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RELATION BETWEEN SCHOOL BUILDING CONFIGURATION AND HEAT MITIGATION EFFECTS OF LAWNS IN URBAN REGIONS

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ABSTRACT

Results of this study show how heat mitigation effects of planting elementary school lawns in urban regions differ according to eight school building configurations and two surrounding building models.

Results show the following. 1) Heat mitigation effects with high-rise buildings (MODEL_H) are higher than those with normal height buildings (MODEL_N) for eight school building configurations. 2) For MODEL_H, with higher surrounding buildings, enclosure-type school building configurations show high heat mitigation effects of lawns in terms of temperature differences. 3) School building configurations with no west-facing school buildings show high heat mitigation effects of lawns for the new effective temperature for outdoors (OUT_SET*) both for Model_H and Model_L.

INTRODUCTION

Recently, several government and enterprise grants have been awarded to schools to launch lawn planting on school grounds in anticipation of beneficial effects on child education, local community formation, the biological environment, and thermal conditions in Japan. That lawn planting is evaluated by its many educational effects such as increasing the frequency and variety of outdoor playing, arousing pupils' interest in nature, and keeping mental conditions calm. School grounds are valuable areas for the greening of crowded urban districts having few garden areas. Planting has been undertaken as a countermeasure against heat island phenomena in Japan.

Yokoyama et al. (2006) demonstrated that the air temperature 1.5 m above the school yard was decreased as much as 1.6 K by lawn planting during daytime at times of peak summer heat. Harada et al. (2011) examined the degree to which that mitigation effect changes according to the configuration of surrounding buildings. The effects can be decreased by fluid properties related to surrounding school buildings or configurations of neighboring buildings. Using CFD analysis of a typical elementary school in urban regions of Osaka City in Japan, this study investigates the arrangements and shapes of surrounding buildings, which have remarkable effects on the thermal environments of school grounds.

Results of this study show how heat mitigation effects of planting elementary school lawns in urban regions differ according to school building configurations of eight types and two surrounding building models.

METHODS

Survey of elementary schools in the city

Sixty two elementary schools in Osaka city were investigated along with buildings surrounding the schools in a 400 m × 400 m area. Surrounding areas were divided into eight zones around the school site along with the school boundary. Figure 1 shows that mode of division. Results clarified the following: 1) typical schools have a street, railway, or waterway of more than 20 m width. 2) The zone building coverage ratio is 32.36–49.0%. 3) The total building volume ratio is 550–1600% for 41 schools, 1850% for one school, and 2200% for one school. The mean and standard deviation are 923% and 1381% for 41 schools. 4) The mean and standard deviation of the school area are 5915.3 and 11,242.7 m^2. 5) The school area has four apices. It can be said that 14 schools with building volume ratios of 550–1600% and a school with a building volume ratio of 2200% are typical school areas. Consequently, two schools were selected for these analyses.

Modelling

The objective time was August 12, 14:00. Air temperatures are highest in mid-August in Osaka, ordinarily reaching their highs at 14:00. Measured values of surface temperatures of the lawn and the sand, air temperature, and wind velocity were used. The wind direction was presumed to be westward, the most frequent direction in the city during such times.

The analytical domain was 800 m × 800 m. The height was 550 m. The domain size was decided empirically not to have effects on fluid properties around buildings. Figure 2 shows the analyzed area. Typical cases are MODEL_N, with building volume ratios of 550–1600%, and MODEL_H, with a building volume ratio of 2200%. Figures 3 and 4 portray the respective models.

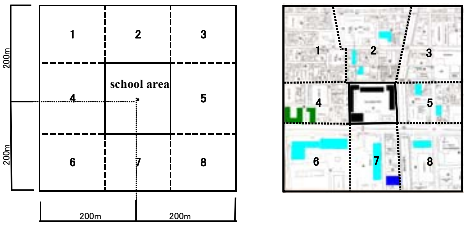

Figure 1 Division of the surrounding area.

