RELATION OF SURROUNDING BUILDING CONFIGURATION AND MITIGATION EFFECTS OF SCHOOL LAWN PLANTING

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ABSTRACT

Lawn planting in schoolyards is expected to mitigate heat-island phenomena. This study, using CFD analysis, examines the degree to which this mitigation changes according to the configuration of surrounding buildings. Existing school shapes, modified configurations of school buildings, and shortened high-rise buildings neighboring schoolyards are assessed in a summer thermal environment of a schoolyard with bare soil and when covered with a lawn. Results show that surrounding buildings have greater effects than the ground surface on the thermal environment of schoolyards.

INTRODUCTION

Recently, lawn planting on school grounds has been undertaken as a countermeasure against heat-island phenomena. However, the effects might be decreased by fluid properties related to surrounding school buildings or neighboring building configurations.

Using CFD analysis of a typical elementary school in urban regions of Osaka City, this study investigates the arrangements and shapes of surrounding buildings, which have remarkable effects on the thermal environments of school grounds.

Several government grants for schools have been awarded to launch lawn planting on school grounds in anticipation of beneficial effects on child education, local community formation, the biological environment, and thermal conditions. Nevertheless, lawns on school grounds are not increasing. We conducted a survey related to school ground lawn planting for 100 elementary school maintenance managers from all 297 schools in Osaka City. We also measured sky factors and sunshine duration during the summer and winter solstices and the equinoxes for 36 elementary schools (Nakanaga et al. 2010). Results show that 1) only 35.3% of the schools satisfy the condition of sunshine duration for raising a lawn, 2) subjective evaluation of sunshine and contentment with school grounds strongly relate to sky factors and sunshine duration, and 3) the sunshine duration is shorter and sky factors are even lower for schools with ‘completed lawn planting’.

The reasons for choosing Osaka City as the city to be analyzed were the following.

In Osaka City, mean temperatures have risen about 2.0 K during the last century, but only about 1.0 K throughout Japan. The average number of tropical nights during 1996–2005 is 42.1 days, which is the highest in Japan.

Little green space exists in Osaka City. The park area per person was 3.46 m² in 2003, which is extremely low among ordinance-designated cities. It is thought that heat-island phenomena in Osaka are partly attributable to the dearth of green space. To secure green space is important not only for comfortable city planning but also for preserving residents’ health. Nevertheless, finding new areas for greening is extremely difficult because Osaka has extremely high population density. For these reasons, school playgrounds are receiving attention as a valuable space that can be modified in the city.

ANALYTICAL OBJECTS

Elementary schools used as analytical objects were selected from 100 schools of questionnaire survey responders in an earlier study (Nakanaga et al., 2010). Regarding land use near the schools, 70% were located in residential districts. Reportedly, high-rise buildings exist in surrounding areas for 47% of responders; 64% of the school buildings were of four stories. From these results of the earlier survey, S elementary school was chosen as a typical elementary school of the Osaka City urban area. The tallest building in the surrounding areas was 45 m. Figure 1 shows the S school.

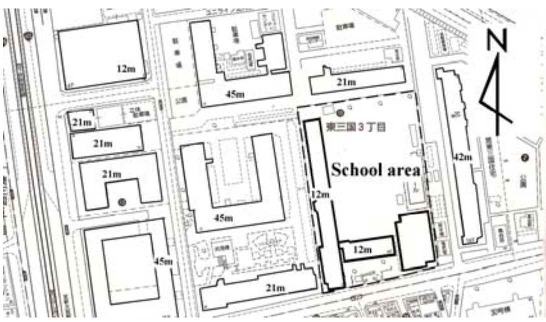


Figure 1 School location

THE ANALYTICAL MODEL

A three-dimensional analytical model of the school and the surrounding areas was produced. Standard k-ε model was used.

Air temperature and surface temperatures

The building's surface temperature and the air temperature were set as the mean value of the measurement data measured during 12:00–15:59 in the daytime, August 25, which was a typical clear and sunny day in summer. The lawn surface temperature was set according to the leaf surface temperature measured in our earlier study (Sakurai et al., 2011). Surface temperatures were used for the thermal transfer boundary condition on the surfaces.

Wind speed and the wind direction

In boundary conditions in the analytical model, the wind speed was 1.66 m/s and the direction is westward, as referred from measured data of 12:00–15:59 obtained by the Osaka District Meteorological Observatory.

