Effective Turf Planting Layouts for Heat Mitigation in School yards

Noriko Umemiya¹, Takeshi Kishimoto¹ and Tomohiro Kobayashi¹
¹Osaka City University, Osaka, Japan

Abstract
Using CFD simulation, this study compared heat mitigation effects of partial turf planting in school yards and of overall turf planting. Typical school lots and surrounding buildings were modelled according to actual conditions. Temperature contour lines and air flow vectors on school yards showed that heat mitigation effects are dependent on wind speed and direction. The wet bulb globe temperatures were evaluated and compared. Turf planting in western parts of the school yards was most effective. Heat mitigation at leeward wind areas was slight.

Introduction
Turf planting for heat mitigation on school grounds has expanded throughout urban areas of Japan, simultaneously providing benefits related to sports activities, injury prevention, emotional stability, and improved interest in nature and science (Tanabe et al., 2000; Umemiya et al., 2010). Local governments have offered subsidies for turf planting, but funds are strained: turf planting for whole school grounds is difficult in some cases. Little budget help is forthcoming from governments for maintenance (Moriyama, 2004).

This study used CFD simulation to compare heat mitigation effects of partial and comprehensive planting. Effective layouts were also investigated.

Typical models of school building layouts in Osaka city were selected considering the surrounding building height and density, building orientations and positions, and turf planting layout and size according to the actual state. We conducted CFD simulation based on measured surface temperatures.

Methods
Survey of school yards
Surveys using questionnaire sheets and aerial photographs were used to clarify the actual state of school yard turf planting in Osaka city. Questionnaire forms were sent to 66 primary schools that were supposed to have turf planted school yards: 28 schools answered. Requested items were the area and layout of planting, reason for the layout, expectations, effects and problems, methods of maintenance, and so on. Also, aerial image surveys, site surveys, and governmental information of all 291 schools in the city were used. Data of 49 turf-planted primary schools were collected.

Actual state of turf planting
Sizes, shapes, and layouts
Figure 1 presents a frequency distribution of turf areas. All turf areas of the 31 schools were less than 1000 m²: 10 schools had 900–1000 m²; 5 had 700–800 m² of turf planting. Figure 2 portrays six typical turf shape and layout types in school lots. Actual shapes and layouts are also shown. They were classified as follows: 1) Overall...
(All), almost all school yard planting; 2) Closed square (Sq), square with limited turf area; 3) Belt (La), long linear shape turf along buildings; 4) Niche (Cv), buildings surrounding turf; 5) Courtyard (CY), turf in an enclosed courtyard; and 6) Detached site (SY), turf at a detached site outside of the school site.

Figure 3 shows respective frequency distributions of the six types for turf area under and over 1000 m². Turf shapes and layouts are related to area amounts. Belt type was frequent for smaller turf areas. Overall type was frequently associated with larger turf area. Niche type was frequently associated with smaller and larger turf areas.

**Surrounding buildings and blocks of schools**

After the school lot area, school building layout, and swimming pool and gymnasium sizes for schools with a green ratio value lower than the 25th percentile. These schools are inferred to need more green space. Their most frequent school building pattern had buildings on the north and west of the lot, with the swimming pool and gymnasium located separately. Means and standard deviations of the school lots were 9,961 m² and 3,167 m².

Eight schools met the condition.

The heights and densities of the schools’ surrounding areas were found from the number of buildings in the west side of the school lots higher than school buildings. West is the most frequent wind direction in the city. Two schools were selected: Model_K with high and middle buildings built at low density and Model_H with low buildings built at high density. Figure 5 presents a model of schools and surroundings: Model_K had a school lot of 11,550 m² with a school yard of 6,520 m²; Model_H had a school lot of 11,865 m² with a school yard of 6,510 m². They were used as models for CFD simulation.

**Methods of CFD simulation**

After the 400 m × 400 m areas surrounding the selected two schools were modelled, we carried out a CFD simulation for a peak summer afternoon in Osaka. STREAM® by Software Cradle Co., Ltd. was used for calculations. Figure 6 portrays the analysis domain and mesh layout. A cubic mesh was applied. The mesh widths

**Table 1: CFD analysis conditions.**

<table>
<thead>
<tr>
<th>Analysis Domain</th>
<th>1500m×600m×450m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis Model</td>
<td>400m×400m(highest building 45m)</td>
</tr>
<tr>
<td>Turbulence model</td>
<td>Standard k-ε model</td>
</tr>
<tr>
<td>Discretization Scheme</td>
<td>first - order upwind differencing scheme</td>
</tr>
<tr>
<td>Boundary Condition</td>
<td>Inlet(West)</td>
</tr>
<tr>
<td></td>
<td>Outlet(East)</td>
</tr>
<tr>
<td></td>
<td>other</td>
</tr>
<tr>
<td>Thermal Boundary Condition</td>
<td>Coefficient of Heat-Transfer 23 W/m²°C</td>
</tr>
<tr>
<td>Number of Mesh Elements</td>
<td>6,001,328(MODEL_K)/5,889,372(MODEL_H)</td>
</tr>
</tbody>
</table>