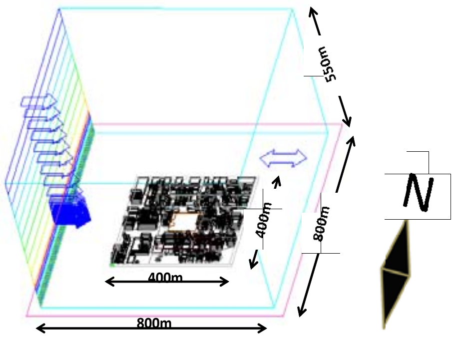

Figure 2 Analytical model and domain.

The computer fluid dynamics simulation model is a standard k-ε three-dimensional turbulent flow model for an incompressible fluid. The mass, momentum, and energy are under the laws of conservation. The boundary condition is based on the measured surface temperatures, as shown in Table 1. The inflow conditions are assumed to be under the law of exponents in the vertical distribution for air velocity and log-law for stress on the building surface for turbulent energy. The difference between lawn planted areas and bare ground is given as the difference of ground surface temperature based on the measurements.

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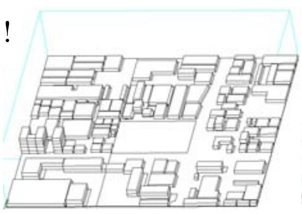

Figure 3 MODEL_N. surrounding area with normal height buildings.

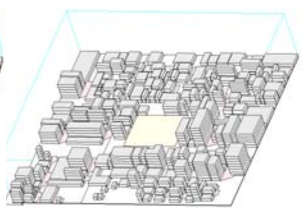

Figure 4 MODEL_H. surrounding area with high-rise buildings.

Table 1 Set contents of surface temperatures

Building surface temperature					
[℃]	North	East	South	West	inside
1.2.3F	35.84	35.79	39.95	38.48	36.58
4.5F	36.84	36.79	40.95	39.48	37.58
6.7F	37.54	37.49	41.65	40.18	38.28
8.9F	38.24	38.19	42.35	40.88	38.98
10.11F	38.94	38.89	43.05	41.58	39.68
12.13F	39.64	39.59	43.75	42.28	40.38
14.15F	40.34	40.29	44.45	42.98	41.08
The horizonal plan		The school yard surface temperature			
No shade	shade	soil	soil (shade)	lawn	lawn (shade)
51.80	37.60	51.2	37.94	46.73	34.64

ANALYSIS RESULTS

Examination points

The examined points in the school area are presented in Figure 5. In all, 25 points for air temperature and velocity were examined, as were 5 points for OUT_SET*. The examined height was 1.0 m from the ground, approximating the height of elementary school children.

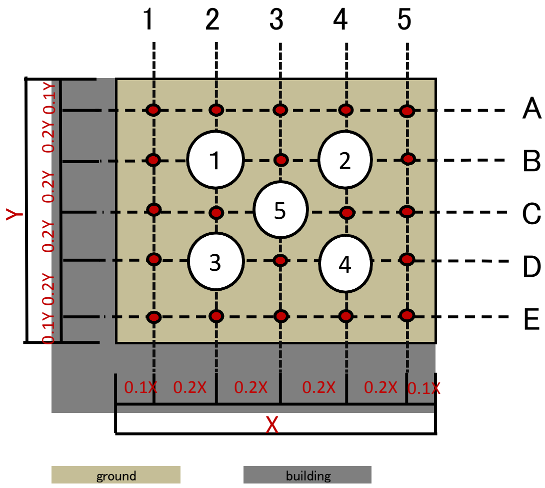

Figure 5 Examined points.

Modelling of school buildings

Table 2 shows cases of school building configurations, with L-shaped, U-shaped and enclosed building configurations. The table also shows the frequency of the types and directions. Figures in the table show the frequencies of the cases.

Opened directions are shown. Direction of 'nothing=' for U-shaped shows the direction of the opening. Figure 6 shows a model of an enclosure type. Table 3 shows the schoolyard area of the case for MODEL_N and MODEL_H.