The main set contents of the analytical model are presented in Table 1.

Parts that became shady were calculated using the chart of solar shadow curves. Different surface temperatures were set for a shadow area and sunny area. A bird's-eye view of the analytical domain is portrayed in Figure 2.

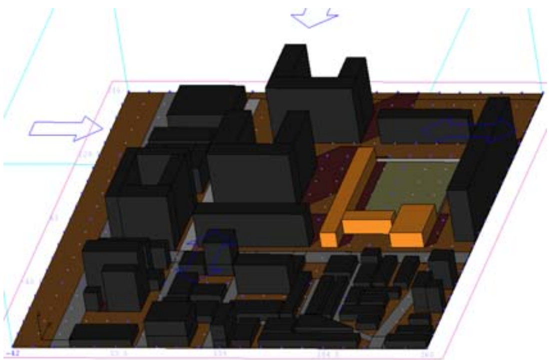


Figure 2 Analytical model

Table 1 Main set contents of analytical model

Item	Set Content
Analytical domain	302×345m×151m X:−42m～260m Y:−130m～215m Z:−1～150m
Analytical outline	Turbulent flow: Non-compresion, Analusis steady state
Initial condition	Initial temperature: 33.47℃
Boundary conditio	Inflow: East 1.66m/s 33.47℃ In or Outflow: North・South・West
Surface temperatur	Building North side :32.92℃ South:43.67℃ East:38.13℃ West:43.65
	The horizonal plan:52.79℃ Inside:36.00℃
	Ground: 52.79℃ Ground in the shadow: 39.32℃
	Lawn :40.99℃ Lawn in the shadow:34.69℃
Turbulent model	Standard k-ε model
Thermal boudary	Building Heat transfer rate 23.3W/m²℃
Condition	The sky :1×10^{23} W/m²℃
Element division	The number of all element 127764

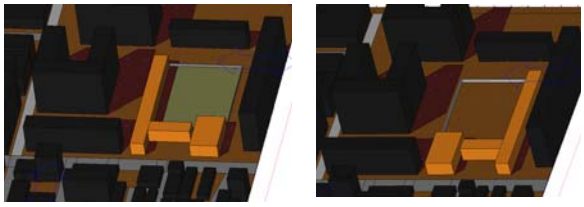
EXPERIMENT

Eight cases were examined in this study.

An outline of the cases is presented in Table 2.

School shape

CASES 1–4 use existing school shapes. CASES 5–8 respectively use symmetrical configurations from east to west of CASES 1–4.
Their appearances are shown in Figure 3.



(1)(Table 2) (CASE 2) *(2)(Table 2) (CASE 5)*

Figure 3 Two school shapes

Examination points

As presented in Figure 4, 25 examination points are set in the schoolyard. They are located over 10 m from the edges of the schoolyard. Their heights from the ground are 1.5 m.

Hedges in school playgrounds

A 3-m-high hedge encloses the schoolyard. We set hedges of two types, with 0% and 70% aperture rates.

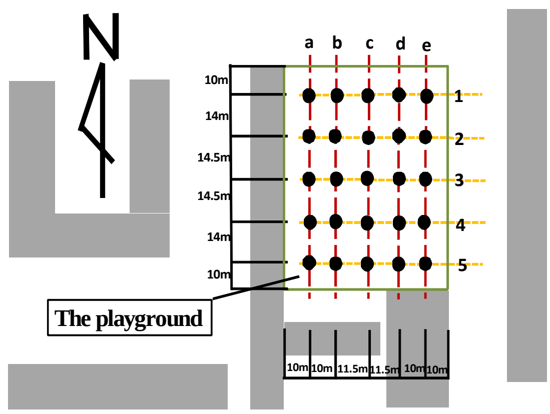


Figure 4 Examination point positions (CASES 1–4)

Table 2 Cases

	school's shape	hedge's type(height 3m)	school yard
case1	①	aperture rate 0%	soil
case2			lawn
case3		aperture rate 70%	soil
case4			lawn
case5	②	aperture rate 0%	soil
case6			lawn
case7		aperture rate 70%	soil
case8			lawn

RESULTS OF ANALYSIS

The wind speed distributions of CASE 1 (soil) and CASE 2 (lawn) are shown respectively in Figure 5 and Figure 6. Results of air temperature and velocity distribution at examination points of the schoolyard are presented in Figure 7. The direction of graphs in Figure 7 agrees to the direction of the row of examination points in Figure 4, an apartment building of 45 m height is located on the left side of each graph in the figure. Few differences are found in wind speed distribution between soil and lawn. The differences are 0.02 m/s or less at all examination points in all cases. Therefore, only graphs of wind speed for bare ground are shown in Figure 7.

