NUMERICAL SIMULATION OF OUTDOOR THERMAL ENVIRONMENT FOR A SUSTAINABLE LAKE TOWN

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ABSTRACT

In order to make sustainable single houses, it is very important to control the outdoor thermal environment. Therefore, various relaxation methods for the outdoor thermal environment are often planned, e.g. utilizing of the cooling effect of a water face, arrangement of water permeable material, planting trees etc. In this paper, a coupled simulation of CFD and radiation transfer is conducted in order to evaluate the outdoor thermal environment in riverside detached single houses near to Tokyo in Japan. 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 Lake Town is studied.

KEYWORDS

Radiation Transfer, Sustainable Lake Town, Wind environment, Thermal environment, CFD

INTRODUCTION

In the metropolitan city the population is increasing now. To solve the insufficiency of houses, new town projects have been constructed. Because of the increasing in population and urbanization, the heat island effect in the city become a big issue now.

Thermal environment in urban area become worse in recently, also global warming phenomenon become a serious problem. We must consider about sustainable urban planning. In order to make sustainable Town houses, 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 town houses 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 Lake Town houses 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 town houses, three cases are studied.

PLAN OF LAKE TOWN HOUSE

According to the new town plan, there are about 130 low-rise detached houses which will be built around a new railroad station near Tokyo in Japan. Figure 1 shows the layout of Lake Town and the surrounding area. There are high-rise apartment buildings in the east side of the location of the Lake Town. The canal with the maximum width of 35m will be made between the low-rise houses and high-rise apartment buildings. It will give a great cooling effect in summer to residences in the Lake Town and beautiful circumstances and wonderful view.

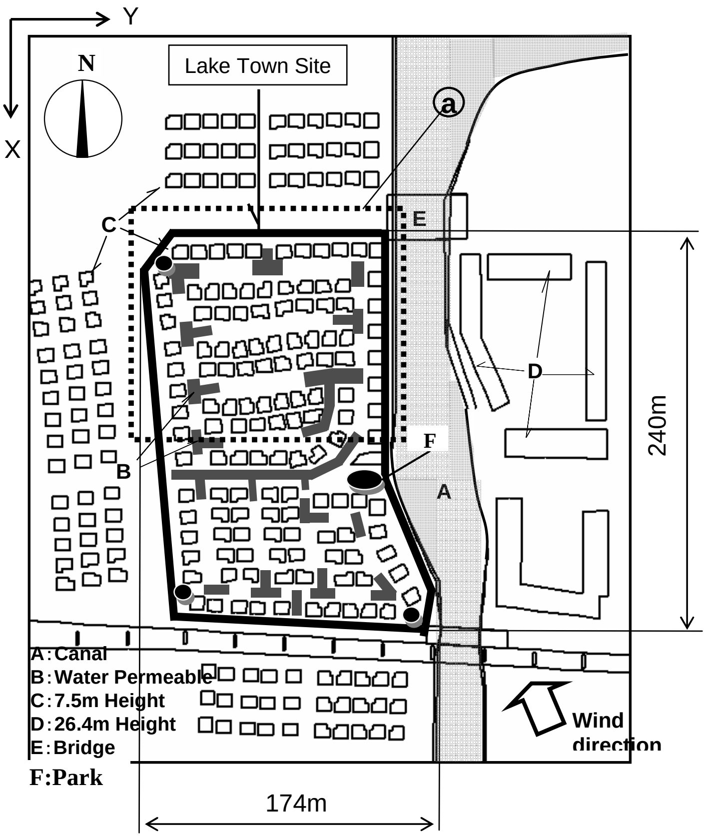


Figure 1 Lake Town site

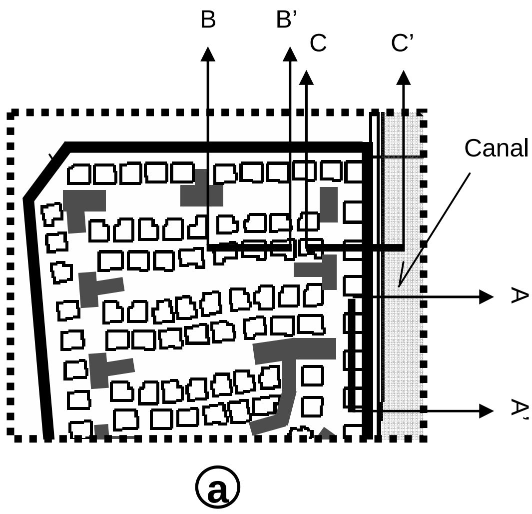


Figure 2 Zoom in ⓐ Area

To make sustainable townhouse, water permeable material pavement and parks are designed; wide water face of the canal is also designed. The route of wind along the canal will produce the cooling effect into the Lake Town site in summer. Therefore, the residence living in the Lake Town will enjoy a pleasant environment. Lake-side town houses will indicate a new concept of the sustainable houses. Figure 2 shows the ⓐ area and the layout of sections (A-A', B-B' and C-C') where the simulation results will be described in Figures 6~8.

