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NEW DEVEOLPMENTS IN APPLIED URBAN CLIMATOLOGY

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ABSTRACT

Shrinking cities in Europe and increasing cities in Latin America, Africa and Asia are the factors to consider within applied urban climatoloy. Urban climate guidelines must understand the principle physics of urban climate on the one hand but have to follow the different local city developments on the other. In the past a lot of world wide guidelines, limits for air pollution and thermal aspect were derived but none of them accepted totally as they were never adapted to local circumstances and behaviours.
The paper discusses methodologies how local adoptions can be derived in different climates and in different cities, which all of them again have different heat island or ventilation patterns. In a comparision between urban climate studies in tropical and moderate climates proof the importance to evaluate results on the background of planning aims an the social component. Behaviour of people is influenced by characteristic thermal sensations of a city or region. General aim for urban climate studies is to find ways how results can be used for planning processes anate different scales. Focus is given to urban climate function maps and there translation to an urban climate recommendation map with planning advices.

1 URBAN CLIMATE AND URBAN DEVELOPMENT

Huge urban an population changes lead in nearly all continents and all countries lead to a demands problems in urbanisation as well as in industrial developments. Air pollution and thermal comfort is in focus of the applied urban climatology.
Some of the urban developments which are relevant to urban climate can be observed:

- Increase of population (formal and informal developments)
- Shifting of the industrial productions
- Increase of the density of cities
- Vertical developments
- Reduction of green and open spaces
- Traffic

Planner starts to react on that. At the example of the Pearl River Delta you see the population development and land use on the left side of figure 1, as well as a planning concept could look like and the right..
For a European country this might be quite different as here within a shrinking society other priorities of urbanisation occur. Here the general aim is an inner city development with increased density near city centre and a second one near infrastructure places like train stations. Destroying not needed house is also possible. For further planning discussions this concept has to be brought into connection to the urban climate aspects. To which extent do dense building sites effect heat island and thermal conditions of the open spaces and what potentials does the concept have to improve thermal conditions and air mass exchange for example along roads and parks.
Before discussing some conflicts between planning and urban climate it is important to see the interactions between climate and use of spaces. Investigations with interviews from previous studies (KATZSCHNER, 2002) showed very clearly the need of certain microclimates in neighbourhoods. At the example of Kassel the ideal thermal conditions could be derived as follows:
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- the use open spaces is more frequent in the centre of the heat island and increases with high values of the thermal indices,
- street are seen as comfortable for pedestrians if thy have the choice between sun and shadow,
- ventilation areas have to be judged in the frame of the city as such and should be classified as important yes or no. Otherwise there will be no influence on planning.

Figure 1 - Example of land use development in the Pearl River Delta and planning reaction

The definition of the ideal urban climate by Mayer et al. (MAYER, 1990) considers the areas and time concept as important evaluation criterion: *The "ideal urban climate" is an atmospheric situation within the UCL with a high variation in time and space to develop inhomogeneous thermal conditions for man within a distance of 150 m. It should be free from air pollution and thermal stress by means of more shadow and ventilation (tropical areas) or wind protection (moderate and cold climates)*
Evans and others (EVANS et al., 2001) have already developed some proposals for architects and planners on how to achieve this situation on a micro scale level. These general proposals have to be devoted to concrete urban places as seen before:

Planning possibilities	thermal effect
• Width of streets	using shadow and sun in a daily and annual variation
• Pergolas and arcades	sun protection in summer, using winter radiation
• Vegetation	sun and wind protection, long wave radiation
• Colours	reflection and daylight
• Materials	heat storage, dust

2 URBAN HEAT ISLAND

Urbanization is the growth of the proportion of the population living in urban areas. The world is experiencing unprecedented urban growth. Only 3% of the world's population lived in urban areas in 1800 and this figure increased to 14% and 47% in 1900 and 2000. The rapid urbanization and the emergence of many mega cities trigger a number of environmental issues. The Urban Heat Island is one of the effects of urbanization. The UHI refers to the phenomenon that the temperature in the urban place is always higher than that in surrounding rural areas, especially at calm and cloudless night. Figure 3 illustrates an idealized heat island profile for a city, showing temperatures rising from the rural fringe and peaking in the city centre. The profile also demonstrates how temperatures can vary across a city depending on the nature of the land cover, such that urban parks and lakes are cooler than adjacent areas covered by buildings.