Results show that the air temperature of the schoolyard for CASES 1–4 (existing configurations) is decreased by lawn planting at almost examination points except on line-a. Lawn planting has some effects on air temperature for CASES 1–4, although the air temperature falls slightly at examination points on line-a for CASE 4 (hedge aperture of 70%) but not for CASE 2 (hedge aperture of 0%).

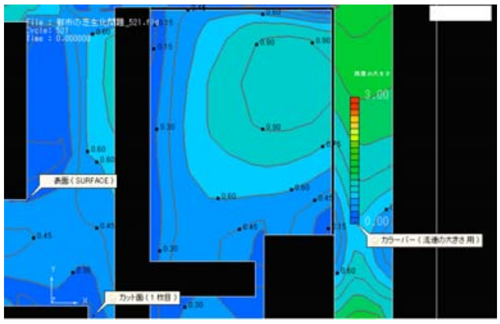


Figure 5 Wind speed distribution of CASE 1, soil (GL+1.5 m)

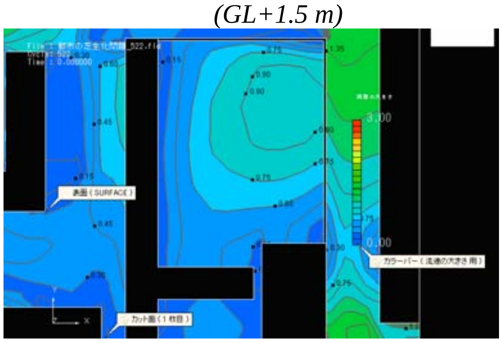


Figure 6 Wind speed distribution of CASE 2, lawn (GL+1.5 m)

