Original Research

Wetlands Appraisal Method to Alleviate Urban Heat Island Effect

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Abstract

Hangzhou is in the process of becoming a world-famous city known for its quality of life and advancement of environmental protection. This research evaluates how the city's surrounding environment is affected by the development of urban wetlands. It is simulated upon the numerical model on an urban scale, with the full advantage of meteorological data and updated techniques related to RS (remote sensing), GIS (geographic information system), and meteorological numerical simulation. Results with figures and meteorological data show that urban wetlands in Hangzhou alleviate the urban heat island effect as well as high temperatures in summer, and significant economic benefits can also be derived from this environmental improvement.

Keywords: Hangzhou weltands, alleviating urban heat island effect, numerical simulation

Introduction

With the progress of industrialization and urbanization, implications on urban ecological and environmental problems have been widely extended. Besides some general natural disasters, cities, especially metropolis, have confronted a series of threats such as climate change, significant urban heat island effect, acid rain, air pollution, poor visibility, increasing ash haze, etc., due to socioeconomic factors, including an oversized population and excessive concentrations of industries and activities, etc. Cities with high level of modernization also can be sensitive to urban security. Since cities are concentrations of population, construction, material possessions, and productive factors together with potential risks, once they encounter unexpected disasters they are bound to suffer a massive loss. In order to tackle those challenges resulted from extreme climates, it is necessary to take some timely measures to optimize urban layout and industrial structure. Even more importantly, it is essential to emphasize and enhance the endogenous capacity of cities, especially for the improvement of the ability of the current ecosystem to mitigate and adapt climate change. Therefore, the study on the exploitation and protection of natural resources (i.e. wetlands) interacted with urban spatial planning in Hangzhou, is pragmatic. On the basis of general characteristics of wetlands beneficial to urban ecological environments, this research provides practical implication to the development of Hangzhou City, particularly for the establishment of a world famous city with quality life and the advancement of an environment-oriented city. In addition, remote sensing (RS) and geographic information systems (GIS) is a very effective method to simulate changes of time and space, which is widely used in many areas of study [1-4]. In this paper, with full advantage of meteorological data and updated techniques related to RS (remote sensing), GIS (geographic information system),

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and meteorological numerical simulation, climatic diagnostic numerical models that are simulated upon numerical models on an urban scale are applied to evaluate the inter-relationship between the alteration of urban layout in Hangzhou (particularly for the planning of Xixi Wetland) and the regional climate change of this city.

Introduction about the Restoration and Protection of Wetlands

According to the principle 'positive protection, scientific restoration, sustainable development,' wetlands in Hangzhou are regionally classified into three parts: Renhe Wetland in the northern part of the city, and Tangxi and Xixi wetlands in the western part of the city. Among these three wetlands, Xixi, altered from a natural wetland to a secondary one, is composed of Jiangcun Wetland and Wuchang Wetland with reference to the administrative jurisdiction [5]. Xixi is divided into three functional blocks with different characteristics for protective exploitation. The first functional block is the wetland park, the establishment of which can be regarded as the core means of protection. The park covers an overall protected area of 10.64 km^2. Secondly, it is a certain area of ecological protection zone which surrounds the park. It can be considered as a buffer between protective exploitation and human activities outside the wetland park. Another functional block is the area outside the ecological protection zone. This is the coordination zone with an overall coverage of 50 km^2 to accommodate and integrate the peripheral landscape to offer more attractive ecological scenes, idyllic scenic spots and diversified surroundings that include two water regions scattered in Wuchangxiang and Xianlin.

According to Ramsar's Ann Aldersey from accompanying data, Xixi is composed of a series of ca.400 permanent freshwater ponds connected by channels and rivers representative of both natural and human-made wetlands in Eastern China. Through channels and sluices, fresh water in this wetland can be managed for both fish feeding and flood control. 126 species of birds have been recorded at the site, including 28 water birds. The site is important for nine threatened species of birds and provides breeding and feeding habitats for a great variety of fish species, including 5 endemic species. (China's 37th Wetland of International Importance – Xixi Wetlands, n.d.) [6].

