Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 12	No. 4	pp. 645-650	2013

Original Research Paper

Research of Urban Thermal Environment Based on Digital Technologies

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 25-4-2013
Accepted: 19-5-2013

Key Words:
Urban thermal environment
Heat island
Digital technologies
Digital simulation

ABSTRACT

Digital simulation is a fast, effective and economical research method. Compared to traditional research method, it can not only save a lot of manpower and material resources but also can fill the blank of traditional research. In this research, we simulate Shanghai's thermal environment in July under typical afternoon working conditions by the comprehensive application of Ecotect software and CFD software. The research enhances our understanding of the distribution and cause of "urban heat island effect", and the climatic factors (wind velocity, temperature, solar radiation, atmospheric pressure, etc.) that are closely related to urban thermal environment.

INTRODUCTION

With the rapid acceleration of China urbanization, there is also a rapid growth of urban population and land utilizing scale. And these lead to the conflict against limited capacity of environment and resources. Thus, "urban sickness" begins to appear, and "urban heat island effect" is one of it. The main cause of "urban heat island" is modification of the land surface by urban development which uses materials which effectively retain heat. Waste heat generated by energy usage is a secondary contributor. As population centres grow they tend to modify a greater and greater area of land and have a corresponding increase in average temperature (Liu 2010). The phenomenon was first investigated and described by Luke Howard in the 1810s. And it has been widely concerned around the world since his introduction of it. Especially because of the rapid growth of urban amount in China, relieving "urban heat island effect" has become an urgent task. The formation of urban heat island is shown in Fig. 1.

In this paper, we regard main urban areas of Shanghai (Fig. 2) as the research objects, and use digital simulation technology to simulate the thermal environment of them in summer which aims to provide certain references for future urban planning and spatial arrangement. With the constant improvement of digital technologies, they have been widely used in architectural and planning industry. Compared to common observation method or simulation method of models, digital simulation technology has the advantages of low cost, short research cycle, and visual and direct display of the research results. In this research, Air-pak software and Ecotect are adopted. Air-pak software is one kind of Computational Fluid Dynamics software. Computational Fluid Dynamics was developed at the beginning of 1930, and it is the combination of modern fluid dynamics, numerical mathematics and computer science. Ecotect is an environmental analysis tool that allows designers to simulate building performance right from the earliest stages of conceptual design. It combines a wide array of detailed analysis functions with a highly visual and interactive display that presents analytical results directly within the context of the building model, enabling it to communicate complex concepts and extensive datasets in surprisingly intuitive and effective ways (Yang 2010a).

ANALYSIS OF THE METEOROLOGICAL CONDITIONS OF SHANGHAI

In order to simulate the urban thermal environment of Shanghai in summer, we have to study the typical meteorological conditions of Shanghai in summer, and regard them as the initial simulation conditions. Shanghai is located in eastern China, at the middle portion of the Chinese coast, and sits at the mouth of the Yangtze River. According to the Climatic Regionalization Map of China (Fig. 3), Shanghai belongs to climatic region of hot summer and cold winter. The typical characteristics of hot-summer and cold-winter region are high temperature and humidity in summer. Because of the high humidity in summer, it is hard for sweating and this is the main reason of poor thermal comfort in summer. According to the Ecotect analysis of the annual temperature, solar radiation and thermal comfort of Shanghai (Figs. 4, 5), it can

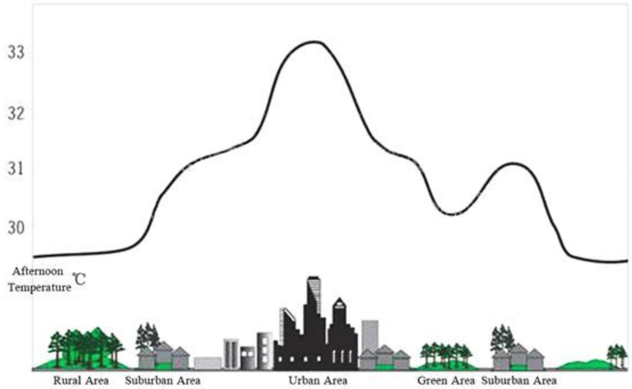

Fig. 1: Diagram of urban heat Island.

be seen that the strongest solar radiation value appears in May, the highest temperature appears in June, the highest average temperate appears in July and it is 28°C. Thus, we choose July which has the highest average temperature as the simulation time. Fig. 6 is the wind direction, frequency and velocity distribution graph of July (from 10:00 a.m. to 14:00 p.m.). It can be seen from Fig. 6 that the main wind directions of July (from 10:00 a.m. to 14:00 p.m.) are south, southeast and southwest, the highest wind velocity is 50 km/h, and the average wind velocity is 15km/h. According to the Ecotect statistics, in order to make it convenient for calculation, we designate the ingoing wind direction as south, the wind speed as 15km/h, and the temperature as 28°C.

