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The Objective and Methodology of Urban Climate Map for the City of Xiamen

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Abstract

Aiming at mitigating urban climate issues, from the perspective of the correlation between the morphology of underlying surface and urban climate, based upon Xiamen's natural, economic and social conditions and urban development strategies, new approaches for compiling urban climate map for the coastal city in southeast Fujian province are explored. With the idea of problems-solving and cost-control, the approaches are anchored in the assessment of the differences between the theoretical value of urban climate issues distribution which are calculated with morphological zoning and corresponding observed results, therefore the main objective of climate analysis is redefined to locate areas where inappropriate constructions occur and map the city according with a hierarchy of carrying capacity of urban climate environment. Findings show that the Xiamen urban climate map produced with mentioned approaches may lay a foundation for generating customized urban design strategies along with providing quantitative analysis from urban climate research.

Keywords: urban climatology; carrying capacity; urban planning; urban climate map

1. Instruction

As a best bridge between urban planning and urban climatology, urban climate map system can scientifically guide urban planning and decision-making for sustainable development [1]. As an information and evaluation tool, the concept of urban climate map ("UCMap") was created by German researcher Prof. Knoch in the 1950s and introduced to other countries after 1980 [2-3]. As a tool for translating climatic related information into urban planning process, urban climate map can indicate the status quo of urban climate environment and probable urban

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climate issues in two-dimensional maps, and evaluate climate function of each individual zone and clarify challenges for spatial planning [4-6]. As it can help urban planners understand the effect of urban climatic issues solving on decision making in urban planning, urban climate map can bridge the gap between urban climatology and urban design [7-9]. Practices show that it is necessary for cities in different climate zones to find appropriative way to evaluate the carrying capacity of urban climate environment based on the diversity of available resources and practical challenges. A research project was carried out to produce urban climate map for the city of Xiamen in 2014-2015 to enable planning authorities to take care of the urban climate and its interrelation with urban structures.

At present, there are two common ways to establish an UCMap system .One is based on outdoor human comfort evaluation, the other is based on regional climate function identification. The former can hardly avoid the issue of objectivity when evaluate the effect of meteorological factors on human body. And most relevant research works ultimately had to use qualitative analysis methods such as questionnaire survey to determine the classification threshold in terms of human comfort feeling. The latter can indicate the climate function of different regions, but it is hard to define the actual disturbance of the development of each region on original urban climate function. Considering the diversity and huge scale of urban sprawl in China, it is necessary for each city to explore custom-made ways to present and mitigate urban climate issues, and to rethink the objectives and method of compiling UCMap. The research focused on developing and implying localized approaches for the city of Xiamen, as well as providing technical reference for the other coastal cities in southeast Fujian province in China

2. Objectives and tasks

2.1. Framework condition

The objectives of establishing UCMap system must be based on a further investigation of natural, economic, social and other basic framework conditions. With an area of 1699.39 km^2,the city of Xiamen lies between Zhangzhou plain and Quanzhou plain and is located at 24°26′46″ N 118°04′04″ E, where Jiulong River meets the sea. Since 1980, Xiamen has been changed into a central city of southeast coastal areas, a shipping center and a most popular tourism destination from a front fort. In the 21st century, under the guidance of the ‘trans-island development’ strategy, the integration of Xiamen island and coastal region is realized. According to the draft of Urban Master Plan for Xiamen (2010-2020), the land for construction will increase to 440km^2 in 2020 and the main structure of urban layout will be composed of one island, one belt, and dual-core via the development of new towns, the concentration of industrial parks, as well as the decentralization of traffic infrastructure. All urban clusters will be separated by sea, mountains and ecological corridors and will be blended into natural environment.

The city has a monsoon humid subtropical climate, characterized by long, hot and humid summers and short, mild and dry winters. The monthly mean temperature in February is 12.4°C (285.5K), while in July it is 27.8°C (300.9K). The annual mean temperature of northwestern Xiamen, which mainly consists of mountainous terrain, is lower than other parts. The mean annual rainfall is around 1350mm (53in). Monthly average relative humidity of the August is 85%. Due to the impact of land and sea breezes as well as monsoon, the annual average wind speed is about 2.7m/s and is on a downward trend from the 1950s. Meanwhile, with the influence of topography, the prevailing wind direction of each zone shows great diversity from observational data.

