Design of the Outdoor Thermal Environment for a Sustainable Riverside Housing Complex using a Coupled Simulation of CFD and Radiation Transfer

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ABSTRACT

A coupled simulation of CFD and radiation transfer was conducted in order to evaluate the outdoor thermal environment in riverside housing complex near to Tokyo in Japan. The effects of relaxation methods in summer for example canal and water permeable material pavement are estimated from the results of this simulation. Furthermore, an optimum design of the outdoor thermal environment for the riverside town houses is studied. In this study, the prevailing wind direction of the site in summer is SSE. In the case of planning of canal and water-conserved pavement, the temperature of site was lower than before.

KEYWORDS: Sustainable housing complex, Canal, Water permeable material, Wind environment, Thermal environment, CFD and Radiation Transfer

1. INTRODUCTION

Thermal environment in urban area become worse in recently, also global warming phenomenon become a big issue. We must consider about sustainable urban planning. In order to make sustainable housing complex, it is very important to control the outdoor thermal environment. Therefore, various relaxation methods for the outdoor thermal environment are often planned, e.g. planting trees, utilizing of the cooling effect of a water face such as lakes or rivers, arrangement of water permeable material etc. A coupled simulation of CFD and radiation transfer is conducted in order to evaluate the outdoor thermal environment. The effects of various relaxation methods in summer described above are estimated from the results of this simulation. Furthermore, an optimum design of the outdoor thermal environment for the riverside housing complex is studied.

The urban thermal environment simulation is developed based on a CFD(Computational Fluid Dynamics) method coupled with radiation calculation. There have been a number of studies concerning on the thermal environment simulation of outside buildings, such as Yoshida et al. (2000). More recently, Chen et al. (2004) and Huang et al. (2005) performed on studies.

In this paper, a coupled simulation of three dimensional CFD and radiation transfer is conducted in order to evaluate the outdoor thermal environment in riverside housing complex where is actual site near Tokyo in Japan. The effects of various relaxation methods in summer described above are estimated from the results of this simulation. To get an optimum design of the outdoor thermal environment for the riverside housing complex, three cases are studied.

2. THE DESIGN OF SUSTAINABLE HOUSING COMPLEX

In the new town plan, the Lake Town(240m×174m), near Tokyo in Japan, there are about 130 units low-rise detached houses beside high-rise apartment buildings at the new railroad station. The canal which is 35m maximum wide is situated between the low-rise houses and high-rise apartment buildings as shown in the Figure 1. The prevailing wind direction of the site is SSE at 13:00 in summer. It will give a great cooling effect in summer to residences of the housing complex, and beautiful circumstances and wonderful view.

To make sustainable housing complex, water permeable material pavement and parks are also designed with utilizing the cooling effect of water face of this canal. The wind over the canal will produce the cooling effect into the Lake Town site in summer, so in the Lake Town the residence will get a pleasant circumstance. Lake-side housing complex will indicate a new concept of the sustainable houses. Figure 1 shows the layout of Lake Town and the around area and Figure 2 shows the zoom in area of leeward of the wind. The gray hatched area indicates the area covered with water permeable material.