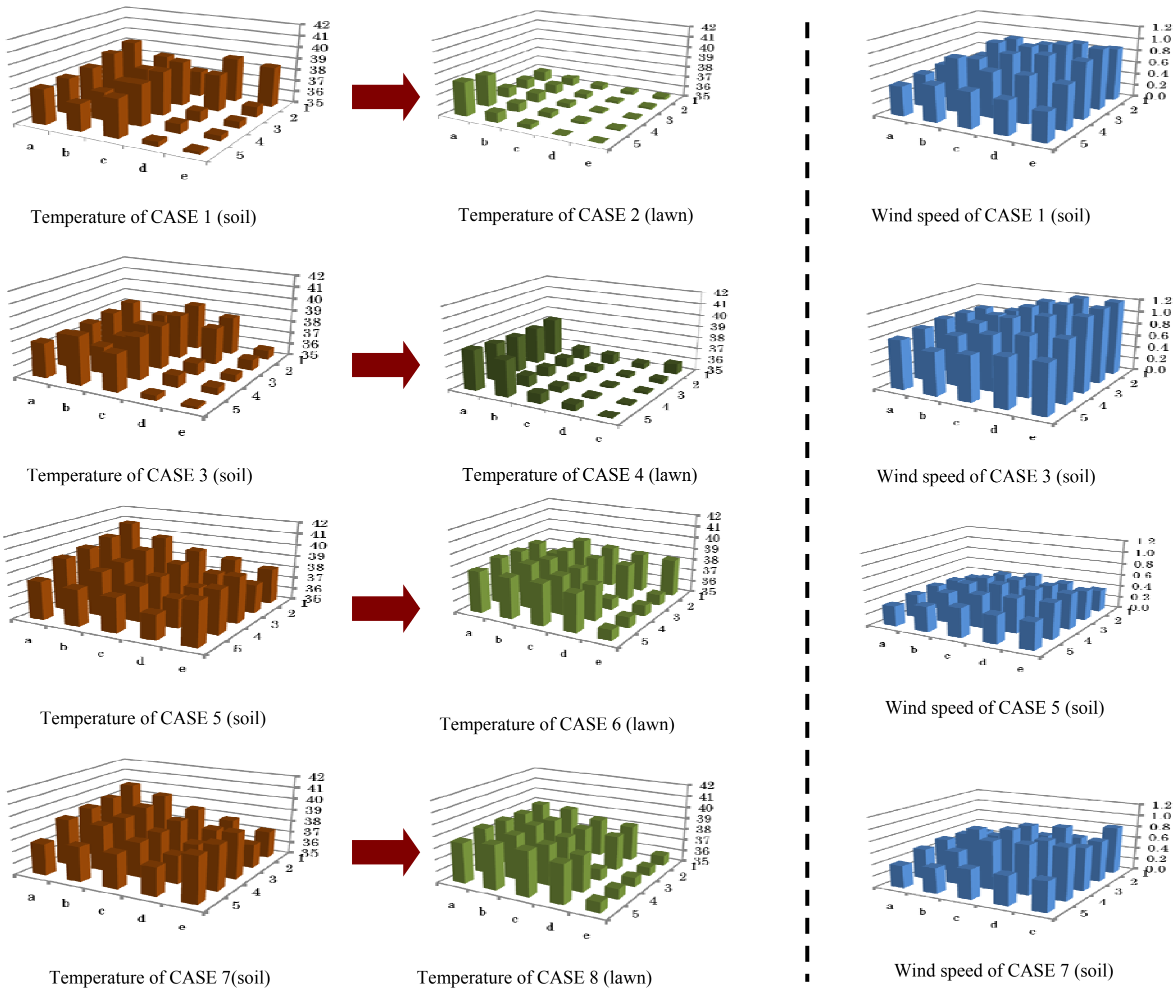


Figure 7 Temperature and wind speed distributions for different surface materials

In contrast, little effect of lawn planting is observed in CASES 5–8 (modified configurations). The temperature distribution changes little, except for examination points on line-e. Little relation between the air temperature decrease and wind speed is apparent in CASES 5–8 or in CASES 1–4.

DISCUSSION

Only slight effects of lawn planting are observed in CASES 5–8 (modified configurations) because a warmer area exists at the west side of the schoolyard. The higher temperature areas appear in cross sections of the temperature distribution on line-3, Figure 8 for CASE 2 (lawn, existing school configurations), and Figure 9 for CASE 6 (lawn, modified configurations). Figures 10–13 of the wind speed distribution show that the flows from the west side are obstructed by a tall (45-m-high) apartment building. Presumably, warmer air flows into the schoolyard, raises the air temperature, and decreases the effects of lawn planting in CASES 5–8, because the schoolyard is opened toward the warm fluid in modified configurations.

Figure 7 shows that the air temperature does not fall by lawn planting at examination points on line-a in CASES 3–4 (hedge aperture of 70%), although it falls in CASES 1–2 (hedge aperture of 0%). Warmer fluid stagnant caused by hedge might decrease the effects of lawn planting in CASES 3–4.

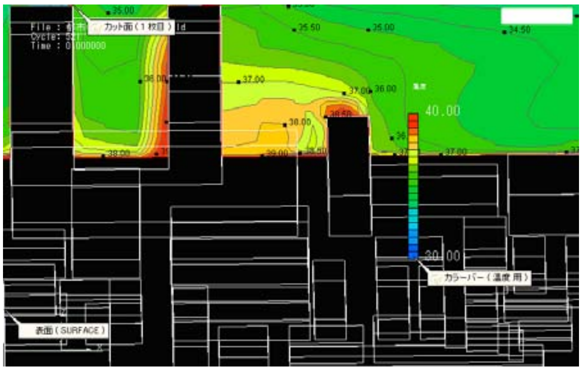


Figure 8 Temperature distribution of CASE 2, lawn, existing configurations (cross section on line-3)

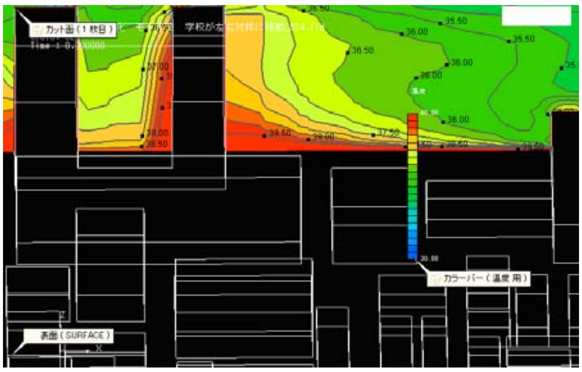


Figure 9 Temperature distribution of CASE 6, lawn, modified configurations (cross section on line-3)