The idea of wetland park construction combines natural resources together with cultural resources to achieve the target of protection and restoration so as to pass down this heritage from generation to generation. This project can also give full play to attain the goal of composite benefits of natural and cultural resources, which shows a great significance in promoting economic development, social advancement, and the construction of spirit civilization to achieve the coordinated development among economic society and the eco-environment. Since its establishment in 2005 [7], Xixi Wetland Park has set a good examples in striking a balance between environmental protection and tourism. With an average 720,000 visitors per year, Xixi has been built as an important center for wetland education, which is constructed based upon ecotourism and ecological management plans. For the conservation of Xixi wetland, Hangzhou municipal government invested RMB 4 billion Yuan (close to ₤400 million) into the second-phase construction in 2006, and the conservation program had been listed in the legislative plan by Hangzhou City National People's Congress. (¥4 Billion Investment to Conserve Xixi Wetland for the Future Generation, n.d.)[8]. However, environmental conservation is a long-term project and should be sustained by cooperation from different fields.

Meanwhile, in 2003 'the western expansion of Westlake' restored the virtuous cycle of the whole ecosystem in the area of Westlake, and the water area has been broadened to the western region of the lake, from 5.6 km^2 to 7.96 km^2 [9]. Generally, this project has restored Westlake back to its normal appearance by opening up a great deal of aquatic surface for in-depth tourism. Through this comprehensive protective construction project, the resilience of the natural environment has been enhanced with improvement of air and water quality, and positive impact on biodiversity. It can improve the human-induced stability and carrying capacity of the ecosystem or the natural environment. With a full consideration of ecotourism in Hangzhou, Xixi Wetland can be associated with Westlake in terms of functional similarities and complementary advantages.

Nevertheless, due to long-time interactions from intensive human activities, Xixi has been changed from natural to secondary wetlands. The original ecological environment has been completely destroyed but cannot be easily observed due to the superficial similarities to the natural wetlands. Many rivers, streams, and swamps have transformed into ponds for fish feeding. Multitudes of farmlands have been used for construction. Moreover, discharge of sewage water has degraded the water quality, which exerts a direct and indirect influence to other agricultural production. Furthermore, some protection measures have even raised some new damage problems. Therefore, it is imperative to recover some ecosystem functions as well as improve the ecological environment of Xixi.

In order to sustain the protection in a longer time scale, it is of great significance to awaken people's awareness to realize the importance and benefits of the conservation of Xixi as early as possible. Furthermore, part of the reason for wetland restoration and creation arrives from the fact of losing wetland resources as well as their ecosystem values, and government policies, such as 'no net loss' [10], which lead to the replacement of wetlands to mitigate the unavoidable losses. Current and potential threats of losing wetlands require an intelligent idea on utilization. Before taking action, it is necessary to have comprehensive knowledge about wetlands in order to help people manage and utilize natural resources, such as wetlands, in a sustainable way. With the appreciation on wetland values and threats, this research is carried out focusing on the conservation of Xixi, but on the perspective of the inter-relationship between wetlands and urban heat island effect in the summer. From empirical analysis, these urban wetland clusters are of great

Table 1. A comparison of temperature differences, 1954 to 1993.

Factors	Time intervals	Spring	Summer	Autumn	Winter	Annual
Annual average temperature	1954-1993	15.1	26.9	17.8	5.2	16.4
	1994-2003	16.3	27.3	18.4	6.6	17.3
	Differences	1.2	0.4	0.6	1.4	0.9
Annual maximum temperature	1954-1993	19.7	31.4	22.3	9.4	20.7
	1994-2003	21.1	31.8	23.3	10.6	21.7
	Differences	1.4	0.4	1.0	1.2	1.0
Annual minimum temperature	1954-1993	11.6	23.5	14.4	2.0	12.9
	1994-2003	12.7	23.9	15.4	3.5	13.9
	Differences	1.1	0.4	1.0	1.5	1.0

Data source: original figures of temperatures are all obtained from the Hangzhou Yearbook (1955-2004) [11].

significance to alleviate the urban heat island effect, which will play a vital role in improving the climate and ecological environment of Hangzhou.