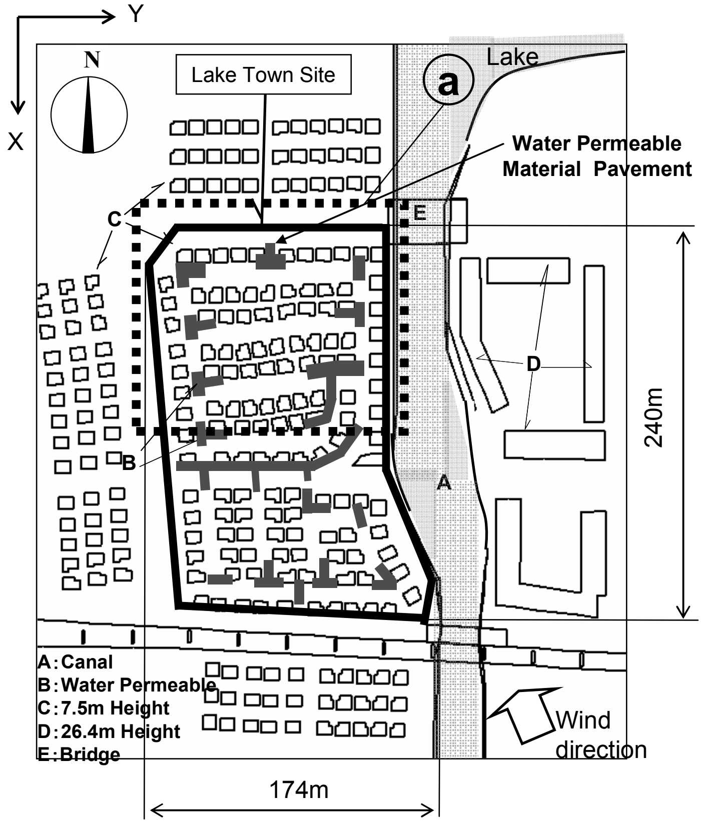


Figure 1. Town house site

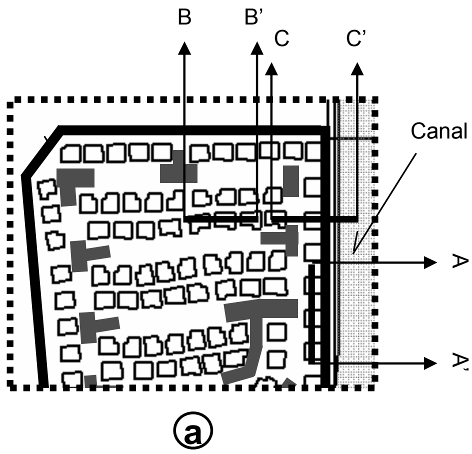


Figure 2. Zoom in ⓐ Area

3. OUTLINE OF COMPUTATION

The calculation domain is 480m×400m×130m, in the center of calculation model there was the Lake Town site. This simulation use unstructured computational grid system which is most effective for

CFD simulation in such a complex urban area. The radiation and conduction analysis is performed for 24 hours from 0:00 on Aug. 1st to 24:00. The CFD analysis is performed at 13:00, Aug. 1st using the surface temperature of the ground and building walls calculated by the radiation and conduction analysis. We use the weather data from AMeDAS(Automated Meteorological Data Acquisition System (latitude:35.54°, longitude:139.5°)) near the site, the wind speed for the site is 2m/s(H=6.5m) and prevailing wind direction is SSE in summer. The inflow wind velocity is set at 1/4th power profile. In other to compare the method of sustainability we simulate 3 cases as shown in Table 1. There are no canal and no water permeable material on the pavement of the site in Case1. There is only canal in Case2, and there are canal and water permeable pavement in the Case 3. The other conditions are shown in Tables 2 and 3.

Table 1. Simulation Cases

	Case 1	Case 2	Case 3
Canal	with out	with	with
Water Permeable Pavement	with out	with out	with

Table 2. Physical properties of surface material

	Long-wave emissivity	Albedo	Soil moisture availability
Asphalt road	0.95	0.1	0
Water permeable pavement	0.9	0.1	0.3
Wall, roof of house	0.9	0.2	0
Site, land (water permeable material)	0.9	0.2	0

Table 3. Weather condition

Indoor air temperature	26°C
Air temperature (August 1st 13:00, H=1.5m))	32.6°C
Wind speed (August 1st 13:00, H=6.5m)	2 m/s
Wind direction (August 1st 13:00, H=6.5m)	SSE

