CFD analysis on thermal environmental characteristics in city block due to varying some parameters

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Abstract

Urban Heat Island phenomena have become serious problem in Japan. Computational Fluid Dynamics model that can consider effects of long and short wave radiation was developed. The 24 hour unsteady simulations were carried out due to varying some of parameters such as buildings and ground surface albedo. In order to analyze the thermal environmental characteristics, sixteen buildings were arranged in the calculation domain. The albedo of buildings and roads, wind direction were varied as parameters. The result showed that when solar altitude was high, air temperature was effectively lowered at high albedo condition.

1. Introduction

Recently Urban Heat Island (UHI) phenomena have become serious problem in a lot of urban area all over the world as well as in Osaka Japan. Change of ground surface, effect of latent heat flux, reflection of solar insolation by buildings and anthropogenic heat release were considered as factors of UHI. Assessment of UHI with CFD model is useful and a lot of studies were carried out [1] [2] [3] [4]. However, almost all those are unsteady analysis with macro model of 1km×1km mesh and steady analysis at daytime with micro model. Unsteady analysis with micro model is not carried out so much because the calculation of view factor for solar radiation requires much computational time. In this study, the 24-hour unsteady simulations about micro urban climate were carried out using PPM method [5] for calculating view factor. The albedo of buildings and roads, wind direction were varied as parameters, and the mitigation of air temperature was discussed.

2. Urban Model

The urban model in this study is shown in Figure 1. It is consisted of ground and sixteen buildings with same shape. The size of buildings were 8m(x)×8m(y)×12m(z) and the width of streets were arranged as 8m equally. The calculation domain was 184.8m(x)×184.4m(y)×75m(z) and the number of mesh was 50×50×40 at each axis with the unequal size. The standard *k*- *ε* model was used as the turbulent model [6] and was solved by SIMPLE method.

$$\frac{\partial k}{\partial t} + \frac{\partial (U_j k)}{\partial x_j} = \frac{\partial}{\rho x_j}\left[\frac{\nu_j}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + P + G - \varepsilon \tag{1}$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial (U_j \varepsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\frac{\nu_t}{\partial_\varepsilon}\frac{\rho \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(P+G)(1+C_{3\varepsilon}R_f) - C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{2}$$

$$\nu_t = C_\mu \frac{k^2}{\varepsilon},\quad -\overline{u_i u_j} = \nu_t \left[\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right],\quad P = \nu_t \left[\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right]\frac{\partial U_i}{\partial x_j},\quad G = -\beta g \frac{\nu_t}{\sigma_T}\frac{\partial T}{\partial z}$$

where, ν_t is turbulent coefficient; σ_k , σ_ε , $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ and C_μ are model parameters; β is volume coefficient of expansion($3.51\times10^{-3}K^{-1}$); g is acceleration of gravity($9.81m/s^2$); σ_T is turbulent Prandtl number; T is temperature.

The surface temperature of buildings and roads were calculated by the heat balance equation.

$$(1-\alpha)S\downarrow - \varepsilon\sigma T_S^4 + f_S R\downarrow + \sum f\varepsilon T_j^4 = G + H + LE \tag{2}$$

where α is albedo, $S\downarrow$ is solar radiation, ε is radiation emissivity, σ is Stefan-Boltzman constant, T_S is surface temperature, f_S is sky view factor, $R\downarrow$ is long wave radiation, f is view factor for each element, T_j is surface temperature for each element, G is heat flux into internal, H is sensible heat flux, and LE is latent heat flux. In this study, LE was not considered. The hourly direct solar radiation for each element was preliminarily calculated by PPM method. Diffused solar radiation was assumed to reach each element evenly. View factor was also calculated by PPM method. Ground surface temperature was calculated by force-restore method.

$$\frac{\partial T_S}{\partial t} = 2\sqrt{\pi}\frac{G}{\rho_{soil}c_{soil}d} - 2\pi\frac{T_S - T_2}{T_1} \tag{3}$$

where, $\rho_{soil}c_{soil}$ is heat capacity of soil near the ground surface, d is depth of soil, T_2 is internal temperature at depth d.