**Figure 4:** Green space ratios in 400 m ×400 m areas surrounding 291 elementary school lots in Osaka city.

**Figure 5:** School lots and surrounding buildings of Model_K and Model_H.

**Figure 6:** Analysis domain and mesh layout.

**Figure 7:** Cases of turf layout patterns for calculation.
were 750 mm in the school, 1,500 mm in the model, and 9,000 mm out of the model. These mesh sizes were generally used for urban size simulation in earlier studies. Table 1 presents the CFD analysis conditions (Sakai et al., 2004; Harada et al., 2011; Umemiya et al., 2013).

Seven cases of Model_K and six cases of Model_H in Figure 7 were calculated considering frequent turf layout patterns of the Belt and the Niche and the west wind direction. Mean surface temperatures shown in Table 2 were measured at 13:00–14:00 on August 12, 2011 in Osaka under stable sunshine were used (Umemiya et al., 2013). Shade/sunlit conditions of the grounds were decided by solar position at 14:00, although wall temperatures were the same irrespective of the sunshine conditions.

Figure 8 shows 36 points on school yards for calculations. They were measured 1.0 m from the ground to conform to schoolchild size.

Results of CFD

Model_K

Fig. 9 presents a comparison of air temperature contour lines around school lots for Case 0 without turf and Case 1 of comprehensively turf for MODEL_K. Temperatures at study points were 33.47–36.16°C for Case 0 and 33.25–35.44°C for Case 1. They were within the range of measured air temperatures. The temperature in Case 1 was lower than that in Case 0 for all study points. Differences

Table 3: Maximum difference and mean difference from Case 0 (without turf) for each case.

<table>
<thead>
<tr>
<th></th>
<th>K_Case 2</th>
<th>K_Case 3</th>
<th>K_Case 4</th>
<th>K_Case 5</th>
<th>K_Case 6</th>
<th>H_Case 2</th>
<th>H_Case 3</th>
<th>H_Case 4</th>
<th>H_Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum (K)</td>
<td>0.40</td>
<td>0.43</td>
<td>0.54</td>
<td>0.70</td>
<td>0.78</td>
<td>0.42</td>
<td>0.20</td>
<td>0.16</td>
<td>0.40</td>
</tr>
<tr>
<td>Mean (K)</td>
<td>0.24</td>
<td>0.18</td>
<td>0.18</td>
<td>0.32</td>
<td>0.56</td>
<td>0.21</td>
<td>0.11</td>
<td>0.15</td>
<td>0.27</td>
</tr>
</tbody>
</table>
difference from Case 0 are shown in Table 3 for each case. The difference was large east of gymnasiums southwest of school lots and niches in the school yard for Case 1. Differences are shown only for turf for Cases 2–6. Mean differences on turf areas were 0.56 K for Case 6. Differences from Case 0 in Cases 2, 5, and 6 that had turf in west and south of school yard were as large as those in Case 0. By contrast, differences from Case 0 in Cases 3–4 were only 0.1–0.4 K, even on turf.

Airflow vectors in Figure 11 show leeward turf areas. Results show that turf existing in a leeward direction wind exerted less effect on heat mitigation because hot air passed on hot surfaces and flowed on turf when turf existed leeward.

**Model_H**
Fig. 12 presents a comparison of temperature contour lines of school yards for MODEL_H. Figure 13 shows contour lines of temperature difference from Case 0. Airflow vectors and flow lines for MODEL_H are shown in Figure 11.

The maximum difference and mean difference are shown in Table 3 for each case. The mean difference on turf area was 0.27 K for Case 5. Results show that it was the most effective case aside from Case 1. Turf existing leeward was less effective also in Model_H. Temperatures on turf were higher in Case 3 and Case 4. Turf was present east or north in school lots at direction of leeward in these cases.

![Figure 11: Air flow vectors and flow lines in school yards.](image)

![Figure 12: Temperature contour lines around school lots for Case 0 and Case 1 (MODEL_H).](image)

![Figure 13: Contour lines of temperature difference from Case 0 (without turf) (MODEL_H).](image)
Wind speed and temperature

Figure 14 portrays the relation between wind speed and temperature difference at study points from Case 0. Heat mitigation effects were greater at high wind speed points (Yagi et al., 2013). The temperature off of the turf was higher in Case 0. Results show that heat mitigation effects depend also on wind speed.