ESTABLISHMENT OF CFD MODELS

After finishing the initial conditions of outer environment, the following thing is to convert the complex city into numerical models which can be calculated by CFD software. City is a very complex object which is combined by various kinds of information. Reflecting all information of the city is a tremendously heavy task. Thus, we have to tackle the main contradiction when we establish the CFD models of the city. Specifically speaking, we only need to consider the related information of urban thermal environment, treat two different regions which have the same attributes as a whole, reduce the city to its simplest form according to the current situation of the city, divide the city into various regions (replaced by block), and attach corresponding attributes to every region. Fig. 7 is the land utilization planning map of the main urban areas of Shanghai (1999-2020). Fig. 8 presents the functional zonings of Shanghai.

According to some research results of Chinese scholars, the effect of ventilation shaft whose width is below 100m is not obvious under the situation of common wind ventilation when establish CFD models, and the effect is ideal only when the width of ventilation shaft is about 150m (Li & Yu 2006). Thus, in the aspect of river system, because of the narrow width of Suzhou River, we will neglect it during the modelling process. In the aspect of green land, the effect of reducing the surface temperature is most obvious only when the area of it reaches 1.44ha (Han & Liang 2011). Thus, we will neglect those small street green lands. Considering the differences of building density, plot ratio, green coverage, population density, etc., the numerical models may show different characteristics during the simulation process (Yu & Zhang 2007). We divide the main areas of Shanghai into 5 levels (Fig. 9). Grid analysis of Shanghai main urban regions based on CFD is shown in Fig. 10.

The first-level areas are the commercial areas which includes Lu jiazhui Central Commercial Area in Pudong District, one city commercial centre (People Square and

Fig. 2: Location of Shanghai.

Fig. 3: Climatic regionalization map of China.

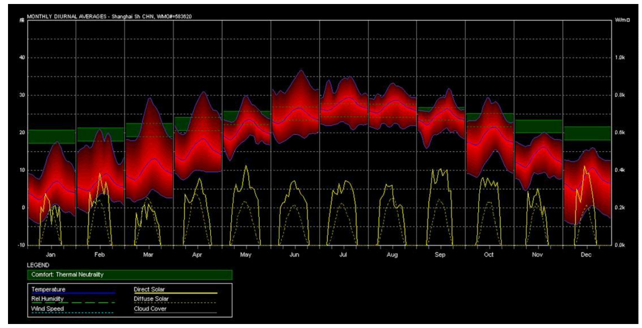

Fig. 4: Annual temperature, solar radiation and thermal comfort of Shanghai.

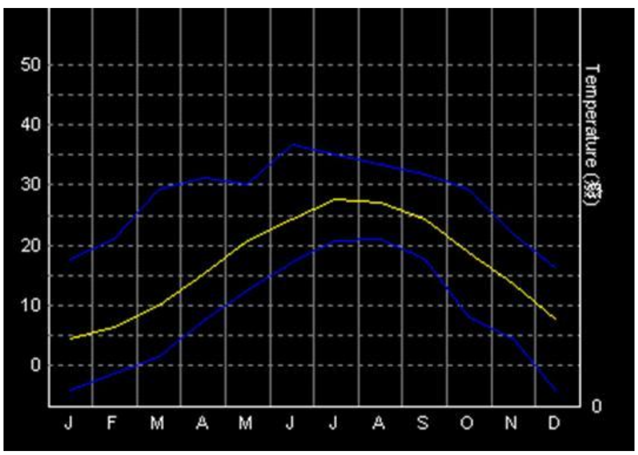

Fig. 5: Annual temperature distribution.(Yellow line-average temperature, upside blue line- highest temperature, and underside blue line-lowest temperature).