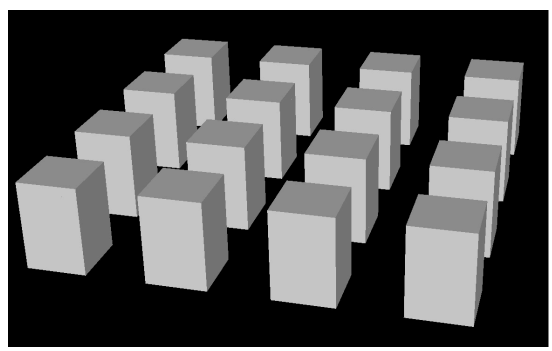


Fig.1 3D urban model

3.Boundary condition

Wind velocity U at the lateral boundary condition was given by the equation (4) The hourly vertical profile of air temperature was calculated by Businger's law with experimental data.

$$U = U_0\left(\frac{z}{z_0}\right)^{0.25} \tag{4}$$

where, U_0 is 4.0[m/s], and z_0 is 75m.

Osaka City in Japan was selected as calculation area, and the day was chosen as fine day in summer.

4.Calcuation conditions

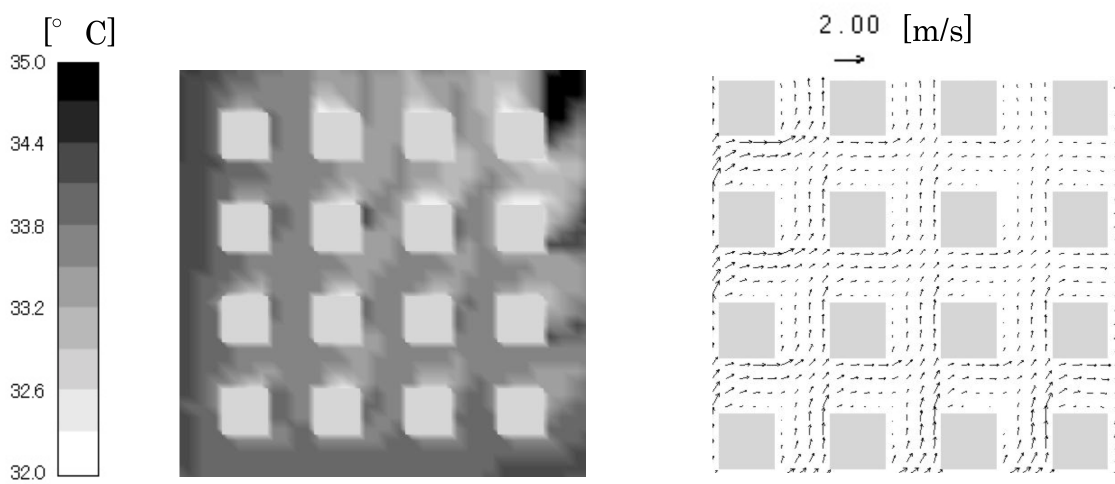
The 24-hour unsteady calculations from 6 a.m. were carried out due to varying the albedo of buildings and roads and for two wind directions of southwest and west. The albedo values of buildings and roads is shown in Table 1

Table 1 Albedo values of buildings and roads

Albedo of buildings	Albedo of roads		
	0.2	0.3	0.4
0.2	0.2-0.2	0.2-0.3	0.2-0.4
0.2	0.3-0.2	0.3-0.3	0.3-0.4
0.3	0.4-0.2	0.4-0.3	0.4-0.4