2.2. Characteristics of Xiamen’s urban climate issues

Along with the economic boom, the urban climate issues of Xiamen have been deteriorating during past three decades. In summer, days of high-temperature, cloudburst and smog were continuously increasing, while the atmospheric visibility and the sunshine duration were decreasing. Extreme weather events occurred more frequently. By 2012, the average annual temperature has risen from 20.1°C (293.3K) to 21°C (294.1K) and its uptrend is particularly obvious in the new century. The average annual relative humidity has declined from 78% (in 1990’s) to 72% or even lower. From 1954 to 2004, the annual rainstorm days of Xiamen increased from 3 days up to 5 days.

It should be noted that the number of annual smog days surged since the year of 2003, which is called “the first year of private auto age in China”. Meanwhile, the duration of smog events kept growing up to 7 days and continuous 3-days of haze occurs several times per year. In addition, the prevailing wind of Xiamen is not always beneficial to improve the air quality because of the unique geographical and climatic conditions. 70% of smog days occur in winter and spring, when the prevailing wind blows pollutants from northern continent to Xiamen. That means, the growing environmental load is not only caused by economy boom and growing use of vehicles, but also affected by the urban development of Putian, Quanzhou and other adjacent cities.

2.3. Planning requirements

Under complicated geographical conditions, the quality issues of urban climate environment cannot be simply attributed to urban development and the morphology of artificial underlying surface. Instead, assessing the contribution rates of each area to urban climate and estimating the impact of new development on urban climate change may form a more reliable basis for policy making and resource allocation. For instance, to a concrete developed area, the observed values of its urban climate indexes should not be directly used as the criterion to decide the renewal mode. It will be replaced by the results of comparison between the simulation values under typical conditions and practical statistical values of climate indexes of the area. In other words, if the simulation value of the urban climate issue is lower than the current situation, then the development of this area may be regarded as suitable, development measures such as increasing land use intensity may be acceptable. For instance, if most urban development projects in a serious thermal pollution area are low-density, it can be concluded that urban heat island effect should be attributed more to other factors such as bad ventilation condition instead of urban construction. So, under complex climatic and geographical conditions, strong urban heat island is not consequently related to urban construction.

Fundamentally, what urban planners need to know is where inappropriate developments occur and where is suitable for future development instead of where is comfortable or not. The practical traits of urban planning determine that, the new approaches for UCMap compiling are of two advantages. On one hand, the discussion on the evaluation criteria of urban climate environment is here converted into studies on the correlation between the underlying surface and the urban climate issues; on the other hand, being restricted to the irreversibility of built environment and technical conditions, it is pursued that it is more realistic to control the influence of urban construction on urban climate, instead of eradicating urban climate issues in an utopian way. In other words, the UCMap should not only show the current situation of climate environment, but also to predict climate change triggered by the construction activity.

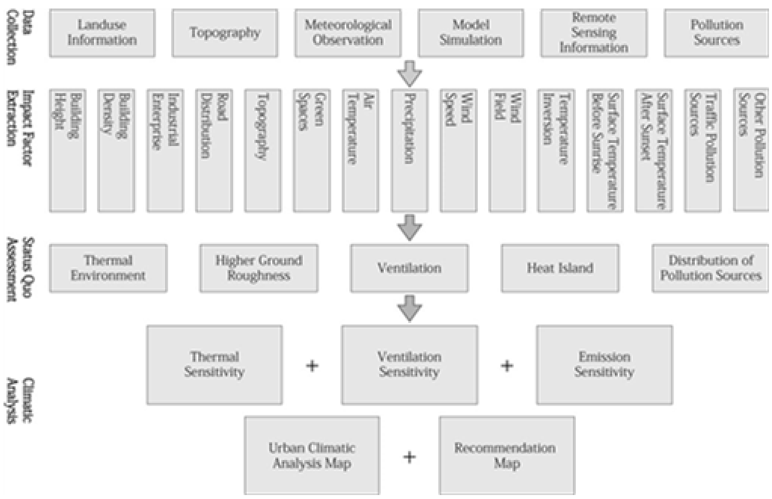

Fig. 1. Technical route of urban climate map system of Xiamen

3. Methodology

Considering the numerous factors and complex relationships of urban climate issues, it is necessary to clarify the relationship between different factors, and to make breakthroughs from the perspective of systematology to improve the urban climate environment quality based on climate function analysis (Fig. 1).