Table 2 School building configurations.

L type			U type				Closed	others
W=S	W=N	E=S	No=S	No=E	No=W	No=N		
3	12	8	12	5	5	2	6	6

N, north; E, east; W, west; S, south; No, nothing; C, enclosure type.

Table 3 Schoolyard areas in respective cases.

MODEL_N (m^2)							
W=S	W=N	E=S	No=S	No=E	No=W	No=N	Closed
6800	6800	6800	5525	5300	5300	5525	4505
MODEL_H (m^2)							
W=S	W=N	E=S	No=S	No=E	No=W	No=N	Closed
4725	4725	4725	3780	3600	3600	3780	2880

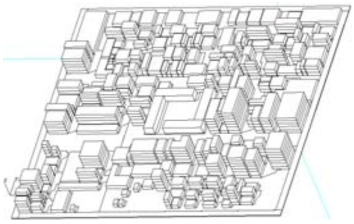

Figure 6 Closed type (type C).

Results for MODEL_N

Figure 7 shows wind speed and heat mitigation effects of lawns in examination points for W=N for MODEL_N. Here heat mitigation effects are defined as differences of air temperature between sandy ground and lawn-planted ground. The mitigation effects are greater near the walls, but the effects are 0.4–0.6 K. The back stream of lower temperature affects only a small part of the ground. Figure 8 shows wind vectors for school type C of MODEL_N. It shows that the wind direction is eastward in the back stream area and westward in other areas of the schoolyard. There is apparently only a slight relation between wind speed and heat mitigation effects.

Figure 9 and Figure 10 show the wind speed in line C in Figure 5 in school type W=S of MODEL_N and school type E=S of MODEL_N. The back stream area apparently depends on the west school building because the school building height is 12 m, whereas the height of surrounding buildings is 6 m.

Table 4 shows analytical results obtained for MODEL_N. The heat mitigation effect of the enclosed type is 0.78 K: the largest. Table 5 also shows larger effects in most cases of MODEL_H.

Table 4 Analysis results of MODEL_N.

	W=S	W=N	E=S	N_0=S	N_0=E	N_0=W	N_0=N	C
Diff.(Soil-Lawn)(K)	.56	.58	.55	.74	.60	.71	.67	.78
Air vel.(m/s)	.81	.81	1.02	.41	.77	.87	.41	.38
Soil temp.(K)	34.08	34.60	34.25	35.30	34.34	34.88	34.59	35.32
Lawn temp.(K)	33.52	34.02	33.70	34.56	33.74	34.17	33.92	34.54

Table 5 Analysis results of MODEL_H.

	W=S	W=N	E=S	N_0=S	N_0=E	N_0=W	N_0=N	C
Diff.(Soil-Lawn)(K)	.73	.83	.94	.89	.90	.91	.82	.93
Air vel.(m/s)	.70	.45	.50	.37	.78	.66	.44	.54
Soil temp.(K)	35.55	35.82	36.62	36.25	36.26	36.63	36.12	36.42
Lawn temp.(K)	34.82	34.99	35.68	35.36	35.36	35.72	35.30	35.49

Table 6 Heat mitigation effects of lawn by OUT_SET*

MODEL_N								
	W=S	W=N	E=S	N_0=S	N_0=E	N_0=W	N_0=N	C
Diff.(Soil-Lawn)(K)	.56	.58	.55	.74	.60	.71	.67	.78
OUT_SET*(°C)	.70	.58	.68	.62	.64	.70	.58	.58
MODEL_H								
	W=S	W=N	E=S	N_0=S	N_0=E	N_0=W	N_0=N	C
Diff.(Soil-Lawn)(K)	.73	.83	.94	.89	.90	.91	.82	.93
OUT_SET*(°C)	.66	.66	.74	.64	.70	.74	.74	.78

Results for MODEL_H

Figure 11 shows wind speed and heat mitigation effects of the lawn of W=N of MODEL_H. The back stream area is shown to be distributed over various schoolyards irrespective of the west school buildings for MODEL_H in Figure 13 and Figure 14 because the school building height is 12 m, whereas surrounding buildings are over 30 m high. Figure 11 for the W=N type of MODEL_H shows that heat mitigation effects are greater than those of MODEL_N.

