Numerical Analysis about Urban Climate Change by Urbanization in Shanghai

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Abstract
After the industrial revolution, megalopolis beyond the population of 10,000,000 appears one after another, and makes big impact to the earth environment. The urbanization in Asian developing countries is tremendous. Especially the rapid urban sprawl and the change of land use are bringing urban climate changing such as heat island phenomenon in China Shanghai in recent years. To evaluate heat island phenomenon in Shanghai by urbanization, this study constructed a land use database using land use map of Shanghai. Using a numerical analysis method, the influence on urban climate with the urban sprawl and the change of land use of Shanghai was evaluated from 1845 to 1995. As a result, analyzed the influence on the urban climate affect by the urbanization of 25kmx19km range, the maximum temperature and average temperature rose by about 1.7°C because of the rapid sprawl of urban area and the changes of land use for this 150 years in Shanghai.

Keywords: Shanghai; urban climate; urbanization; heat island; numerical analysis

1. Introduction
After the industrial revolution, megalopolis beyond the population of 10 million appears one after another, and makes big impact to the earth environment. The urbanization in Asian developing countries is tremendous. Especially the rapid urban sprawl and the change of land use are bringing urban climate changing such as heat island phenomenon in Shanghai, China in recent years. Now, the heat island phenomenon of Shanghai is collecting a lot of attention, and a large-scale temperature observation is going ahead.

To evaluate heat island phenomenon in Shanghai by urbanization, this study construct a land use database using land use map of Shanghai. Using a numerical analysis method, the influence on urban climate with the urban sprawl and the change of land use of Shanghai was evaluated from 1845 to 1995.

2. The Urbanization in Shanghai
After the industrial revolution, accompanied the rapid growth of urban population in an earth scale, various urban problems were brought about in the metropolis in the 20th century. In London, the growth of metropolis was controlled by the greenbelt policy. But in Japan, metropolises like Tokyo were formed with high economic growth postwar. From the second half of the 20th century, urban population increases explosively in Asian developing countries at the speed that has not been experienced in advanced nation. Many Asian metropolises are faced with very serious environmental problems.

Figure 1 shows the urban area changes in 50km range of five megalopolises in the past 100 years. The urban area of New York, London, and Tokyo has already been over the range of 50km, but the Asian developing countries, such as Shanghai and Bangkok, kept in the range of 30km in the 1990’s. When seen from the urban zone and the population of central area of each metropolis, Asian developing countries, such as Shanghai and Bangkok, had already reached the almost same level as London, New York, and Tokyo (Figure 2)³. Compared with the metropolis of advanced countries, the metropolises of Asian developing countries are holding large population in the small urban area can be considered.

Shanghai was established in 1292, and the total area was about 2,000km². In1997, it has already exceeded 6,341km², and the urban area and the construction district area have reached to 2,057km² and 412km². The changes of the urban area and the population in Shanghai are shown in Figure 3². Compared with 1845, the urban area increased more than 10 times and the population also to about 40 times for the 150 years.

3. Construction of Urban Thermal Environment Evaluation Database by Using Land Use Map
3.1 Outline of Thermal Environment Evaluation Database Construction System
In Japan, many digital databases, such as remote
sensing and GIS data, are used well in urban thermal environmental evaluate simulation. However, in Asian developing countries, there are few such databases and the construction of database required for evaluation simulation takes much time. Since urban land use maps are easy to come to hand in Asian cities, this study created a database construction system for evaluating urban thermal environment by using land use map (Figure 4)

The system flow is shown in Figure 4. First, resolution is set up and land use maps can be downloaded from scanner to personal computer. It is painted over with the color decided as every classification of each type of land use such as green etc., and the colors will be corrected to enhance color distinction precision. Then the maps can be taken in the special software (color of pixels can be changed into numbers), and the mesh data based on the color numbers of pixels are outputted to a text file. Furthermore, mesh size necessary for the thermal environmental evaluate simulation is set up, and by the mesh conversion program, land use database for performing thermal environment evaluation can be created automatically.

This system can create the mesh data of various mesh sizes by the settlement of the take-in resolution of scanner.

3.2 Create the Land Use Database of Shanghai

Using the database construction system, the land use database for analyzing urban temperature by using land use map of Shanghai from 1845 to 1995 was created. The layer attribute of land use mesh data is set up with water, green, road, nakedness area, and building. The mesh size is set up with 500m, and the evaluation area is 25kmx19km range.

4. Thermal Environmental Simulation

4.1 Thermal Environment Evaluation Simulation Model

In order to observe urban heat island phenomenon, a three dimensions model has been used in this study. The conservation equation for momentum, mass, and energy can be generally described as below,

\[ \frac{dT}{dt} = D \frac{\partial^2 T}{\partial x_1^2} + Q \]

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Continuation Formula
\[ \frac{dU_i}{dx_i} = 0 \]

Momentum Formula
\[ \rho \frac{dU_i}{dt} = - \frac{\partial P}{\partial x_i} + \rho D \frac{\partial U_i}{\partial x_i} + \rho g_i \]

Where,
- \( T \): air temperature (°C)
- \( U_i \): (U, V, W): average wind velocities at X, Y, Z directions (m/s)
- \( D_i \) (DX, DY, DZ): dispersion coefficients of X, Y, Z directions (m²/s)
- \( Q \): internal heat source (kW/m³)
- \( P \): air pressure (N/m²)
- \( \rho \): the density of the air (kg/m³)
- \( C_p \): air specific heat (kJ/kg°C)
- \( g_i \): air gravity (m/s²)

