Planning and evaluation of urban green space for thermally comfortable environment in the station square—Numerical analysis using 3D CAD–based thermal environment simulator—Maiko Ishikawa* , Akira Hoyo* , Kazuaki Nakao* , Eiko Kumakura* 
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Abstract

In this paper, in order to create thermally comfortable urban living spaces under Japanese hot and humid climate in the summer, the urban park with green canopy is proposed in a station square, taking the effects of climatic factors into consideration, and evaluated through a numerical analysis. The thermal environment of the proposed green canopy is compared with the present square by the numerical analysis. These results show that the thermal radiation environment largely improves due to the effects of the mass green on the artificial ground compared with the previous station square.

Key words: green spaces, cool spot, thermal environment, urban park

1. Introduction

In recent years, the heat island phenomenon is a serious problem for many urban areas during the summer in Japan. The main causes of the heat island phenomenon are the change in land cover and enormous energy consumption in the area. Especially, green spaces in an urban area decrease with the change in land cover. Therefore, the change in land cover and the decrease in the green spaces cause not only poor thermal environment but also deterioration of urban landscape. The central government of Japan and the local government are active to not only maintain the present urban green but also increase renewed green in the urban space. The places on rooftop, wall, public open space and artificial ground have the potential to be able to create the green space. Furthermore, public space like a station square has the potential for such greening and is expected to be the important subject area for the governmental greening policy.

In this paper, in order to create thermally comfortable urban living spaces under Japanese hot and humid climate in the summer, the urban park with green canopy is planned in a station square. The thermal environment of the proposed urban park is compared with that of the present square by using a numerical analysis, and the effects of the proposed green canopy on thermal environment are evaluated. First of all, the thermal control effects by trees are researched by surveying the related previous studies to get the knowledge of these effects. The thermal environment of the present station square is grasped using the numerical simulation. Then, the urban park is designed in the station square, taking into account the surveyed results of the thermal control effect by tree, the effective greening method and the examination result of the thermal environment in the present square. Finally, thermal control effect by trees in the proposed urban park are predicted and assessed quantitatively by the numerical simulation.

2. Survey of thermal control effect by mass greens

In this study, “mass green” means the green space where people can walk under the tall trees, like a green canopy. The reason why this study takes the mass green in the station square is because the mass green has the potential to create the so-called “cool-spots”. Fig.1 shows the thermal control effect by mass greens. Table.1 shows the surveying results of the difference of air temperature between “mass green” of urban park and the urbanized area obtained from the previous studies. The difference of air temperature between inside and outside of urban park almost depends on the scale of the park, and becomes from 1°C to maximum 4°C. Narita et al (2004) observed cold air-seep phenomenon under calm condition at nighttime at the large park with the area of 58 ha. In the observation, a cooled air seeped out within the range of 80-90m from the park boundary. Hagishima et al (2004) performed the field measurements of the microclimate around the building that has the large stepped roof garden and grasped the occurrences of nocturnal cold-air flow along the green slope due to the gravity flow at nighttime. These results indicate the potential of mass green for the mitigation of the urban thermal environment.

3. Analysis of thermal environment in the present station square

A station square in harbor districts, Yokokarna, was chosen as the subject site. This square has an area of 1 hectare, including bus terminal and taxi pool. There is the Tokyo Bay within 1km south from the station. The present square has only a few trees and shading objects. The high rise commercial buildings are located in the north of the station and a number of people who use the station head toward these buildings (Fig. 2). In order to grasp the thermal environment of the present station square, the thermal environment was predicted by using a 3D CAD-based thermal environment simulator previously developed by the

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authors’ research group and CFD (Computational Fluid Dynamics) simulation tool. The 3D CAD-based thermal environment simulator can calculate the surface temperature distribution of urban area using the detailed geometry model of substantial urban area.

3.1 Surface temperature distribution of the present station square

3.1.1 Reproduction of the station square on 3D CAD and the calculation conditions

3D geometry information and component material of buildings and ground existed in the substantial station square were collected. Then, the 3D CAD model having these component material data was generated. The weather condition used in this examination was for a summer day with clear sky in Yokohama.

3.1.2 Calculation results

Fig.3 shows the surface temperature distributions of the present station square. The surface temperature of the station square is approximately 55°C at 12:00, when the air temperature is 32.3°C. The reason of this high surface temperature is that there are nothing to shade from the solar radiation and the ground are exposed to the strong solar radiation. The surface temperature is 40°C, which is still 10°C higher than the air temperature, at 20:00, because the square consists of high thermal capacity materials such as concrete and asphalt. Fig.4 depicts the calculation result of MRT (Mean Radiant Temperature) distribution, calculated by the surface temperature distribution, at a height of 1.5 m, so as to confirm the thermal radiant environment in the present square. The MRT under the tree is 38°C, which is 5°C higher than the air temperature. This is because the shape modulus of the shaded area with relatively low surface temperature under the tree crown is smaller than that of the surrounding ground, where the surface temperature is high.

In the present square, the deterioration of thermal radiant environment is confirmed through this examination.

