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Meteorological zoning strategy for high-density cities based on urban climatic map

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Abstract: There is a clear link between the climate of a settlement and its potential sustainability. The development of cities should pay attention to the local geographic and topographic characteristics and the advantages (disadvantages) it brings, using as little artificial energy consumption as possible to improve the urban environment and the comfort of buildings. Environmental climate map is one of the important tools for urban meteorological zoning, which can play an effective technical support role for ecological planning and design of cities, especially high-density cities. This paper describes the meteorological characteristics of high-density cities and proposes the application of ambient climate map in heat island ventilation zoning and color zoning of high-density cities, aiming to provide research ideas for ecological zoning of high-density cities.

Keywords: Urban climatic map; Urban zoning; High density city; Eco city; Urban planning.

1. Urban climatic map

World urban development experience shows that too low an urban population density results in uneconomic construction and utilization of urban infrastructure and wastes a lot of energy. Cities are highly dense with industries, populations, resources, and activities and are major energy consuming areas. About 75% of global energy consumption and 60-70% of carbon emissions are generated in cities, thus showing that the high energy consumption of cities is one of the main problems of the imbalance between their development and environmental game. With the rapid expansion of urban population and the increasing size of cities, energy consumption remains high and "urban diseases" are emerging, therefore, the correlation between urban creation and environmental research results needs to be explored in depth.

There is a clear link between the climate of a settlement and its potential sustainability. The climate in which it lives largely controls its access to energy, as well as its need to store energy and its ability to dispose of airborne waste. Urban design decisions will create microclimates such that they exacerbate or adjust the properties of the background climate. The application of urban climatology has obvious functions in the planning of sustainable human settlements [1]. Urban energy consumption depends to some extent on the geographical and topographical location of the city. By considering a city as a point in a geographic climate system, this determines the characteristics of the city in terms of daily variations and seasonal fluctuations in climatic factors such as sunlight, wind, temperature, and precipitation. When a city is considered as a region, changes in topography will change the climate of the region, for example, by blocking air currents from a certain direction to the location of the city, or by drawing sea breezes into the system of local circulation of the city to enhance the monsoon. The development of the city should pay attention to the local geographical and topographical characteristics and the advantages and disadvantages it brings, using as little artificial energy consumption as possible to improve the urban environment and the comfort of the buildings. For example, in cold climate regions, common urban layout patterns such as city streets and neighborhood types are one of the main elements of using urban climate research to optimize the poor human comfort caused by cold climate, and to explore how urban development affects changing climate in the form of "urban environment climate maps", and how the changed urban climate reacts to the study uses the "urban climate map" to explore how urban development affects the changing climate and how the changed urban climate affects the city itself, thus changing the urban design strategy.

Urban climatic maps are usually divided into urban climate analysis maps and urban climate planning proposal maps. The urban climate analysis map consists of three aspects: (1) analysis of the thermal environment, such as heat island effect, bioclimatic distribution of different cities, uncomfortable areas affected by cold or heat pressure (heat load), etc.; (2) analysis of the wind environment, if necessary to describe and express the pattern of air exchange, circulation, and flow; (3) identification of air pollution areas. The urban climate planning proposal map is to "translate" the climate information and assessment results analyzed in the urban climate analysis map into an operable, usable and expressible "planning language", which not only represents the characteristics of the existing urban climate environment with two-dimensional spatial diagrams, but also It can clarify the climate conflicts and sensitive areas, and propose corresponding planning strategies and guidelines for later urban development and land development, in order to protect the existing good climate environment and reduce the environmental burden.

The urban environmental climate map should firstly start from the relationship between urban atmospheric environmental problems and urban planning, and analyze the deviations, contradictions, and confusions between them at the cognitive level at the present stage and ask questions [2,3]. Based on urban geographic information data, urban meteorological elements observation tests, wind tunnel experiments, etc., an urban planning and construction atmospheric environment impact assessment index system is established on the basis of numerical simulation, and objective, scientific and operable assessment indexes and assessment methods are proposed based on three mesoscale meteorological variables of urban central areas, neighborhoods and buildings; and application software is developed to use GIS and 3D visualization technology for computational data display, analysis and assessment work [2], develop assessment reports, and then carry out multiple scenario comparison, analysis, design and optimization based on the assessment results, and the overall technical route and the general framework of environmental effect assessment indexes for planning scenarios are shown in Figure 1 and Figure 2.