According to Landsberg (LANDSBERG, 1981) Urban Heat Island, as the most obvious climatic manifestation of urbanization, can be observed in every town and city, such as New York, Washington, Tucson, Phoenix, Mexico City, Tokyo and Shanghai etc.

The urban heat island is mainly caused by the storage of solar energy in the urban fabric during the day and release of the energy into the atmosphere at night. The process of urbanization and development alters the balance between the energy from the sun used for raising the air temperature (heating process) and that used for evaporation (cooling process).

The strength of the urban heat island is measured by the ‘urban heat island intensity’, which describes the maximum difference in temperature between urban and rural locations within a give time period. The highest values of the urban heat island intensity, in the region of 3-8 $^{?}$C, are often reached between about 11 o’clock at night and 3 o’clock in the morning (Figure 2). This is why the urban heat island is often referred to as a nighttime phenomenon. UHI intensities are also greater in summer than winter because of contrasts in the amount of energy received from the sun, which is absorbed by the urban surface during the day and released at night. The urban heat island keeps Hong Kong warmer in winter. This could be one additional reason explaining the decreasing cold days within the whole year, besides the contextual greenhouse effect that the annual mean temperature is increasing.

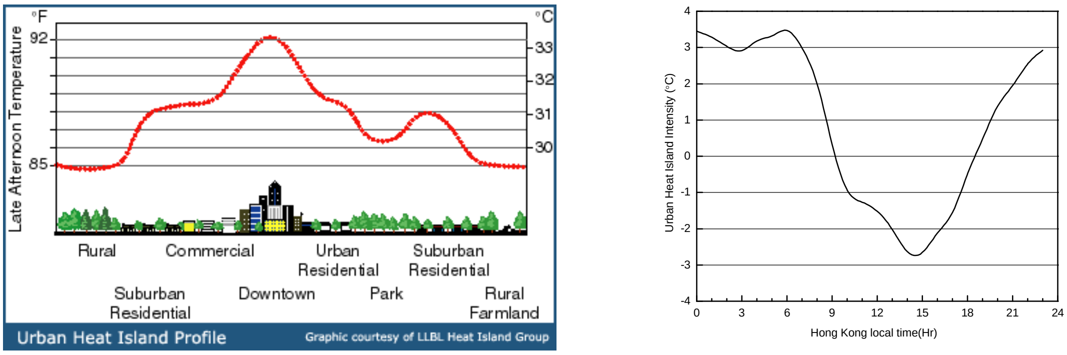

Figure 2 - Sketch of an Urban Heat Island profile and the variation in UHI intensity for Hong Kong over 24 hours for Autumn 2006

The heat island effect is welcomed in short winter in Hong Kong will increase the city temperature, make the citizens comfortable and decrease the energy consumption for heating. Anyhow, Hong Kong lies in the sub-tropical region and experiences a very long hot and humid summer so that in such case the heat island effect is a negative effect. The planners, architects, urban designers and developers should keep in mind that the urban heat island intensities should be mitigated and planning and construction should not deteriorate the heat condition.

The UHI is an ‘inadvertent’ modification of the climate, caused by changes to the form and composition of the land surface and atmosphere. When a land cover of buildings and roads replaces green space, the thermal, radiative, moisture and aerodynamic properties of the surface and the atmosphere are altered. This is because urban construction materials have different thermal (heat capacity and thermal conductivity) and radiative (reflectivity and emissivity) properties compared to surrounding rural areas, which results in more of the sun’s energy being absorbed and stored in urban compared to rural surfaces. In addition, the height of buildings and the way in which they are arranged affects the rate of escape at night of the sun’s energy absorbed during the day by building materials. The result is that urban areas cool at a much slower rate than rural areas at night, thus maintaining comparatively higher air temperatures. Urban areas also tend to be drier than their rural counterparts because of the lack of green space, a predominance of impervious surfaces and urban drainage systems, which quickly remove water from the urban surface. This combination of effects alters the energy balance of the urban environment. Consequently in urban compared to rural areas, more of the sun’s energy absorbed at the surface goes into heating the atmosphere and thus raising the air temperature than into evapotranspiration (water uptake and loss by plants), which is a cooling process.