Figure 11 shows that only a slight relation exists between wind speed and heat mitigation effects for W=N of MODEL_N. Figure 12 for C type shows that the wind direction is eastward for almost all schoolyards, that the eddy area is larger, and that the back stream extends widely.

Table 5 shows that heat mitigation effects are greater for C type also for MODEL_H.

Evaluation by OUT_SET*

Table 6 shows the mean heat mitigation effects as evaluated using OUT_SET* for five points in the schoolyard for each case of MODEL_N and MODEL_H. Heat mitigation effects are greatest for the enclosure type when evaluated according to air temperature, but the effect is small for MODEL_N when evaluated using OUT_SET*, although it is still large for MODEL_H. The effect is greater for the case without west buildings when evaluated using OUT_SET*.

CONCLUSIONS

When heat mitigation effects are evaluated according to air temperature, the following are inferred.

1) The effect of lawn planting is greater in back stream areas because of westward winds, in eddy areas, and in boundary layers.
2) The effect is greater for MODEL_H (0.87 K) than MODEL_N (0.65 K) in a back stream area because of buildings located to the west.
3) Enclosure type is the most effective type of configuration for both MODEL_H (0.93 K) and MODEL_N (0.78 K).

When the heat mitigation effect is evaluated using OUT_SET*, the following are inferred.

4) The effect is greater for MODEL_H (0.71 K) than for MODEL_N (0.64 K).
5) The effect is greater for an enclosure type for MODEL_H (0.93 K), but lower for MODEL_N (0.78 K).
6) The effect is greater for the cases without west buildings (0.70 K) for both models.

Results of this study show that the most effective cases for schoolyard lawn planting are those with enclosed school buildings and higher surrounding buildings.

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[m/s]	1	2	3	4	5
A	0.39	0.24	0.57	0.93	1.11
B	0.41	0.41	0.76	1.05	1.21
C	0.51	0.48	0.80	1.09	1.21
D	0.56	0.55	0.84	1.05	1.24
E	0.48	0.88	0.98	1.15	1.30

[K]	1	2	3	4	5
A	1.09	0.66	0.62	0.66	0.69
B	0.82	0.54	0.54	0.56	0.58
C	0.61	0.46	0.49	0.52	0.55
D	0.53	0.44	0.48	0.51	0.54
E	0.50	0.45	0.51	0.53	0.55

Figure 7 Wind speed (left) and heat mitigation effects (right) for W=N of MODEL_N.

[m/s]	1	2	3	4	5
A	0.89	0.86	0.72	0.6	0.64
B	0.31	0.44	0.41	0.57	0.97
C	0.28	0.29	0.28	0.48	0.87
D	0.34	0.18	0.16	0.24	0.65
E	0.27	0.12	0.16	0.13	0.48

[K]	1	2	3	4	5
A	1.48	1.15	1.09	0.94	0.70
B	1.11	0.83	0.77	0.69	0.45
C	1.12	0.82	0.75	0.67	0.51
D	1.10	0.80	0.74	0.69	0.42
E	1.23	0.85	0.55	0.72	0.49

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Figure 11 Wind speed (left) and heat mitigation effects (right) for W=N of MODEL_H.

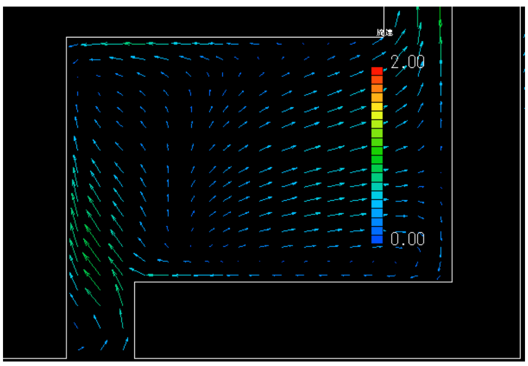

Figure 8 Wind vectors in type-C of MODEL_N.

