Urban Climatic Studies for hot and humid tropical coastal city of Hong Kong

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Abstract

In 2006, the government of Hong Kong commissioned studies towards producing an urban climatic map (UCMap). The extraordinary urban morphology of Hong Kong and the complex wind environment makes the task a unique challenge. Using planning and land use data, a GIS based UCMap has been created. Land uses, ground coverage, building bulk, greenery intensities, topography, and so on have been incorporated. Wind data is available from the Observatory, as well as simulated using MM5/CALMET. CFD simulations, wind tunnel tests, field studies and user surveys have been conducted. The map, targeted for 1:5000 scale planning will be referred to by planners when making strategic planning decisions for the future.

Key words: Urban Ventilation, Urban Climate, City Planning

1. INTRODUCTION

High density and compact city design is a topical issue. There are needs to deal with the scarcity of land, to design for a viable public transport system, and to re-build the community of our inner cities. High density living is increasing an issue that planners around the world have to deal with. Hong Kong is a high density city with a population of 8 millions living on a piece of land of around 1,000 square kilometres. The urban (city) density of Hong Kong is around 60,000 to 100,000 persons per square kilometre. When the roads, open spaces and so on are taken away, for residential developments, the estate (site) development density of a piece of land in the city can be up to 3000 to 4000 persons per hectare. In a nutshell, there are a lot of people, and therefore activities happening per square metre of land and its air space in a high density city. Moreover, urban Hong Kong has been multi-zoned. That is to say, commercial, amenity, residential, and sometimes industrial buildings are mixed and co-exist in close proximity.

Recently, the general public of Hong Kong is increasing aware of “over development” and “poor designs” of recently completed estates and projects. In order to maximise the site’s own aspects, sea view and hence profitability, property developers tends to construct high rise towers that occupy the frontage of the site thus forming tall and wide slab blocks. These blocks, aptly termed “Wall Buildings” by the locals, are “effective” wind blocks that seriously restrict the flow of air ventilation of the city. With lower air mass transport through the city, the dynamic potentials to mitigate urban heat island are seriously reduced; thermal stresses in the summer months are increased; and air pollutions dispersion is reduced. All in all, an unfavourable outdoor urban condition has resulted.

Finding ways to strategically plan a city environmentally requires climatic information that is scientifically based. Hong Kong is a high density city with a sub-tropical climate and a hilly topography. The government of Hong Kong has recently commissioned studies towards producing an Urban Climatic Map (UCMap). The extraordinary urban morphology of Hong Kong and the complex wind environment makes the task a unique scientific challenge.

2. KEY METHODOLOGY

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 (PlanD-www 2009). The Urban Climatic Analysis Map 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 (Figure 1).

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 Urban Climatic Analysis Map (UC-AnMap). The collated information of the draft 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 draft 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.

3. THE STRUCTURE OF THE URBAN CLIMATIC MAP OF HONG KONG

The draft Urban Climatic Analysis Map is a synergetic evaluation and analysis of the positive and negative effects to the urban climate based on Thermal Load Analysis and Dynamic Potential Analysis (Figure 2). Thermal Load Analysis – the analysis focuses on the important variables contributing to the localized thermal loads. A major negative factor to increase thermal load is building volume, whilst topography and green space are positive factors contributing to a reduced thermal load. Dynamic Potential Analysis – the analysis focuses on the important variables (ground roughness) affecting the wind environment. A major negative factor to decrease air ventilation is ground coverage, whilst natural landscape and proximity to openness are the main positive factors contributing to increased air movement. Urban climatic and geometric data are assembled and analysed according to their thermal or cooling characteristics. Positive and negative classification values are assigned corresponding to gain or loss in thermal load and/or dynamic potential resulting from varying scales of each parameter. The resultant value denotes the net effect of the parameters on the urban climate.

The UC-AnMap of Hong Kong is made up of a number of GIS coded layers. For Thermal Load understanding, they are:

**Building Volume (Layer 1)** The building volume data are measured in cubic metres and converted to percentages of the highest building volumes in the Territory. High building volume traps solar radiation and reduces air flows. It does not just store more solar heat, but also reduces sky exposure slowing the release of solar heat at night. As a result, high building volume contributes to a significant increase in thermal load.

**Topography (Layer 2)** The topography data are measured in metres above Principal Datum according to the Digital Elevation Model of the Planning Department. Air temperature is lower at higher altitude due to adiabatic cooling (cooling due to pressure changes). Thermal load effect is less severe in areas of higher topographical height. As Hong Kong is a hilly city, topographical condition is therefore an important factor when assessing thermal load.

**Green Space (Layer 3)** Greenery has a cooling and shading effect and can reduce the surrounding air temperature. Therefore, the extent and distribution of greenery are important in affecting the thermal load. Two different classification values are assigned to urban and rural areas with or without greenery.