According to Oke et al (OKE, 1987), those important factors influencing the UHI include:

Canyon radiative geometry decreases the long-wave radiation loss from street canyons since the complex exchange between buildings and the screening of the skyline. It could be graphically illustrated in Figure 11. Owing to this reason, the UHI intensity is correlated with the geometry of the urban canyon, as expressed by the relationship between the building's height (H) and the distance between them (Width)

Urban Heat Island Studies around the world:

The UHI has attracted much attention of the researchers around the world. Countries which have studied the UHI are illustrated in Figure 3.

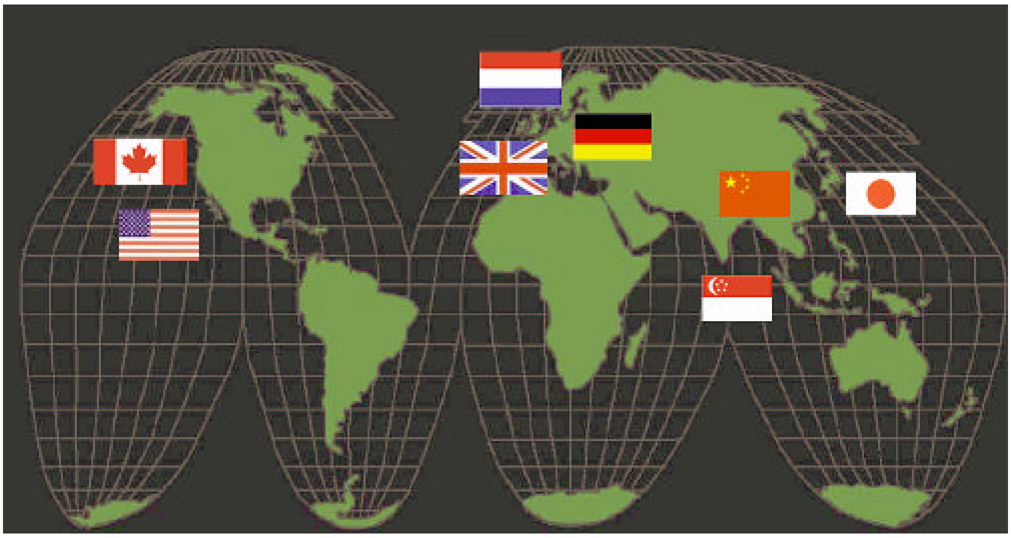

Figure 3 - Countries which have studied the UHI around the world

In Europe, various studies on the intensity of the UHI have been done for many cities. A daily upper docile limit of 3.1$^{?}$C was reported by Chandler (Chandler, 1965) in a comparison of Kensington and Wisley over a period of ten years. Lyall (LYALL, 1977) observed the average magnitude of the nocturnal heat island effect was 2.5 $^{?}$C in June and July in London. An average UHI intensity of around 7$^{?}$C was found by Barring (BARRUNG, 1985) during the winter and spring seasons in Malmo, Sweden and the UHI intensity observed in Essen, Germany by Swaid and Hoffman [SWAID, 1990) was between 3 to 4 $^{?}$C for both day and night time.