OUTLINE OF COMPUTATION

The calculation domain in this study is 480m ×400m×130m. This simulation uses unstructured computational grid which is most effective for CFD simulation in such a complex urban area. The radiation and conduction analysis is performed for 24 hours during 0:00 to 24:00 on Aug. 1st. 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.

The weather data of AMeDAS (Automated Meteorological Data Acquisition System (latitude: 35.54°, longitude:139.5°)) is used for this simulation. The inflow wind velocity is set at 1/4th power profile. The measurement value for the site is 2m/s (H=6.5m) and direction of prevailing wind is SSE.

In order to design sustainable lake town houses, four cases of simuations are carried out. In Case 1, there was no canal and no water permeable material/park in the lake town. There is a canal in Case 2, and there are a canal and water permeable pavement in Case 3. Finally, based on Case 3, park area is also designed in the Lake Town in Case 4. The other detail setting of simuation is listed in Tables 2 and 3.

Table 1 Simulation Cases

	Case 1	**Case 2**	**Case 3**	**Case 4**
Canal	with out	with	with	with
Water permeable pavement	with out	with out	with	with
Park	with out	with out	without	with

Table 2 Weather condition—August 1st 13:00

Air temperature	32.6°C
Wind speed at 6.5m height	2 m/s
Wind direction	SSE

Table 3 Physical properties of surface materials

	Long-wave emissivity	Albedo	Soil moisture availability
Wall and roof of house	0.9	0.2	0
Asphalt road	0.95	0.1	0
Site land	0.9	0.2	0
Water permeable pavement	0.9	0.1	0.3
Park	0.9	0.2	0.3

RESULTS AND DISCUSSION

Figure 3 shows the surface temperature for these 4 cases. In Case 1, the canal surface is 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℃, which is much higher than that in Cases 2~4.