Variability of Climatic Environment and the Distribution of Heat Island

As regards the variations of temperature in the urban area of Hangzhou and urban island heat effect, assessment is carried out through a statistical comparison of the measured data and a thorough analysis about the data distribution on the urban heat island. It is carried out by a monitoring system by thermal infrared RS and a numerical simulation for final analysis.

Comparison of the Measured Data

Compared to the past 40 years, the average temperature of the most recent 10 years in Hangzhou has increased. From changes ine annual average, maximum, and minimum temperatures between 1954 and 2003, it shows a remarkable accelerating tendency after the 1990s, which indicates an obvious warming trend. Specifically, if we classify this trend into two time intervals, 40 years from 1954 to 1993 and 10 years from 1994 to 2003, we can figure out that the obvious differences on the average, maximum, and minimum temperatures in winter and spring are the most obvious among the four seasons, with an average difference 1.1-1.5ºC. In autumn, temperature differences on average are 0.6-1.0ºC, while it is about 0.4ºC in summer. Totally, annual differences on average go to 0.9-1.0ºC (Table 1).

Spatial Distribution of Urban Heat Island

In 2001, 16 mesoscale remote-sensing automatic weather stations were set up as the integration of sensor techniques, computer techniques, and mechanics of communication. The establishment and application of this full-set equipment is committed to improving the atmospheric probing techniques, intensify the density of atmospheric probing, ensure the accuracy of atmospheric probing, and meliorate the observation methods, modify the observation patterns, and enhance observation precision. It can be utilized to gather and record a large number of meteorological technical parameters such as temperature, direction and velocity of wind, and amount of precipitation. On the basis of observed data from several stations in several years, trend surface analysis in temporal-spatial distribution is adopted to transfer discrete data into continuous data. In order to improve the distribution accuracy on the control surfaces, it is essential to use a mobile observatory to supplement the observation. From the above analysis and the measured data, results (Fig. 1) show that the gradient-phenomenon of the urban heat island effect in Hangzhou is quite apparent. The distribution of the urban heat island center is in the region of Wulingmen.

Monitoring by Thermal Infrared RS

Thermal infrared remote sensing technique has been widely acknowledged and applied in the survey of urban

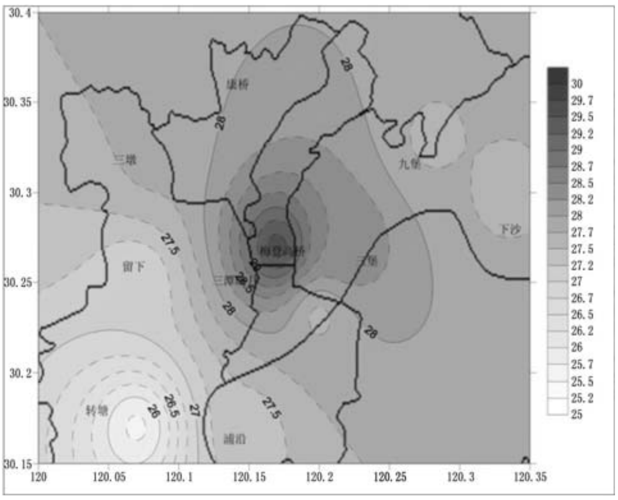

Fig. 1. The distribution map of monthly mean temperature on 7:00 a.m., 7 January 2001.

thermal environment, which can be regarded as one of the most advanced techniques for measuring the surface temperature with high precision from the air by virtue of scanning imaging methods. Data of thermal infrared RS from different time intervals and different seasons are analyzed by adopting the grading objectively quantitative calculation method so as to obtain the cloud pixel values, cloud top brightness temperature, and the value of function of radiance (Fig. 2).