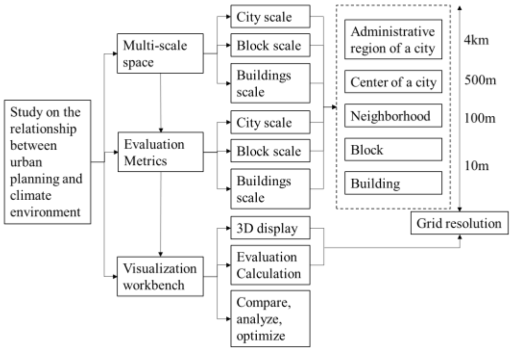

Figure 1. Technical route of the relationship between urban planning and urban climate

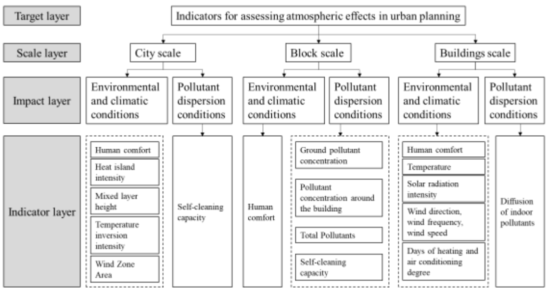

Figure 2. The framework of meteorological environmental effects assessment indicators for planning programs

2. Urban density and urban climate

The high-density layout of buildings in cities can be divided into three types: high density layout of high-rise buildings(H-H), high density layout of multi-story buildings (M-H) and high-density layout of low-rise buildings (L-H). These three types of high-density layouts may exist in the same area or in different areas of the city, and their common characteristics are high building density and population density, which are shown in Table 1.

Urban planning and urban climatic environment impact assessment complement each other, on the one hand, planning and design need to be based on urban climatic environment; on the other hand, the special morphology of its substratum, high-density building layout and human activities in high-density urban areas will have different degrees of influence on urban meteorological environment, thus changing urban microclimate [4].

Urban microclimate is a special phenomenon in the space between buildings that is unique to the metropolis and distinct from the surrounding suburbs, and is a climate island (local climate) when viewed in the context of the surrounding suburbs or the wider rural area. The high-density layout form with its function is an important reason for producing a unique urban (micro) climate. While cities around the world share many similarities in terms of high-density layout forms and urban functions, the urban (micro) climates from which they derive differ.

Due to the different climate issues and different urban planning systems, the proposed urban climate planning maps and applied planning strategies vary accordingly. For example, the thermal environment map of Tokyo, Japan - the typical high-density urban - clearly identifies four priority areas with severe heat island effect and lack of ventilation (Figure 3, where ground cover, artificial heat exhaust and concentrated buildings are analyzed and divided into 10 categories plotted on the map) [5]. Therefore, the Tokyo Metropolitan Government has adopted a series of improvement programs by concentrating financial and human resources, especially by increasing green coverage, controlling the wind-blocking surfaces of buildings, and reducing anthropogenic heat emissions to improve urban ventilation in order to reduce the heat island effect [6].

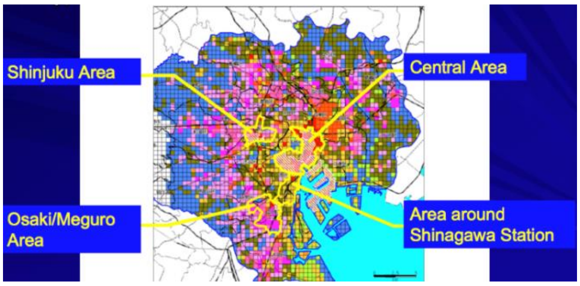

Figure 3. Urban climate forecasting system developed by Dr. Ashinage's team - Tokyo Metropolitan Thermal Environment Map

Source: Reference [7]

For the characteristics of high-density urban morphology, the proposed urban climate planning map can be applied to the 1:2000 urban functional zoning map to provide relevant climate information for urban center, neighborhood planning and supporting decision making to save energy consumption: (1) reflectivity of building or paving materials; (2) green vegetation; (3) shading; and (4) ventilation. shows the details of climate planning strategies and measures and the spatial scale and climate impact range of their operation. In the process of using urban environment and climate map, the scale issue is very important (Table 3). In terms of urban planning perspective, it is more appropriate to use 1:25000 scale map for urban master plan, 1:10000 scale map for urban functional zoning, and 1:5000 for detailed planning.