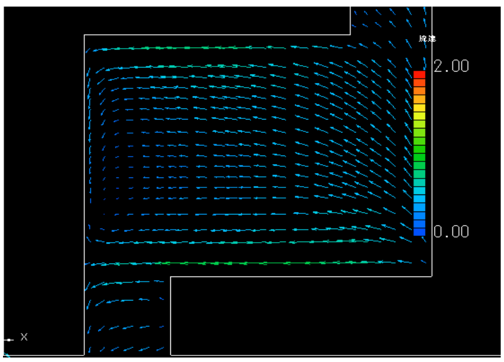

Figure 12 Wind vectors in type-C of MODEL_H.

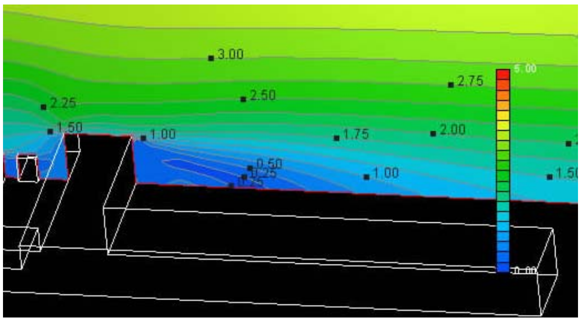

Figure 9 Wind speed in line-C (in Figure 5) for W=S of MODEL_N.

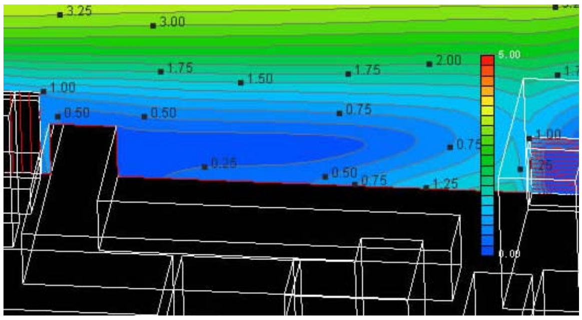

Figure 13 Wind speed in line-C (Figure 5) for W=S of MODEL_H.

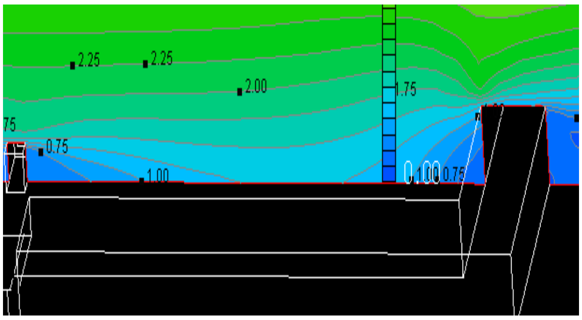

Figure 10 Wind speed in line-C (in Figure 5) for E=S of MODEL_N.

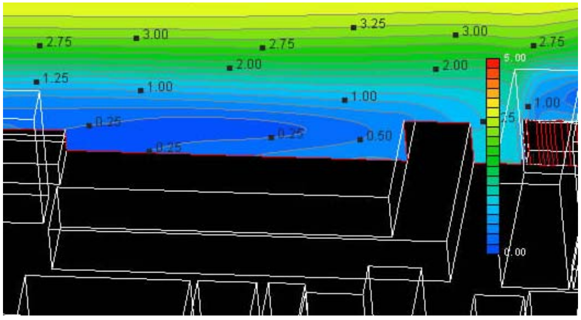

Figure 14 Wind speed in line-C (Figure 5) for E=S of MODEL_H.