Meteorological Monitoring of Xixi Wetland

The above two methods (indicated in 3.2 and 3.3) have been utilized to reveal the climatic features and environmental characteristics of cities on the control surfaces. In order to grasp comprehensive real-time monitoring about the ecosystem of Xixi, an ecological and meteorological station was built in October 2005 and entered to operation in 2006. Observed data contain the following items:

1) Temperature, humidity, air pressure, precipitation, direction and velocity of wind

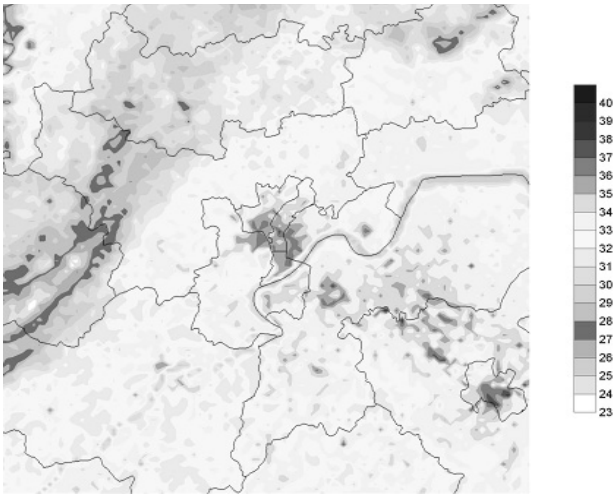

Fig. 2. Satellite retrieval temperature distribution map at 10:30 on 16 June 2001.

2) Sunlight, visibility, total solar radiance, net radiance and photosynthetically active radiation
3) Temperatures and humidity of five soil layers, ventilation rate of three soil layers

Automatic monitoring stations that capture and acquire data provide model simulation with sufficient technical supports.

The Establishment of Optimized Numerical Model

By adopting the advanced and worldwide accepted mesoscale MM5V3.6 (3rd version), a large number of experiments and explorations have been conducted specific to MM5 mesoscale model according to the practical situation of Hangzhou City. This localized numerical modeling makes the calculation much simpler to operate, more practical, and more accurate. For the following analysis, we will choose three typical cases from station data in 2006 with the daily maximum temperature over 37ºC and take them into the modeling to conduct a responsive simulation test on the basis of urban areas after the conservative extension of Xixi. From this point of view, the influence of wetland planning and exploitation to alleviate the urban heat island effect and high temperatures in summer can be assessed.

Classification of Underlying Surfaces

Classification of underlying surfaces can be inquired and retrieved with the aid of GIS (Fig. 3a). Three representative examples with different weather conditions were chosen to specify and verify the numerical model through repeated computation and strict simulation. By amending the underlying surfaces in the simulation, the model becomes much more idealized. To put it into practice, the third phase of the Xixi Wetland planning is simulated according to this amended model that covers an area of 50 km^2 (Fig. 3b). Numerical simulation is classified into four categories:

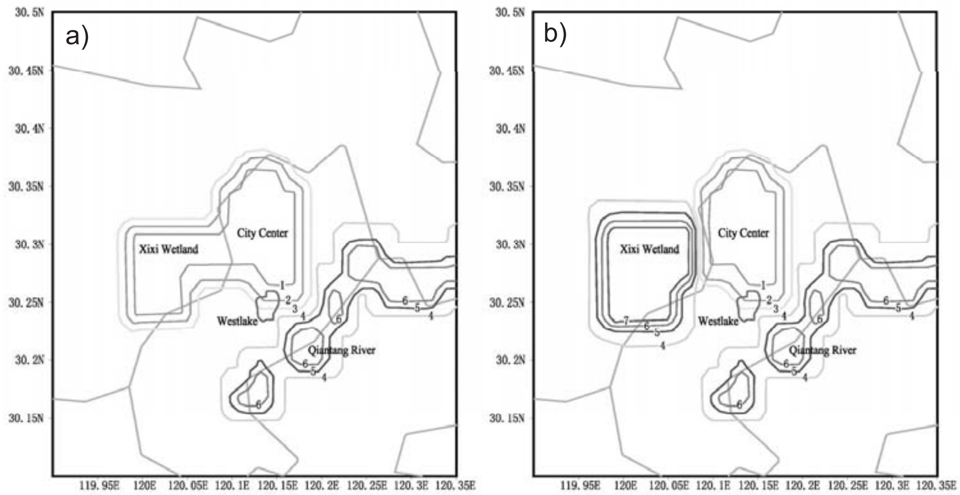

Fig. 3. Xixi Wetland before (a) and after recovery (b).