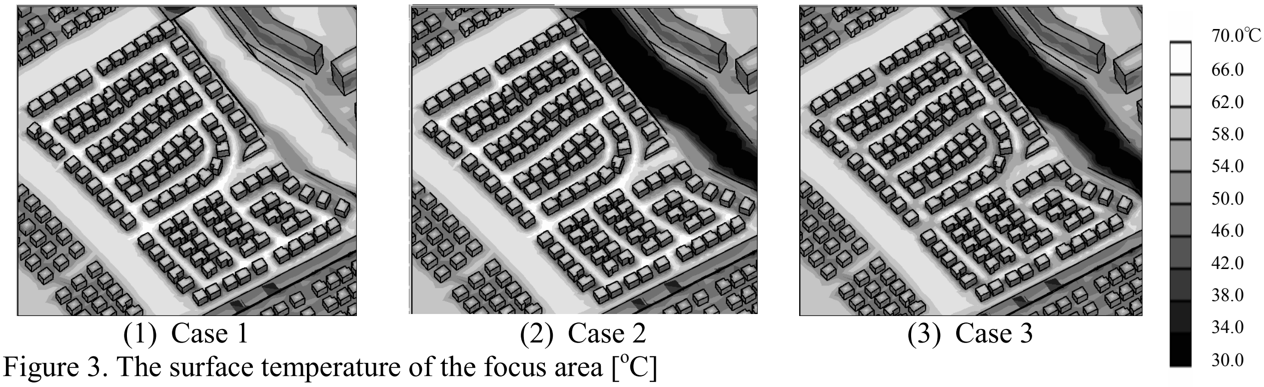
4. RESULT and DISCUSSION

4.1 Simulation results of the whole focus area

Figure 3 shows the surface temperature for these 3 Cases. In Case 1, the canal surface is assumed to be paved by asphalt which is the same as the material of road in the focus area. It is found from the simulation result that the average surface temperature of canal area is 66°C, which is much higher than that in Cases 2 and 3. Furthermore, in the Case 3, part of the asphalt road in the focus area is replaced by water-permeable pavement. The surface temperature of water-permeable pavement is found lower than that of asphalt pavement.

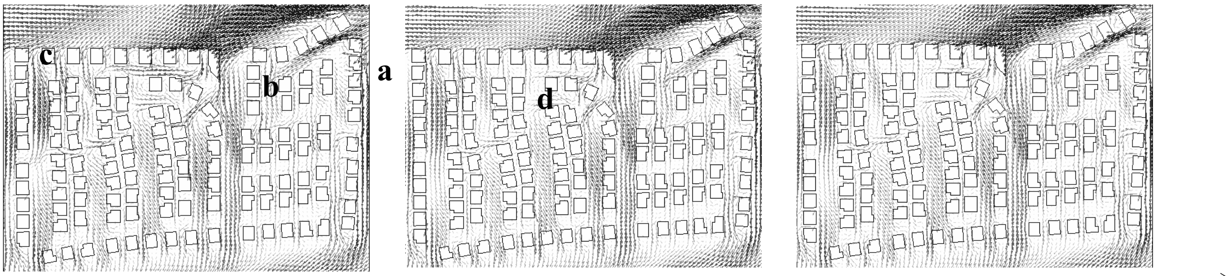
Figure 4 shows the wind velocity at height of 1.5 m in the focus area. The wind coming from SSE flowed into the focus area mainly in three paths (a, b and c). Compared to Cases 2 and 3, the average wind speed is higher in Case 1. The higher temperature of canal surface paved by asphalt results in stronger convection flow and therefore increases the velocity of air.

Figure 5 shows the air temperature at height of 1.5 m in the focus area. Although the wind velocity is higher in Case 1, the wind actually flows with higher temperature from the area over the canal paved by asphalt. Therefore, it is found from the simulation results that the air temperature around the buildings near the canal side is higher. Moreover, according to the configuration of building complex, the wind velocity at point d becomes low (Figure 4-(2)). It is found that the heat is accumulated around point e and the air temperature becomes higher than that of surrounding area (Figure 5-(1)).



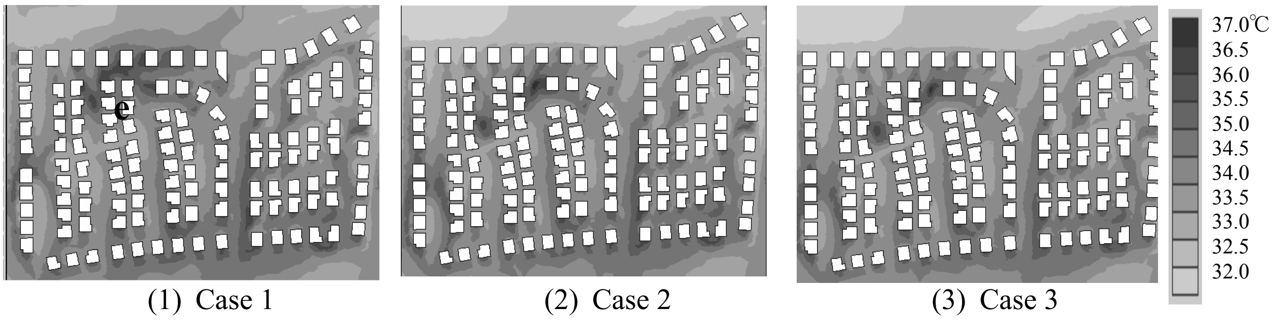
(1) Case 1 (2) Case 2 (3) Case 3

Figure 3. The surface temperature of the focus area [^{o}C]



