PLANNING OF GREENING BASED ON INTEGRATED EVALUATION OF THERMAL ENVIRONMENTS AND ECOSYSTEM

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1. Introduction

In recent years, planning of preservation and creation of greening in urban space are advanced. There are several purposes to create the green space in Japan. For example, trees have been planted around the high-rise building for the purpose of wind speed reduction. Of course, green spaces have been created to mitigate the urban warming by the reduction of air temperature. Furthermore, the importance of ecological network has been pointed out from the viewpoint of urban biodiversity in recent years. Compatibility of the urban climate regulation and the habitat creation is expected as ecosystem services by urban greening.

In order to create the good environments for many organisms and human, it is important to understand and use the various effects of greening. The purpose of this study is to comprehensively evaluate the effect of green space. In this paper, not only the thermal environments in the outdoor space as the impact on the human thermal sensation, but the ecological network as the effects on the habitat of organism in the surroundings were evaluated for several greening plans near the central part of Tokyo.

2. Target site and analysis cases

The target area is an ideal site assumed to be a park which size is 100m×100m located in the Tokyo Bay area as shown in Fig.1.

3 different green plans in the target site are evaluated in terms of the ecological network as the effects on the habitat of organism in the surroundings and the thermal environments as the impact on the human thermal sensation. Table1 shows green plans of analysis cases. Each plan has trees along the pathway and in the open space. The ground surface is covered with asphalt in Plan A, and grass in the other cases.

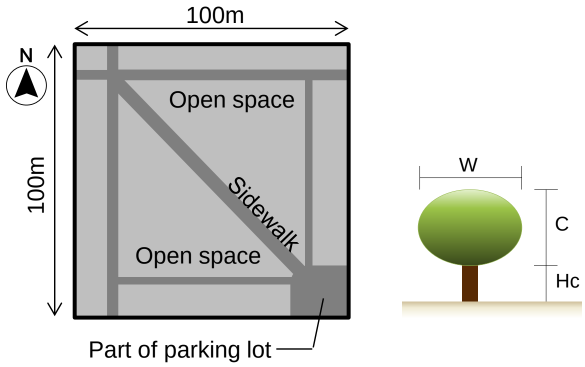
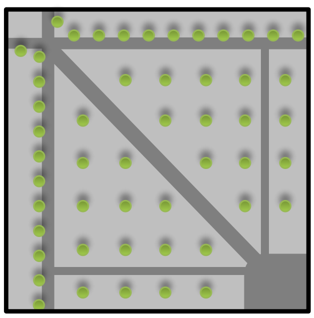
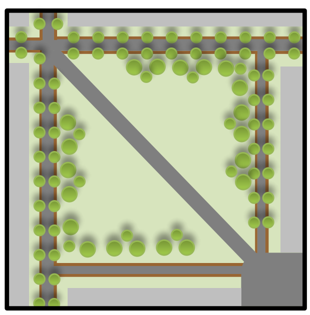
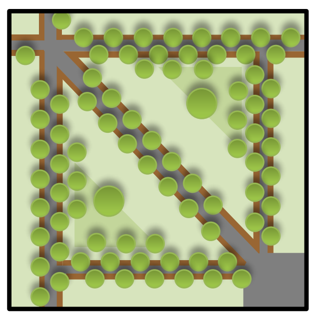


Fig.1 Target site

Table1: Analysis cases

Case	(1) Plan A	(2) Plan B	(3) Pan C
Tree arrangement in the target site			
Shape of the tree	W:3.5m C:4.0m Hc:2.0m	W:3.5m C:4.0m Hc:2.0m, W:6.0m C:6.0m Hc:2.0m	W:6.0m C:6.0m Hc:2.0m, W:10.0m C:6.0m Hc:2.0m
Ground surface type of open space	Asphalt	Grass	Grass

3. Evaluation of urban ecological network

3.1 Outline of urban ecological network simulation system

Urban ecological network simulation system (Yokota et al., 2013) evaluates the potential habitat suitability of indicator species in the surrounding area of the development site and visualizes the effect of green plans to the surrounding ecological network (Fig.2). The habitat suitability for indicator species is evaluated from the distribution of area for food, breeding and cover based on HEP (Habitat Evaluation Procedure) developed in USA (US Fish and Wildlife Service, 1981).