Table 2. Physical features of different kinds of underlying surfaces (in summer).

Underlying surfaces	Surface albedo (%)	Relative humidity (%)	9 μm Emissivity (%)	Surface roughness (cm)	Thermal inertia (cal·cm^{-2}·k^{-1}·s$^{-1/2}$)
Urban construction	18	5	88	50	0.03
Marshes or wetlands	14	50	95	20	0.06
Body of water	8	100	98	0.01	0.06
Grassland	19	15	92	12	0.03

1) Urban construction
2) Marshes and wetlands
3) Body of water
4) Grasslands

Physical Parameters of Different Kinds of Underlying Surfaces

There are several factors that may affect high temperature changes in summer (or changes in intensity of urban heat island). That is, the prerequisite of this analysis will only consider the characteristics of meteorological conditions and underlying surfaces (except for other factors) in order to quantify and expound the role of underlying surfaces in adjusting the high temperature in summer as well as the urban island heat effect. Table 2 indicates the physical features of different kinds of underlying surfaces.

Verification of Simulation Models

According to the results, observed from an automatic weather station around 15:00 on 31 July 2006, the daily maximum temperature in the central area (Hangzhou High School in Fig. 4) is about 4.2ºC, much higher than the surrounding areas (Shanhusha in Fig. 4). Based upon the measured temperature, figures and numerical model are simulated (shown in Fig. 5) and the maximum temperature appears on the eastern side of the Westlake, 37.2ºC, whose location is consistent with Hangzhou High School with a temperature difference of 1.9ºC. Among all the measuring points, the difference of the simulated daily maximum temperature in urban areas is generally much lower, about 1-2ºC, and the difference in the suburb is much smaller. This is mainly due to different levels of human interruption that more man-made heat flux plays an important role in urban heat environment while less interruption of heat flux in the suburb. Therefore, verification with control test is basically dependable, which gives an index to the formation of urban island heat effect with full consideration of daily maximum temperatures in Hangzhou, and the deviation is relatively small, which is reasonably predictable.

A Comparative Analysis of the Expansion and Replacement of Wetland Conservation

For the following discussion, more detailed comparisons with explicit examples will be illustrated to figure out

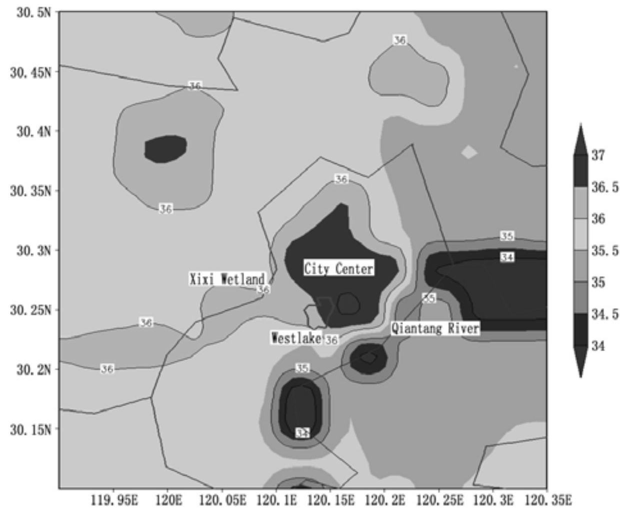

Fig. 5. The simulation of the surface temperature at 15:00 on 31 July 2006.

the influence of urban sprawl on more natural resources, such as wetlands, being replaced by urban construction. From this perspective, three typical weather cases (with daily maximum temperatures observed from ground-reference station over 37ºC) in 2006 will be studied on the assumption of urban sprawl together with conservative expansion of Xixi Wetland. From this experiment, the influence of the planning and exploitation of Xixi to the tem-

Fig. 4. The distribution of measured temperature on 31 July 2006.

perature (high temperature in summer and intensity of urban heat island) in downtown Hangzhou can be verified and assessed. After screening (three typical weather cases with a category two wind or below), simulated results are discussed as follows:

1) Simulated results are perceived at 15:00 on 4 July 2006 (Fig. 6) under weak low pressure, clear sky before the daily maximum temperature and southwest by westerly wind.
2) Simulated results are perceived on 31 July 2006 (Fig. 7) under the peripheral control of average pressure field of subtropical high pressure, clear sky, and southwest by southerly wind.
3) Simulated results are perceived on 28 August 2006 (Fig. 8) under the control of average pressure field, three layers of cloud and southwest wind.

