Mitigating the Urban Thermal Environment of Tokyo through a Cluster Planning

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Abstract
Tokyo suffers a lower land use efficiency and environmental problem. In this study, we have a proposal of urban plan for Tokyo in order to solve the problem of worse living condition. This proposal plan is called “Cluster Model”, which introduce the high rise building into the projected area to save the land and regain the open space.

And then a theoretical model to predict the thermal environment in the urban area has been introduced. Using this model, the effect of the green area and urban structure on the urban thermal environment can be determined. The results suggest the green area has a significant effect on lowering the air temperature. Through comparison of the thermal environment between the present and cluster model, the efficiency of the cluster model to mitigate the environment in the urban area has been proved.

Keywords: thermal environment; clusterization; evaluation; urban planning

1. Introduction
The impact of the urban activities on the climate mainly includes the change of land use, the increase of artificial heat release, the increase of pollution, the greenhouse effect due to the increase of CO2. These factors result in the temperature difference between the urban area and rural area that has been called "heat island" phenomenon. One of the effective methods to lower the intensity of the heat island in the urban area is to introduce the green space including water space such as rivers and canals. Urban environmental quality is also as much a product of building design as of spatial differentiation. The purpose of this study is to provide a theoretical analysis of the urban thermal environment. The mitigated effect of green area on the urban thermal environment has also been discussed by using the model presented. Finally the comparison of thermal environment in the 23 Ward of Tokyo has been made between the present situation and future cluster planning suggested by Ojima Laboratory, Waseda University.

2. Cluster Model for Tokyo
Global approaches are required to understand the relationship between trade, economic policies and the environment, the establishment of global and regional accords, and policies to respond to environmental challenges on a planetary scale. Globalization of the world's economy, international communications, trade liberalization, and adoption of a worldwide non-sustainable consumption model, coupled with the absence or uneven application of worldwide standards, widespread external debt and increased threats to atmospheric and oceanic commons, all argue for global approaches.

At the same time, we find that a large part of the environmental problem is due to industrialization, which tends to concentrate in urban sectors. The Industrial Revolution in Europe was accompanied by a rapid increase in urban population. Urban centers followed an unsystematic sprawl, and around 1970 representative, gigantic cities, such as New York, London, Paris, and Tokyo appeared. Towards the end of the 20th century, a dramatic urbanization was observed in developing countries, especially in Asia. The top 20 largest cities of the world, in terms of population, are found in Asia and Latin America. For the 21st century, 70% of the world's population is expected to live in developing countries\(^1\). Approximately half that population will be living in urban areas. Such urbanization will proceed at a terrific pace, causing serious problems in the environment. It is clear that a solution to urban environmental problems will be one of mankind's major challenges.

This has led us to the proposal for a cluster model (figure 3)\(^2\). We think this model is able to solve the problem of efficiently allocating urban space to greenery and transportation networks. As can be seen from the figure 3, greenery is allocated as much space...
as possible. This, of course, decreases livable space, but is compensated by building taller buildings. Each urban cluster is enclosed in a green area, and is interconnected by a network system passing through the center of each cluster. Each different cluster, therefore, is integrated into one network. This approach is different from the current approach of zoning, where greenery is located in the center of urban spaces and partitioned by the transportation network. In the zoning model there is less interconnection among urban centers and the space for greenery is severely limited.

It is clear that the clustering described above prevents local environmental problems from spilling over to the rest of the globe, resulting in a "globe-unfriendly" type of globalization. Local environmental problems are, in fact, contained and resolved within the locality. Clustering basically achieves this by letting natural forces, the adequate allocation of green space, heal the wounds of environmental destruction brought about by rapid urbanization and development. In this way, different spaces can coexist in harmony.

The present land use in Tokyo has been shown in figure 1. The built area has been sprawled significantly to the suburb area, which may enforce the urban heat island. Although there are some high density use of land such as in Shinjuku. Shibuya, Ikebukuro, low efficient use of land in the other area has been observed, in which the gross bulk ratio is lower than 100%.

The urban renewal or renovation recently has attracted many designers and the people because of the worsened living environment in an urban with the extremely high land cost and the increase of the urban population and a huge part of energy consumption. Most of the renewal projects have adopted the ecological idea that is

1) Living together with Nature.
2) Decreasing the impact of the urban activities on the Earth environment.
3) Keeping the rich urban life. Most of the renewal projects therefore have referred to introduce the high-rise buildings into the projected area to save the land and regain the open space. A new planning, called "cluster model", and has been proposed to try to improve the nature and living environment, which was shown in figure 2. In the figure 3, the concept of cluster model has been shown.
Our Model is set based on following conditions:

1. Population: Maintain existing population of Tokyo.
2. Green land and water areas: Reserve existing water area and green land. Take river as center to do planting, thus to join water area with green land. And the area of water and green land accounts for at least 50% of the total.
3. Residential facilities: Residential area will be 2 times of existing area. Try to construct independent dwelling houses as possible.
4. Non-residence facilities: Maintain the present floor area.