3.1. Thermal Environment Assessment

Thermal environment assessment is designed to acquire cooling capacity of land at night-time by visualizing the difference between surface temperatures in the morning and evening, so as to show the intensity and distribution of urban heat island. Due to the current large grid of weather monitoring networks in Xiamen, the monitoring data is difficult to meet the requirements of the meso scale research. At the same time, the instant surface heat radiation temperature grasped by means of satellite remote sensing technique cannot be equated with air temperature information from the thermometer shelters at about 2 meters above the ground [10]. Therefore, the integration of remote sensing information and climate monitoring data is treated as the idea of thermal environment assessment in Xiamen. The research group selected the remote sensing data at 10:00 and 13:00 in 4 representative days (namely 2 days in summer and 2 days in winter) under clear weather from 2011-2015, and obtained the synthesized radiation information using multi-channel remote sensing data, namely infrared, near-infrared and thermal infrared. The revised surface brightness temperature maps in the morning and at noon are used as the foundation of thermal environment assessment. Thereinto, cooling ability of the land at nighttime is defined as the surface temperature difference between morning and noon, while average temperature index is defined as the mean value of morning surface temperature and noon surface temperature. The higher the average surface temperature is and the poorer the cooling ability is, the more intense the urban heat island effect is. For the same reason, the lower the average surface temperature is and the stronger the cooling ability is, the more cooling ability the open space has at night. Therefore, 12 grades of thermal environment in Xiamen and its distribution can be obtained (Fig. 2). Research shows that the current urban heat island in Xiamen is rendered as several independent patches, and in summer several heat cores are going to join into large pieces, meanwhile heat core areas are strongly associated with the distribution of industrial zone.

3.2. Ventilation Condition Assessment

It is not enough that only using wind environmental monitoring information grasped from local weather stations to assess the ventilation condition in Xiamen. Firstly, the low density of monitoring network causes low accuracy of mapping. Secondly, the summary of wind roses from automatic weather stations shows that, regional prevailing wind direction of each district within the study scope cannot be fully consistent with the general prevailing wind direction of the whole city [11]. It demonstrates that regional flows are seriously influenced by local topography and local circulation. Therefore, the key factors that affecting local flows must be identified [12]. First of all, with a subtropical monsoon climate, Xiamen has typical monsoon characteristics (northerly winds in autumn and winter,

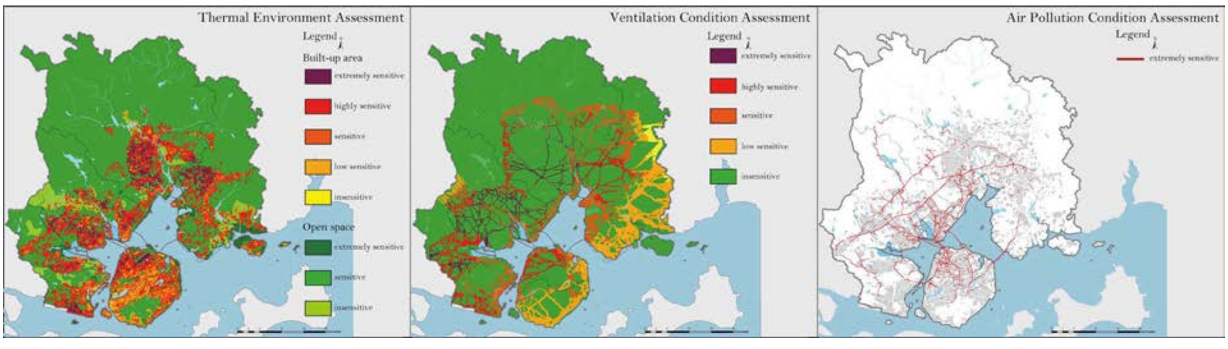

Fig. 2. Thermal environment assessment map, ventilation condition assessment map and air pollution condition assessment map of Xiamen