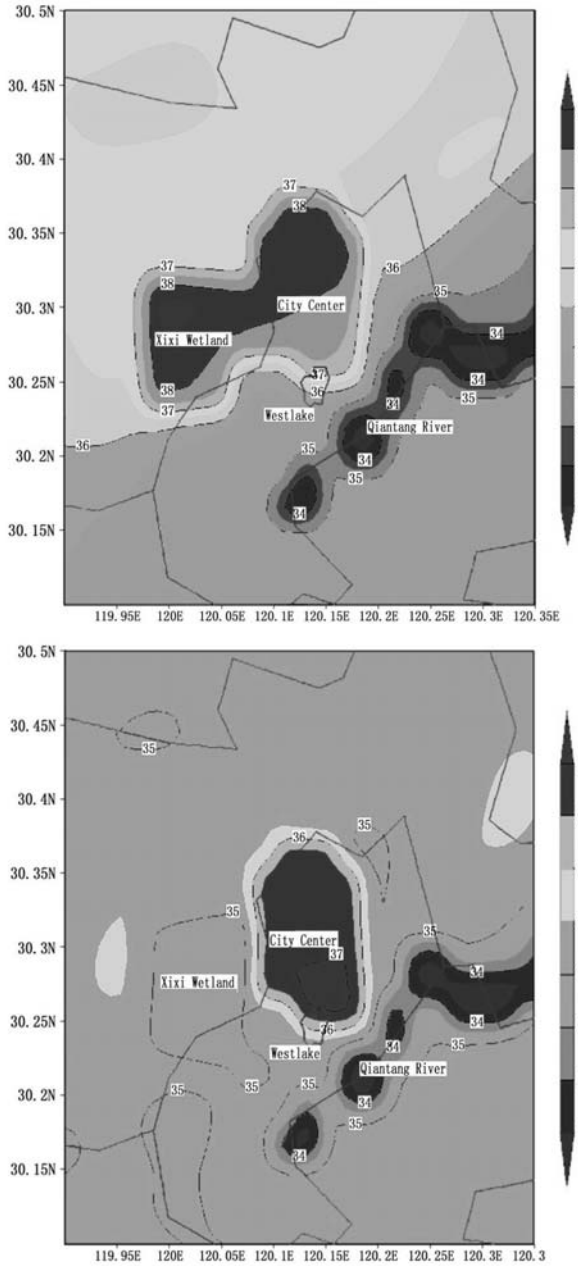

Fig. 6. The 2 m temperature distribution simulation of Hangzhou at 15:00 on 4 July 2006.