The steps for cluster planning showed in figure 4. We divide urban space to a nature layer and an artificial layer. On natural layer, we investigated the present situation of river and green area (N-step1) and recover the past river (N-step2) and then introduce the green area (N-step3). On the artificial layer, we first grasp the situation of urban infrastructure (A-step1) and then introduce business facilities in cross-position of infrastructure. At last, commercial, living facilities and residential building around cross-point to form a cluster. Through the network of natural layer and artificial layer, the environment can be improved. The figure 2 showed cluster plan that is proposed

3. Method to Predict the Urban Thermal Environment

3.1 Theoretical Model

In order to observe the wind pattern by changing the urban land use, the three dimensions model has been used in this study. The conservation equation for momentum, mass, and energy can be generally described as below,

Energy equation
\[ \frac{DT}{dt} = D_i \frac{\partial}{\partial x_i} \frac{\partial T}{\partial x_j} + \frac{Q}{C_p \rho} \]

Mass equation
\[ \frac{\partial U_i}{\partial x_i} = 0 \]

Momentum equation
\[ \rho \frac{DU_i}{dt} = \frac{\partial P}{\partial x_i} + D_j \frac{\partial U_i}{\partial x_j} + \rho g \]

Where, T : air temperature (°C)
Ui(U,V,W): air velocities at x, y, z directions (m/s)
Di (Dx,Dy,Dz): diffusive coefficients at x, y, z direction (m²/s)
Q: internal heat source
gi : air gravity( Kgf/m³)
P: air pressure (kg/m )
C : air specific heat(kJ/kg°C)

In this study, the following assumption has been used to simple 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 effects of thermal capacity of the buildings are neglected.
4) the air flow is divided into two arts. one is the general current and the natural current defined as follows.
   \[ U_i = (\overline{U}_i + u_i) \quad P = (\overline{P} + p) \]
5) the vorticities are defined as follows,
   \[ \omega_j = \frac{\partial U_i}{\partial x_j} - \frac{\partial U_j}{\partial x_i} \]
6) the natural current flow \((a.b)\) is generally smaller than the general current flow\((A.B)\). Therefore the follow assumption can be assumed.
   \[ AB = (\overline{A} + a)(\overline{B} + b) = \overline{AB} + a\overline{B} + \overline{A}b + ab \]
   \[ = \overline{A}B + a\overline{B} + \overline{A}b \]

3.2 Boundary Condition
The calculated area has been selected in this study shown in figure 5. 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. The wind pattern 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
   \[ Q_s = Q_{cv} + Q_{d} + Q_{vp} + Q_{cd} \]
where
   \[ Q_s=\text{solar radiation absorbed by the ground surface (kJ/m}^2\text{h)} \]
   \[ Q_{cv}=\text{convection heat flow (kJ/ m}^2\text{h)} \]
   \[ Q_{va}=\text{evaporation heat flow (kJ/ m}^2\text{h)} \]
   \[ Q_{rd}=\text{long-wave radiation heat flow (kJ/ m}^2\text{h)} \]
   \[ Q_{cd}=\text{heat conduction into the earth (kJ/ m}^2\text{h)} \]

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 distribution.

3.3 Calculated Condition
The weather data on 10 August 1992 has been used as reference climate. In order to determine the effect of natural convection due to the difference of surface temperature, a nearly no wind conditions have been assumed to run a simulation on the computer. In the no wind condition, general wind speed at 30m heights is assumed as about 0.5m/s.

3.4 Comparison of Artificial Heat Release between Present and Cluster Model
Artificial heat release in both cases at 13 in typical summer has been calculated by the data of Ojima in figure 7. Artificial heat release in present situation was concentrated in the center of Tokyo, especially in Shinjuku, Otemachi and Shibuya. The artificial heat release has spawraled to the whole area of Tokyo even though the density of artificial heat release is not high, which has made the warmth of urban area.

In the cluster model, the points of high artificial heat release have been separated in the area of Tokyo, though there is high density of artificial heat release in the active area with office, commercial buildings.

3.5 Comparison of Surface Temperature
Surface temperature at 13 in summer has been calculated in figure 7. In the present situation, the whole area has shown a higher temperature up to above 40 degree centigrade. In the cluster model, the surface temperature has been lowered to about 35 degree centigrade due to the increase of green and river area.

3.6 Comparison of Air Temperature and Wind
Figure 8 shows the distribution of air temperature at 2m after 30-minute calculation for present and cluster model. In the present situation, the areas, such as Shjnjuku, Otemachi and Ikebukuro have shown a higher air temperature compared to that of the Kokyou with a large park. It can be observed that the heat islands in Tokyo have been formed in Shinjuku, Shibuya, Otemachi and Ikebukuro. The air temperature near the Arakawa river has been 0.9 degree centigrade lower than that in Shinjuku, Shibuya, Otemachi and Ikebukuro.

In the cluster model, the green and water network has separated the present heat island area. It is obvious that green area has made the whole Tokyo a lower air temperature. The air temperature in cluster model was about 1 degree centigrade lower than that of present situation.
The figure 9 has shown the distribution of air velocity in both cases. Although the air flow due to the difference of the surface temperature is smaller, the air flow has moved along the river in the present situation. It can be said that the river is an effective space to form a wind road.

4. Summary
In this study, a theoretical model to predict the thermal environment in the urban area has been introduced. Using this model, the effect of the green area and urban structure on the urban thermal environment can be determined. The results suggest the green area has a significant effect on lowering the air temperature. Through comparison of the thermal environment between the present and cluster model, the efficiency of the cluster model to mitigate the environment in the urban area has been proved.

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