The simulation procedure is as follows;

Step1: Study area containing target site is classified into 3 cover types, grassland, forest, and water by analyzing satellite image with high resolution enough to visually distinguish kind of trees on the street.

Step2: Representative species of 3 cover types are selected as indicator species respectively.

Step3: Habitat suitability for indicator species in the study area is evaluated based on geographical distribution of each cover types. In this step, ecological conditions of study area are converted into scores according to habitat requirements of indicator species (Suitability Index; SI). For example, as the ecological conditions of Japanese Tit (Parus minor), forest area, forest area ratio in 250m zone from each forest patch, deciduous tree area and scrub forest area are selected and relative scores of forests in 1km zone from the site are calculated. And then, the habitat suitability index (HSI) is calculated by weighted averaging of them (Fig.3).

The effect of several green plans of target site to the surrounding ecological network can be evaluated and compared spatially and quantitatively by summarizing the habitat suitability of forests and woods within and around a target site.

3.2 Results

In this study, Japanese Tit is selected as an indicator species and study area is within 250m zone from the target site. Fig.4 shows the result of habitat suitability of each case. These results show the relative values in the range of 0 (unsuitable habitat) to 1 (optimal habitat). Plan C, has largest green spaces, shows the largest values of habitat suitability within and around the target site of all cases. It is shown that green space provides positive effects on the ecological network clearly.