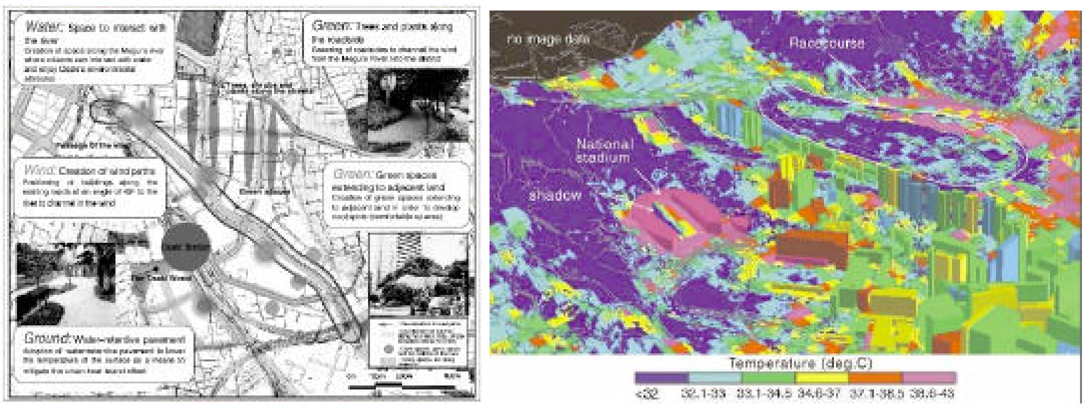

Figure 4 -Proposed measures to mitigate the UHI effect in Shinagawa and UHI distribution in Wan Chai (Hong Kong), derived from the satellite remote sensing images.

In North America, there are also lots of studies of UHI carrying on in many cities. In 1997, the Environmental Production Agency (EPA) instituted the "Heat Island Reduction Initiative" (HIRI) in the wake of the heat wave that struck Chicago in July 1995, resulting in a death toll of over 700 people. As part of this initiative, the "Urban Heat Island Pilot Project" (UHIPP) was launched in 1998 to investigate the UHI effect, raise public awareness of the issue, and quantify the effects of mitigation

measures (URANO, 2003). Subsequently, five cities have been selected for inclusion: Baton Rouge, Chicago, Houston, Sacramento, Salt Lake City.
In Asia, numerous studies on the UHI have also been done in some countries. Chow (GHOW, 1992) reported the magnitude of the urban heat island effect in Shanghai, China. A systematical study on UHI was carried in Singapore [WHONG, 2000). In many cities in Japan, such as Tokyo, Kobe, Osaki etc, studies on UHI were carried on as well. Strategies as well as guidelines that mitigate the UHI intensity were proposed. For example, network of water, green space and wind paths along the Meguro river in Shinagawa was proposed in order to mitigate the UHI effect, as illustrated in Figure 5.
In Hong Kong, Prof J. Nichol et al. have utilized the ETM+ satellite images to investigate the UHI and proved this technology an useful technology to study the UHI. Spatial distribution of the UHI and the effect of building structure and material could be derived from remote sensing image, as shown in Figure 4 (NICHOL, 2005).
Besides the UHI, another term named as Physiological Equivalent Temperature (PET) [HÖPPE, 1999) is used to describe the effective temperature, which considers all the environmental factor, such as temperature, solar radiation, wind speed, humidity etc. It is an effective thermal index for the urban planners and architects to evaluate the environmental condition. An example of the PET distribution in Hong Kong with 1km*1km resolution is shown in Figure 4. That heat waves and mortality are closely correlated is can be studies from European investigations figurer 6.