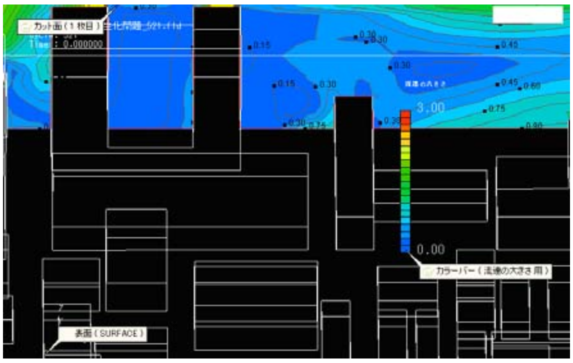


Figure 10 Wind speed distribution of CASE 2, lawn, existing configurations (cross section on line-3)

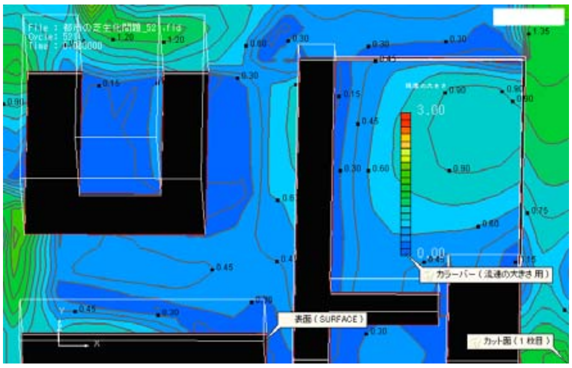


Figure 11 Wind speed distribution of CASE 2, lawn, existing configurations (GL+1.5 m)

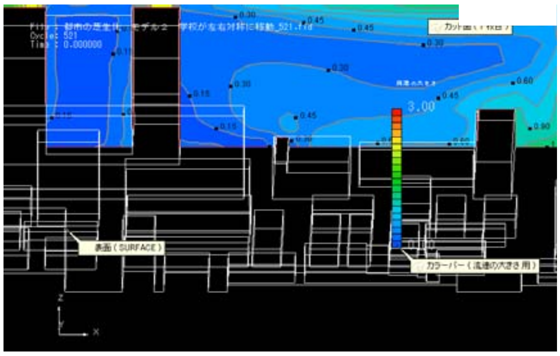


Figure 12 Wind speed distribution of CASE 6, lawn, modified configurations (cross section on line-3)

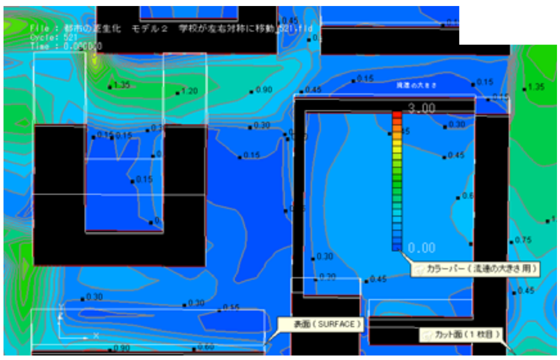


Figure 13 Wind speed distribution of CASE 6, lawn, modified configurations (GL+1.5 m)

Additional simulations

We simulated new configurations of apartment buildings of half height (22.5 m) because a high-rise apartment building located west of the school presumably raises the temperature around the west side area of the schoolyard.

Herein, we discuss the temperature and wind speed for examination points using graphs for which the direction agrees to the direction of the row of examination points shown in Figure 4. That figure shows the temperature and wind speed distributions at examination points. Only the results of bare ground for wind speed are presented in Figure 14 because the differences are 0.02 m/s or less in air speed between the soil and lawn at all examination points as they are in Figure 7.

