitative guidelines**
District Level	(1) Site disposition
	(2) Breezeways/Air Paths
	(3) Street Orientation, Pattern and Widening
	(4) Waterfront Sites
	(5) Height Profile
	(6) Greening and Disposition of Open Space and Pedestrian Area
Site Level	(1) Podium Structure
	(2) Building Disposition
	(3) Building Permeability
	(4) Building Height and Form
	(5) Landscaping
	(6) Projecting Obstructions
	(7) Cool Materials

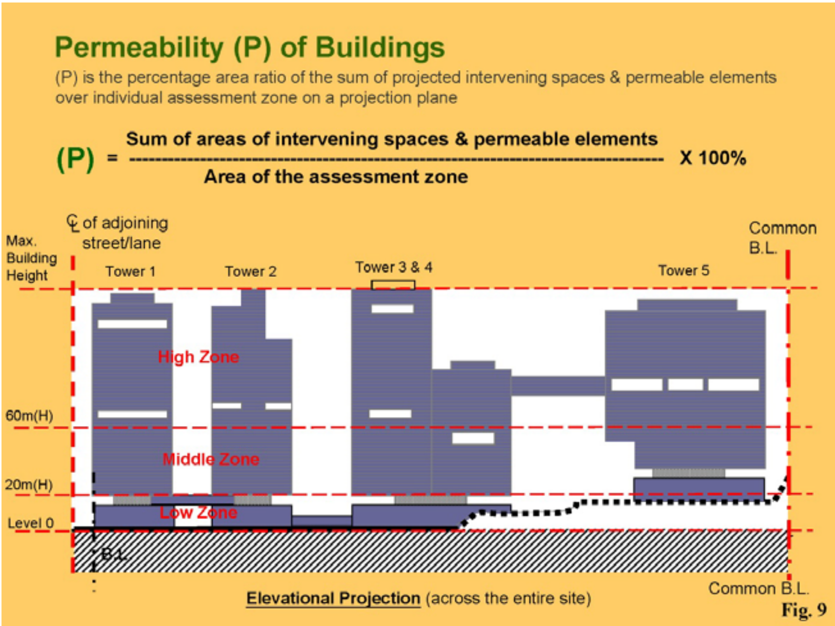

Fig.2 A illustration of permeability of buildings in SBD guidelines in Hong Kong (Hong Kong Buildings Department, 2011).

5. Climatic considerations in urban planning and design

According to the studies in mitigating negative impacts of urban climate based on thermal comfort understanding in tropical and sub-tropical regions, urban geometry is one of the factors that are beneficial to urban climate. These factors should be translated to planning and design languages which can be implemented in planning and design practices.

In Hong Kong, based on the scientific understanding that thermal comfort can be achieved by enhancing the natural ventilation(Ng and Cheng, 2012), an Air Ventilation Assessment (AVA) System was introduced in 2006 for a better urban living(Ng, 2009). Hong Kong Planning Standards and Guidelines (HKPSG) (Hong Kong Planning Department, 2011) then incorporated guidelines on air ventilation as Chapter 11 in 2006. Several qualitative guidelines on air ventilation at district and site level were recommended (Table 3). In 2011, The Buildings Department (BD) of Hong Kong promulgated "Sustainable Building Design (SBD) Guideline" to quantify three building and urban design strategies including "building separation and permeability", "building set back" and "site coverage of greenery of buildings"(Hong Kong Buildings Department, 2011). These quantitative requirements include: 1) 20% to 33.3% permeability of buildings (Figure 4) are required for lot frontage over 60m, depending on the site size and the height of the tallest building; "buildings abutting a narrow street less than 15m wide shall be set back"; and 10% to 30% site coverage of greenery are required depending on the size of the site(Hong Kong Buildings Department, 2011).

6. Discussion and conclusions

Based on the related studies, some concluding remarks can be given:

(1) There is a growing understanding of the incorporation of climate information into urban planning and design practice in (sub)tropical regions. However, comparing to studies of the scientific understanding of urban climate

(Grimmond et al., 2010; Roth, 2007), this incorporation into design guidelines with climate concerns in tropical and sub-tropical regions is still insufficient.

(2) Correct understanding of local climate and urban morphology is crucial for climate-based urban planning and design. The effects of urban form on urban microclimate vary in different climate conditions. Some finding based on local climate condition may not applicable to other places. For instance, more compact urban form or higher H/W ratio may be beneficial to some cities in the summer, but, on the contrary, may have some negative effects in other cities. In high-rise high-density Hong Kong, high H/W ratio of street canyons without reasonable gaps between building blocks may cause “wall effects” to block the natural ventilation (Wong et al., 2011; Yim et al., 2009), causing thermal discomfort in hot and humid summers.

(3) The translation of the scientific understanding of mitigation strategies to urban planning and design guidelines is little in tropical and sub-tropical regions. Climatologists, planners, designer and policy makers should work together to translate the findings of scientific studies to implementable guideline and standards for urban planning and design. Quantitative guidelines and standards are particularly useful.

Future agenda could be focused on the following aspects:

Climate change and its impact on tropical and sub-tropical living. The climate change will intensify the impact of urban microclimate on tropical and sub-tropical environments and make city more vulnerable. One of future urban climate studies in these regions needs to incorporate the consideration of climate change and its impact at city level.

The need for better low latitude climate studies. Much of the developing world is located in tropical and subtropical regions. At the same time they are experiencing rapid urbanization over the last 50 years. However their urban development has been lack of knowledge transfer and application based on methodological and objective protocol scientifically. These cities urgently require the application of urban climatic knowledge in urban planning for sustainable urban development in these regions and develop a series of climatic studies to fit the needs of different local developments from city level to building site level.

The need for better impact and risk assessments. A number of environmental problems and degradation in these regions have been brought about, like air pollution and heat stress, which affect a significant impact on the citizens’ health and comfort. Thus, tools for better assessing the impact of urban climate on urban living and the public health risk for population are needed in tropical and sub-tropical regions.

The joint effort and collaboration among climatologists, urban planner and local policy makers are needed. Although some scientific studies on urban climate as pilot study have started in tropical and subtropical regions since the 1990s, sustained on-going efforts on transferring scientific understanding of urban climate into daily urban planning practice are needed.

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