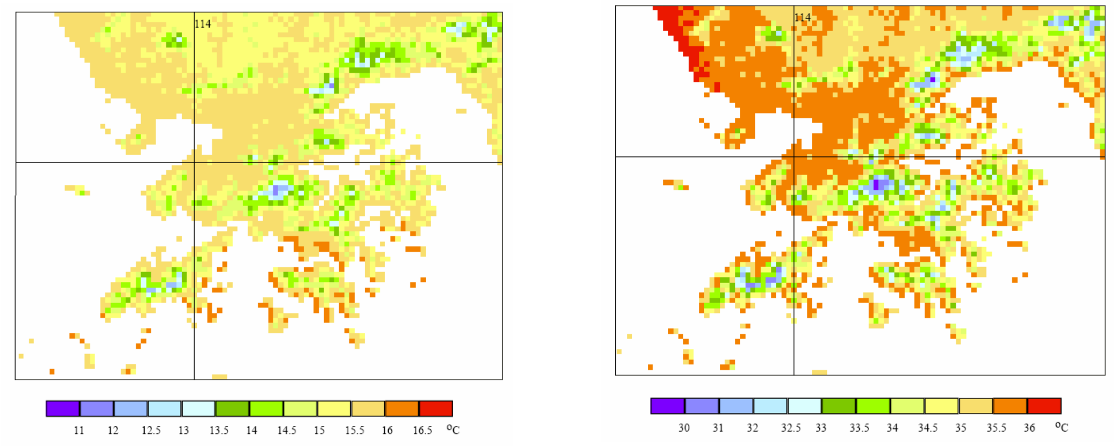

Figure 5 - Distribution of calculated PET in Hong Kong , in Jan (left) and July (right). (source: Prof A. Matzarakis)

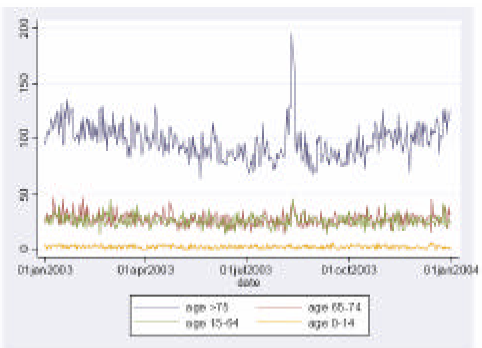

Figure 6 - Total daily deaths in London, by age group in 2003. The peak in deaths is coincided with the August heat wave

3 URBAN CLIMATE MAP

Urban climate cannot only be described and analysed it also has to be translated to planning. It is the main task to explain how urban climate results can be used. Therefore in a first step urban recommendation maps were developed. In figure 6 the example of Kassel is shown

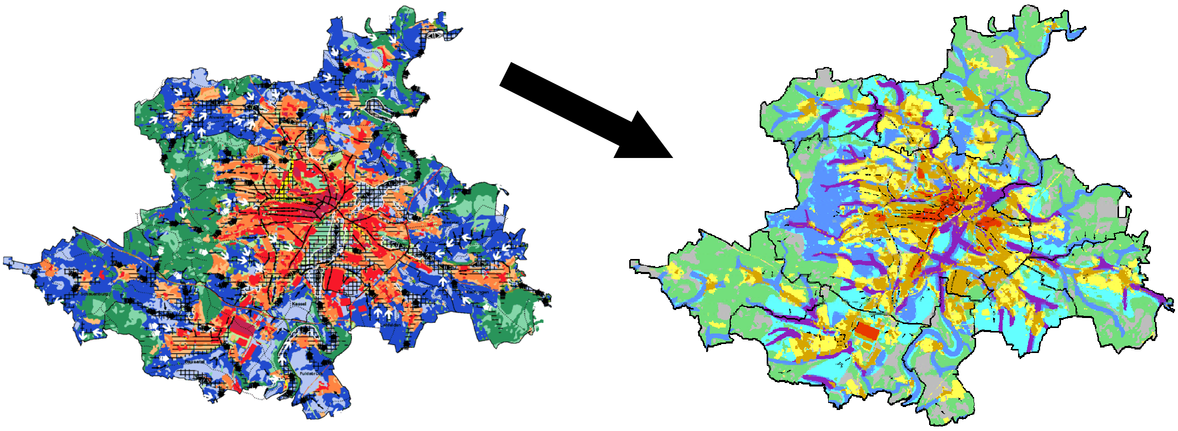

Figure 7 - Urban Climate Function Map an a eight classification system for an Urban Climate Recommendation Map

To discuss urban climate analysis and their result it is important to clarify climate scale sand their accuracy and planning levels.