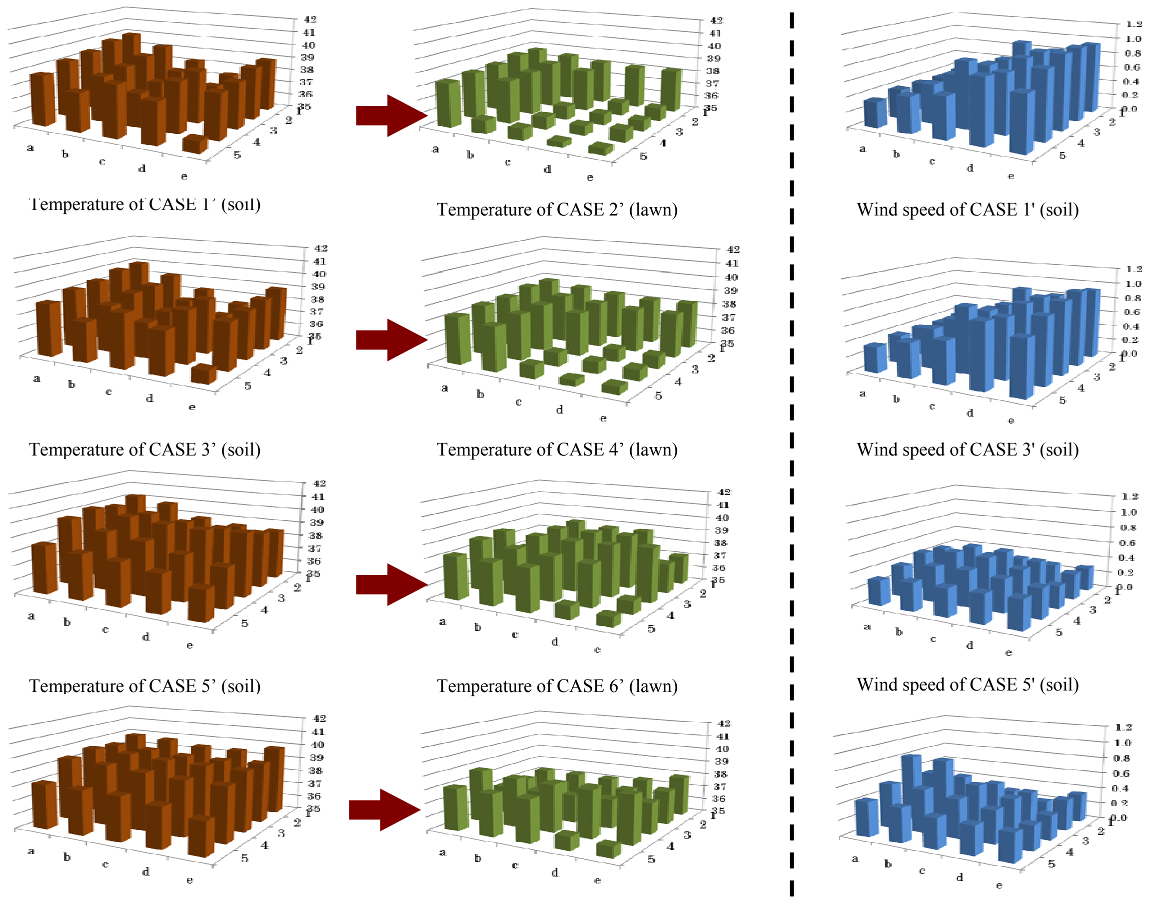
Analytical results show the effects of lawn planting in all cases by shortened buildings.

Regarding the wind speed at 1.5 m height from the schoolyard, stagnation of the fluid of 0.15–0.30 m/s in wind speed is distributed on the east side of the apartment building, irrespective of its height. Figure 11 (CASE 2) and Figure 13 (CASE 6), with an existing apartment building of 45 m, and Figure 16 (CASE 2') and Figure 18 (CASE 6'), with a half-height (22.5 m) building do not differ so much.

In addition, little relation was found between the wind speed distribution and the building height at examination points on line-3, when cross sections of wind speed distribution are compared. The wind speed distributions in Figure 10 (CASE 2) and Figure 12 (CASE 6) with apartment buildings of 45 m height and Figure 15 (CASE 2') and Figure 17 (CASE 6') with half-height buildings do not differ greatly.

The effects of lawn planting appear in all cases if the apartment building located west of the school is only half its usual height. However, air stagnates irrespective of the building height. In other words, the occurrence of stagnant air is unrelated to the building height.

These analytical results show that the reason for increasing effects of lawn planting might be the building's height itself. The warm building wall presumably influences the air temperature by retaining the warm air along the wall when the air speed is low. The greater the wall surface area, the more it influences the air temperature.