(1) Case 1 (2) Case 2 (3) Case 3

Figure 4. The horizontal distribution of wind speed [m/s]



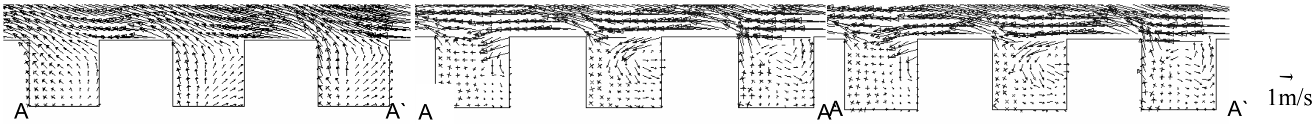
(1) Case 1 (2) Case 2 (3) Case 3

Figure 5. The horizontal distribution of air temperature [^{o}C] (Height:1.5m)

4.2 Simulation results at different sections

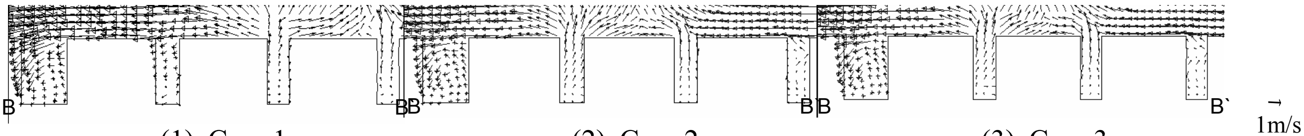
Figures 6 and 7 show the distribution of wind speed at different sections (Figure 2.) separately. The larger wind speed above the roof of houses was found in Case 1. On the other hand, air circulating flow was obvious between buildings in both Cases of 2 and 3.

Figure 8 shows the air temperature profile near the canal side. Compared to Case 1, a lower air temperature was found in Case 2 and 3 around the canal surface. Although the elevation of canal surface is 4 m below the road surface in the Lake Town site, the influence of air temperature on the buildings nearby was found significant. The maximum temperature difference was found 0.8^{o}C between Figures 8-(1) and 8-(2).



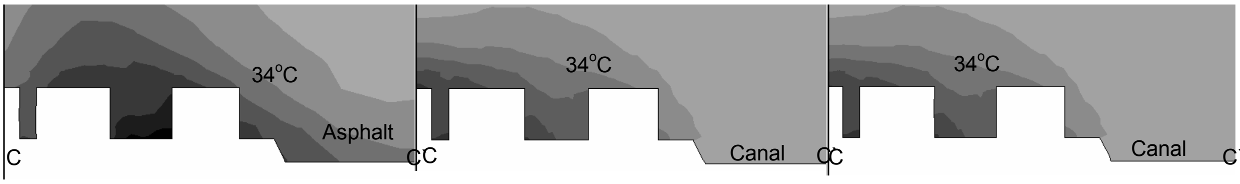
(1) Case 1 (2) Case 2 (3) Case 3

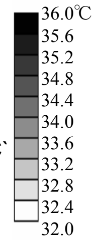
Figure 6. The vertical distribution of wind speed (at A-A` section-Figure 2.)



(1) Case 1 (2) Case 2 (3) Case 3

Figure 7. The vertical distribution of wind speed (at B-B` section-Figure 2.)





(1) Case 1 (2) Case 2 (3) Case 3

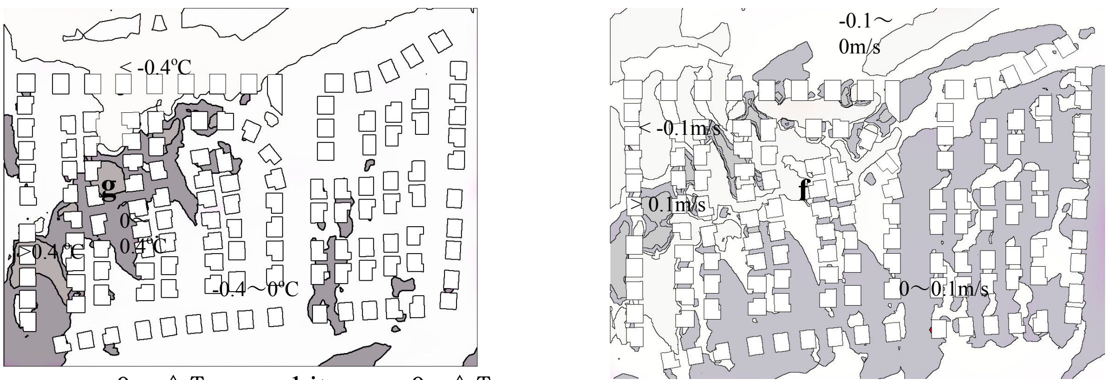
Figure 8. The vertical distribution of air temperature (at C-C` section)