Table - 1 Urban climate and planning scales

Administration level	Planning level	Urban climate issue	Climatic scale
city 1:25.000	urban development; master plan	heat island effects; ventilation paths	meso scale
neighbourhood 1: 5.000	urban fabric system	air pollution	meso scale
block 1: 2.000	open space design	thermal comfort	micro scale
single building 1:500	building design	radiation and ventilation effects	micro scale

3 Urban Climate Map as Planning Tool

The principle underlying methodology is an areal evaluation of urban climate conditions. This is based on land use from digital grid data sets together with topographical data in 200 m grids. The meteorological input parameters were mean air temperatures and humidity, wind speed and wind directions from near by meteorological stations or from recorded data in existing analysis like in the Environmental Atlas Hessen (HLUG 1999) and measured data.
In order to use planning aims and combine them with possible changes in urban climate the maps have to be linked to each other so that conflict immediately can be recognized. For example where future buildings will effect ventilation and how air pollutions is distributed. The climatic functions then were translated to an evaluation with means for planning.
Through the Geographical Information System (GIS Arc.Info) geographical data and land use data were classified and transformed to urban climate functions like, thermal aspects (i.e. heat and cooling rates), a wind classification with ventilation paths and topographically influenced downhill movements. The building fabric was classified through roughness length and thermal radiation processes.

The following factors were used (table 2)

- Land use classifications for thermal and radiation with categories of city structures, industrial areas, gardens and parks, forests, greenland and agricultural areas. Water was only used from lakes while train tracks got a special classifications as they have a large daily variation in surface temperature and therefore radiation differences,
- topographical and geographical data which influence the local circulation pattern,
- ventilation through an analysis of the roughness length.

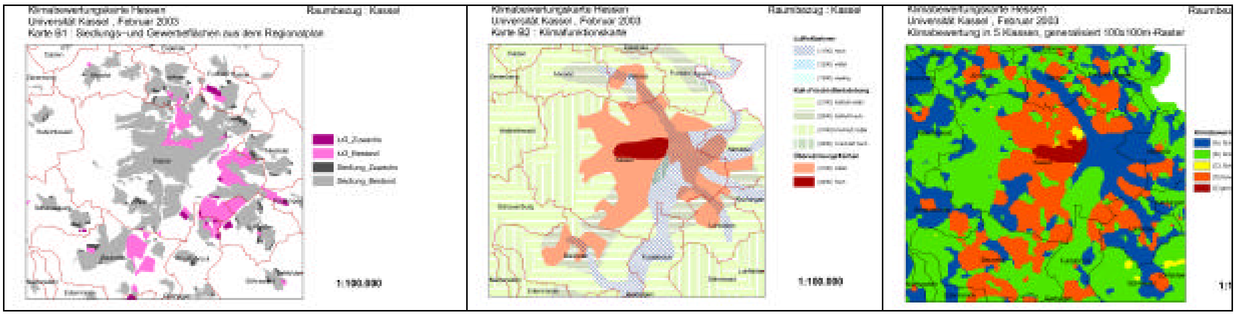

Figure 8 - Spatial development plan, urban climate and evaluation in the city of Kassel

Evaluation was carried out through a GIS based calculation method, which calculated weighting factors for every grid with a result for thermal and dynamic map. This then was combined to the urban climate function map with an evaluation to the urban climate map for planning use.
Due to this methodology the climate map has two levels: one is dealing with the thermal and the second one with the dynamical aspect. Therefore it is possible to have a classification in the final map, which can differ between the advices for heat island effects and the well ventilated areas or weak ventilated areas for improvement. The method of a GIS based urban climate calculation can be used at all different scales with various grids in order to get answers on different planning levels.

Table 2 - Overview of GIS calculation layers for Urban Climatic Analysis Map

Physical criterion	Input layer based on the criterion
(I) Urban Heat Island	Layer 1 – Land Use Map
	Layer 2 – Ground Coverage Map (Built-up Areas)
	Layer 3 – Building Volume Map
	Layer 4 – Topographical Height Map
(II) Urban Heat Island Mitigation Potentials	Layer 5 – Sea Breeze Map
	Layer 6 – Land Coverage Map (Open Spaces)
(III) Dynamical Potentials	Layer 7 – Ventilation Map
	Layer 8 – Green Area Map
	Layer 9 – Slope Map
	Layer 10 – Air Path Map