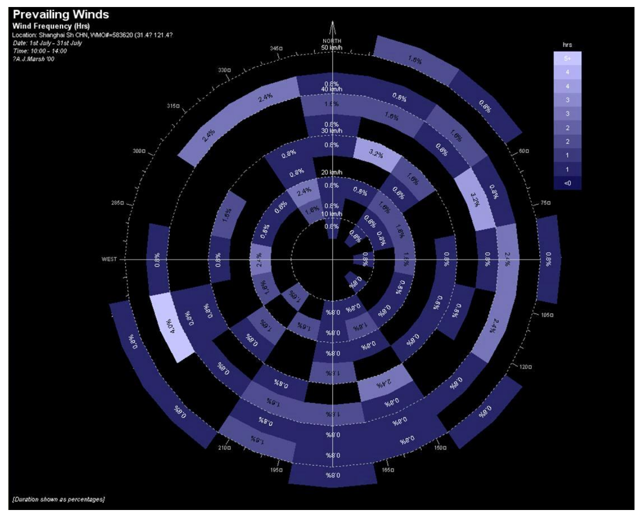

Fig. 6: Wind direction, frequency and velocity distribution of July (from 10:00 a.m. to 14:00 p.m.).

surrounding areas) and four city sub-commercial centres (Xu Jiahui, Hua Mu, Jiang Wan-Wu Jiaochang, Zhen Ru); the second-level areas are high-density commercial and residential areas; the third-level areas include low-density commercial and residential areas; the fourth-level areas include urban parks and large green lands; and the fifth-level areas include urban river systems. We should choose the average value of various parameters according to the building density, plot ratio, green coverage, population density which are closely related to urban thermal environment. Generally speaking, from level 1 to level 5, the building density, plot ratio and population density present continuous decrease, and the green coverage presents continuous increase. Because the river system (Huang Pu River) acts like a ventilation shaft and its heat absorption capacity is stronger than green land, we place it at the fifth level (Yang 2010b).

After the determination of levels, we need to give corresponding attributes to every block, namely, set the numerical parameter of the model. To different-level regions in the city, we should have a comprehensive consideration of the solar radiation and wind, and transfer the building density, plot ratio, green coverage and population density to the attribute parameters of the block (Gauzin 2002). For example, the block attribute of fifth-level regions (Huangpu River and Yangtze River) is set to be fluid, and the fluid material is set to be H_2O. Because of the evaporation caused by solar radiation, we also have to set an air outlet whose superficial area is the same with the block. According to the measurement data, the initial temperature of the air outlet is set to be 25°C. To the fourth-level regions (green lands), their thermal radiation ability is obviously weaker than the building surface, and their thermal capability of them is relatively large,

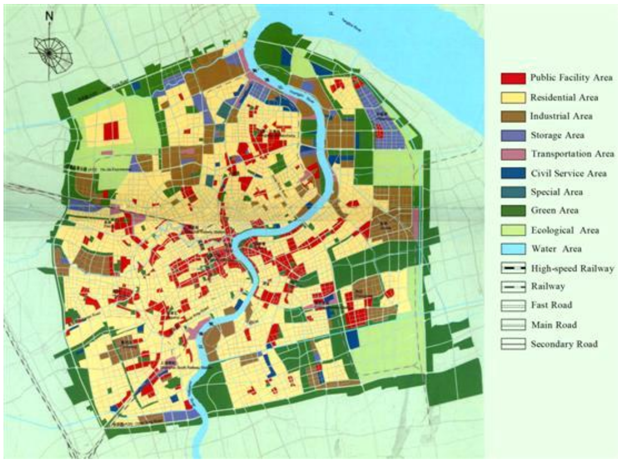

Fig. 7: Land utilization planning map of the main urban areas of Shanghai (1999-2020).