The urban environmental climate map outlines the influence pattern of human cold/heat comfort in a city. Using the human cold/heat comfort index in a city can represent the possible elevation that marks the temperature heat stress and therefore can be used as a comprehensive factor to adjust the data of the urban climate map. Simply put, it is a planning and design response by dividing meteorological zoning according to the urban environment climate analysis map and expressing the function of climate in the form of space.

Table 1. Characteristics of the three types of high-density environments

Type	Space form	Stereoscopic degree	Monolithic buildings			Elements			Cases
			Floors	Size	Layout	Scale	Quantity	Interval	
H-H	Vertical Growth	High degree	Lots of	Large	Sparse layout	Small	Many	Large	CBD
M-H	Lateral growth ＞ Vertical growth	General	Many	Middle	Slightly dense layout	Small	Many	Small	Residential Area
L-H	Lateral growth	Low degree	A few	Small	Close layout	Smaller	Lots of	Very small	Historic district

Table 2. Urban Climate Planning Proposals and Spheres of Influence

Objectives	Aspects	Measures	Operation scale	Influence range
Bioclimatic conditions + urban heat island effect + urban ventilation + urban air quality	Reflectivity of paving materials	Construction and paving material cooling	Intervention and alteration of materials and surface layers	Mesoclimate and Microclimate
		Roof and building façade cooling		
		Water Retention Paving Materials		
	Greenery	Planting Greenery		
		Parks and open spaces	Landscape planning/land use level interventions	
		Green Belt		
	Shade	Design consideration of building geometry	Interventions and changes at the architectural design level	Microclimate
		Shading design		
		Control the ratio of building height to street width		
		Selection of street orientation	Interventions at the urban planning/zoning level	Mesoclimate and Microclimate
		Planting street trees	Landscape planning/land use level interventions	Microclimate
	Ventilation	Design of reserved ventilation corridors	Interventions at the urban planning/zoning level	Mesoclimate and Microclimate
		Control of building footprint and building form		
		Selection of street orientation		
		Control of building plan layout		
		Control the ratio of building height to street width	Interventions and changes at the architectural design level	Microclimate
		Connecting and controlling the distribution of open space and green space	Landscape planning/land use level interventions	Mesoclimate and Microclimate

Source: Reference [4]:30.

Table 3. Urban climate and planning ratios

Level	Scale bar	Planning Levels	Urban Climate Issues	Climate scale	Energy saving potential
City	1:25000-1:5000	Master planning, urban development	Heat island effect, turbidity island effect and ventilation paths, etc.	Mesoclimate	Wind shelter/ventilation
Center of a city	1:10000-1:5000	Master planning, functional zoning			Zoning and layout
Neighborhood	1:5000-1:1000	Detailed Planning	Cold and hot comfort, air pollution, etc.		Road structure and alignment; neighborhood scale, etc.
Block	1:2000	Urban design, spatial development design	Cold and hot comfort	Microclimate	Building Cluster and Open Space Design
Building	1:500	Architectural design	Solar radiation, ventilation, etc.		Energy-efficient building design

Source: Redrawn from Reference [4]:85 Table 7.1

3. Meteorological zoning in high-density urban

Taking China's cold climate zone-IIA as an example, the region needs to prevent cold and warmth in winter and ventilation and heat requirements in summer, coupled with the high complexity of high-density urban areas, urban meteorological zoning is carried out based on urban environmental climate maps using urban spatial heat balance analysis, including zoning that considers ventilation, zoning for heat islands (dry islands, turbid islands), and zoning for color.

3.1. Heat Island and ventilation zoning

Urban form, buildings, and green pavement directly affect the distribution of temperature. Depending on the density of greenery and the arrangement of buildings, they are usually roughly divided into three categories, namely dense green space and fewer buildings, dense buildings and half green conditions, and open space with less greenery. As shown in Table 4, green spaces with dense trees, such as parks, can not only provide shade during the day, but also play an evaporative cooling role around the clock; then, appropriate greenery between street trees and buildings, although they can provide shade during the day, their evaporative cooling effect is not very obvious at night, which is not sufficient to relieve the heat released from surrounding buildings and hard surfaces; while open spaces with sparse greenery can generate high temperatures during the day due to maximum solar radiation, and at night the absence of shade allows the heat absorbed during the day to be released more quickly, resulting in a relatively rapid decrease in temperature [4]. This also reveals that a higher degree of open sky (SVF) corresponds to a lower nighttime temperature [8].