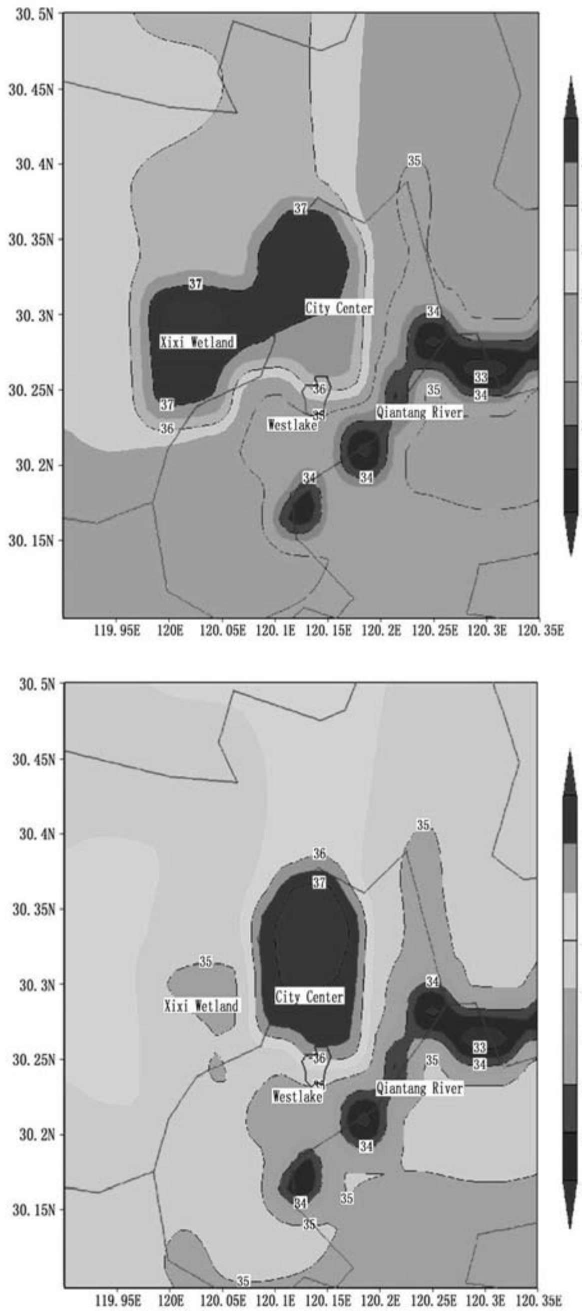

Fig. 7. The 2 m temperature distribution simulation of Hangzhou at 15:00 on 31 July 2006.

From Figs. 4 to 6, referring to one case on the date July of 4th, besides the north side of the Westlake where the temperature reduction ranges from 0.5ºC to 1.0ºC, the daily maximum temperature drops around 1.0ºC to 1.5ºC due to the conservative recovery of wetlands. Around 50 km^2 urban construction has been recovered into wetlands. Referring to 31 July and 28 August, a reduction of the daily maximum temperature is not significant, which is less than 0.5ºC, but areas with high temperature in the downtown have been narrowed down a bit, especially for the west side of Xixi. More details can be figured out as follows according to the simulation of those typical cases:

1) Under certain meteorological conditions, Xixi Wetland after the completion of the third phase of the project can

Table 3. Relationship between daily maximum temperature in Hangzhou and water/electricity consumption.

Intervals of daily maximum temperatures (ºC)	No. of days	Total amount of daily water usage on average (tons)	Difference of water usage compared with the previous temperature interval (tons)	Total amount of Daily electricity usage on averag (million kWh)	Difference of electricity usage compared with the previous temperature interval (million kWh)
>37	5	1,299,914	/	10,276	/
36-37	6	1,284,549	15,365	9,654	622
35-36	4	1,257,987	26,562	9,277	377