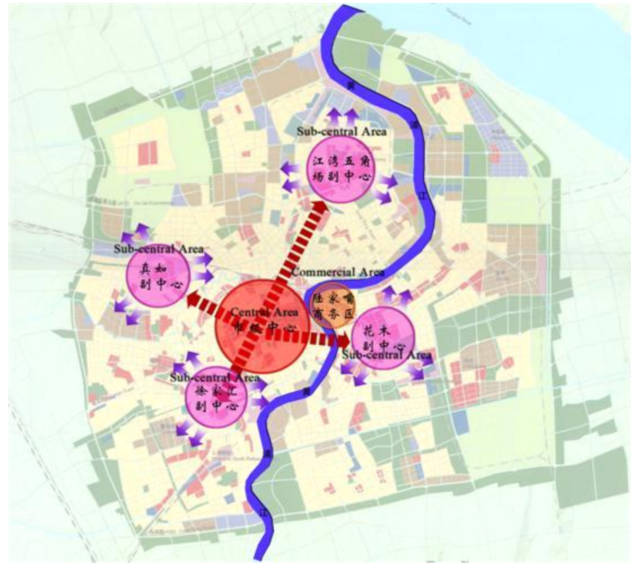

Fig. 8: Functional zonings of Shanghai.

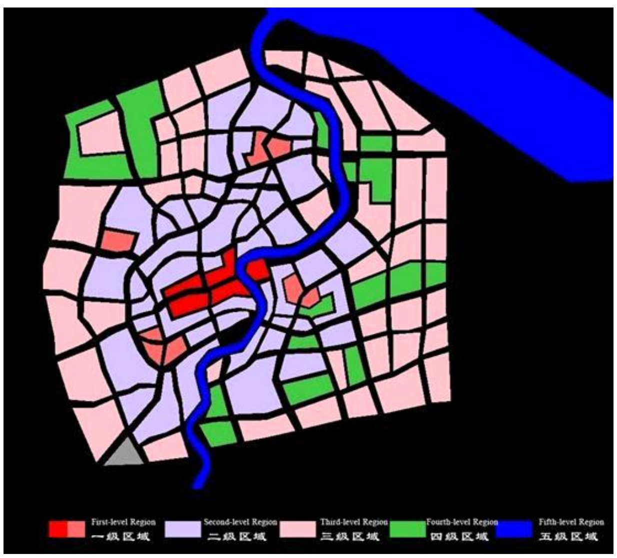

Fig. 9: Different levels of Shanghai main urban regions based on CFD.

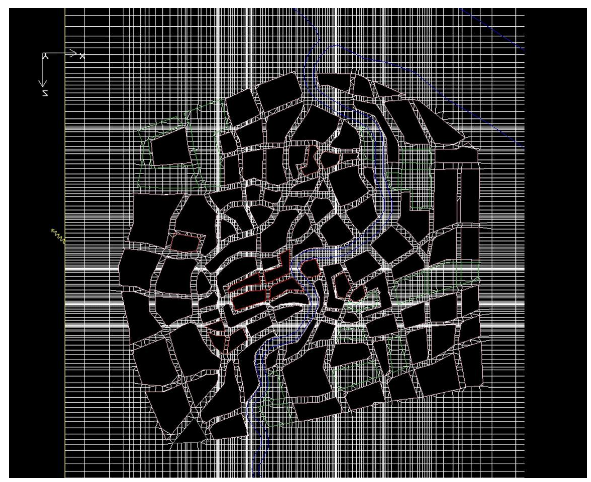

Fig. 10: Grid analysis of Shanghai main urban regions based on CFD.

so they will have a positive effect on the improvement of urban thermal environment. Thus, the block attribute of them is set to be hollow and the initial temperature of them is 26°C. To the second-level and third-level regions, which mainly consist of residences, the person flow is relatively light compared to the first-level regions and their inter areas generally have a high-level green. Thus, the block attribute is set to be hollow, the material is set to be brick, and the initial temperature is set to be 30°C. To the first-level regions, because of crowded population and high-density buildings, the material of the block is set to be solid, and the initial temperature is set to be 40°C. To the specific attributes of materials, we can set them according to their reflectivity to solar radiation and heat absorption. After the finish of setting the block attributes, we need to set the outer environment which are mainly the solar radiation and wind environment. According to the above-mentioned wind direction, velocity and average temperature of July in Shanghai, we use the Ecotect to simulate the typical wind environment of July (from 10:00 a.m. to 14:00 p.m.) in Shanghai; combining with the analysis of Ecotect, we set the corresponding solar incident angle, air refractivity index, intensity of solar diffuse reflection in CFD. So far, the first-phase preparations of simulation have been finished.