Table 1. Difference in air temperature between inside and outside of urban park

| Meiji Jingu | 70.0 | 4.0 | Kanda(1999) |
| Singoku Gyoen | 69.0 | 3.0 | Narita(2004) |
| Osaka Castle Park | 50.0 | 2.5 | Monpi(2001) |
| Izumi Shizen Park | 40.0 | 5.0 | Fukushima(1994) |
| Kōkyō | 21.0 | 4.1 | Mikami(2007) |
| Shikoku Park | 18.8 | 2.1 | Mushita(1995) |
| Setagaya Park | 7.9 | 1.5 | Mushita(1995) |
| Utsubo Park | 6.6 | 2.0 | Monpi(2001) |
| Sano Park | 6.0 | 3.0 | Maruta(1995) |
| Motofuchie Park | 4.0 | 1.5 | Maruta(1995) |
| Mioji Park | 1.2 | 1.2 | Maruta(1995) |

Temperature difference between open space and urban area

Table 2. Thermal control effect by rooftop

<table>
<thead>
<tr>
<th>Measured site</th>
<th>Size (ha)</th>
<th>Temperature difference(°C)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saitama Keaki Park</td>
<td>0.9</td>
<td>0.55</td>
<td>Fukushima(2002)</td>
</tr>
<tr>
<td>Akurosu Fukuoka</td>
<td>0.8</td>
<td>1.0</td>
<td>Nagaihima(2004)</td>
</tr>
<tr>
<td>Nanto Parks</td>
<td>0.6</td>
<td>0.133</td>
<td>Nagaihima(2007)</td>
</tr>
</tbody>
</table>

Figure 2. Visible image at station square, Yokohama

Figure 3. Simulation results of the surface temperature distribution of the present station square (clear sky day in summer)
3.2 Airflow and air temperature distribution of the present station square

3.2.1 Calculation condition

Around the site, the general wind direction is from the seaside to the station square, because the Tokyo bay is located within 1km from the site. The airflow and air temperature distribution are calculated in the station square using a CFD simulation model. The high-Reynolds k-ε model is used in this calculation. Table. 4 shows the calculation conditions for the CFD simulation. The surface temperature distribution calculated in the previous section is set for the boundary condition of the CFD simulation. The tree model is based on a previous study by Yamamura et al.

3.2.2 Calculation result

Fig. 5 shows the calculation result of the airflow and air temperature distribution at 12:00. The air temperature in the station square is 1.5 °C higher than that of the inflow from the sea. This reason is because the airflow is exposed to the sensible heat flux from the ground where the surface temperature is over 50 °C. It is clarified that the increase of the surface temperature of the ground causes the deterioration of the thermal radiation environment and the increase of the air temperature in the square.

4. Proposal and planning of the urban park in the station square

The purpose of this section is to propose the urban park with mass greens in which people can enjoy and feel thermal comfort by the effects of these greens. There are three concepts to propose the urban park in the station square.

1) The green space where people spend comfortably and relaxed is created.
2) The green space like a forest creates cool-spots and the cooled air spreads to the surroundings with the wind from the seaside.
3) The mass green is designed to produce ecological system and biodiversity. The artificial ground is constructed around 5m above the present public transport space on the ground, and is designed to be an urban park with a “forest” on that (Fig.7).

In particular, the consecutive shadow is made by the big trees crown so as to create comfortable thermal environment. The wind from the sea flow through under the tree canopy that people can feel airflow in the space (Fig.6). Leaf mulch is put on the artificial ground and tall trees are planted on the artificial ground. By setting Cafe shop in the area, the space in which people gather and spend for a long time is newly created.

5. Analysis of thermal environment in the proposed station square

The surface temperature distribution of the proposed square was calculated using the 3D CAD-based thermal simulator. Fig. 7 shows the 3D-CAD model and the simulation result of the surface temperature distribution of the proposed station square. The calculation conditions are same with the above present case. The surface temperature on artificial ground is 35°C due to shading by big tree crown. The surface temperature under the trees is
Figure 7. Simulation results of the surface temperature in the proposed urban park at the station square (clear sky day in summer).

Figure 8. MRT distribution of the proposed urban park at height of 1.5m (12:00).

almost equal to air temperature all day. In contrast, the highest surface temperature is 50 °C on the artificial ground where the trees are not planted (Fig. 7). The surface temperate at 20:00 on artificial ground is equal to the air temperature, because the surface consists of the materials with small thermal capacity (Fig. 7). Consequently, the MRT under the tall trees is around 32 °C at 12:00 (Fig. 8), and these areas expand in the park, because huge shadow is generated by those many tall trees on the artificial ground. These results show that the thermal radiation environment largely improves due to the effects of the mass green on the artificial ground compared with the present station square.

6. Conclusions

In this paper, urban park with mass green were designed in the station square and the thermal environment created by the trees is predicted and evaluated. The main results are summarized as follows:
(1) The previous studies regarding the thermal control effects by trees are researched for the proposal of the thermally comfortable urban park in the station square.
(2) A station square in harbor districts, Yokohama was chosen as the subject site and the present thermal environment is simulated by CFD simulation and the 3D CAD-based thermal environment simulator.
(3) In the station square, the urban park with mass green was proposed so that people can enjoy and feel thermal comfort.
(4) The surface temperature distribution and thermal radiant environment of the proposed station square were predicted and evaluated using the numerical simulator. Consequently, the thermal radiation environment largely improves due to the effects of the mass green on the artificial ground compared with the present station square.

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Reference