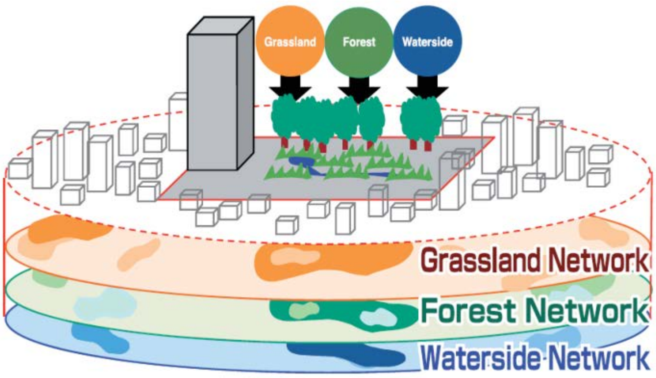


Fig.2 Concept of urban ecological network simulation system

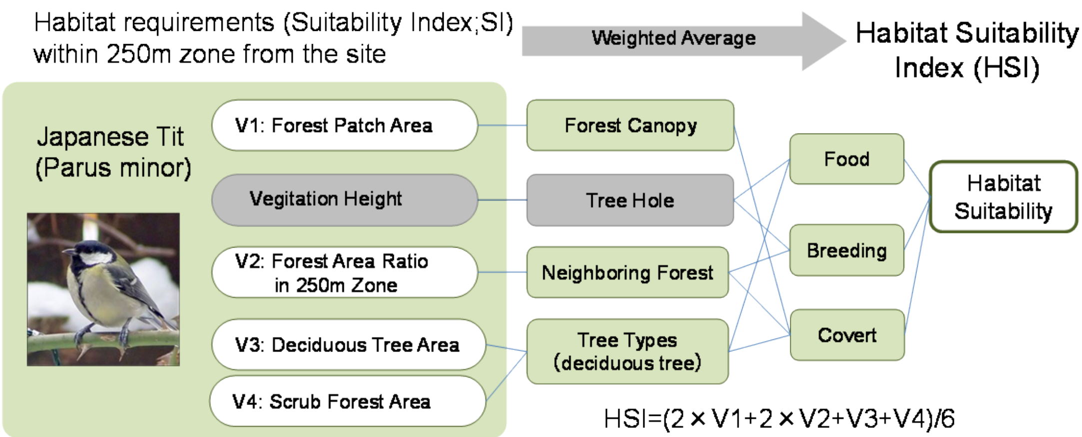
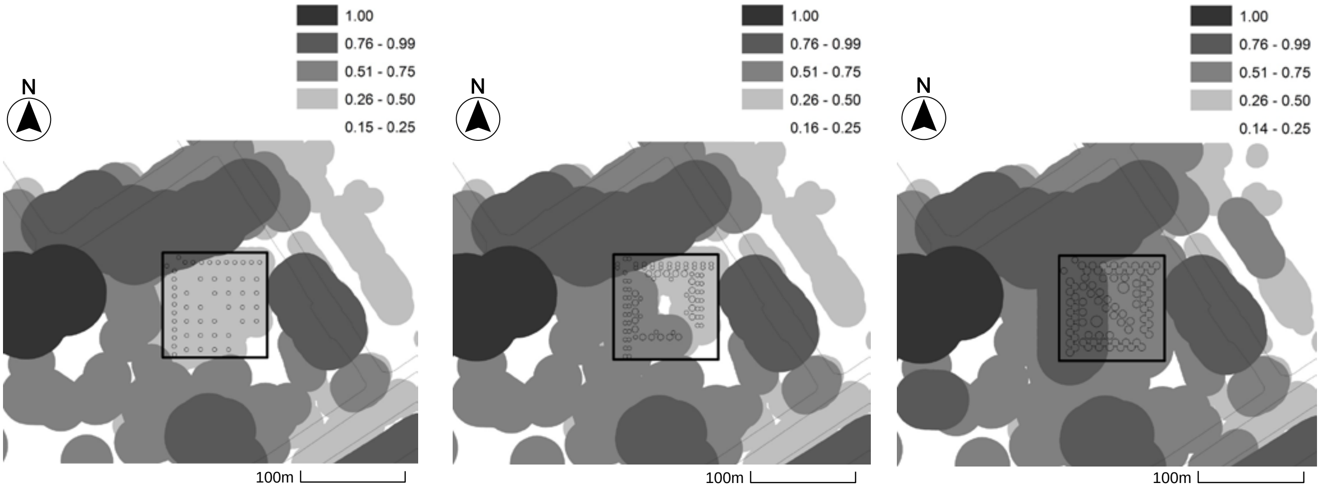


Fig.3 Evaluation procedure of habitat suitability (Japanese Tit)



(1) Plan A (2) Plan B (3) Plan C

Fig.4 Evaluation of habitat suitability

4. Analysis of thermal environment

4.1 Outline of analysis

The procedure to evaluate thermal comfort is given below.

Step1: Unsteady state surface heat balance analysis is conducted in the target site in order to get the surface temperature of ground and spatial distribution of MRT (mean radiant temperature).

Step2: Non-isothermal CFD analysis is carried out in the target site by using the outcomes of heat balance analysis. The surface temperature of ground is set from the result of heat balance analysis.

Step3: Thermal sensation is evaluated using SET* in the target area. SET* is calculated from the outcomes of Step1, 2 and personal variable as activity and clothing.

4.2 Numerical setup

Target day of unsteady state heat balance analysis is on August 1st, 2014. The meteorological data of Tokyo is used. The thermal environment in the target site is evaluated using the results obtained at 12:00. The meteorological conditions of air temperature, wind velocity, wind direction, relative humidity, the amount of global solar radiation, and the amount of downward atmospheric radiation at 12:00 are assumed to be 32^{o}C, 2.1m/s at the height of 20m, S, 55%, 943W/m^2, 394W/m^2, respectively.

The computational domain size of non-isothermal CFD is 100m×100m×100m. The standard k-ε model is applied and the tree canopy model proposed in previous studies (Hiraoka, 1993, Yoshida et al., 2006 and Mochida et al., 2008) is used to reproduce the aerodynamic effects of trees.