ANALYSIS OF THERMAL ENVIRONMENT SIMULATION RESULTS OF SHANGHAI

We can see the obvious temperature distribution of the mod-

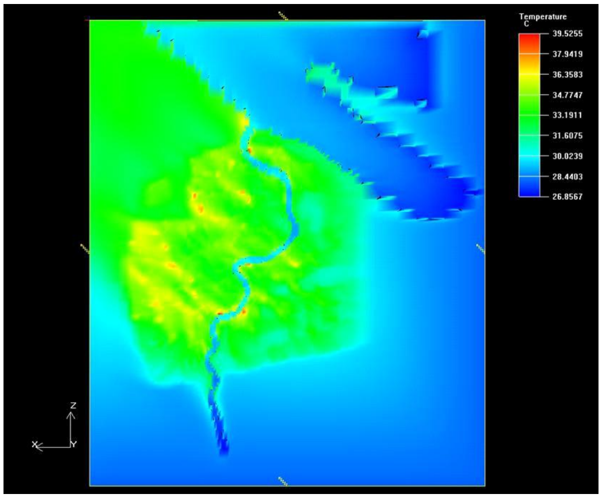

Fig. 11: Temperature distribution graph above the main urban regions.

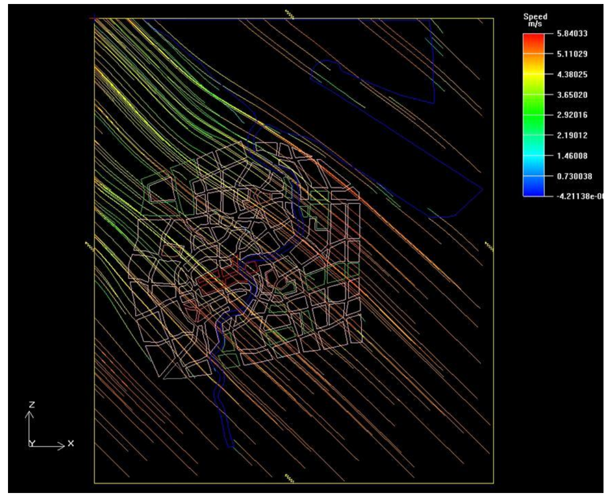

Fig. 12: Wind velocity flow graph above the main urban regions.

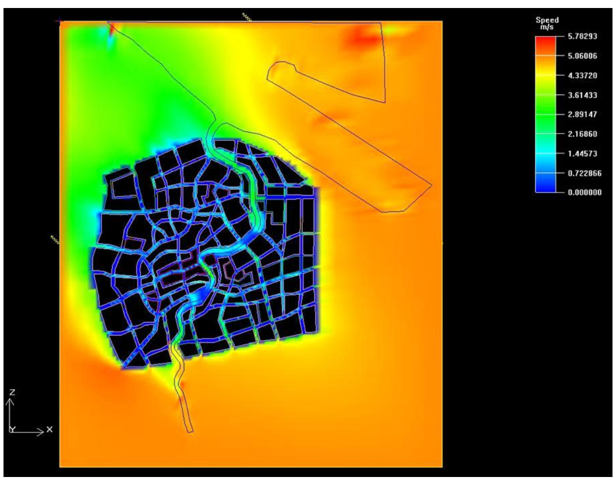

Fig. 13: Wind velocity plan graph of the main urban regions.

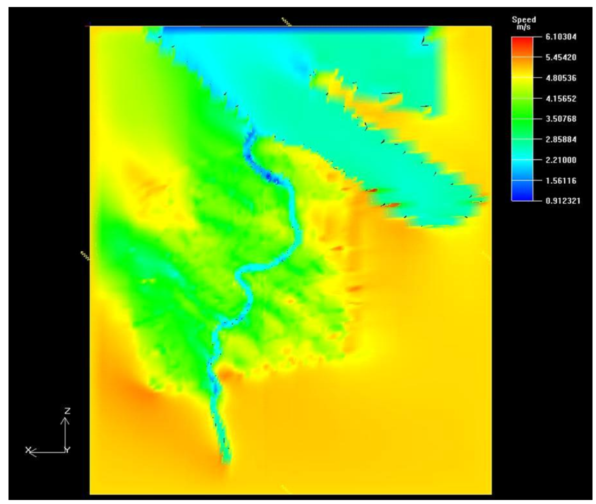

Fig. 14: Wind velocity plan graph above the main urban regions.