southerly winds in summer). Secondly, formed by several islands and coastal regions, Xiamen has a circuitous coastline. The shoreline length of Xiamen island is already about 234km. Effects of sea-land breeze become apparent after 15:00 every day. Finally, Xiamen is controlled by cold high pressure in winter so the air is dry and atmosphere layers are stable. Under this condition, temperature inversion appears frequently, which restrains the diffusion of pollutant near surface and results that high PM10 pollution risk (70%) in winter from beginning of this century. So, in this case the coupling among prevailing wind, sea-land breeze and odds of temperature inversion is treated as the idea of ventilation assessment in the case. The research group chose typical days with prevailing wind in 2014 (January 5th, 15th, and 21st, June 12th and 14th are northerly wind typical day. June 6 and 21st are easterly and southerly wind typical day) and simulated the distribution of wind direction and wind speed at four points in time (02:00, 08:00, 14:00, 20:00). Also we selected typical days that wind direction changes obviously and which are in accordance with characteristics of sea-land breeze, after being simulated by using the WRF model and multiply nested, the distributions of wind direction and wind speed at 02:00, 08:00, 14:00 and 20:00 can be obtained. And, the temperature data of each height level at 20:00 every day in 2014 are used to calculate the annual odds of temperature inversion. Results show that ventilation condition in Xiamen generally declines from southeast to northwest, because of the frequent temperature inversion the ventilation condition of inland built-up areas like Tong'an Jimei and Haicang is the poorest (Fig. 2).

3.3. Air Pollution Condition Assessment

Concentration distribution of air pollution in Xiamen had a decreasing character in the order like "industrial area - residential area - eco region", it indicated that local air pollution was mainly resulted from industrial emissions and vehicle emissions. Considering the segmentation and strip isolation of environmental protection and urban construction sectors in China, the difficulty to get the pollution source list was an insurmountable barrier for compiling urban climate maps in China. As a result, the main contents of the air pollution assessment in this case