4.3 Results

4.3.1 MRT

Fig.5 shows the horizontal distribution of MRT at the height of 1.25m. Plan A and Plan B show large values of MRT above the sidewalk because of the direct solar radiation and high values of ground surface temperatures. Plan C shows quite low value of MRT over the whole area in the site by effect of tree shade.

4.3.2 Wind velocity

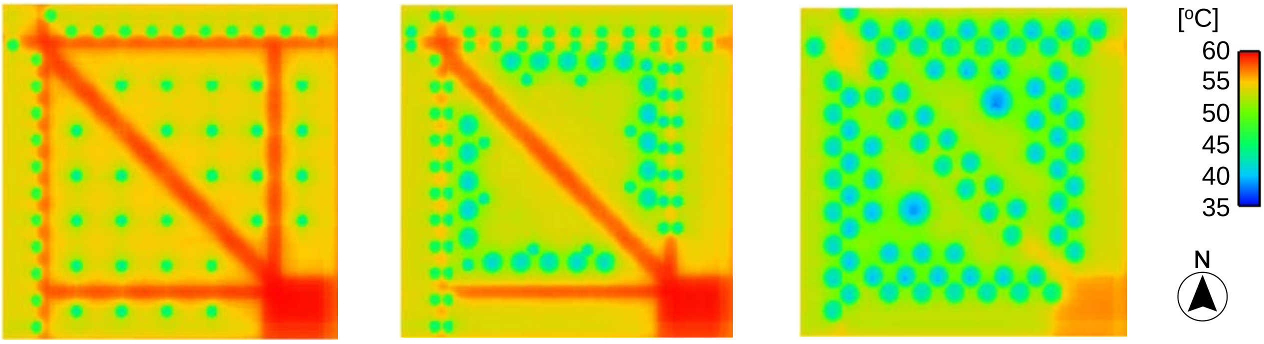
Fig.6 shows the horizontal distribution of wind velocity at the height of 1.25m. The wind blows into the target site from south to north. In each case, wind velocity reduces in the behind the tree area clearly. Plan A keeps wind velocity from inflow boundary to outflow boundary except behind the tree. In Plan C, wind velocity increases in the windward area of the site and reduces in the leeward area.

4.3.3 Air temperature

Fig.7 shows the horizontal distribution of air temperature at the height of 1.25m. Each case shows increase of air temperature from windward area to leeward area of the site. It is because that heated air by the ground of high temperature is transported to leeward by wind. In Plan A, air temperature in the leeward area is approximately 2^{o}C higher than that in windward area. On the other hand, Plan B and Plan C show low values of air temperature in the leeward area compared to Plan A. This is caused by low temperature of the ground surface covered with the grass. In addition, Plan C shows quite low value of air temperature over the whole area in the site due to significant cooling effects of tree shade.