4 What can be done?

Policies designed to mitigate the UHI may need to balance the need to manage heat at the building, neighbourhood and city scales, talking into account the nature of development (new versus existing) and be conscious of what is achievable in reality. Furthermore, the climate of Hong Kong is changing because of alteration to global-scale climate processes. This has implications for the planning and design and current and future urban developments from the local to city scale. Urban designers and planners need to acknowledge this, and in doing so base design criteria on data that describes the current and projected future climate of cities, and be especially aware of the critical importance of minimum temperature for human thermal comfort, health and patterns of energy consumption.
As mentioned in the previous section, the principal causes of the UHI are the storage by day of solar energy in the urban fabric and release of this energy into the atmosphere at night, and the fact that the

process of urbanization alters the balance between the energy from the sun used for raising the air temperature and that used for evaporation. The urban buildings' geometry, construction material (which affects the effective albedo, thermal capacity and conductivity), decrease of plants and vegetation are account for this effect. In addition, anthropogenic heat could become an important future contribution of energy for the development of the UHI, depending on energy consumed in air conditioning/heating for example The future construction and planning strategies that will mitigate the UHI should consider every aspect according to the main causes of the UHI.

To manage UHI form and intensity would require the alteration of existing land cover characteristics for large areas of central cities. From a practical point of view this is not possible. However there are opportunities to change microclimates and therefore manage climates at the street canyon to neighborhood scale. Over time the cumulative effects on UHI form and intensity of a staged programme of local scale climate modification could be significant. Effective strategies that can be implemented within the context of the existing urban structure and have impacts at the local and near local scale include cool roofs, green roofs, planting trees and vegetation and cool pavements.

Cool roofs & walls: Roofs and walls in color (the albedo of which are usually lower than that of light color materials) and will probably reach temperature of 50-60 $^{?}$C on hot sunny days. The stored energy will be released to the urban atmosphere and is the major resource contribution to the UHI. The higher the temperature of these roofs and walls is, the higher the UHI intensity will be. The heat of the buildings' surface will also transfer into inside of the building, causing higher energy consumption for air conditioning. In addition, higher temperature of roofs and walls will also accelerate the deterioration of the construction materials. In contrast, roofs and walls built with materials with light color, high reflectance/albedo and low heat capacity in future building construction are welcome. They will strategically change the effective albedo of the whole city.

Cool Pavements: Like many roofs, the streets and to a lesser extent, the pavements in many cties are typified by dark surfaces. The employment of 'cool pavements' comprised of material with high solar reflectivity and good water permeability is potentially a very effective way of mitigating high urban temperatures through decreasing absorption of solar energy and encouraging water storage in the urban surface and thus evaporative cooling. The high albedo roads and pavements may have benefits for nighttime street lighting. For Hong Kong, discernible climate impacts of cool pavements could be achieved for large parking areas, terminal facilities, air ports and urban roadways with large expanses of paved surfaces when re-surfacing or new surfacing is planned.

Planting Trees and Vegetation: 'Urban Greening' would be the most cost-effective way of ameliorating harsh urban climates at the individual building to neighborhood scale. Trees and vegetations are good climate modifier due to the following three reasons:

1They provide shade, which reduces the temperature by 5-20 $^{?}$C, compared to the places with solar radiation and provide better outdoor thermal comfort environment. Trees planted along the roads will have significant impact reducing the temperature of road, as mentioned in the last paragraph, which is a big factor causing the UHI.

2 Water is easier to be kept at the vegetated places while it is always drained away at concreted places. The trees and grass etc will convert the water beneath the vegetation surface into water vapor and release to the atmosphere. Thus much part of the solar radiant energy transferred to latent heat, instead of sensible heat (which raises the air temperature and causes human discomfort). It is estimated that evapotranspiration can result in reduction of the micro-scale temperature by 1-5 $^{?}$C.

3 The trees and vegetations consume large amounts of solar radiant energy through the process of photosynthesis.

Apart from that mentioned above, there are a lot of additional benefits arising from urban trees and plants. They can act as carbon store, reduce urban flooding, concrete the groundsill, filter air pollutants and CO_2, and contribute to quality of life. So the urban greening is a very important and cost-effective way to modulate the UHI, as well as the urban micro-climate. Policies should be made regarding to the urban greening.