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

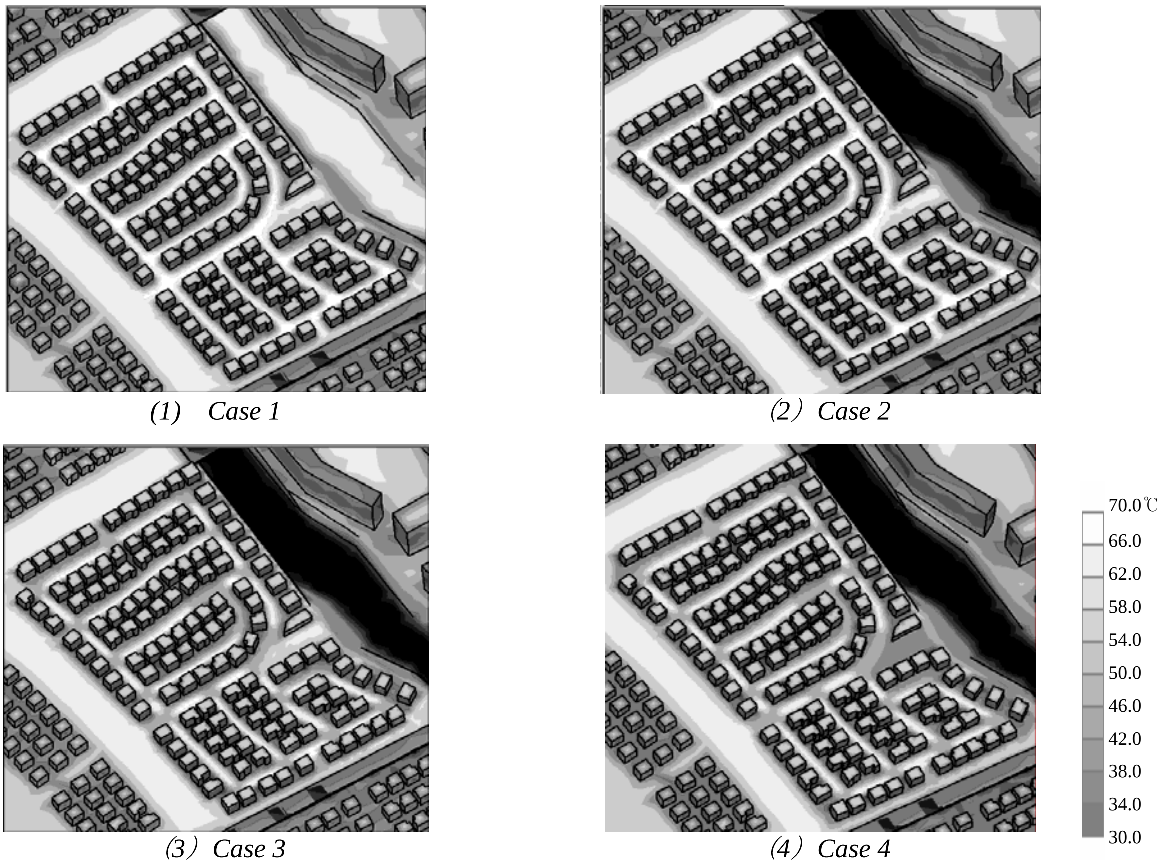
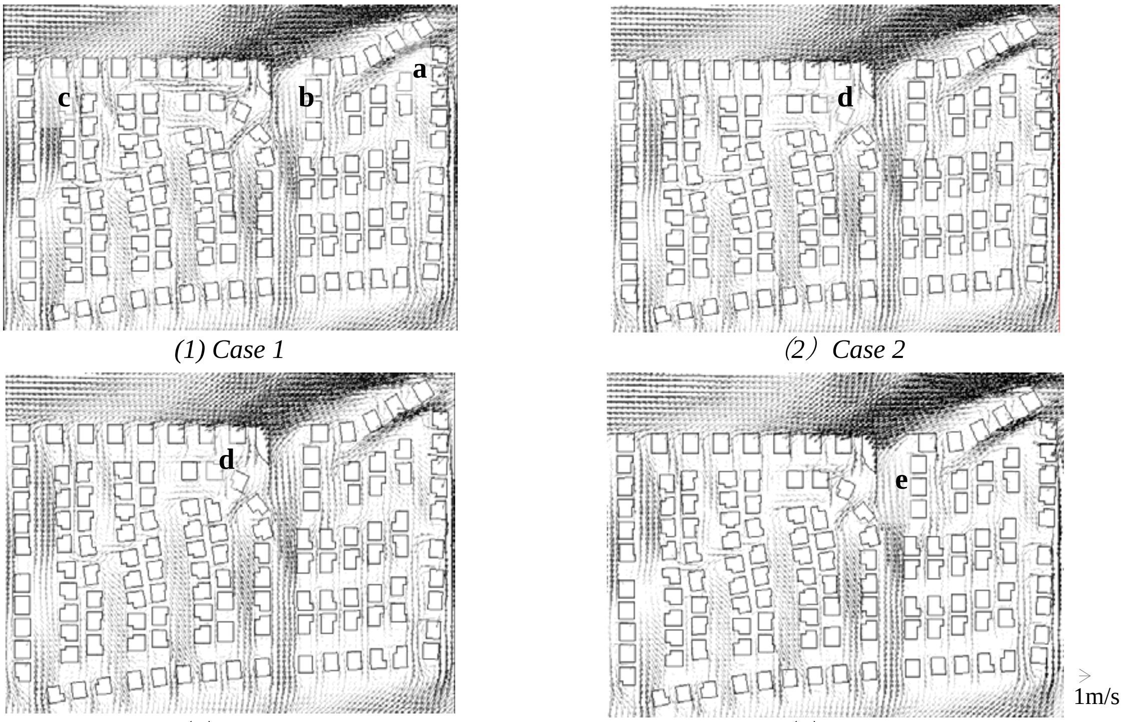


Figure 3 The surface temperature of the focus area

any other surface in Case 2. Furthermore, in Case 3, a part of the asphalt road in focus area is replaced by water-absorptive pavement. The surface temperature of water-absorptive pavement is found lower than that of asphalt pavement. Park area is designed in Case 4, and it is shown that park area has lower surface temperature compared to the streets.

The area of water-permeable pavement(B area in Figure 1) is small and therefore it is found that there is no obvious difference between Cases 2 and 3 in Figure 3. However, the velocity is found reduced at point d area in both Cases 2 and 3 in Figure 4. In Case 4, the wind speed is slightly reduced at point e area near the park.