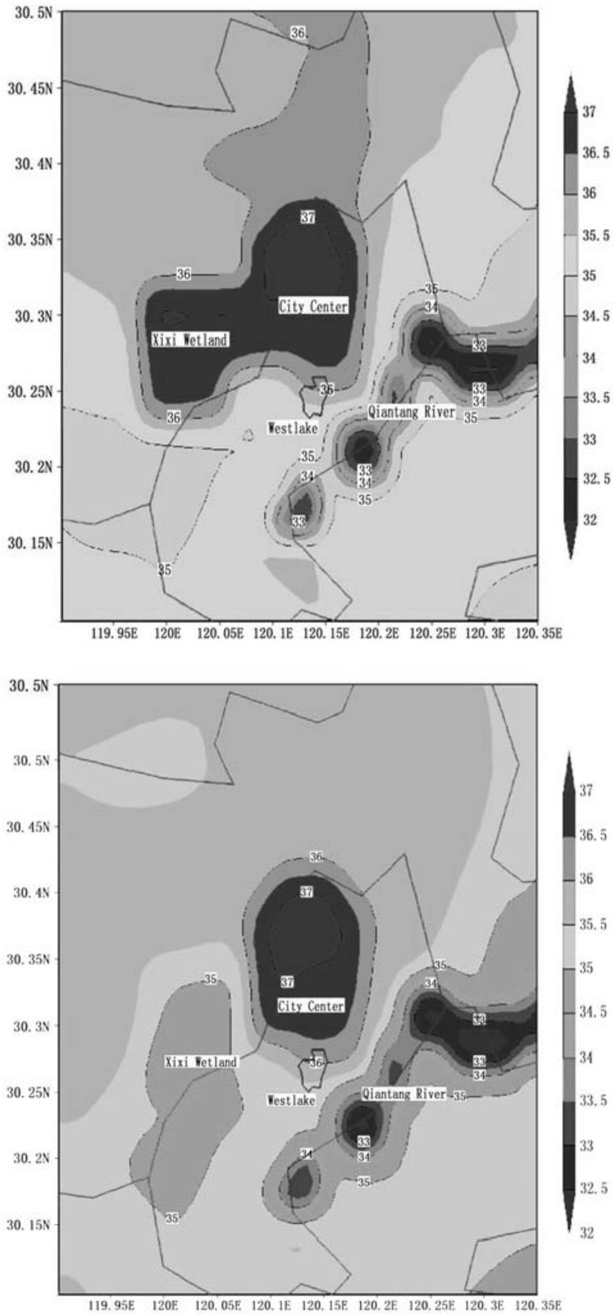

Fig. 8. The 2 m temperature distribution simulation of Hangzhou at 15:00 on 28 August 2006.

prominently give some effect to alleviate the urban island heat effect and high summer temperatures of Hangzhou.

2) There exists a close relationship between environmental wind fields and the influence induced by Xixi Wetland to high temperature together with the urban island heat effect; compared with the south wind or southwest by southerly wind, the adjusting role of the wetland seems to be much more significant when it is under the wind field of a southwest by westerly wind.
3) Results show that with the recovery of 50 km^2 of Xixi Wetland, the maximum temperature in summer can be reduced by 1.5ºC, which can weaken urban heat island intensity (which refers to the temperature difference between maximum and minimum temperatures), which can be up to 1.0ºC, and in this case, the adjusting role of Xixi shows a more significant effect to the north and west of Westlake.

The Analysis of Socioeconomic Benefits

After a thorough analysis on the numerical simulation modeling, we can carry out an analysis of socioeconomic benefits by comparing the peak values of daily water and electricity usage in those high-temperature days. By picking data of high-temperature days (whose daily maximum temperature is over 35ºC) in July 2006, results show that water and electricity consumption in summer days in Hangzhou remains in a close relationship with daily maximum temperature (Table 3).

Through a comprehensive calculation, the correlation coefficient between daily maximum temperature and daily electricity usage is over 0.72 while that between daily maximum temperature and daily water usage is about 0.76, and both of them have been significant at the level of 1%. According to Table 3, there are altogether 5 days with maximum temperatures over 37ºC in July 2006, with daily average water consumption about 1,299,914 tons and daily average electricity consumption about 10,276 million kWh. Compared with the previous temperature interval (over 37ºC), daily water usage will decrease by 15,365 tons on average while daily electricity usage will decline by 622 million kWh on average, referring to the temperature interval 36-37ºC. For the temperature interval 35-36ºC, daily water usage on average is about 26,562 tons – few than that of the previous temperature interval (36-37ºC), while daily electricity usage is about 377 million kWh – fewer than that of the previous temperature interval (36-37ºC). In total, a reduction of 1ºC in daily maximum temperature can bring a massive economic benefit with a decrease of 15,000-25,000 tons in total amount of daily water usage and a reduction of 300-600 million kWh in total amount of daily electricity usage.

Conclusion

With the technical support of GIS and RS, our project gives full consideration to the importance of urban planning in social development as well as ecological conservation by evaluating and analyzing the interrelationship between meteorological elements and varieties of underlying surfaces. By means of this in-depth investigation, results offer technical support to optimize urban planning on both overall and local scales. It is necessary to practice a 'human-oriented' concept in urban planning, which provides the scientific foundation for the comprehensive evaluation of living environments both on overall planning (macro level) and individual construction layout (micro level). This will contribute a lot to technological transformation and compensate for the weaknesses of conventional approaches, which might be unbiased and be unable to quantify. This can more or less promote the development of environmental science, the technological advancement of industries, and prominent social and economic benefits.

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