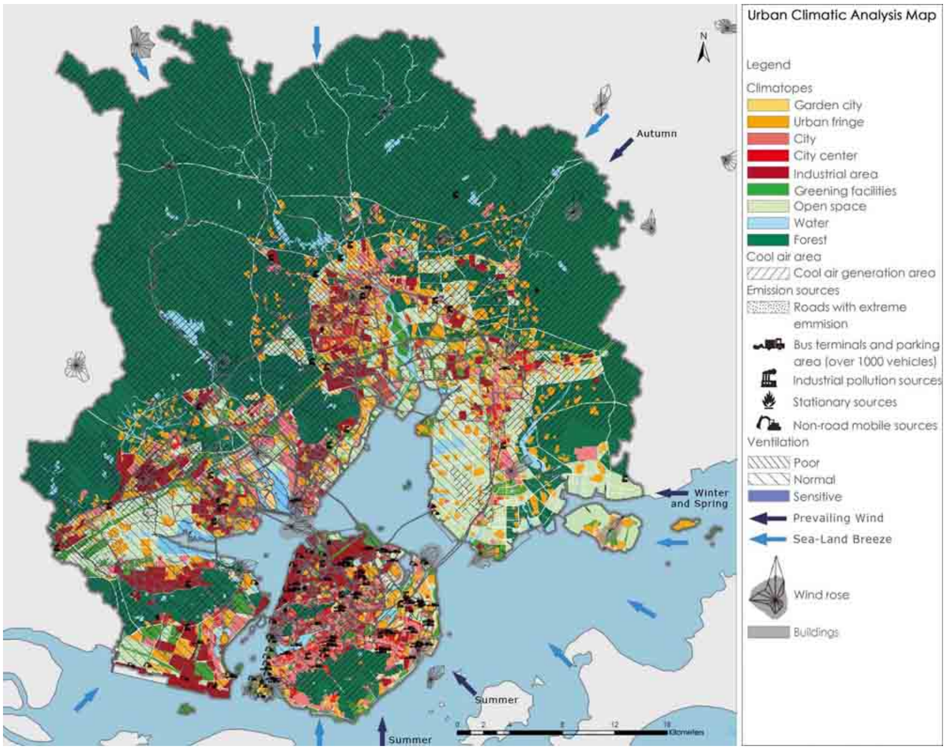

Fig. 3. Urban climatic analysis map of Xiamen

aimed at assessing the air pollution caused by motor vehicle traffic, which was to a large extent influenced by traffic flow. So traffic flow was treated as an important index for assessing air pollution in this case, factors such as terrain and building barrier were not involved in. On the basis of the motor vehicle traffic flow statistics in a morning peak period (7:00-9:00) in 2014, which was carried out by associate professor Xu from Department of Urban Planning of Xiamen University, the research group calculated the traffic flow per hour, and treated the roads in which the traffic flow per hour above 10 000 as seriously polluted roads. According to the results, the seriously polluted roads were mainly distributed in link sections between the main island and other regions, the link sections between districts, and docks at northwest of Xiamen Island and industrial areas (Fig. 2).

3.4. Urban Climate Analysis Map

The basic task of this study is to produce the urban climate analysis map and recommendation map for urban planning of Xiamen. The former can provide a basis for the latter, and with advances of research methods in the further it can be also as basis for making materialization of planning proposals. Based on existing descriptive data, land use data and topographic data, urban climate analysis map of Xiamen integrated the most important climate information of this region, and showed the status quo of the local urban climate, as well as distinguished the differences between urban climate effects from different kinds of urban zones. The precision of the drawing grid cell in the case is about 100m×100m (Fig. 3). Urban climate analysis map of Xiamen indicated the climatopes, distribution of cool air generation area, distribution of air emission sources, ventilation condition, prevailing wind in all seasons, wind roses in all regions and so on. Among them, climatopes were divided into nine categories, namely garden city, urban fringe, city, city center, industrial area, greening facilities, open space, water and forest. Practical experience of previous studies shows that development goals and planning strategies of different categories should be developed separately.

3.5. Recommendation Map for Urban Planning

Recommendation map for urban planning was used to evaluate the carrying capacity of urban climate environment in case of land-use structure adjustment or building scale changes, and to provide the planning proposals for each class. Principles of climate sensitivity assessment in Xiamen are as follows. Firstly, in thermal-sensitive areas urban renewal measures should be taken based on viewpoint of urban climatology in order to improve the urban climate environment in the region as well as to avoid the spread of thermal and air pollution. Secondly, in view of the disperse function of cool air from the ventilation corridor to mitigate the thermal and air pollution, existing ventilation corridor should be extended and its ventilation efficiency should be optimized. Thirdly, vegetation is an important resource for climate regulation because of its generation of fresh and cool air at night, and it can be used as thermal compensation areas during the day. Therefore vegetation should be retained and

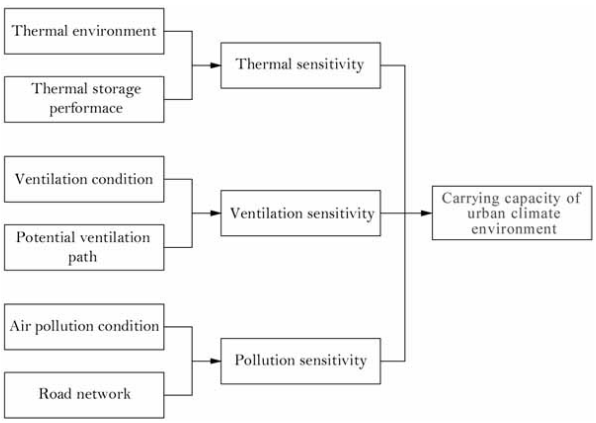

Fig. 4. Technical route of compiling recommemdation map for uban planning

expanded [13]. Based on climatology, large open space was not suitable for further urban development. Therefore, thermal sensitivity, ventilation sensitivity and pollution sensitivity were used as important indicators of climate sensitivity assessment in Xiamen (Fig. 4). Here, the thermal sensitivity was obtained through comparing the thermal storage performance with the thermal environment assessment result, ventilation sensitivity was obtained through interconnecting the potential ventilation path with ventilation condition assessment result, and pollution sensitivity was confirmed by the air pollution condition assessment result. Eventually, the land within the study scope is divided into nine classes based on climate sensitivity assessment, border of each class was defined and planning recommendation for each was provided as well. Among the nine classes, three classes involved the so far undeveloped open space, five classes aimed at developed built-up area, the other one involved roads with heavy pollutants (Fig. 5).