els under the situation of southeast direction of Shanghai from the temperature distribution graph (Fig. 11). The main hot regions of Shanghai are the urban central and sub-central regions. Generally speaking, the temperature of first-level regions is obviously higher than other regions. It is progressively decreased from the first-level regions to the fifth-level regions (Weng & Yang 2004). The main urban area is obviously split into two pieces by Huangpu River, and the temperature of riverfront area is relatively lower for the reasons of heat absorption of evaporation and natural ventilation. Fig. 12 is the wind velocity flow graph above the main urban regions, and we can see obvious change of wind direction and velocity. Because of the urban influence, the monsoon direction basically remains the same, but the wind velocity decreases a lot (Walton et al. 2002). It can be seen that the wind velocity is fast in suburban regions and the air age is short from the analysis of the plane figures of wind velocity (Figs. 13, 14) and air age (Figs. 15, 16). The velocity of the wind will decrease for the reason of building obstacles when it sweeps through the main urban areas. In the main urban areas, the air age of some streets whose direction is the same with the wind will be relatively short. The Huangpu River is the obvious watershed of urban thermal environment. This is due to the effects of heat absorption of water evaporation and ventilation shaft of the city. Compared to the actual measurement data, the simulation results of CFD is basically the same with it (Murakawa et al. 1990).

CONCLUSION

Numerical simulation is a very fast, effective and economic research method. Compared to traditional research method,

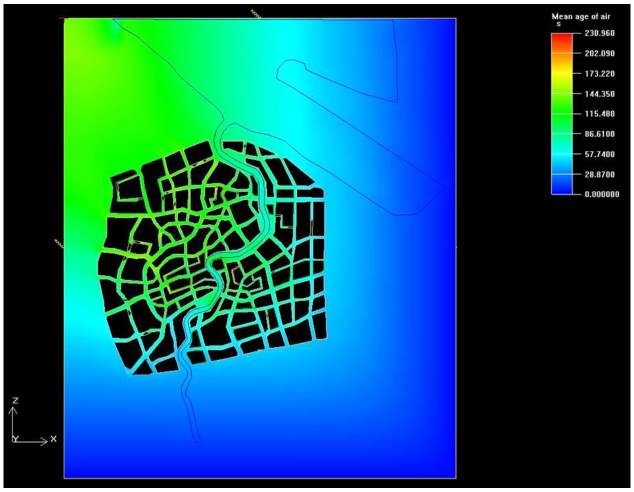

Fig. 15: Air age graph of the main urban regions.

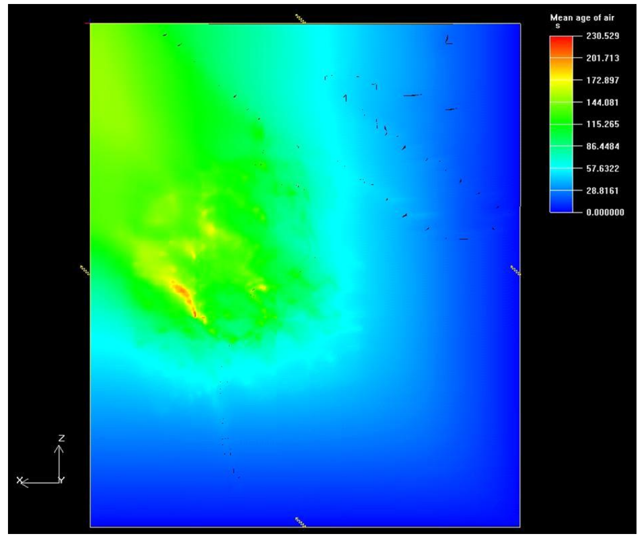

Fig. 16: Air age graph above the main urban regions.

it can not only save a lot of manpower and material resources but also can fill the gap of traditional research. In this research, we simulate Shanghai's thermal environment in July under typical afternoon working conditions by the comprehensive application of Ecotect software and CFD software. And this research makes us have a deep understanding of "urban heat island effect" from the aspects of wind velocity, temperature, solar radiation and atmospheric pressure which are closely related to the urban thermal environment. We can also popularize the application of them to improve the thermal comfort of the city and provide design basements for regions of different climates.

ACKNOWLEDGEMENTS

This work was financially supported by the National Twelfth Five-Year Science & Technology Support Plan: the city high density space efficiency optimization key technology research (Subject Numbers: 2012BAJ15B03).

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