Development of Prediction and Evaluation System of Heat and Wind Environment in Urban Areas and Blocks

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1 INTRODUCTION

Recently functions of a social infrastructure are demanded a reduction of an environmental disruption and a sustainability. Furthermore, new businesses that deal in a value and a function of infrastructures are coming up, such as Private Finance Initiative (PFI) and Real Estate Investment Trust (REIT). The subject of this study is to make values and functions of a community development and buildings clear. This paper shows the outline of the developing the general environment prediction and evaluation system that can make the heat and wind environment in outdoors using numerical simulations.

2 THE FLOW OF THE DEVELOPED SYSTEM

In this system [1], three simulations for predicting and evaluating the heat and wind environment in outdoors are executed.

At first, the meso scale atmospheric simulation in wide areas is executed, which is inputted the presser distribution in upper atmosphere and land use data as input data and calculates distributions of wind directions, wind speeds, air temperature and humidity in 3D area for from 400km around to 25km around by use of the nesting calculations in three times. Next, the wind around a building simulation is executed, which uses boundary data of wind speeds and directions from results of the meso scale atmospheric simulation at the required area during the calculation period. This simulation provides time changes of distributions of wind speeds and directions around buildings. Finally, using these distributions and time changes of temperature and humidity provided from the meso scale atmospheric simulation as input data, the heat radiation environment simulation is executed and provides surface temperatures at grounds and structures and globe temperatures at required points.

3 MESO SCALE ATMOSPHERIC SIMULATION

Basic equations are conservation equations of mass, motion, heat and humidity in the 3-dimensional atmosphere, which are applied the Bousinessqu’s approximation, the hydrostatic approximation, and terrain-following coordinate systems.[2] In the lower boundary, conservation equations of mass, heat and humidity in six categories (water, bare ground, paddy field, field, woods and structures) depending on a kind of a land usage are calculated and these fluxes of each categories in a calculation mesh are summed and took into atmosphere. In the horizontal boundary, the nesting calculation is done using Open boundary condition method.[3]
4 WIND AROUND A BUILDING SIMULATION

Basic equations are conservation equations of mass and motion of incompressible flow and governing equations of the modified Launder-Kato-type $k$-$\varepsilon$ model. These are applied the vegetation canopy model of Hiraoka [4] that estimates the turbulence structure in the vegetational canopy. Pressure ($P$) and velocity ($U_i$) that are variables of these equations are defined on grid points in a staggered grid on the 3-dimensional Cartesian coordinate. The QUICK scheme is applied for the difference approximation of the advection terms in transform equations of motion, turbulence kinetic energy ($k$) and turbulence dissipation ($\varepsilon$). The SIMPLER method is applied for the time integration. The basic equations show below. It is assumed that the calculated flow is steady so that the calculation time step is took very large number ($\Delta t=1.0\times10^20$ sec).

$$\frac{\partial U_i}{\partial x_i} = 0 \quad \text{(1)}$$
$$\frac{\partial U_i}{\partial t} = -\frac{\partial P}{\partial x_i} + \text{Adv} + \text{Dif} - Fr_i \quad \text{(2)}$$
$$\text{Adv} = -\frac{\partial U_i U_j}{\partial x_j} \quad \text{(3)}$$

$$\text{Dif} = \frac{\partial}{\partial x_j} \left( \nu \frac{\partial U_j}{\partial x_j} - \frac{u_j u_j}{2} \right) \quad \text{(4)}$$
$$\frac{\partial k}{\partial t} = \frac{\partial}{\partial x_j} \left( \nu \frac{\partial k}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \nu_r \frac{\partial \varepsilon}{\partial x_j} \right) + P_k - \varepsilon - F_k \right) \quad \text{(5)}$$
$$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial x_j} \left( \nu \frac{\partial \varepsilon}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \frac{C_{\eta}}{\sigma_{\eta}} \frac{\partial \varepsilon}{\partial x_j} \right) + \frac{\varepsilon}{k} P_k - C_{\eta} \varepsilon + C_{\varepsilon} F_k \right) \quad \text{(6)}$$