For Thermal Load understanding, they are:

**Ground Coverage (Layer 4)** Ground coverage measures the ground roughness in terms of percentages of ground occupied by buildings in a locality and indicates the urban permeability to wind. Larger ground coverage such as large podium will contribute to a reduction in pedestrian wind speed. Therefore, the extent of ground coverage is important in affecting the dynamic potential.
Natural Landscape (Layer 5) Natural landscape, particularly grassland, has low roughness, which possesses higher dynamic potential than other landscape types, such as, woodland and urban landscape. Thus, grassland will contribute to dynamic potential to the city. 2 classification values are currently assigned, “Grassland” and “Woodland and Urban Landscape”.

Proximity to Openness (Layer 6) This layer consists of 3 sub-layers of 3 different parameters: proximity to waterfront, proximity to open space and slope with vegetation. Waterfront, open areas and vegetated slopes are sources of air ventilation, and the locations of building developments in close proximity in relation to these features can benefit from them. For example, sea breezes decrease as the distances to sea shore increase. Distances in metres to waterfront, open space or slopes are given different classification values to estimate their dynamic potential.

Figure 2: The structure of the urban climatic analysis map (UC-AnMap) in Hong Kong.

3. THE URBAN CLIMATIC ANALYSIS MAP

Information regarding meteorological, topographical, land use, building volume, building coverage, open spaces, urban and natural landscaping are evaluated and generalised to form the draft Urban Climatic Analysis Map at 1:5000 scale useful for the planning purpose. The reference time frame of the Map is the summer months of 2007. The Map is useful for planning purpose at OZP level. Based on the Map, eight climatic classes have been categorized and grouped into four urban climatic value / sensitivity zones. They are:

<table>
<thead>
<tr>
<th>Urban Climatic Class</th>
<th>Impact on Thermal Comfort</th>
<th>Urban Climatic Value / Sensitivity Zone</th>
<th>Possible action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moderately negative Thermal Load and Good Dynamic Potentials</td>
<td>Moderately</td>
<td>(A) Urban climatically valuable area</td>
</tr>
<tr>
<td>2</td>
<td>Slightly negative Thermal Load and Good Dynamic Potentials</td>
<td>Slight</td>
<td>Preserve</td>
</tr>
<tr>
<td>3</td>
<td>Low Thermal Load and Good Dynamic Potentials</td>
<td>Neutral</td>
<td>(B) Slightly urban climatically sensitive area</td>
</tr>
<tr>
<td>4</td>
<td>Some Thermal Load and Some Dynamic Potentials</td>
<td>Slight</td>
<td>Preserve &amp; enhance</td>
</tr>
<tr>
<td>5</td>
<td>Moderate Thermal Load and Some Dynamic Potentials</td>
<td>Moderately</td>
<td>(C) Urban climatically sensitive area</td>
</tr>
<tr>
<td>6</td>
<td>Moderately High Thermal Load and Low Dynamic Potentials</td>
<td>Moderately strong</td>
<td>Action desirable</td>
</tr>
<tr>
<td>7</td>
<td>High Thermal Load and Low Dynamic Potentials</td>
<td>Strong</td>
<td>(D) Highly urban climatically sensitive area</td>
</tr>
<tr>
<td>8</td>
<td>Very High Thermal Load and Low Dynamic Potentials</td>
<td>Very strong</td>
<td>Action necessary</td>
</tr>
</tbody>
</table>

Note: “cooling” impact
1. moderately negative Thermal Load due to higher altitude and adiabatic cooling, and greenery and trans-evaporative cooling
2. some negative Thermal Load due to vegetated slope and trans-evaporative cooling
3. to 8 various classes of warming impact due to increasing Thermal Load and decreasing Dynamic Potentials

Impact on thermal comfort is evaluated and categorised using PET based on the intra-urban temperature differences due to thermal load and dynamic potentials. Typically, from moderate cooling to neutral impact, the PET value differences are approximately 2 to 3 degrees, from neutral to very strong impact, the PET value increases are approximately 3 to 5 degrees (All PET values quoted here assume conditions under shade in the summer month conditions of Hong Kong.)

The categorization and grouping are by magnitudes of their positive dynamic potentials and negative thermal load effects. 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.

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. This urban climatic class includes the summits of various mountains and peaks.
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. This urban climatic class includes many country park areas, beaches and outlying islands.

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. This urban climatic class includes some undeveloped coastal urban areas and many low-density developments in the urban fringe areas or sub-urban outskirts.

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, e.g. in the sloping areas with a fair amount of open space between buildings. As a result, the temperature is slightly warm.

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. This urban climatic class includes many medium density developed urban areas with urban greenery.

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.

Figure 1: The Urban Climatic Analysis Mao of Hong Kong.

4. ACKNOWLEDGEMENT

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References