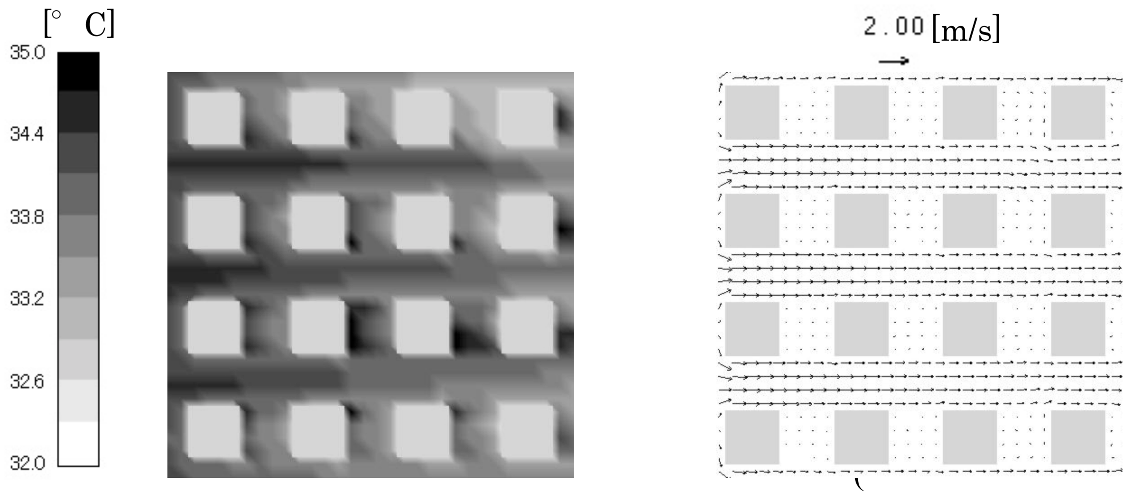
5.Calcuation result

The air temperature and the wind vectors at the height of 1.5m on noon are shown in Fig. 2 and Fig. 3. At the area where wind speed was fast, the air temperature becomes high. At the case of the west wind, the air temperature on the west-east roads became higher. On the other hand, at the case of the southwest wind, the leeward air temperature was relatively low.



(a) Air temperature (b) Wind velocity

Fig. 2 Result of southwest wind condition at 1.5 m height



a) Air temperature (b) Wind velocity

Fig. 3 Result of west wind condition at 1.5 m height

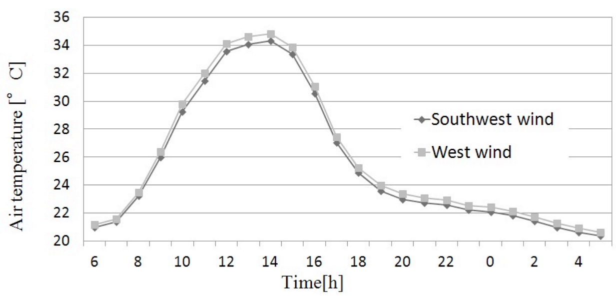
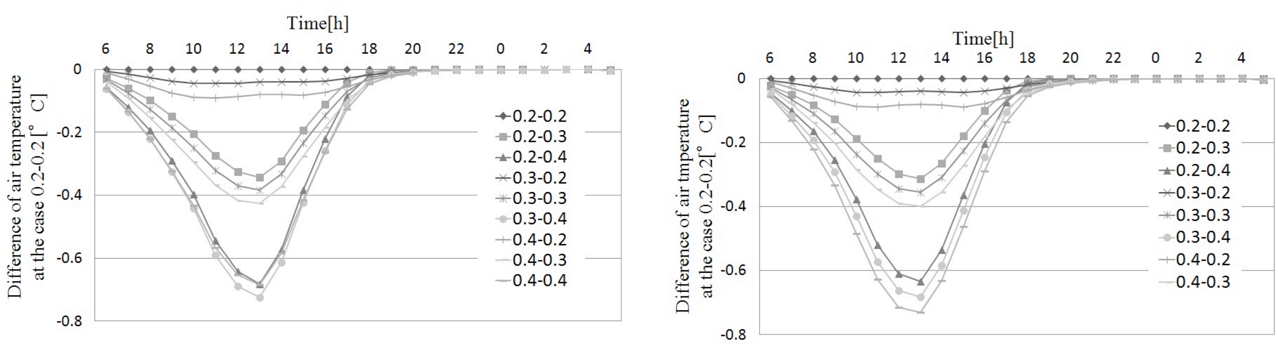


Fig. 4 Result of air temperature at 1.5 m height



(a) Southwest wind (b) West wind

Fig. 5 Differences of air temperature at the case 0.2-0.2 at 1.5 m height

The diurnal average air temperature at the southwest wind and at the west wind is shown in Fig. 4. The average air temperature at the west wind was higher than at the southwest wind because of the fast wind speed at the west wind. The difference of the average air temperature at the albedo of 0.2 is shown in Fig. 5. According to the increase of albedo of roads, the average air temperature became low. According to the increasing of albedo of buildings at the same albedo of roads, the average air temperature became low. These results suggested that the albedo of roads strongly affected the air temperature.

6.Conclusion

The 24-hour unsteady simulations were calculated for varying the albedo of roads and of buildings and wind directions. When the wind direction was normal to buildings, the air temperature became higher compared with the wind direction with 45 degree to buildings. The albedo of roads was more sensitive for the air temperature compared with the albedo of buildings.

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