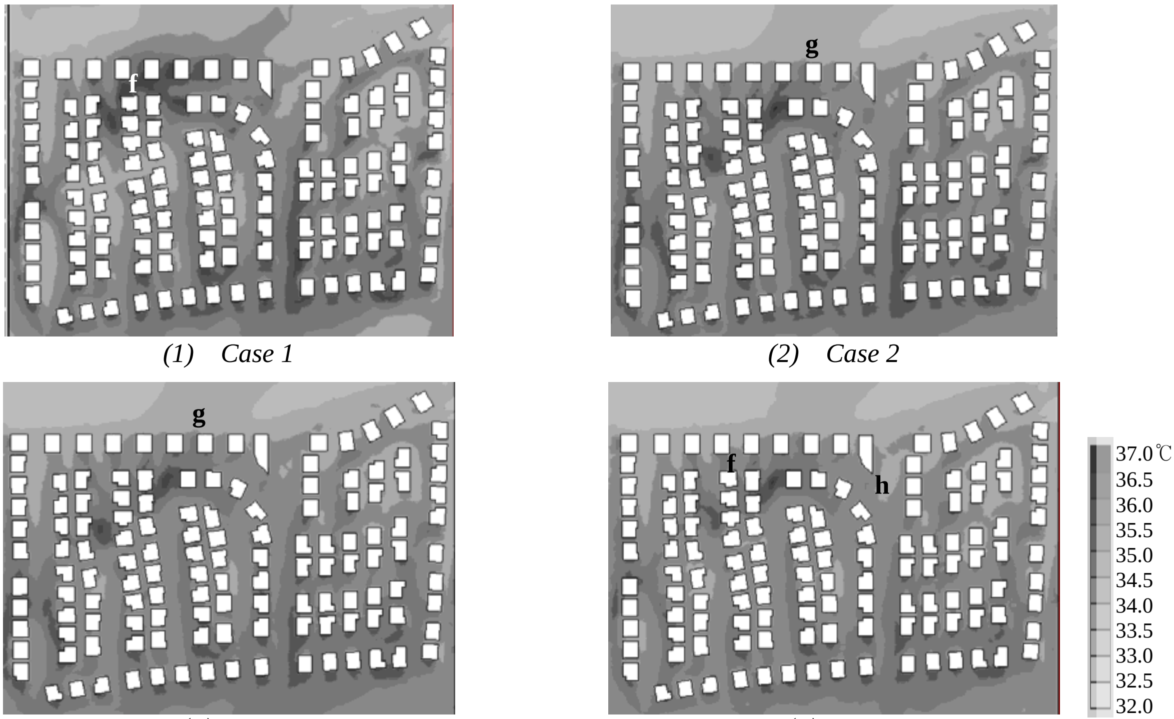


(1) Case 1 *(2) Case 2*

(3) Case 3 *(4) Case 4*

Figure 4 The horizontal distribution of wind velocity (Height:1.5m)

Figure 5 shows the air temperature at height of 1.5 m in the Lake Town area. Although the wind velocity is higher in Case 1 than the others, the wind actually flows with higher temperature from the area over the canal paved by asphalt. Therefore, it is found that the air temperature around the buildings near the canal side is higher (Point f). On the other hand, the air temperature upon the canal (Point g) in Cases 2 and 3 is lower than that in Case 1. Moreover, the reduction of air temperature in most of the focus area is obserbed and it is shown around the points f and h.



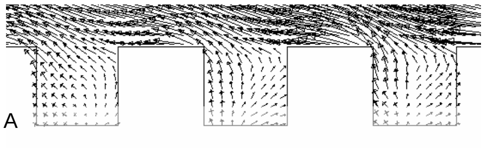
(1) Case 1 *(2) Case 2*

(3) Case 3 *(4) Case 4*

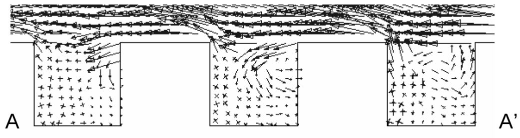
Figure 5 The horizontal distribution of air temperature (Height:1.5m)

Figure 6 and Figure 7 show the distribution of wind velocity of sections. The larger wind speed above the roof of houses is found in Case 1. Air flow going upwards is seen at A-A' section in Case 1. On the other hand, air circulating flow is obvious between buildings in both Cases of 2 and 3. However, the circulating flow is weak between buildings in Case 4.