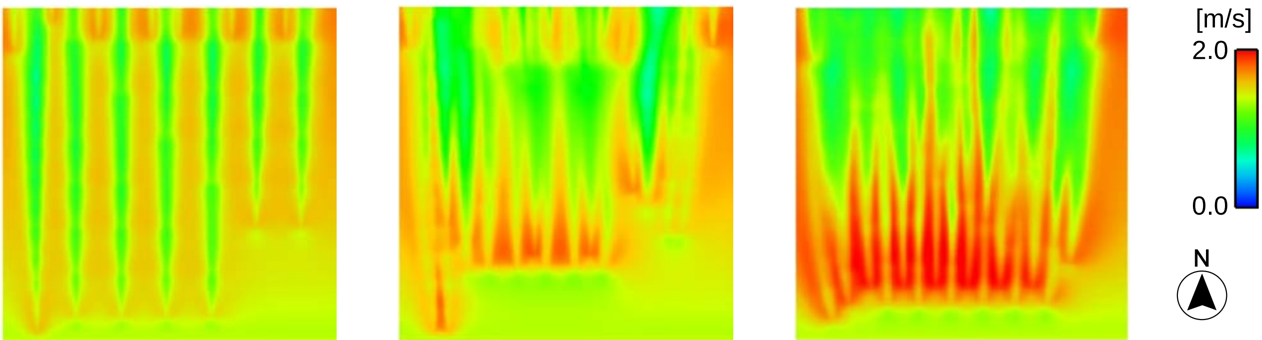
4.3.4 SET*

Fig.8 shows the horizontal distribution of SET* at the height of 1.25m. Each case shows increase of SET* from windward area to leeward area of the site. Plan A shows large value of SET* above the sidewalk due to high values of air temperature and MRT. Plan C shows almost the same value of SET* as that of Plan B around the sidewalk in the leeward area although quite low value of SET* is shown in the windward area by cooling effects of tree shade. This is caused by poor ventilation in the leeward area. It illustrates that too much trees does not provide remarkably positive effect on thermal sensation because of low wind velocity in the leeward area.



