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The 24-h unsteady analysis of air flow and temperature in a real city by high-speed radiation calculation method

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ABSTRACT

Heat island phenomenon is an important issue in environmental studies. Many studies involving observations and simulations have been performed. Computational Fluid Dynamics (CFD) analysis including the effects of solar radiation and longwave radiation heating/cooling are limited in the extreme conditions at midday, when solar radiation intensity are at maximum; and the 24-h unsteady analyses are not done due to the difficulties of the boundary conditions. Authors developed Computer Graphics (CG) method for calculating solar radiation and longwave radiation with high speed, and developed the 24-h unsteady analytical method from the data calculated by Weather Research and Forecasting (WRF). The integrated CFD was applied to the real city. The results showed that the integrated CFD was the useful tool to analyze the heat island phenomena.

1. Introduction

Urban heat island phenomena are a very important issue in the environmental studies. Many studies with observations and simulations have been performed. Many researchers reported [1–5] that the temperature difference between urban and suburban is more significant in nighttime than in daytime, and more so in winter than in summer. These were also obvious from the satellite data [6–8]. Heat island phenomena are considered to be due to change in ground surface, decrease of latent heat flux, changes of reflection and radiation by buildings, and artificial heat flux [9–13] and were summarized by Oak [14,15]. There were a lot of researches of heat island using simulations with the macro model (Meteorological Model version 5, MM5) and the micro models (Computational Fluid Dynamics, CFD). The macro models with simplified buildings including the effect of solar radiation/longwave radiation [16–19] have been used for heat island phenomena in Tokyo and in Osaka. However, the horizontal resolution was about 1 km and not good enough to represent the impact of urban structures. The micro model with solar radiation/longwave radiation into complicated urban structures has been studied [20–24] but only for midday when the effects of heat island become extreme.

Almost cities face ocean, and see and land breezes have significant daily variation in wind direction [25]. Amount of solar radiation receiving building surfaces and road surfaces varies largely depending on their direction and on solar zenith. The accumulated heat into building delays heat transfer to atmosphere. Therefore, in order to estimate urban heat island, it is really important to simulate a whole day by CFD.

However, the 24-h unsteady analysis accompanying with solar radiation/longwave radiation by CFD does not commonly apply for the actual planning. This is mainly because of the large amount of time required for calculating solar radiation received by building surfaces and by road surfaces, which depends on solar zenith, solar azimuth, and the direction of buildings. Moreover, there is no suitable method to define the unsteady boundary conditions for temperature, wind speed, and wind direction. Therefore, the 24-h unsteady analysis accompanying with solar radiation/longwave radiation, which can evaluate wind fields and temperature fields, has hardly been performed in real cities. The steady analysis was commonly carried out by using the boundary conditions fixed.

Kaga et al. [26] demonstrated that the required calculation time of view factor could be shortened significantly by using CG (Parallel Projection Method (PPM) method), and Ikejima et al. [27,28] proposed the effective calculation method of solar radiation by using CG.

In this study, both calculation methods of view factor and solar radiation are integrated into CFD and the unsteady boundary

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