Statistical analysis shows that urban structures have a severe effect on the local climate environment. Firstly, Building density is the main factor of strong urban heat island effect in Xiamen. The intensive land use of industrial zone is the trigger of strong heat island effect; at the same time, all kinds of high density built up areas are mostly warmer than low density built areas. Secondly, the urban villages and industrial zones are most likely to trigger serious negative climate effect. So, it is of great value to initiate green urban renewal in order to relieve heat island effect as well as to improve ventilation situation. Thirdly, Because of the high green coverage rate, super high-rise built up areas and the central business districts usually generate less climate interference compared with their building volume. Fourthly, other kinds of built up areas exhibit similar climate interference from the statistical results. Therefore, microclimate situation should be evaluated in concrete develop project in order to provide the detailed guidance from aspect of urban climate problem solving.

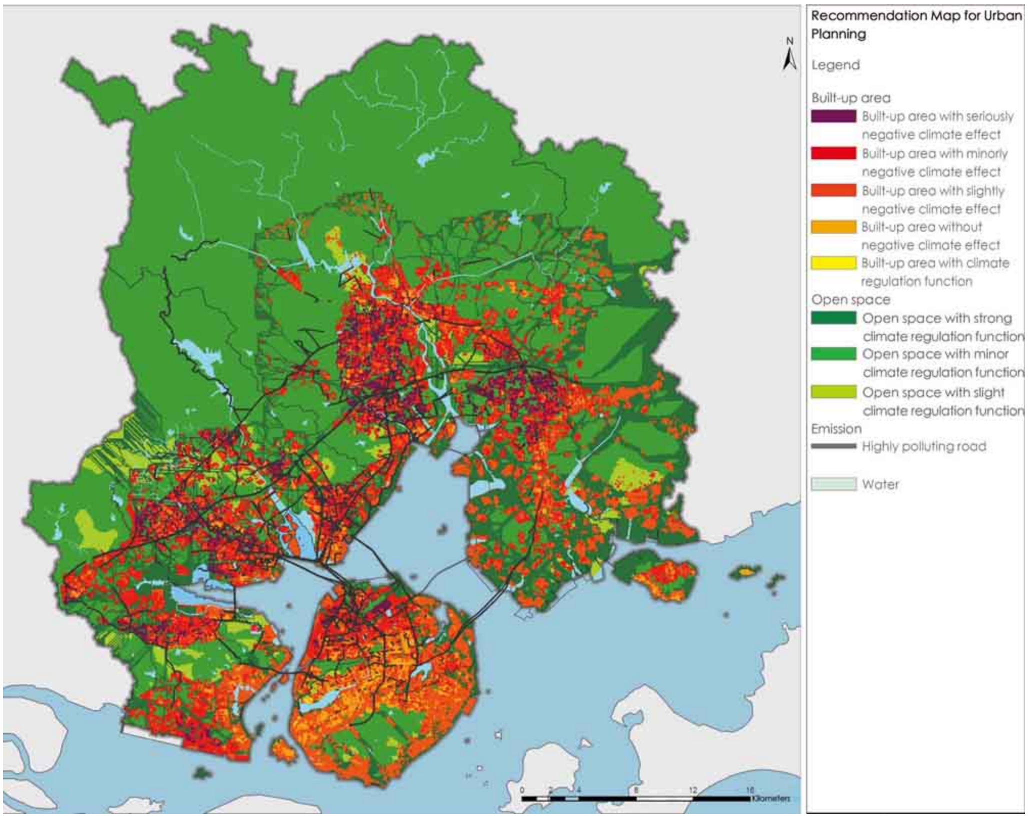

Fig. 5. Recommendation map for urban planning of Xiamen

4. Conclusion

In Xiamen, a common UCMap is unable to cope with the complex geographical and climatic conditions. The fast-growing population of Xiamen is continuously creating driving force to urban sprawl, while the changes of urban underlying surface caused by urban sprawl is the key factor of urban climate issues. If there is no sufficient precaution or improvement, the rapid urbanization will definitely increase the frequency and severity of urban climate issues. As urban construction and its impact are hard to be changed, it is necessary to clarify the current situation of various types of urban climate issues, to analyse the impacts of natural and man-made elements on urban climate, to identify available local resources, and to propose corresponding measures and implementation framework comprehensively, so as to provide scientific and feasible technical references to decision-making in urban planning.