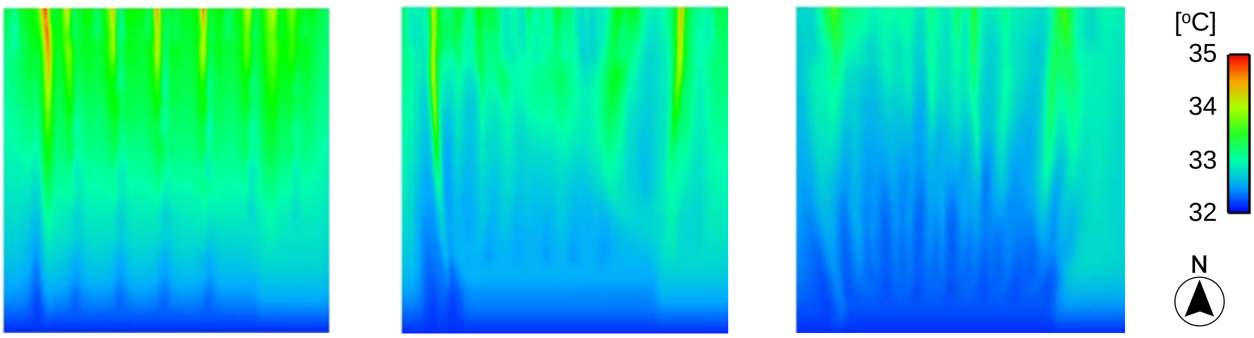
(1) Plan A (2) Plan B (3) Plan C

Fig.5 Horizontal distribution of MRT at the height of 1.25m



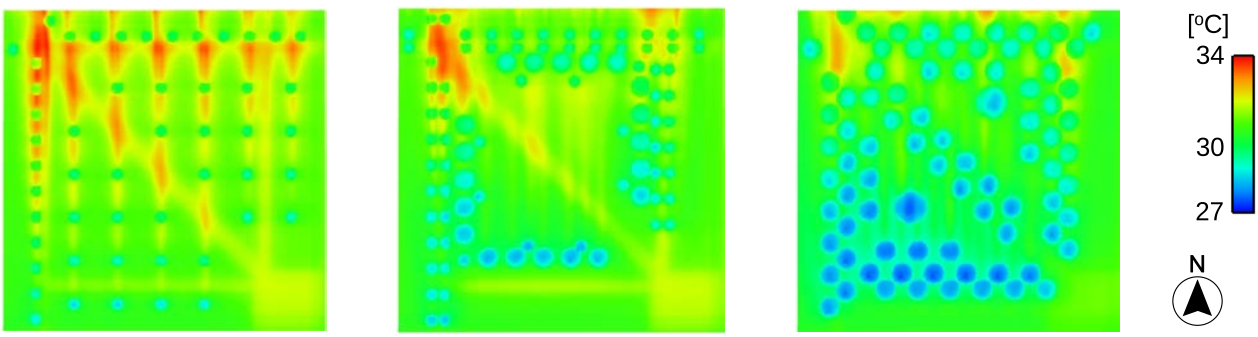
(1) Plan A (2) Plan B (3) Plan C

Fig.6 Horizontal distribution of wind velocity at the height of 1.25m



(1) Plan A (2) Plan B (3) Plan C

Fig.7 Horizontal distribution of air temperature at the height of 1.25m



(1) Plan A (2) Plan B (3) Plan C

Fig.8 Horizontal distribution of SET at the height of 1.25m*

5. Relationship between ecological network and thermal environment

Fig.9 shows the relationship between the evaluation of ecological network and spatial averaged SET* at the height of 1.25m. The evaluation of ecological network is spatial average of the habitat suitability in the study area (within 250m from the target site) and expressed in relative values to Plan A, defined as 1. It is shown that significant improvement of both ecological network and mean SET* in the target site of Plan C compared to Plan B. However, the value of mean SET* in leeward area of Plan C is almost the same value as that of Plan B. This shows that increasing of green spaces provides positive effects for ecological network, but too much tree plant is not very effective for human thermal sensation because of the wind velocity reduction. Thus, trees need to be arranged with appropriate arrangement in order to improve thermal environment.

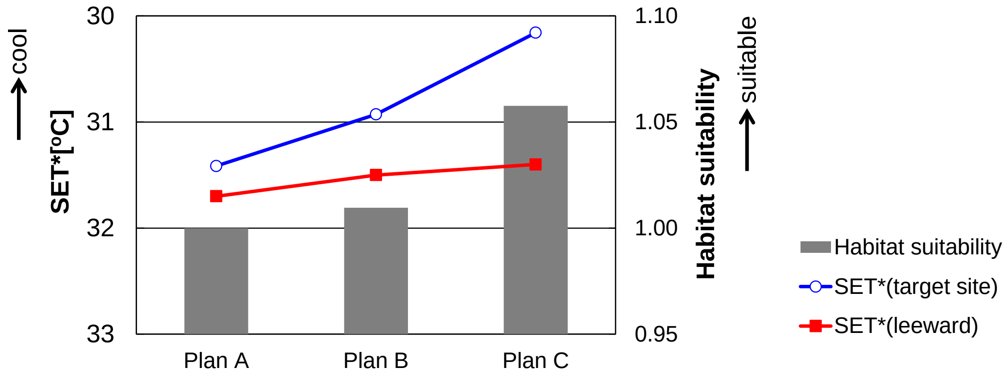


*Fig.9 Relationship between habitat suitability and mean SET**

6. Conclusions

3 different green plans in the target site located in the Tokyo Bay area are evaluated in terms of the ecological network as the effects on the habitat of organism in the surroundings and the thermal environments as the impact on the human thermal sensation. As a result, increasing of green spaces provides the positive effects for ecological network, but it is shown that too much tree plant does not show remarkably positive effect for human thermal sensation because of the wind velocity reduction. It is important to consider not only the quantity but also the arrangement of trees in order to improve both ecological network and human thermal environment.

References

Yokota S., Hayashi Y., Nasu M., Yonemura S., Oda S., Komatsu H., Kannari A., Watanabe T.,2013: Development of “Urban Ecological Network Simulation System (UE-Net)” and its application to urban greening. *Proceedings of 41st Annual Meeting of Environmental Systems Research 2013,* 189-196 (in Japanese)

US Fish and Wildlife Service, 1981: Standards for the development of habitat suitability index models. Ecological Services Manual 103. Washington, D.C.

Hiraoka H.,1993 : Modelling of turbulent flows within plant/urban canopies. *Journal of Wind Engineering and Industrial Aerodynamics*, **46**, 173-182.

Yoshida S., Ooka R., Mochida A., Murakami S., Tominaga Y., 2006 : Development of Three Dimentional Plant Canopy Model for Numerical Simulation of Outdoor Thermal Environment. *The 6th International Conference on Urban Climate (ICUC6)*

Mochida, A., Tabata, Y., Iwata, T., Yoshino, H., 2008 : Examining tree canopy models for CFD prediction of wind environment at pedestrian level. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, p1667-1677.

Tominaga Y., et al., 2008 : AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, **96**, p.1749-1761.