4.3 Comparison of simulation results

Figure 9 shows the difference of simulation results between Cases 1 and 2. In Case 2, the significant reduction of air temperature is found near the canal side and the maximum decrease of air temperature is 1.6°C. On the other hand, it is also found that the wind velocity decreases around point f (Figure 9-(2)), and the increase of air temperature around point g is also observed (Figure 9-(1)). Compared to Case 3, a reduction of 0.085°C the horizontal average air temperature is found in focus area (Table 4). Figure 10 shows the difference of simulation results between Cases 2 and 3. Although the obvious difference of velocity was not seen, the maximum reduction of 0.5°C of air temperature is found around the position of installment for water permeable pavement.

Table 4. Horizontal average air temperature and wind speed at height of 1.5 m

	Air temperature	Wind speed
Case 1	34.544 °C	0.763 m/s
Case 2	34.494 °C	0.727 m/s
Case 3	34.459 °C	0.724 m/s



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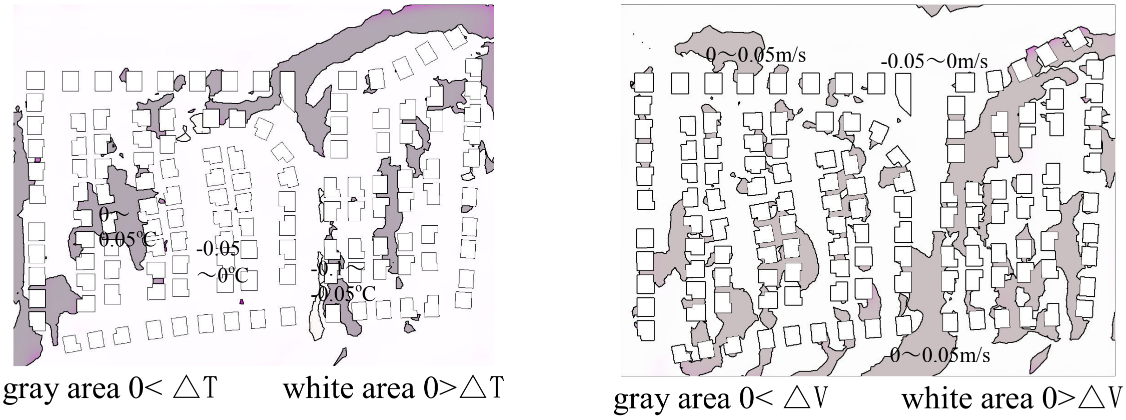
(1) Air temperature (2) Velocity

Figure 9. The difference of simulation results between Cases 1 and 2 [Case 2- Case 1] (Height:1.5m)



(1) Air temperature (2) Velocity

Figure 10. The difference of simulation results between Cases 2 and 3 [Case 3-Case 2] (Height:1.5m)

5. CONCLUSIONS

In this study, sustainable methods such as utilizing the cooling effect of water face and water permeable material of Lake Town house were studied.

The conclusions of this study are as following;

1) The surface temperature of water-permeable pavement was found lower than that of asphalt pavement as the results of radiation transfer simulation.
2) According to the effect of canal, the air temperature of horizontal section at 1.5m was decreased by 1.6°C at maximum in the Lake Town site (Figure 1). In general, horizontal average air temperature is decreased by 0.05°C and wind speed is also decreased by 0.036m/s.
3) Compared to Cases 3 and 2, there is an effect of water permeable material. In the place where water permeable pavements situated, the horizontal air temperature decrease by 1.0°C at maximum. The horizontal average air temperature is decreased by 0.035°C and horizontal average wind velocity is decreased by 0.003m/s.
4) The case 3 which is installed both the canal and water permeable pavement, the air temperature is decreased more by 2.2 °C at maximum.

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