$$P_k = \nu \Omega \cdot S = 2\sqrt{S_y S_y}, \quad \Omega = 2\sqrt{\Omega_y \Omega_y}, \quad S_y = \frac{1}{2} \left( \frac{\partial U_j}{\partial x_j} + \frac{\partial U_i}{\partial x_i} \right), \quad \Omega_y = \frac{1}{2} \left( \frac{\partial U_j}{\partial x_j} - \frac{\partial U_i}{\partial x_i} \right) \quad \text{(7a, b, c, d, e)}$$

$$Fr_i = a C_i U_i \sqrt{\frac{U_i^2}{L}}, \quad F_k = U_j F_{jk}, \quad F_{\varepsilon} = k \frac{\varepsilon}{L}, \quad L = 1/a \quad \text{(9a, b, c, d)}$$

Where $a$ is the leaf area density. $C_f$ is the drag coefficient. $C_{\eta}$ is the correctional coefficient of turbulence Shumit number. $C_{\eta}$ is the coefficient of turbulent dissipation. $\nu$ is the molecular viscosity. $C_D, C_I, C_2, \sigma_k, \sigma_{\varepsilon}$ are empirical parameters and take the below numbers.

$$C_D=0.09, \quad C_I=1.44, \quad C_2=1.92, \quad \sigma_k=1.00, \quad \sigma_{\varepsilon}=1.30$$

5 HEAT RADIATION ENVIRONMENT SIMULATION

In this simulation, building and ground surfaces are classified into three categories (SF1: the bear ground surface, SF2: the vegetation surface, SF3: the ground surface under the vegetation). Heat budget equation is calculated on each surface as below.

$$S_n + R_n + H_n + E_n + G_n = 0 \quad \text{(11)}$$
$$S_n = \frac{S_{0_n} \cdots \text{SF1}}{c_{f_n}(1-c_{f_n})S_{0_n} \cdots \text{SF1}} \quad \text{(12)}$$

$$S_{0_n} = [\mu_n \cdot f_{dn} \cdot S_{dn0} \cdot A_n] + [\mu_n \cdot f_{dn} \cdot S_{dn0} \cdot A_n] + [\mu_n \cdot S_{dnf_n}] \quad \text{(13)}$$
$$S_{df_n} = \sum_{j=1}^{m} a_j \cdot b_j \cdot f_{\sigma_n}^{(j)} \cdot \sigma_j \cdot \cos \theta^{(j)} \cdot S_{dr0} + \sum_{j=1}^{m} a_j \cdot (1-b_j) \cdot A_j \cdot \sigma_j \cdot F_{mn} \cdot S_{dr0} \quad \text{(14)}$$
These equations shown above are calculated on rectangular meshes into which was divided building and ground surfaces. The 4th order simultaneous matrix equations are derived from these equations and calculated with the Newton-Raphson method. The radiation configuration factor is calculated assuming that it is uniform in the fine mesh divided the rectangular mesh into. The heat conduction equation of equation (22) is calculated using the finite differential method in the building surface and the force restore method in the ground surface.

6 CALCULATION AND RESULTS

The heat and wind environment in the site of Kajima Research Institute, where is located in Choufu-shi Tokyo, Japan, was calculated. Figure 1. shows the layout of buildings in the site. The measurement was carried out in this place form 08/26/05 to 08/28/05. The M1 and M2 in Figure 1.
are points of this measurement and these data were averaged in 3 days. Figure 2. shows the comparison of measured and calculated globe temperatures, which depend on the heat and wind environment at the point, such as air temperature, the wind speed, the solar radiation and the heat radiation. Calculation results roughly agree with measurement ones but a difference between them are 5 degree C in the morning. It is because that clouds cannot be calculated correctly. Figure 3. shows ground surface temperatures at same points. It shows same characteristics.

7 CONCLUSION

The prediction and evaluation system, which can calculate the heat and wind environment from the cities scale to the building scale, is developed. From comparison of calculation results with measurement ones, this system can calculate surface temperatures and globe temperatures at any points in the calculation domain within the 5 degree C accuracy.

8 REFERENCES