Compared with the conventional method, the carrying capacity assessment of urban climate environment can point out the importance, necessity, feasibility and potential of a renewal or development region. Thus, not only can it avoid the objectivity of the threshold, but also can it locate the problem area which needs to be improved from relatively deeper thinking. Given the dominated influence from the macro climate, there is a strong input and output relationship between macro climate analysis and micro climate research in certain space-time scope. The qualitative results of climate analysis can provide a better framework for the following micro climate research to develop quantitative indicator systems for urban planning. Therefore, the research approaches discussed in this research can be applied to develop urban design strategies on macro scale, while the research results can be used as efficient up-level guidance to urban design practice on micro scale. In view of the diversity of research tasks, the establishment of urban climate map system must be built in an interdisciplinary and collaborative work way [14-15]. Namely, upgrading the urban planning system, applying the innovative informal planning instruments, and establishing the working platform for collaboration will be beneficial to innovating working methods and improving working efficiency.

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References

[1] Yu B., Song D.F., Liu S.Y., Research on urban climate problem-Solving-Oriented planning approaches in Xiamen. Environmental Science and Engineering (Environmental Science). 148(2015)1-12.
[2] Matzarakis A, Röckle R, Richter CJ, usw. Planungsrelevante Bewertung des Stadtklimas - Am Beispiel von Freiburg im Breisgau. Gefahrstoffe - Reinhaltung der Luft, 68(2008)334-340.
[3] Liu S.Y., Comparative research on integration approaches of urban climate studies in urban planning between China and Germany, Beijing: Science and technology of China press, 2014.
[4] Baumüller J, Reuter U. Demands and Requirements on a Climate Atlas for Urban Planning and Design. Office of Environmental Protection: Stuttgart,1999.
[5] VDI-3787-Part1. Environmental meteorology-climate and air pollution maps for cities and regions, 1997.
[6] Scherer D, Fehrenbach U, Beha H-D, et al. Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning process. Atmospheric Environment. 33(1999)4185-4193.
[7] Ren C., Ng E., Katzchner L., An investigation into developing an urban climatic map for high density living-initial study in Hong Kong. 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, Sep. 2007, Crete island, Greece.
[8] Eliasson I., The use of climate knowledge in urban planning. Landscape and Urban Planning. 48(2000)31-44.
[9] Ren C., Ng E., Yan Y., et al. Urban climatic map studies: a review. International Journal of Climatology, 31(2011)2213-2233.
[10] Verband Region Stuttgart. Klimaatlas Region Stuttgart. Stuttgart: Landeshauptstadt Stuttgart, Amt für Umweltschutz, Abteilung Stadtklimatologie 2008.
[11] Kress R. Regionale luftaustauschprozesse und ihre Bedeutung für die räumliche planung. Dortmund: Institut für Umweltschutz der Universität Dortmund, 1979.
[12] Horbert M. Klimatologische Aspekte der Stadt- und Landschaftsplanung. Berlin: TU Berlin Universitätsbibliothek, Abt. Publikationen, 2000.

[13] Liu S.Y., Shen J.H., Urban ventilation channel planning method based on local circulation: a case study of Stuttgart, Germany, Journal of Zhejiang University (Engineering Science). 44(2010)1985-1991.
[14] Franke E. Stadtklima-Ergebnisse und Aspekte für die Stadtplanung. Stuttgart: Karl Krämer Verlag, 1977.
[15] Koch M. Ökologische Stadtentwicklung - Innovative Konzepte für Städtebau, Verkehr und Infrastruktur. Stuttgart, Berlin, Köln: Kohlhammer, 2001.