In this model, the following assumption has been used to simplify the above equation as below:
1) Air flow is uniform with a constant air gravity and thermal capacity.
2) Turbulent eddy diffusive for energy and momentum are equivalent.
3) The effect of thermal capacity of buildings is neglected.
4) The air flow is divided into two parts. One is the general current and the natural current defined as follows,
\[ U_i = \bar{U}_i + u_i \]
\[ P = \bar{P} + p \]

5) The vorticities are defined as follows,
\[ \omega_i = \frac{\partial U_j}{\partial x_j} - \frac{\partial U_j}{\partial x_i} \]

6) The natural current flow (a, b) is generally smaller than the general current flow (A, B). Therefore, the follow assumption can be assumed.
\[ AB = (\bar{A} + a)(\bar{B} + b) = \bar{A}B + a\bar{B} + \bar{A}b + ab = \bar{A}B + a\bar{B} + \bar{A}b \]

The calculated area has been selected in this study shown in figure 5. Lx, Ly, Lz are the length of X, Y, Z direction. The urban has been assumed to be continuous. The boundary condition above the Z direction has been assumed to the same climate condition, which is a general weather condition recorded in the weather station, and the wind pattern in Z direction is stable where there is no turbulence. So the boundary condition can be described by figure 5.

In the ground surface, the heat balance can be written by the following equation,
\[ Q_s = Q_{cv} + Q_{rd} + Q_{vp} + Q_{cd} \]

Where
\( Q_s \): solar radiation absorbed by the ground surface (kJ/m²h)
\( Q_{cv} \): convection heat flow (kJ/m²h)
\( Q_{rd} \): long-wave radiation heat flow (kJ/m²h)
\( Q_{vp} \): evaporation heat flow (kJ/m²h)
\( Q_{cd} \): heat conduction of the walls (kJ/m²h)

Although the air temperature and wind distribution should be gained through solving the above equation together with the energy and momentum equation, the
separate step has been applied that the surface
temperature distribution firstly is determined by
assuming the air temperature is known and then the
air temperature and wind distribution can be
calculated using the surface temperature distribution.

4.2 Thermal Environment Evaluation of Shanghai

Firstly, a thermal environment evaluation of
Shanghai was performed to confirm the validity of the
system. Mesh size is set up with 500m, and the range
of the area for evaluation is 25kmX19km.

In order to raise the accuracy of mesh data, the
buildings density distribution map (Figure 6, to
calculate the rate of buildings) and the population
density distribution map (Figure 7, to calculate
artificial heat release) were also used except for the
land use map of Shanghai. Furthermore, the
population mesh data, created from Figure 7, multiply
the amount of Shanghai 1 person per energy
consumption 5) to calculate the artificial heat release.

Simulation was started from 13:00 in typical
summer day. The other initial conditions are shown in
Figure 8.

Figure 9 showed the temperature distribution by
land use data only simulation and Figure.10 showed
the temperature distribution by land use + artificial
heat release simulation. In height of 1.5m above
ground level, the maximum temperature of 34.7℃
and 35.5℃ is shown respectively. It is found that
because there are few big green lands, the cool island
is hard to form since the bigger heat island in the
center of Shanghai is being formed. And, the cooling
effect by the river was confirmed, too.

In Table 1, the case of only land use simulation
showed that the difference between minimum
temperature and maximum temperature is 3.1℃. But
in the case of land use + artificial heat release
simulation, the difference went up to 3.8℃, and the
temperature rise by artificial heat release reaches 0.7℃.
It is predicted that increase of the energy consumption
accompanied by the rapid economic development in
Shanghai from now on will has big influence on the
urban temperature.

In Shanghai, there are many high temperature days
of 35℃or more in July and August, and the maximum
temperature difference between the urban area and the
suburbs reaches 4.8℃ in recent years. The simulation
result is close to it having been observed.

Table 1. Comparison of the Air Temperature in 13:00

|                     | Land use only simulation | Land use + artificial heat release simulation |
|---------------------|--------------------------|---------------------------------------------|
| Max value of temperature(℃) | 34.7                     | 35.5                                        |
| Average value of temperature(℃) | 33.3                     | 33.5                                        |
| Min value of temperature(℃)    | 31.6                     | 31.7                                        |

5. Numerical Analysis about Urban Climate Change of Shanghai by Urbanization

By analyzing the influence on the urban climate due to the urbanization, the central area of 25kmx19km range in 1845, 1911, 1978 and 1995 of Shanghai was selected. The numerical simulation result showed in Figure 11. In 1845, the urban area is 38km², the average temperature and the maximum temperature is 31.7℃ and 33.8℃. In 1995, the urban area expanded to about 400km², the average temperature and the maximum temperature rose to 33.5℃ and 35.5℃. The maximum temperature and average temperature of Shanghai rose by about 1.7℃ compared with 150 years ago.

Fig.9. The Temperature Distribution by Land Use Data Only Simulation (1.5m height above ground level)

Fig.10. The Temperature Distribution by Land Use + Artificial Heat Release Simulation (1.5m height above ground level)

Fig.11. The Urban Climate Changes Due to the Urbanization in Shanghai
6. Conclusion
In this study, a database construction system for the thermal environment evaluation by using urban land use map of Shanghai was presented. Using this system, without the existing digital mesh databases, we can also create mesh data from the urban land use map easily and apply to thermal environment evaluation. It expects greatly being used for the thermal environment evaluation in Asian developing countries.

By using the land use map of 1845,1911,1978,1995 of Shanghai, we analyzed the influence on the urban climate affect by the urbanization of 25kmx19km range. As a result, the maximum temperature and average temperature rose by about 1.7℃ because of the rapid expansion of urban area and the changes of land covering for this 150 years following with urbanization of Shanghai.

In this time, the influence on the urban climate due to the sprawl of urban area and the changes of land use was studied. The analysis with considering the artificial heat release of Shanghai will be studied by future study.

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