Temperature of CASE 1' (soil) — Temperature of CASE 2' (lawn) — Wind speed of CASE 1' (soil)

Temperature of CASE 3' (soil) — Temperature of CASE 4' (lawn) — Wind speed of CASE 3' (soil)

Temperature of CASE 5' (soil) — Temperature of CASE 6' (lawn) — Wind speed of CASE 5' (soil)

Wind speed of CASE 7' (soil) — Temperature of CASE 8' (lawn) — Wind speed of CASE 7' (soil)

Figure 14 Temperature and wind speed distributions with half- height buildings

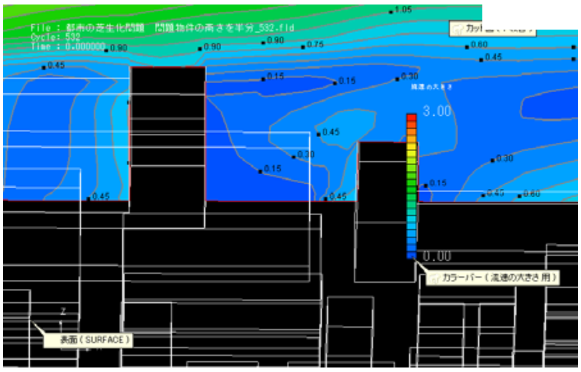


Figure 15 Wind speed distribution of CASE 2', lawn, half-sized and existing configurations (cross section on line-3)

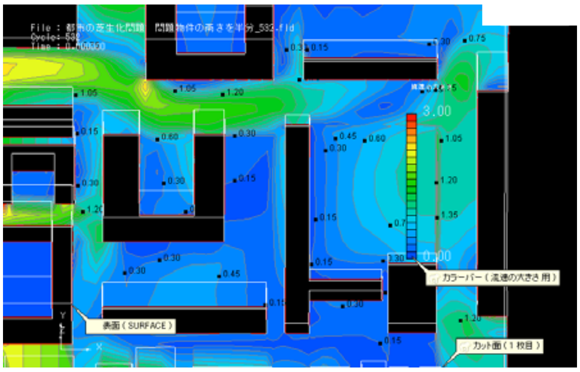


Figure 16 Wind speed distribution of CASE 2' (GL+1.5 m)

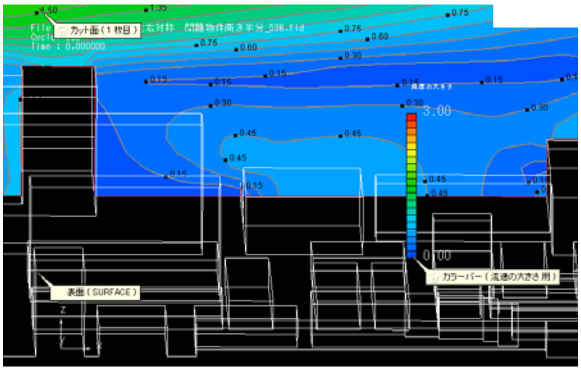


Figure 17 Wind speed distribution of CASE 6', lawn, half-sized and modified configurations (cross section on line-3)

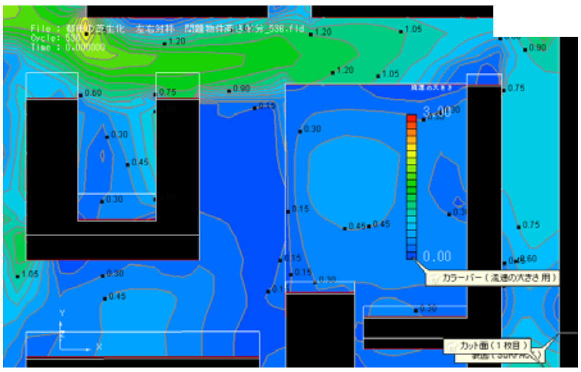


Figure 18 Wind speed distribution of CASE 6' (GL+1.5 m)

CONCLUSIONS

Results of this study show, by simulating typical primary schools in urban regions having tall buildings in surrounding areas, how tall buildings can decrease effects of lawn planting in schoolyards. Results show slight differences in the wind speed distribution when the schoolyard is transformed from bare ground into a lawn. An important consideration related to effects of lawn planting in urban regions is enclosing taller buildings of schoolyards rather than the school buildings themselves. Taller buildings in surrounding areas have more important effects on the air speed and temperature of the schoolyards than ground surface materials.

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