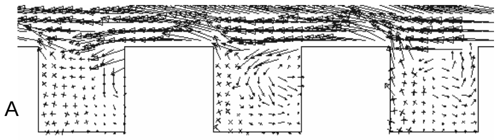
Figure 8 shows the air temperature profile near the canal side. Compared to Case 1, a lower air temperature is found in Cases 2, 3 and 4 around the canal surface. Although the elevation of canal surface is 4 m below the road surface, the influence of air temperature on the buildings nearby is found significant. The maximum temperature difference was found 0.8°C between Cases 1 and 2.



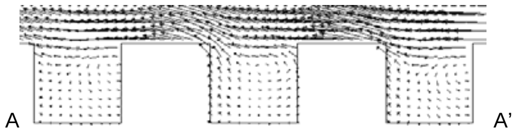
(1) Case 1



(2) Case 2

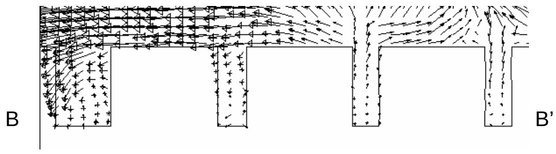


(3) Case 3

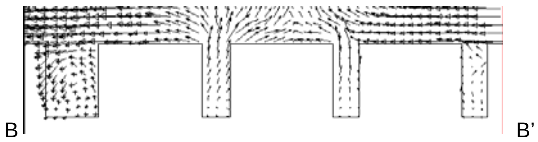


(4) Case 4

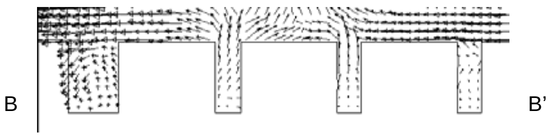
Figure 6 The vertical distribution of wind speed (at A-A' section)



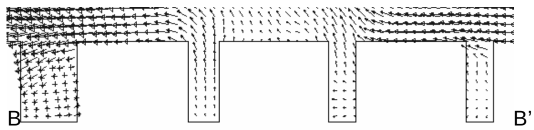
(1) Case 1



(2) Case 2

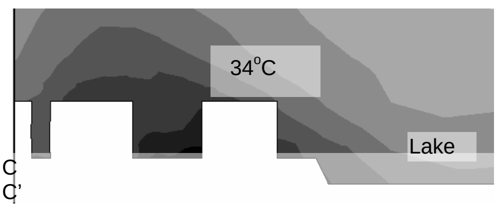


(3) Case 3



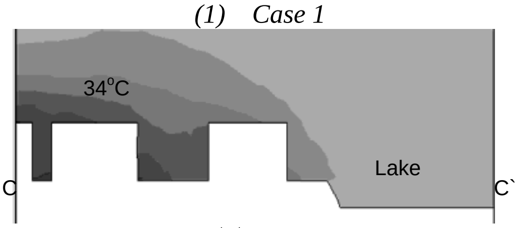
(4) Case 4

Figure 7 The vertical distribution of wind speed (at B-B' section)

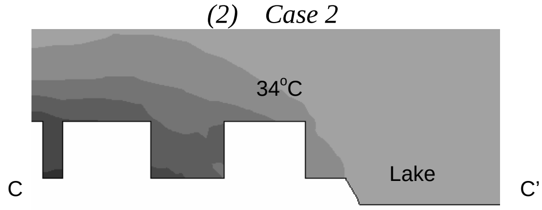


(1) Case 1

(2) Case 2



(3) Case 3



(4) Case 4

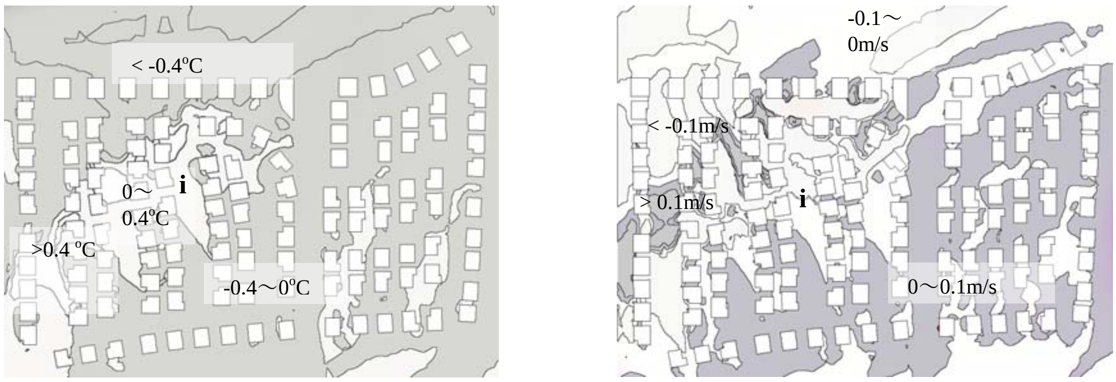
Figure 8 The vertical distribution of air temperature (at C-C' section)