The urban heat island phenomenon is a phenomenon in which urban temperatures are always higher than those in the surrounding rural areas (Figure 4), and is a negative factor affecting urban comfort and accompanied by air pollution. The main causes of urban-specific climatic environments are excessive heat storage, increased roughness, reduced evaporation, and radiation cages, which are particularly evident in high-density urban areas, where the amount of urbanization and development alters the balance of energy used to raise temperatures (warming process) and for evaporation (cooling process) [7]. The urban heat island phenomenon is more pronounced in high-density urban areas where many dense buildings absorb solar energy during the day and release it into the atmosphere at night, when there is no wind, breeze, and cloudless nights. The urban heat island effect in cold climate zone-IIA will reduce human thermal comfort in summer, and to some extent in winter it can be seen as a positive effect, namely the "warm island effect", reducing the energy consumed for heating, but the reduction in ventilation will cause air pollution, and the haze that appears in most cities in winter in China is a clear example.

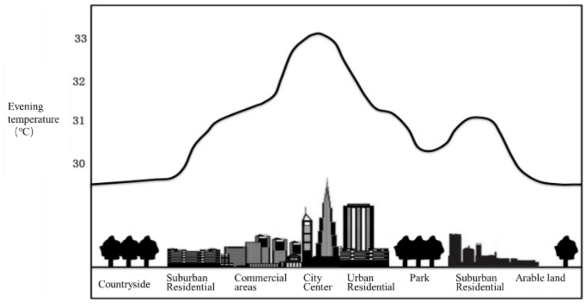

Figure 4. Schematic diagram of urban heat island

Typically, the spatial distribution of urban heat islands is more pronounced, with temperature variations across the city depending on the properties of the land cover, e.g., building-covered ground is warmer than in urban parks and lake areas. In fact, the maximum heat island in urban centers is not always linear with respect to the urban center, but has hot spots, depending on the level of thermal reserve and albedo, and is also directly dependent on the building density and the associated height. The urban heat island effect is usually calculated using the "urban heat island intensity", which expresses the difference between urban and rural temperatures over a set period [9,10]. Define the urban-rural temperature difference (Tu-r) as:

$$T_{u-r} = T_u - T_r$$

Tu is the urban temperature and Tr is the rural temperature. Tu-r greater than 0 means that the temperature measured at the urban temperature measurement station is higher than that measured in the countryside. Usually, the temperature difference between urban and rural areas is smaller during the day than at night, and smaller in summer than in winter, and the difference between urban and rural areas is most obvious under the conditions of sunny days without wind. The urban heat island intensity mainly depends on the natural environment climate of the city, land use condition, building density, population scale and density, etc.

Therefore, urban high-density areas in climate zone IIA need to use open space more frequently in the center of the heat island due to the dual requirements of high-density high-rise development and proper ventilation in winter to protect from wind and summer to increase the heat index value, to divide urban heat island zoning according to the temporal characteristics and spatial characteristics of urban heat island intensity, and to calculate the wind field and temperature distribution gradient in urban high-density areas.

The zoning of urban ventilation based on urban heat island intensity zoning, as Mayer proposed the "ideal urban climate", which "considers space-time as an important evaluation criterion, an atmospheric state in the urban canopy that is available to people within 150 meters. This atmospheric state creates uneven temperature conditions in highly variable space and time. It should avoid air pollution and heat stress with the help of measures such as more shade and ventilation (tropical areas) or wind protection (slightly cool and cold climate)" [11,12]. The urban environmental climate map is analyzed in which areas of the city are needed to introduce artificial winds to blow away pollution in winter and ventilate and cool in summer, and which areas are not needed to cool in summer but only to block cold winds in winter in order to achieve a more desirable high-density urban climate, and Table 5 shows the measures and recommendations to achieve this.