In addition to the cool roofs and walls, green roofs and walls, which consist of a growing medium planted over the roofs or along the walls, can have a marked impact on the climate of the upper floors of buildings and their immediate environs, as illustrated in Figure x. With their cooling effect as a result of the evapotranspiration, the plants have lower temperature compared with the bare concrete surface and could serve as a insulator layer.

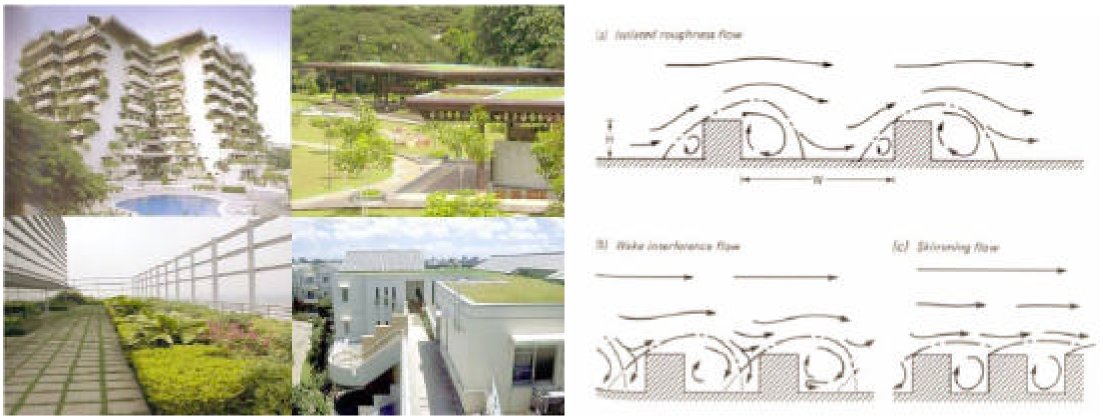

Figure 9: - Some examples of buildings adopting the green roofs and walls and urban geometry

Urban Geometry: The urban geometry, such as the SVF, H/W ratio etc, has great influence on the formation of the UHI. But it is yet unknown that how different urban radiative geometries explicitly cause change of the air temperature and this issue needs further research. Fortunately it is found by previous study (named as AVA project)that optimizing the natural ventilation inside the city could be an effective method to improve the heat extraction rate and to provide more thermal comfort. The UHI is always observed at calm, clear nights or days and disappear when there is wind. The speed of wind is significantly reduced inside the city, which is known as the canyon effect, referring to the Figure 14. The higher the H/W, the urban wind is one that can be dominated and modified by urban design. The main urban design elements which can modify the wind conditions are the overall density of urban area, size and height of the individual buildings, existence of high-rise buildings and the orientation and width of the streets.

Reduction of anthropogenic heat release: Anthropogenic heat, although not a very important factor causing the UHI, it could play significant role in certain condition. It is found that impact of anthropogenic heat may be important in urban centres but negligible in residential and commercial areas (TAHA, 1997). Besides, anthropogenic heat due to, for example the energy consumed for air conditioning, could be reduced by human habit, i.e, by adjusting the air conditioner to comfortable temperature instead of to very low temperature. These kinds of actions not only reduce the anthropogenic heat release to some extent, more importantly, they also have important meaning in saving the energy.

8 CONCLUSIONS

For any urban plan, concept or master plan urban climate maps are important to evaluate thermal comfort for the use of open spaces and ventilation for air pollution problems. One can see that these aspects were separated in different planning levels to which climatic investigations has to be devoted to.

Following the aim of planners to revitalise cities the use of open spaces are in the centre of discussion and here the thermal comfort play an important role. Heat island in this sense can also be seen as positive for mid European cities. Higher varieties of microclimatic situations having the air pollution problem in mind can be good criteria for urban climate. In general it is important to compare the climate pattern with city structures and the use of open spaces at the same levels.

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