Figure 9 shows the difference of simulation results at height of 1.5m between Cases 1 and 2. The figure on the left hand side shows the difference of air temperature and the one on the right hand side shows the comparsion of wind speed. The obvious reduction of air temperature is found near the canal side and the maximum decrease of air temperature is 1.6℃. However, the decrease of wind speed and the increase of air temperature around point i is also observed. Compared to Case 1, the simulation shows that the reduction of average temperature is about 0.05℃ and the reduction of wind speed is 0.036 m/s in Case 2.

Figure 10 shows the difference of simulation results between Cases 2 and 3. Although the obvious difference of velocity is not seen, the maximum reduction of 1.0^{o}C of air temperature is found around the position of installment for water permeable pavement. The improvement of air temperature is found 0.035 ℃ even the install area of water permeable pavement is small.

Figure 11 shows the difference of simulation results between Cases 3 and 4[Case 4-Case3]. The reduction of air temperature aorund the park area is about 0.5℃, and in most area the difference is 0.0℃~0.2℃.

Table 4 shows the simulation results of average temperature and wind speed at height of 1.5m in the Lake Town site. Compared Case 4 to Case 3, the simulation shows that the reduction of average temperature is about 0.073℃ and the reduction of wind speed is 0.015 m/s. It is found from the simulation result that the reduction of average air temperature is 0.15^{o}C and the decrease of wind speed was 0.05 m/s in Case 4 compared to Case 1.



Gray: 0>△T, White: 0<△T   Gray: 0<△V, White: 0>△V

(1) Air temperature   *(2) Wind speed*

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

Gray: 0>△T, White: 0<△T   Gray: 0<△V, White: 0>△V

(1) Air temperature   *(2) Wind speed*

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

Gray: 0>△T, White: 0<△T   Gray: 0<△V, White: 0>△V

(1) Air temperature   *(2) Wind speed*

Fig. 11 The difference of simulation results between Cases 3 and 4
[Case 4-Case 3] (Height:1.5m)

Table 4 Simulation results at height of 1.5m

	Average air temperature in the site	**Average wind speed in the site**
Case 1	34.54 °C	0.76 m/s
Case 2	34.49 °C	0.73 m/s
Case 3	34.46 °C	0.72 m/s
Case 4	34.39 °C	0.71 m/s

CONCLUSION

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

The conclusions of this study are as follows:

1) The surface temperature of water-permeable pavement, parks and canal is found lower than that of asphalt pavement from the simulation results of radiation transfer.
2) According to the effect of the canal, the air temperature of horizontal section at 1.5m decreases by 1.6℃ at maximum in the Lake Town site(Figure 1). The average decrease of air temperature is 0.05℃ and the average decrease of wind speed is 0.03m/s.
3) The effect of water permeable material is proved by comparison with Cases 2 and 3. In the place where water permeable pavements are installed, the horizontal air temperature decrease by 1.0°C at maximum.
4) It is found from the simulation result that the reduction of average air temperature is 0.15°C and the decrease of wind speed was 0.05 m/s in Case 4 compared to Case 1.
5) The simulations of canal, water permeable pavement and parks are carried out separately and the effect of each countermeasure is observed by the simulation results.

REFERENCES

MEJ, 2000, The actual situation and measures of urban heat island phenomenon. Report of Ministry of the Environment of Japan,

Huang, H., Akutsu, Y., Arai, M. and Tamura, M., 2000: A two-dimensional air quality model in an urban street canyon: evaluation and sensitivity analysis. Atmospheric Environment, 34, 689-698.

Chen, H., Ooka, R., Harayama, K., Kato, S. Li, X., 2004. Study on outdoor thermal environmen t of apartment block in Shenzhen, China with coupled simulation of convection, radiation and conduction, Energy and Buildings, 36, 1247-1258.

Huang, H., Ooka, R. and Kato, S. 2005, "Urban thermal environment measurements and numerical simulation for an actual complex urban area covering a large district heating and cooling system in summer", Atmospheric Environment, 39, 6362-6375.