Overlay these measures on an urban climate analysis map, e.g., using urban climate data to select ventilation paths that moderate the urban heat island effect (e.g., sea and land breezes, mountain breezes, etc.). To the extent possible, balance and weigh the combined effects of planning decisions that need to be made and prioritize them in order to provide recommendations for urban development and growth.

Table 4. Spatial thermal characteristics under the influence of greening density and building arrangement form

Type	Characteristics
Dense green space and less buildings	Temperatures are the lowest in the region throughout all day
Dense buildings and half green conditions	Temperatures are relatively low during the day, but the hottest in the region at night
Less green open space	Hottest area in the region during the day and relatively cooler at night

Table 5(a). Positive and negative effects of urban climate

Positive climate effects	Negative climate effects
Ventilation path descending air movement Air exchange Bioclimatic effects originating from vegetation Neighborhood effects Elevation and altitude	Heat island (building as a whole) Artificial heat Reduced ventilation Lack of air flow effect

Table 5(b). Planning possibilities and temperature effects of open space

Planning aspect	Temperature Effect
Street width Shed and arch Vegetation Color Materials	Use of sun and shade with daily and annual variation Summer shade, use of winter radiation Protection from sun and wind; long wave radiation Reflection and daylight Thermal reserve; dust

Source: Reference [13]

3.2. Color zoning

In the past, the positioning of urban color and the selection of architectural color mostly focused on landscape creation and cultural heritage. Urban color zoning usually follows the functional principle of landscape zoning, and further determines the color theme and positioning chromatography of each zoning area by referring to the city master plan, zoning plan and control detailed plan and other superior plans. However, the energy consumption in a city is not homogeneous, as shown by the fact that the energy consumption in densely built-up areas, areas with a high density of human traffic, and areas with a high prevalence of urban activities are relatively large and have a significant "heat island effect". For example, the frequency of air conditioning and refrigeration in residential buildings depends on the hot and cold climatic conditions, and residential buildings in most climatic zones are briefly cooled in summer; while commercial buildings in high-density areas of cities, regardless of climatic conditions, are often cooled all year round regardless of the season, and the energy consumption for refrigeration will reach its peak in summer; therefore, the high energy consumption regions outside hot climatic zones are mainly urban The high-density construction areas that bear commercial business functions. A large amount of material construction in high-density built-up areas of cities, color is a large area that cannot be ignored, and the energy efficiency brought by its thermal efficiency cannot be underestimated [14].

The planning and design of urban color and architectural color should focus on the relationship between the physical properties of color and light and heat, so as to judge its impact on the energy consumption of buildings and cities, and advocate expanding the perspective of urban color research, taking advantage of the presence of urban color and architectural color in large areas of cities, and increasing the proportion of urban color planning in urban planning, as well as increasing the proportion of "energy-saving attributes "Secondly, based on the quantification of the energy-saving effect and software simulation and monitoring, we use remote sensing monitoring and surface temperature inversion to determine the distribution of urban heat island sources, and accordingly carry out regional zoning of urban color heat island. Finally, detailed energy-saving design of building color is carried out for high-density environment. Finally, we will design a detailed building color energy-saving design for the high-density environment, so that urban color can become a new force for urban energy-saving while creating a beautiful appearance.

In addition, the urban meteorological recommendation map is used as a basis to identify the built-up high-density built-up areas with high heat stress, and based on the zoning is able to develop and implement plans related to the use of building materials, such as cooling roofs, insulated walls, cooling road paving, and tree and grass planting, as well as to inform urban geometric factors, such as the sky view factor (SVF) aspect ratio, which in turn influence the formation of the urban climate state and provide future development of the city seeking paths to allow space to regulate air circulation in necessary areas [12].

4. Conclusion

The application of meteorological zoning to urban environmental climate maps aims to balance the thermal requirements of urban scale, neighborhoods, and buildings under the influence of extreme urban climates and local microclimates with effective wind avoidance, proper ventilation and the use of albedo and absorptivity to mitigate the effects of local microclimates, thus considering the nature of development (new and existing), realizability and energy consumption savings. In this way, design criteria are established based on data from the city's current and future climate projections to achieve comfortable cooling and heating environments, healthy minimum temperature requirements and energy consumption patterns for city residents.

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Declaration of Interest statement

There are no conflicts of interest to declare.

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