Heat mitigation effect evaluation using WBGT

The Wet Bulb Globe Temperature is an index representing human heat stress in hot environment standardized by ISO7243. Reference WBGT values for sports activity are shown by the Japan Sports Association: WBGT 21–25°C for ‘attention’, 25–28°C for ‘warning’, 28–31°C for ‘strong warning’ and 31°C for ‘discontinuation’. The Japan Institute of Biometeorology recommends other reference values in daily life. Japan’s ministry of the environment estimates and releases the WBGT value every day in hot seasons to call attention to heatstroke. WBGT is more suitable to estimate heat mitigation effects than air temperature because it is a synthetic thermal index incorporating radiation, humidity, and air velocity.

The mean radiant temperature was estimated from Equations (1) and (2) using measured solar radiation, where \( T_{\text{MRT,L}} \) is the mean radiant temperature, considering long-wave radiation from building surfaces (Pickup et al., 1999; Majima et al., 2007). The globe temperature was calculated by using Equation (3). The wet bulb temperature was estimated with Equation (4) to (6) using humidity measured on turf ground.

Table 4 shows the wet bulb globe temperature (WBGT) averaged for 36 points in each case with and without turf planting. Differences of WBGT from Case 0 (without turf) are also shown. The layout of Case 2 includes turf west of the school yard, which was most effective. Mean differences were 0.33–0.79 K. The maximum difference was 0.98 K. Figure 15 presents the relation between the temperature difference and WBGT difference. The WBGT difference was about 0.2 K greater than the temperature difference.

Conclusion

Actual states of turf-planted school yards were surveyed. Heat mitigation effects of turf in peak summer were calculated using CFD simulation for two typical schools. Results demonstrated the following.

Table 4: Average of WBGT for study points of each case with partial turf.

<table>
<thead>
<tr>
<th>without Turf (°C)</th>
<th>K Case2</th>
<th>K Case3</th>
<th>K Case4</th>
<th>K Case5</th>
<th>K Case6</th>
<th>H Case2</th>
<th>H Case3</th>
<th>H Case4</th>
<th>H Case5</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.68</td>
<td>32.07</td>
<td>32.14</td>
<td>32.12</td>
<td>35.55</td>
<td>29.56</td>
<td>31.92</td>
<td>31.72</td>
<td>31.99</td>
<td></td>
</tr>
<tr>
<td>29.22</td>
<td>31.62</td>
<td>31.74</td>
<td>31.60</td>
<td>34.77</td>
<td>29.18</td>
<td>31.59</td>
<td>31.34</td>
<td>31.53</td>
<td></td>
</tr>
<tr>
<td>Difference (K)</td>
<td>0.47</td>
<td>0.45</td>
<td>0.39</td>
<td>0.52</td>
<td>0.79</td>
<td>0.38</td>
<td>0.33</td>
<td>0.38</td>
<td>0.46</td>
</tr>
</tbody>
</table>
1) The temperature difference from case without turf was 0.1–0.6 K; maximum 0.8 K.

2) Temperature difference from case without turf was greater at slow air points.

3) Heat mitigation effects of turf were almost limited to turf planted points.

4) Heat mitigation effects were small at leeward points.

5) The WBGT difference from case with turf was about 0.2 K greater than the temperature difference from case without turf.

These results demonstrate that some turf planting layouts have almost identical heat mitigation effects to those of bare grounds, although partial turf planting was actually often selected for financial and maintenance reasons actually. Considerations of the wind velocity and direction in the school lots are important.

Nomenclature

$T_{MRT}$: mean long-wave radiant temperature [°C]

$F_{ac}$: projected area factor of plane-i of human body [-]

$T_{prij}$: plane radiant temperature of plane-i [°C]

$F_{ij}$: configuration factor of plane-j [-]

$e_i$: emissivity of plane-j [-]

$T_{s,i}$: surface temperature of plane-j [°C]

$T_{MRT}$: mean radiant temperature [°C]

$f_{p}$: human body’s projected area factor [-]

$\alpha$: albedo of clothing [-] (=0.4)

$S_{d}$: direct solar radiation [W/m²]

$D_{d}$: diffuse solar radiation [W/m²]

$F_{er}$: effective radiation area factor [-] (=0.75)

$\sigma$: Stefan Boltzmann constant (=5.67×10⁻⁸ [W/m²K⁴])

$\alpha_{ground}$: ground albedo [-] (=0.1)

$T_{g}$: globe temperature [°C]

$t_{g}$: wet bulb temperature [°C]

$V_{a}$: air velocity [m/s]

$\varepsilon_{g}$: emissivity of globe [-]

$D$: diameter of globe [m]

$h$: air enthalpy ratio around dry bulb [kJ/kg]

$h'$: air enthalpy ratio around wet bulb [kJ/kg]

$x$: humidity ratio around dry bulb [g/kg dry air]

$x'$: humidity ratio around wet bulb [g/kg dry air]

$f$: vapour pressure around dry bulb [mmHg]

References


